Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements

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NETL Contact:

Sarah Forbes
Technical Monitor
Office of Systems, Analyses and Planning

Prepared by:

Gary J. Stiegel, Jr., Andrea McNemar, Michael Nemeth,
Brian Schimmoller, James Murphy, and Lynn Manfredo
Research and Development Solutions, LLC

National Energy Technology Laboratory
www.netl.doe.gov

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Executive Summary

Growing concerns about freshwater availability must be reconciled with growing demand for power if the United States is to maintain economic growth and current standards of living. Thermoelectric generating capacity is expected to increase by nearly 22% between 2005 and 2030, based on the Energy Information Administration's (EIA) *Annual Energy Outlook 2006* (AEO 2006) projections.[1] A previous water needs analysis conducted by the Department of Energy's National Energy Technology Laboratory (DOE/NETL) in 2004 suggested that national freshwater withdrawals may increase slightly or decline depending on assumptions made, while freshwater consumption will likely increase dramatically.[2] However, regional water impacts can be significantly different than national data averages might suggest. To characterize the significance of the regional impacts on water use, this report compares regional electricity demand and capacity forecasts from AEO 2006 with representative water withdrawal and consumption estimates to identify regions where water issues could become acute.

Future freshwater withdrawal and consumption requirements for the U.S. thermoelectric generation sector were estimated for five cases, using AEO 2006 regional projections for capacity additions and retirements:[a]

Case 1 – Additions and retirements are proportional to current water source and type of cooling system.
Case 2 – All additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system.
Case 3 – 90% of additions use freshwater and wet recirculating cooling, and 10% of additions use saline water and once-through cooling, while retirements are proportional to current water source and cooling system.
Case 4 – 25% of additions use dry cooling and 75% of additions use freshwater and wet recirculating cooling. Retirements are proportional to current water source and cooling system.
Case 5 – Additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system. Five percent of existing freshwater once-through cooling capacity is retrofitted with wet recirculating cooling every five years starting in 2010.

Summary results for the five cases, on a national basis, are presented in Table ES-1. For all cases, withdrawal is expected to decline, and consumption is expected to increase. These results are consistent with current and anticipated regulations and industry practice, which favor the use of freshwater recirculating cooling systems that have lower withdrawal requirements, but higher consumption requirements, than once-through cooling systems. Case 5 provides the most extreme water consumption impacts. Converting a significant share of existing once-through freshwater power plants to recirculating freshwater plants significantly reduces water withdrawal, but significantly increases water consumption. Case 4 indicates that dry cooling could have a significant

[a] See Table 7 in the body of the report for a description of the rationale behind each of these cases and their assumptions.

impact on water consumption; compared to Cases 1-3, which have an average consumption of 8.1 BGD, Case 4 results in a 7% decline, equivalent to more than 200 billion gallons per year.

Table ES-1 - Thermoelectric Water Impacts, National Results

		Freshwater withdrawal or consumption (BGD)					
		2005	**2010**	**2015**	**2020**	**2025**	**2030**
Case 1	Withdrawal	149.2	152.7	145.6	147.6	148.8	148.4
	Consumption	6.2	6.6	6.8	7.3	7.6	7.9
Case 2	Withdrawal	149.2	149.4	141.0	138.6	138.0	136.3
	Consumption	6.2	6.7	6.9	7.5	7.9	8.2
Case 3	Withdrawal	149.2	149.4	140.9	138.5	137.9	136.1
	Consumption	6.2	6.6	6.9	7.4	7.8	8.1
Case 4	Withdrawal	149.2	149.3	140.8	138.3	134.6	135.4
	Consumption	6.2	6.6	6.8	7.3	7.4	7.5
Case 5	Withdrawal	149.2	137.7	122.7	114.2	109.4	103.7
	Consumption	6.2	6.9	7.4	8.2	8.7	9.2

Each of the cases used different assumptions (see Table 7 for rationale behind each case and their assumptions). Due to the differences in assumptions, none of the cases can truly be considered a baseline for comparison with other cases. However, the year 2005 can be used as a baseline against which to measure projected future withdrawal and consumption. As seen in the 2005 column of Table ES-1, the 2005 withdrawal and consumption values for each case are the same. Using this baseline, Table ES-2 was generated to show the percent change from the 2005 baseline to each of the future years. The negative values in Table ES-2 for withdrawal indicate decreased withdrawal while the positive consumption values indicate increasing consumption over time.

Table ES-2 – Percent Change from 2005 Baseline, National Results

		Percent change from 2005 baseline				
		2010	**2015**	**2020**	**2025**	**2030**
Case 1	Withdrawal	2.3	-2.4	-1.1	-0.3	-0.5
	Consumption	6.5	9.7	17.7	22.6	27.4
Case 2	Withdrawal	0.1	-5.5	-7.1	-7.5	-8.6
	Consumption	8.1	11.3	21.0	27.4	32.3
Case 3	Withdrawal	0.1	-5.6	-7.2	-7.6	-8.8
	Consumption	6.5	11.3	19.4	25.8	30.6
Case 4	Withdrawal	0.1	-5.6	-7.3	-9.8	-9.2
	Consumption	6.5	9.7	17.7	19.4	21.0
Case 5	Withdrawal	-7.7	-17.8	-23.5	-26.7	-30.5
	Consumption	11.3	19.4	32.3	40.3	48.4

A comparison of the 2004 and 2006 analysis was conducted for quality control purposes. Even though the 2004 water needs analysis and the 2006 water needs analysis were conducted using different analytical methodologies, different time periods, and different cases, the results are in general agreement. National water withdrawal totals for the two analyses are within about 20% of each other for a given year, and the majority of this

difference can be traced to differences in capacity projections, differences in apportioning additions and retirements between once-through and recirculating systems, and the 10-year time lag between the base years for the two studies (with the 2004 and 2006 studies using a base year of 1995 and 2005 respectively). National consumption totals don't exhibit the same degree of numerical similarity as the withdrawal totals between the 2004 and 2006 analyses, but the consumption trends across equivalent 25-year time periods are in the same direction and of similar magnitude. These observations will be addressed in the results section of this report.

The regional component of the 2006 water needs analysis revealed some significant differences from the national averages. For example, consider Case 2, which represents a plausible future cooling system scenario. The national percent changes in Table ES-2 indicate that water withdrawal will fall by 8.6% and that water consumption will rise by 32.3% between 2005 and 2030. As shown in Figure ES-1 and Figure ES-2 on a regional basis, however, water withdrawal ranges from a 25% increase in Florida to a 30% decline in Texas; and while freshwater consumption increases in all regions, the biggest gains come in California (352%), Florida (199%), New York (132%) and the Rocky Mountain/desert southwest region (74%).

Figure ES-1 – Average Daily Regional Freshwater Withdrawal for Thermoelectric Power Generation – Case 2

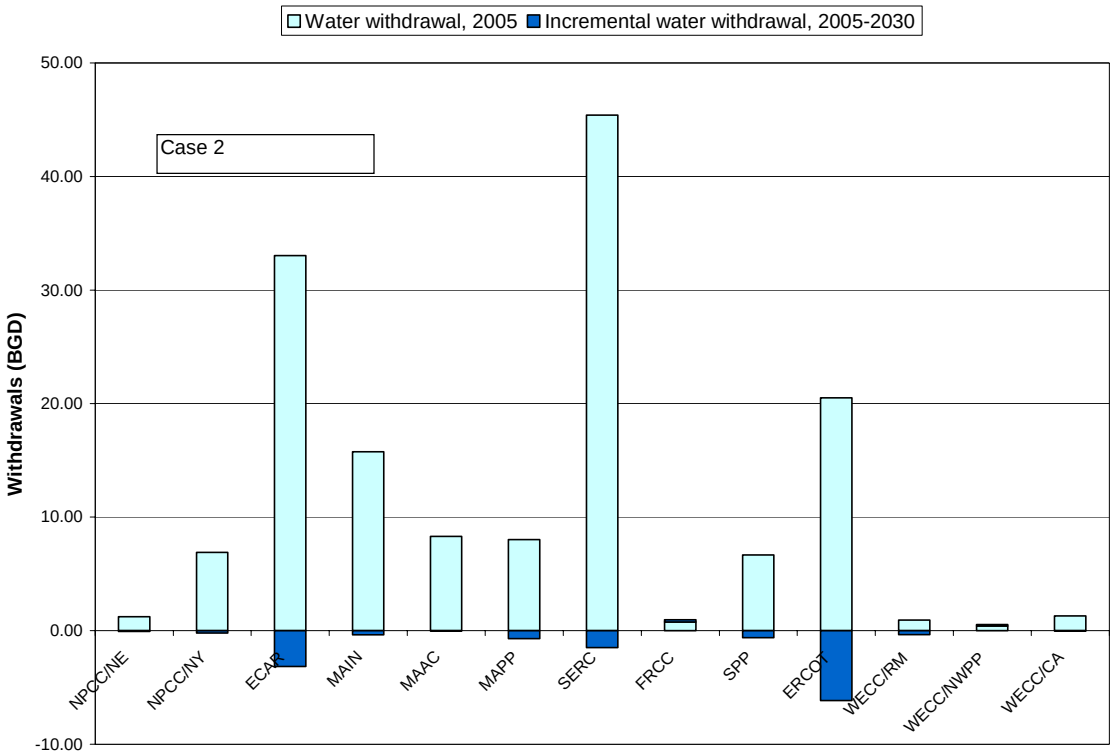
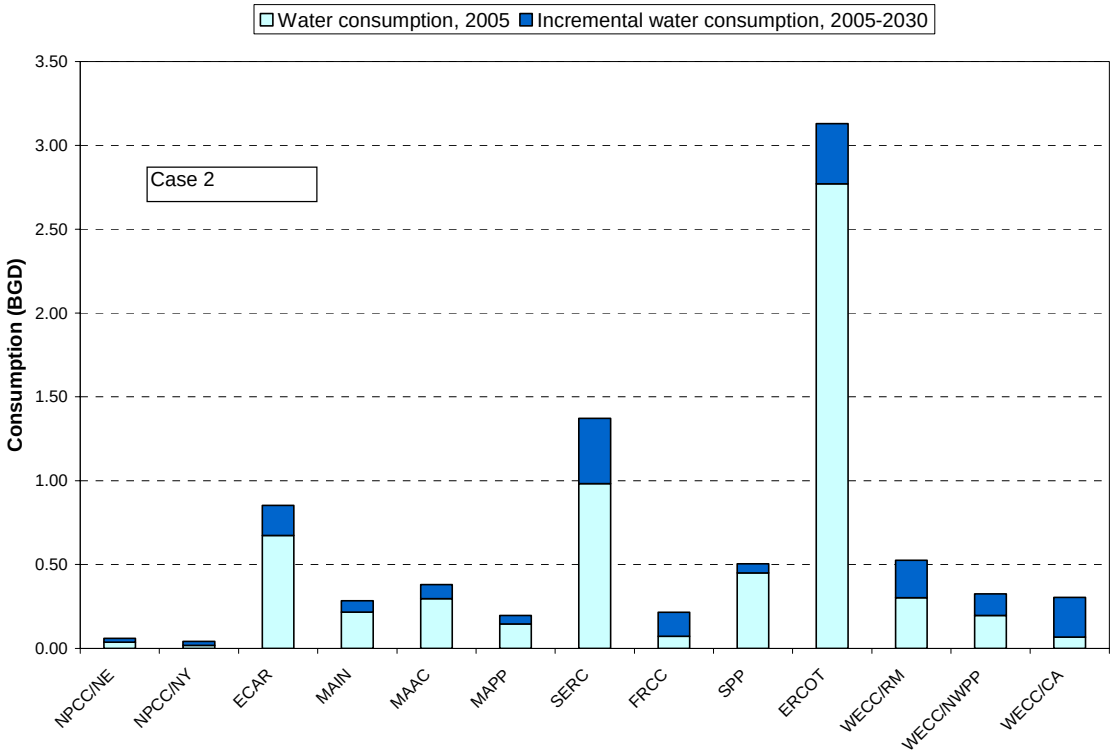


Figure ES-2 - Average Daily Regional Freshwater Consumption for Thermoelectric Power Generation – Case 2



The regional results reflect recent U.S. population shifts. Regions with strong population growth, such as the southeast and southwest, exhibit high growth in water consumption requirements, while regions with minimal to modest population growth, such as the midwest and mid-Atlantic, exhibit modest growth in water consumption requirements.

Specific to coal-fired generation, the analysis projects that by 2030, average daily national freshwater withdrawals may decrease to 66.0 BGD or increase to 98.2 BGD from a baseline level of 91.6 BGD, depending upon case assumptions. The 2005 baseline coal-fired plant withdrawal represents 61% of the total thermoelectric plant withdrawal. Average daily national freshwater consumption resulting from U.S. coal-fired power generation could reach 3.4 BGD to 4.0 BGD from a baseline level of 2.3 BGD, depending upon case assumptions. The 2005 baseline coal-fired plant consumption represents 37% of the total thermoelectric plant consumption. Case 2, coal-fired, regional water withdrawal and consumption are illustrated in Figures ES-3 and ES-4 respectively.

Figure ES-3 – Average Daily Regional Freshwater Withdrawal for Coal-Fired Power Generation – Case 2

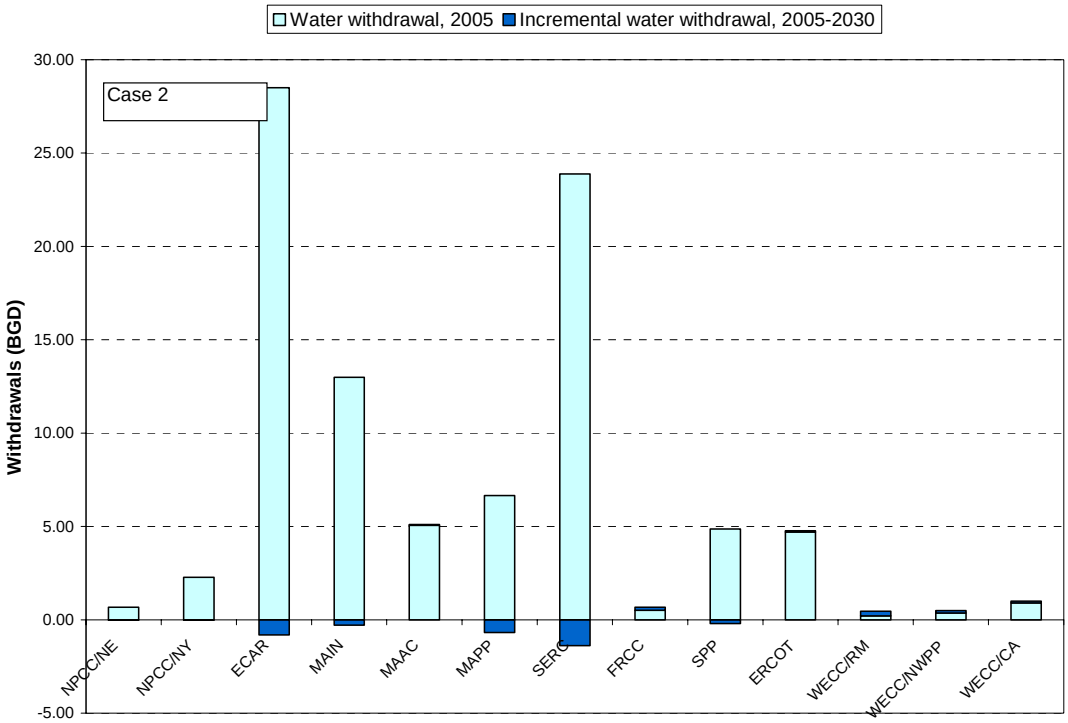
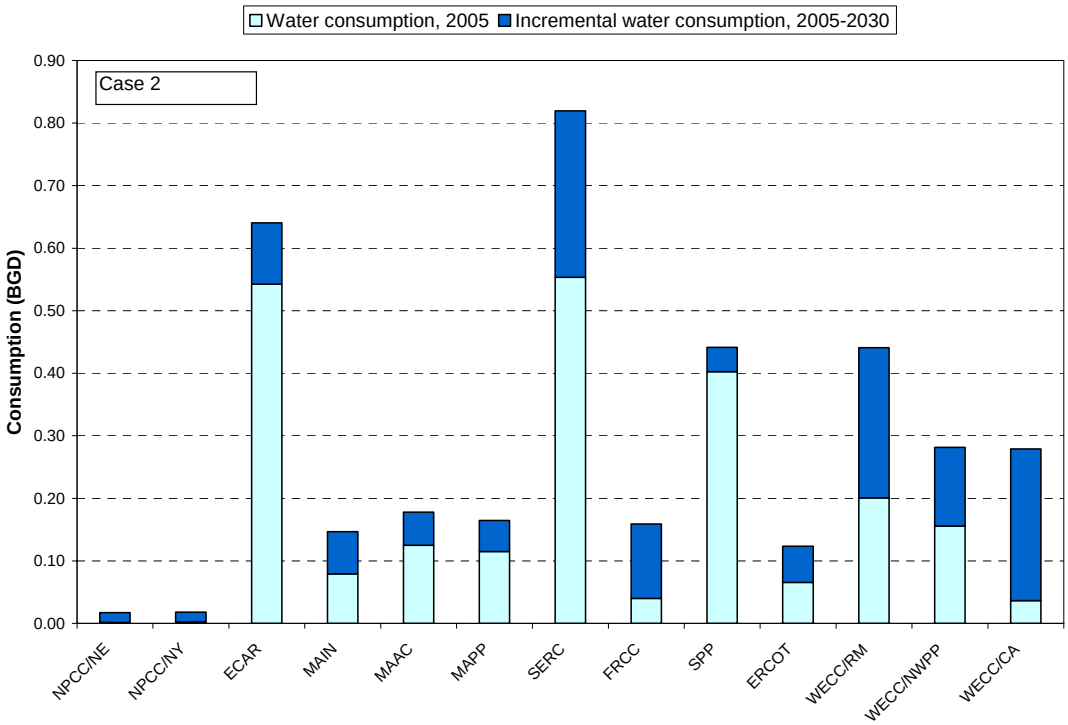


Figure ES-4 - Average Daily Regional Freshwater Consumption for Coal-Fired Power Generation – Case 2



This analysis and accompanying report were completed to estimate future freshwater needs both for coal-fired generation and for total thermoelectric generation. The results from this report will be used as a base forecast against which to compare accomplishments in freshwater withdrawal and consumption reductions. Additionally, report results will be used to better understand the regional impacts of constrained water resources.

Introduction

The purpose of this report is to estimate future freshwater needs for thermoelectric power generation. Thermoelectric power plants – coal, oil, natural gas and nuclear fueled power generators using a steam turbine based on the Rankine thermodynamic cycle – require significant quantities of water for generating electrical energy.[b] For example, a 500-MW coal-fired power plant uses over 12 million gallons per hour of water for cooling steam turbine exhaust.[3,c] The water required for thermoelectric plants is *withdrawn* primarily from large volume sources, such as lakes, rivers, oceans, and underground aquifers. While both freshwater (approximately 70%) and saline water (approximately 30%) are currently used for thermoelectric generation, this report focuses on freshwater because freshwater sources are becoming increasingly strained. *Water consumption* is used to describe the loss of that water, typically through evaporation into the air. The United States Geological Survey (USGS) estimated that thermoelectric generation accounted for approximately 39% of freshwater withdrawals, ranking only slightly behind agricultural irrigation as the largest source of freshwater withdrawals in the United States in 2000.[4] However, the corresponding water consumption associated with thermoelectric generation accounted for only 2.5% of total U.S. freshwater consumption in 1995.[5] As U.S. population and associated economic development continues to expand, the demand for electricity will increase. The Energy Information Administration's (EIA) latest forecast estimates U.S. thermoelectric generating capacity will grow from approximately 704 GW in 2005 to 872 GW in 2030.[6] As such, thermoelectric power plants may increasingly compete for freshwater with other sectors such as domestic, commercial, agricultural, industrial, and in-stream use – particularly in regions of the country with limited freshwater supplies. In addition, current and future water-related environmental regulations and requirements will also challenge the operation of existing power plants and the permitting of new thermoelectric generation projects.

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[b] Natural gas- and oil-fired combustion turbines are not sources of thermoelectric generation.

[c] Most of today's power plants use water as the cooling medium and the amount of water required to condense the steam turbine exhaust is similar whether an open-loop or closed-loop cooling system is used depending on design conditions. Open-loop cooling systems continuously withdraw water from a local water source, and return the same quantity of water to the source. Closed-loop cooling systems circulate a similar total volume of water as open-loop systems for a given plant size, but only withdraw a limited amount of water to replace evaporative loss and blowdown. Additional information on power plant water requirements can be found beginning on page 11 of this report.

Energy-Water Issues

At the nexus of water and energy lies a wide variety of societal issues, policy and regulatory debate, environmental questions, technological challenges, and economic concerns. Water is emerging as a significant factor in economic development activities. Planning efforts must consider the availability and quality of water resources in a given locality or region to ensure that supplies are available to accommodate existing and future water consumers over the long term. Failure to do so can result in stunted growth, economic flight, inequitable development, and even open conflict. In order for the power industry to be ecologically responsible, technologically ready, and economically stable, advanced research is imperative. Energy-water issues have become increasingly visible in recent years, with a variety of concerns on the mind of industry, regulators, Congress, DOE, and the general public. A sampling of these issues includes the passing of the Energy Policy Act of 2005; repeated introduction of the Energy-Water Efficiency and Supply Technology Bill; increasingly severe regional drought conditions across the country; additional difficulty siting new power generating facilities in arid regions; and further media attention and public concern over water availability and supply. The following is a brief summary of some of the technical, regulatory, and political issues that help explain the importance of water to thermoelectric generation. Additional background information on energy-water issues is presented in Appendix A.

Water Availability

Water shortages, potentially the greatest challenge to face all sectors of the United States in the 21st century, will be an especially difficult issue for thermoelectric generators due to the large amount of cooling water required for power generation. According to a GAO 2003 report[7], national water availability has not been comprehensively assessed in 25 years, thus water availability on a national level is ultimately unknown. However, as the report goes on to say, current trends indicate that demands on the nation's supplies are growing while the nation's capacity to store surface-water is increasingly more limited and ground-water is being depleted.

Water availability issues are intensified by the fact that population increases are occurring in water-stressed areas. Figure 1 shows the percent change in population by state from 1990 to 2000 and Figure 2 displays mean annual precipitation from 1890 to 2002. Comparison of the figures shows that areas where precipitation is low, especially in the southwest, are also areas of greatest population growth.

Figure 1 - Percent Change in Population by State: 1990 to 2000[8]

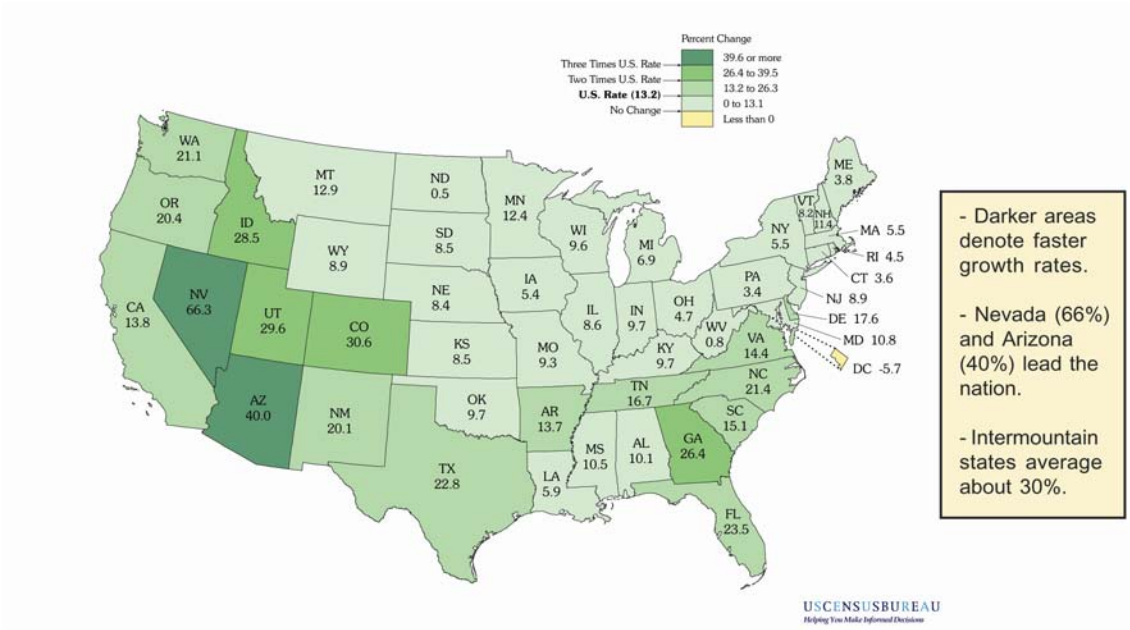
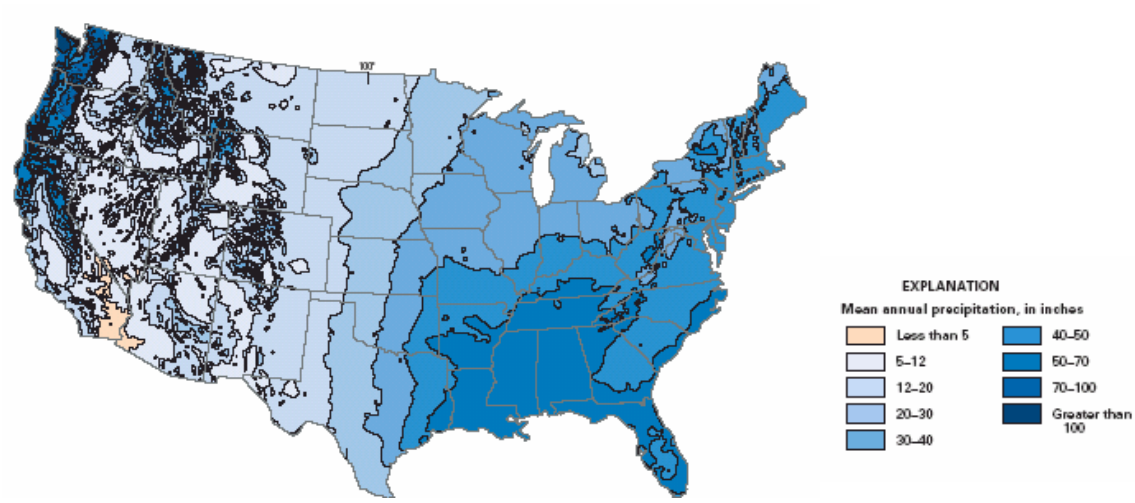


Figure 2 - Mean Annual Precipitation, 1890 to 2002[9,10]



NETL Energy-Water R&D Program

The U.S. Department of Energy, Office of Fossil Energy's National Energy Technology Laboratory (DOE/NETL) is carrying out a comprehensive, integrated research and development (R&D) effort under its Innovations for Existing Plants (IEP) Program. The overall goal of the IEP Program is to enhance the efficiency and environmental performance of the existing fleet of coal-fired power plants, which represent more than 300 gigawatts (GW) of generating capacity, and apply novel concepts to advanced power

systems. The program goal is to ensure that technologies are available for deployment by 2015 that can reduce power plant freshwater withdrawal and consumption by 5% to 10% while minimizing the impacts of power plant operation on water quality. To achieve this goal, the energy-water interface portion of the IEP program conducts research in four areas: Non-Traditional Sources of Process and Cooling Water; Innovative Water Reuse and Recovery; Advanced Cooling Technology; and Advanced Water Treatment and Detection Technology. The portfolio of energy-water nexus technology R&D projects encompasses laboratory studies, modeling, and pre-commercial demonstration full-scale testing. Project success is intimately tied to key collaborations and partnerships with industry, federal, state, and local agencies, and the academic and research communities. This water needs analysis was conducted in support of the IEP energy-water R&D activity.

Previous Water Needs Analysis

In 2004, NETL conducted a similar water needs analysis to estimate how thermoelectric power plants will impact national freshwater resources through 2025. Using the EIA 2004 Annual Energy Outlook's reference case forecast for electricity generating capacity, future freshwater requirements for both total and coal-based thermoelectric generation were estimated and compared to current and past water use by the power sector. A number of different cases were considered to reflect uncertainties about the source of cooling water (fresh or saline) and the cooling technology used by the new and retired capacity projected by EIA.

Case 1 - All additions and retirements occur at facilities using freshwater.
Case 2 - Additions and retirements are proportional to current source withdrawals (70% freshwater/30% saline).
Case 3 - All additions and retirements occur at facilities using saline water.
Case 4 - Additions occur at freshwater facilities, while retirements occur at saline facilities.
Case 5 - Additions occur at saline facilities, while retirements occur at freshwater facilities.
Case 6 - All retired coal units are assumed to be once-through cooling. These units are repowered rather than retired but the existing once-through cooling system continues to be used. New capacity additions are reduced by the repowered units.

The result of these case runs indicated that the amount of freshwater needed to meet forecasted increases in U.S. thermoelectric capacity over the next two decades could increase slightly or decline to some degree in terms of withdrawal. The analysis projected that by 2025 daily freshwater withdrawals required to meet the needs of U.S. thermoelectric power generation could decrease to 113 billion gallon per day (BGD) or increase to 138 BGD depending upon the assumptions made about source of cooling water and type of cooling technology employed for new and retired capacity. This compared with USGS estimates that thermoelectric power plants withdrew approximately 132 BGD of freshwater in 1995 and approximately 136 BGD of freshwater in 2000.

In terms of consumption, several cases projected a large increase on a percentage basis as older once-through cooling plants are replaced by new plants with recirculating cooling systems. The 2004 study projected that by 2025, 3.3 to 8.7 BGD could be consumed compared to USGS estimates that in 1995, freshwater consumption was 3.3 BGD.

The 2006 analysis includes an additional level of detail and resolution that requires a modified methodology from that used in the 2004 analysis. While the 2004 analysis looked at freshwater requirements on a national basis, it was recognized that there are significant regional differences in projected electricity growth and freshwater demand and availability. As a result, the 2006 analysis includes estimates of both national and regional water withdrawal and consumption. In addition, the 2006 analysis utilizes model plants with regionally specific water withdrawal and consumption factors that differentiate coal-fired power plant design parameters including the cooling water system, boiler, and flue gas desulfurization (FGD) system. Table 1 presents a comparison of the major assumptions and methodologies used for the 2004 and 2006 analyses.

Table 1 - U.S. Power Generation Industry Water Withdrawal and Use Analysis – Comparison of Assumptions and Methodologies

Item	2004 Analysis	2006 Analysis
Capacity/Generation Projections	AEO 2004	AEO 2006
Geographical Breakdown	National	National and NERC region
Cooling Water Source Breakdown	Freshwater and Saline	Freshwater and Saline
Cooling Water System Type	Once-through and wet recirculating	Once-through and recirculating (dry, wet, and cooling pond)
Generation Type Breakdown	Total thermoelectric and coal	Total thermoelectric and coal, nuclear, non-coal steam, and natural gas combined cycle
Final Year of Projection	2025	2030
Cases	Six cases representing upper and lower bounds	Five cases with conservative assumptions
Water Use Scaling Factors – Geographic Coverage	National	NERC region with adjustment for capacity factor increase
Water Use Scaling Factors – Coal Plant Design	Not included	Boiler type – subcritical or supercritical FGD type – wet, dry, or none

Water Requirements for Thermoelectric Generation

A significant quantity of water is required for thermoelectric power plants to support electricity generation. The largest demand for water in thermoelectric plants is cooling water for condensing steam. Thermoelectric generation relies on a fuel source (fossil, nuclear, or biomass) to heat water to steam that is used to drive a turbine-generator. Steam exhausted from the turbine is condensed and recycled to a steam generator or

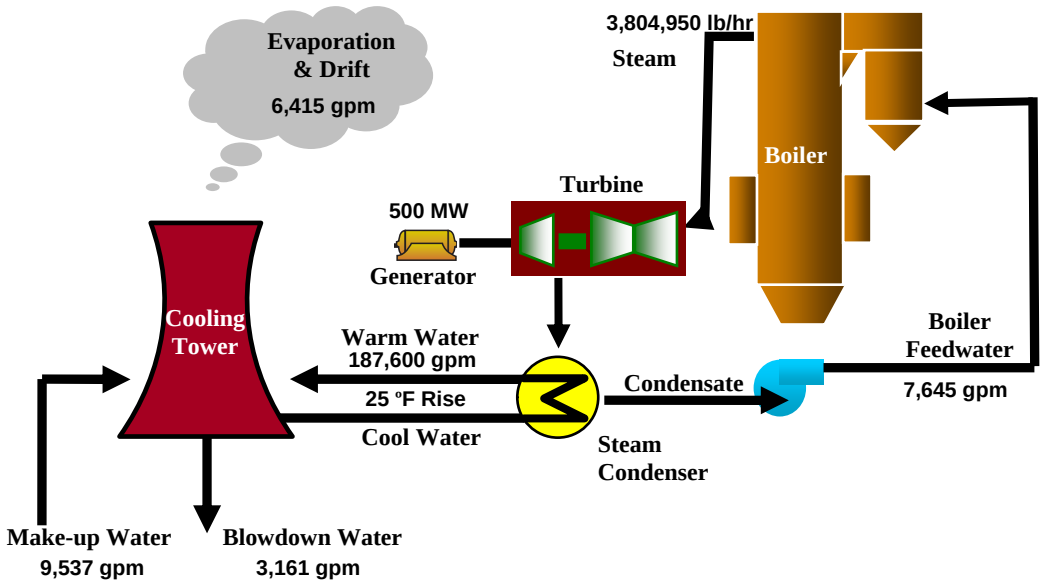
boiler. The steam condensation typically occurs in a shell-and-tube heat exchanger known as a condenser. The steam is condensed on the shell side by the flow of cooling water through tube bundles located within the condenser. Cooling water mass flow rates of greater than 25 times the steam mass flow rate are necessary depending on the allowable temperature rise of the cooling water – typically 15-25°F. The design and operating parameters of the cooling system are critically important to overall power generation efficiency. At higher condenser cooling water inlet temperatures, the steam condensate temperature is higher and subsequently turbine backpressure is higher. The turbine backpressure is inversely related to power generation efficiency: the higher the turbine backpressure, the lower the power generation efficiency.

There are basically two types of cooling water system designs: once-through (open loop) and recirculating (closed loop). In once-through systems, the cooling water is withdrawn from a local body of water such as a lake, river, or ocean and the warm cooling water is subsequently discharged back to the same water body after passing through the condenser. As a result, plants equipped with once-through cooling water systems have relatively high water withdrawal, but low water consumption.

There are three primary technologies used to support recirculating cooling systems – wet cooling towers, cooling ponds, and dry cooling towers. Some plants use a combination of these technologies, known as hybrid cooling systems. The most common type of recirculating system uses wet cooling towers to dissipate the heat from the cooling water to the atmosphere. Figure 3 is a schematic of a wet recirculating cooling water system for a 500-MW coal-fired power plant. In wet recirculating systems the warm cooling water is typically pumped from the condenser to a cooling tower where the heat is dissipated directly to ambient air by evaporation of the water and heating the air. The cooling water is then recycled back to the condenser. Because of evaporative losses, a portion of the cooling water needs to be discharged from the system – known as blowdown − to prevent the buildup of minerals and sediment in the water that could adversely affect performance. For a wet recirculating system, only make-up water needs to be withdrawn from the local water body to replace water lost through evaporation and blowdown. As a result, plants equipped with wet recirculating systems have relatively low water withdrawal, but high water consumption, compared to once-through systems. A cooling pond serves the same purpose as a wet cooling tower, but relies on natural conduction/convection heat transfer from the water to the atmosphere as well as evaporation to cool the recirculating water.

Dry recirculating cooling systems use either direct or indirect air-cooled steam condensers. In a direct air-cooled steam condenser the turbine exhaust steam flows through air condenser tubes that are cooled directly by conductive heat transfer using a high flow rate of ambient air that is blown by fans across the outside surface of the tubes. Therefore, cooling water is not used in the direct air-cooled system. In an indirect air-cooled steam condenser system a conventional water-cooled surface condenser is used to condense the steam, but an air-cooled closed heat exchanger is used to conductively

Figure 3 - Wet Recirculating Cooling Water System for a 500-MW Coal-Fired Boiler



transfer the heat from the water to the ambient air. As a result, there is no evaporative loss of cooling water with an indirect-air dry recirculating cooling system and both water withdrawal and consumption are minimal.

In the United States, existing thermoelectric power plants use each of these types of systems, with estimates indicating that 42.7% of generating capacity is once-through, 41.9% wet recirculating, 0.9% dry cooling, and 14.5% cooling ponds.[11] Table 2 presents a summary of the current percentage distribution of cooling technology by generation type. It should be noted that the data for combined cycle plants represents only about 7% of the total combined cycle plants currently in operation. This is because not all plants provided cooling data, so the table was created using what information was available at the time. If all plants reported cooling data, it is most likely that dry cooling would represent a much smaller percentage of the total combined cycle cooling.

Table 2 - Cooling Technology by Generation Type

Generation Type	Percentage (%)			
	Wet Recirculating	Once-Through	Dry	Cooling Pond
Coal	48.0%	39.1%	0.2%	12.7%
Fossil Non-Coal	23.8%	59.2%	0.0%	17.1%
Combined Cycle	30.8%	8.6%	59.0%	1.7%
Nuclear	43.6%	38.1%	0.0%	18.3%
Total	**41.9%**	**42.7%**	**0.9%**	**14.5%**

Historically, the choice of cooling technology for a particular plant depended on the quantity and quality of local water sources coupled with cost and performance characteristics of the different systems. The use of closed-loop systems, however, is likely to become much more pronounced in the future due to the Clean Water Act 316(b) provisions and public pressures.[d] Although once-through cooling systems can still be legally permitted under 316(b), the complexity of the permitting, analysis and reporting requirements may discourage their use.

Projections of Thermoelectric Capacity and Generation

The EIA publishes its *Annual Energy Outlook* (AEO) to provide a forecast as to where the energy sector will be in the future, including projections of thermoelectric capacity and generation. The AEO projections are based on EIA's National Energy Modeling System (NEMS), which is revised yearly to reflect technology advances, supply and demand adjustments, and other market forces. AEO 2006 projections of capacity and generation to 2030 are used in this analysis to calculate future thermoelectric generation water withdrawal and consumption. Table 3 summarizes projected changes in U.S. electric power generating capacity from 2005 to 2030. Coal-fired generating capacity is projected to increase by 148 GW from 2005 to 2030.

Table 3 - AEO 2006 Thermoelectric Capacity Projections – 2004 to 2030

	2004	2005	2010	2015	2020	2025	2030
Net Generating Capacity							
Coal Steam	309.9	309.3	318.6	319.3	345.3	390.1	457.4
Other Fossil Steam	124.3	122.8	122.4	86.5	80.3	79.3	75.3
Combined Cycle	158.7	171.6	183.8	189.3	213.8	225.7	230.6
Nuclear	99.6	100.1	100.9	104.0	108.8	108.8	108.8
Total Thermoelectric	**692.5**	**703.9**	**725.7**	**699.1**	**748.1**	**803.9**	**872.1**
Cumulative Additions (Planned and Unplanned) - 2005 Baseline							
Coal Steam	0.0	0.4	12.0	16.3	42.2	87.0	154.4
Other Fossil Steam	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Combined Cycle	0.0	13.5	25.7	31.2	55.6	67.6	72.5
Nuclear	0.0	0.0	0.0	2.2	6.0	6.0	6.0
Total Thermoelectric	**0.0**	**14.0**	**37.8**	**49.8**	**103.9**	**160.7**	**233.0**
Cumulative Retirements - 2005 Baseline							
Coal Steam	0.0	0.9	3.0	6.8	6.8	6.8	6.8
Other Fossil Steam	0.0	1.6	2.0	37.9	44.0	45.1	49.0
Combined Cycle	0.0	0.6	0.6	0.6	0.6	0.6	0.6
Nuclear	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Thermoelectric	**0.0**	**3.1**	**5.6**	**45.3**	**51.4**	**52.5**	**56.4**

[d] See Appendix A for more details on CWA 316(b).

AEO 2006 also includes a breakout of thermoelectric capacity and generation by region using the 13 North American Electric Reliability Council (NERC) control regions, excluding Alaska and Hawaii. The NERC regions are shown in Figure 4 and a description of the regional abbreviations is provided in Table 4.

Figure 4 - NERC Regions

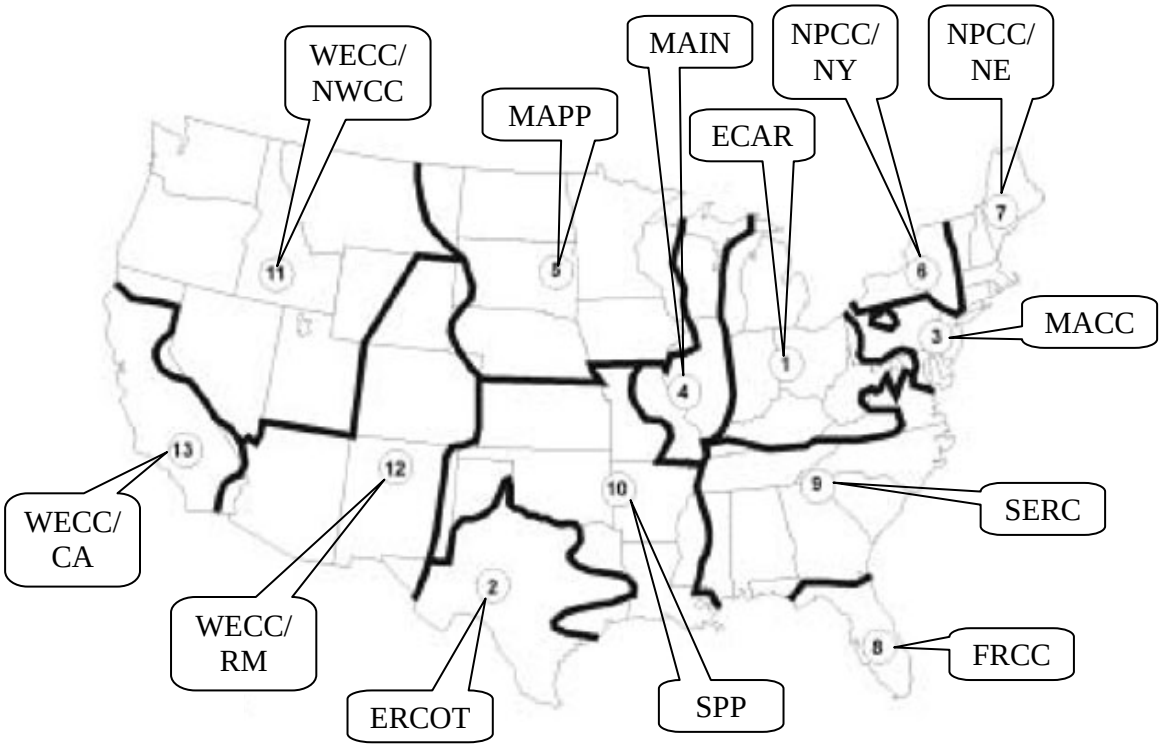


Table 4 – Description of NERC Regions

Region Number	Abbreviation	Region
1	ECAR	East Central Area Reliability Coordination Agreement
2	ERCOT	Electric Reliability Council of Texas
3	MAAC	Mid-Atlantic Area Council
4	MAIN	Mid-America Interconnected Network
5	MAPP	Mid-Continent Area Power Pool
6	NPCC/NY	Northeast Power Coordinating Council/New York
7	NPCC/NE	Northeast Power Coordinating Council/New England
8	FRCC	Florida Reliability Coordinating Council
9	SERC	Southeastern Electric Reliability Council
10	SPP	Southwest Power Pool
11	WECC/NWCC	Western Electricity Coordinating Council/Northwest Power Pool
12	WECC/RM	Western Electricity Coordinating Council/Rocky Mountains, AZ, NM, southern NV
13	WECC/CA	Western Electricity Coordinating Council/California

Figure 5 and 6 show that thermoelectric capacity (GW) and generation (billion kWh) will increase in most of the NERC regions by 2030, reflecting required generation to meet anticipated demand growth. Both capacity and generation growth are presented because the two are not necessarily directly linked. For example, if unutilized capacity exists in a region, generation can increase without a change to capacity. The regions of greatest growth are indicated in the figures, and correspond to the areas where water concerns are growing as well, particularly in the west. The FRCC region and all WECC regions show approximately a 50% increase in thermoelectric generating capacity.

Figure 5 - Thermoelectric Capacity, 2005 vs. 2030, by NERC region

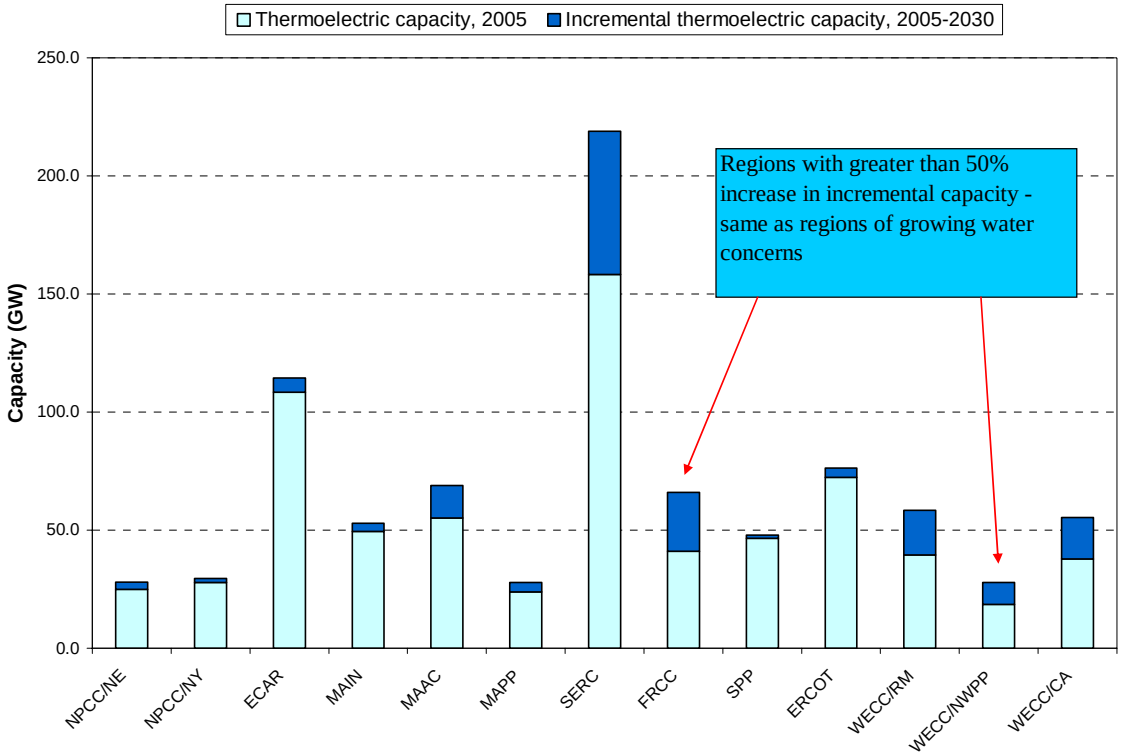


Figure 7 and Figure 8 present the same information for the portion of the total thermoelectric capacity and generation that correspond to coal-fired plants. Coal-fired capacity and generation will also increase in most of the NERC regions by 2030. The regions with growing water concerns are also projected to experience greater than 100% increase in incremental coal capacity.

Figure 6 - Thermoelectric Generation, 2005 vs. 2030, by NERC region

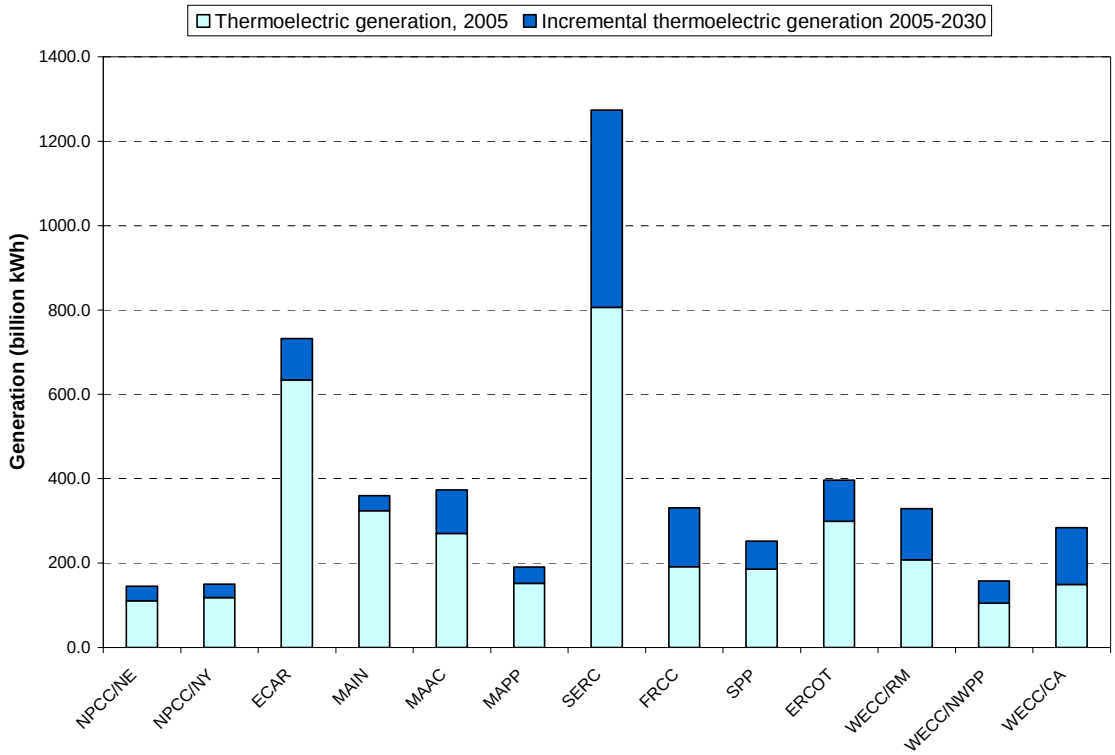


Figure 7 – Coal-Fired Capacity, 2005 vs. 2030, by NERC region

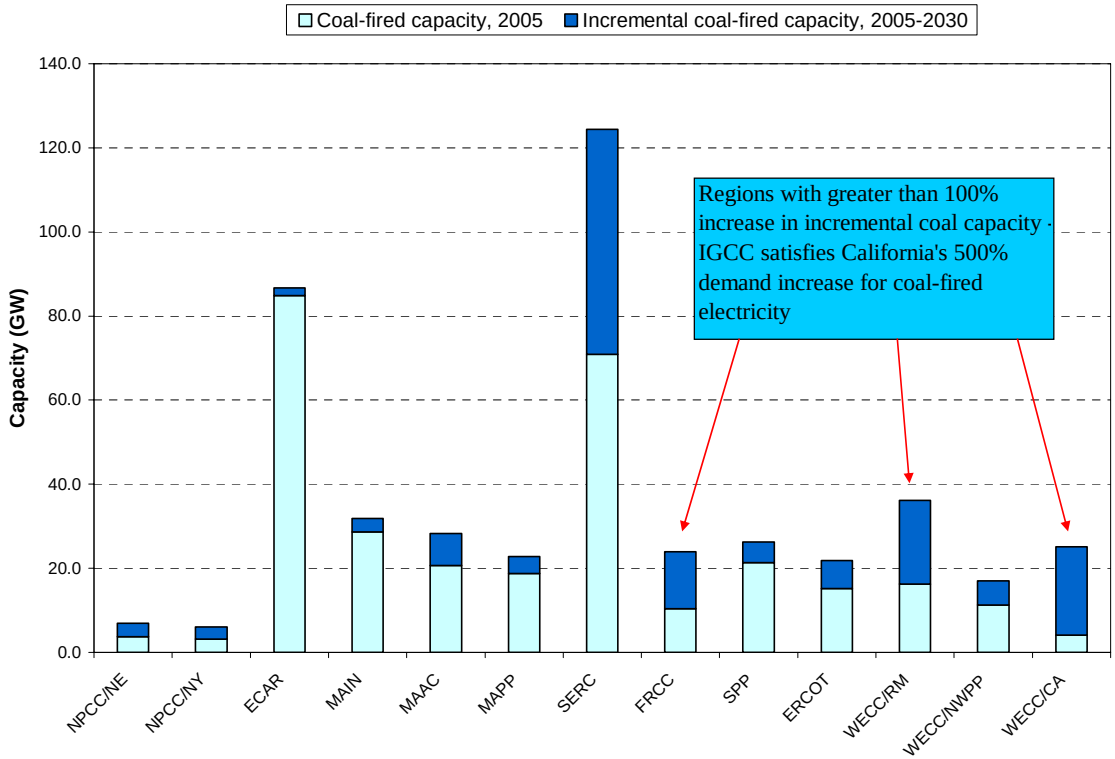
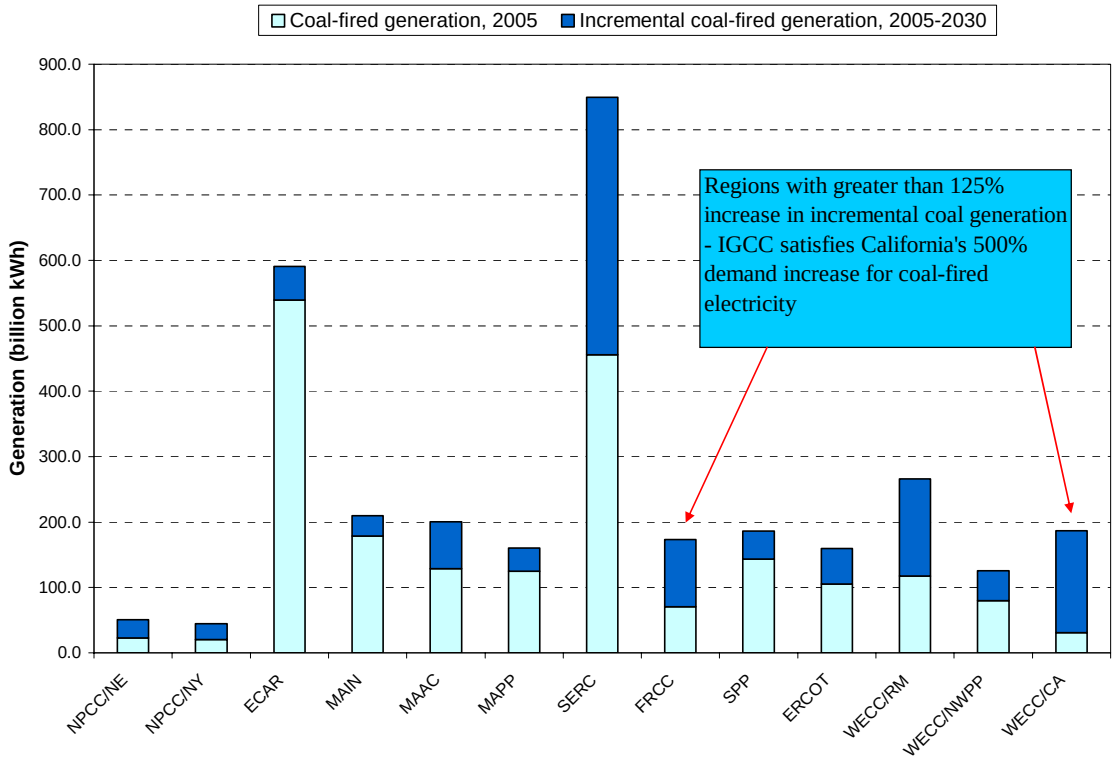


Figure 8 – Coal-Fired Generation, 2005 vs. 2030, by NERC region



Assumptions and Methodology

Using the electricity capacity and generation forecasts provided by AEO 2006 and the water use estimates provided by EIA-767, an estimate of freshwater consumption and withdrawal was obtained for the U.S. thermoelectric power generation industry over the next 25 years. Table 5 lists the resources used for this analysis, and summarizes how each resource supported the analysis.

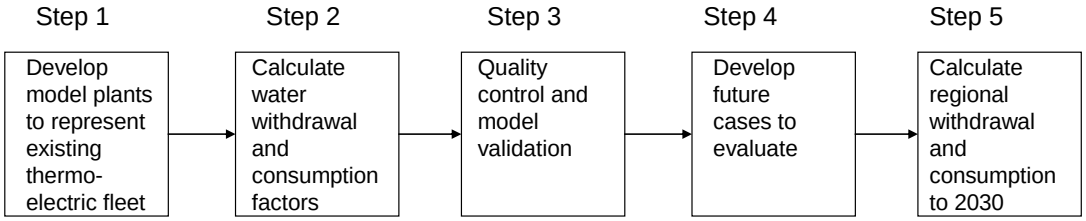
These sources provided data from which water withdrawal and consumption factors (water use scaling factors) could be calculated for a given category of power plant in a given region. The water use scaling factors indicate average rate of water use per unit of electrical output – gallon per hour per kilowatt (gal/kWh).

Figure 9 provides a flowchart depiction of the methodology used to conduct the analysis. A brief description of each step in the process is presented below. A more detailed discussion of the methodology is provided in Appendix B.

Table 5 – Data Resources

Resource	Type of Data
AEO 2006	• Projections of capacity and generation by NERC region for coal, non-coal fossil, and nuclear plants • Coal capacity, generation, and capacity factor breakdown by four categories: existing unscrubbed, existing scrubbed, new PC (scrubbed), and IGCC
NETL 2005 Coal Power Plant Database – Including data from 2003 EIA-767	• Plant generation • Average water withdrawal and consumption • Cooling water source • Type of cooling water system • Type of boiler • Type of FGD system
EIA-860	• Plant location by NERC region • Plant summer capacity
CMU – Integrated Environmental Control Model (IECM)	• Water use factors for wet FGD and dry FGD
Parsons - Power Plant Water Consumption Study, August 2005	• Water use factors for boiler make-up • Water use factors for IGCC plants

Figure 9 - Methodology for the 2006 Water Needs Analysis



Step 1: Develop model plants

To obtain the resolution desired for this analysis, water withdrawal and consumption factors were determined for a large number of plant configurations, based on location, generation type, cooling water source, cooling system type, and where applicable, boiler type and type of FGD system. The existing thermoelectric fleet was segregated into numerous configurations, called "model plants" using data contained in several sources: the NETL Coal Plant Database, EIA-767, and EIA-860.

Fresh versus Saline Water

The analysis focuses on freshwater impacts associated with future thermoelectric power plants. It is recognized that saline water is used at a number of power plants in once-through cooling systems. However, in light of 316(b) regulations for new facilities that favor recirculating systems and siting difficulties for coastal-based power plants, the percentage of saline-based cooling systems at new plants is expected to be relatively

small. Furthermore, no distinction is made between surface and groundwater; both are included as freshwater.

Step 2: Calculate water withdrawal and consumption factors

For each model plant defined in Step 1, water withdrawal and consumption factors were calculated using the data sources outlined above. For coal-fired plants, the water withdrawal and consumption factors were based on the sum of three components: 1) boiler make-up water; 2) FGD make-up water; and 3) cooling water. Average water withdrawal (gal/hr), average water consumption (gal/hr), and summer capacity were used to calculate average withdrawal and consumption scaling factors (gal/kWh) for each model plant in each of the NERC regions. Nuclear, oil steam, gas steam, and natural gas combined-cycle plants were classified according to NERC region, cooling water source (fresh or saline), and cooling water system (recirculating or once-through). A summary of the regional water withdrawal and consumption factors used in the analysis is included in Appendix D.

The following is a brief discussion of the more important assumptions made in calculating the water use factors.

Evaporative Loss Associated with Once-Through Cooling Systems

One important point needs to be made regarding consumption levels for once-through cooling systems. Although once-through consumption levels are extremely small at the plant boundaries, downstream consumption (evaporation) due to the elevated discharge temperature is not insignificant. An Electric Power Research Institute (EPRI) study estimated that once-through consumption levels, when including downstream evaporation, are less than, but of the same magnitude as, wet recirculating cooling system consumption levels.[12] EPRI estimated once-through fossil plant water consumption levels of 300 gal/MWh versus closed-loop water consumption levels of 480 gal/MWh. For nuclear plants, the corresponding numbers are 400 gal/MWh and 720 gal/MWh. However, since this analysis relies on the water withdrawal and consumption data reported by power plants to EIA, it does not account for this downstream evaporative loss.

Subcritical versus Supercritical Boiler for New Coal-Fired Power Plants

The analysis uses different water use scaling factors for coal-fired power plants based on boiler type. A supercritical boiler is more efficient and therefore requires less cooling water flow than a subcritical boiler for an equivalent amount of electrical generation output. Future coal-fired plant capacity is assumed to be split as 70% supercritical and 30% subcritical for the water analysis. Appendix C provides additional background information and justification for this assumption.

Flue Gas Desulfurization Systems for Retrofit and New Coal-Fired Power Plants

The FGD make-up water requirement depends on the type of FGD system – either wet or dry. Dry FGD systems require much less water than wet FGD systems, for example, so different factors were used. The FGD make-up water factors were calculated using

material balance data contained in Carnegie Mellon University's Integrated Environmental Control Model (IECM).[13] The amount of existing non-scrubbed capacity projected to be retrofit with FGD was obtained from EIA based on AEO2006 data. It was further assumed that all new coal-fired plants would be equipped with FGD. Since emission regulations do not dictate technology selection, the analysis apportions FGD type to retrofit and new capacity additions based on the existing split in the coal-fired power fleet (by summer capacity), which is 90% wet/10% dry.

Integrated Gasification Combined Cycle Plants

Water requirements for integrated gasification combined cycle (IGCC) plants were obtained from a study Parsons conducted for DOE/NETL in 2005. Of the several IGCC processes analyzed in the Parsons Study, the Conoco-Phillips E-Gas water withdrawal and consumption estimates were used for this analysis. The water requirements for IGCC facilities differ from those at pulverized coal facilities. While both require cooling water, IGCC requires substantially less since a large fraction of the output from an IGCC plant is produced from the combustion turbines, which require minimal water. Moreover, since IGCC relies on water for significant process (non-cooling) use, it is unlikely that a saline water source would be desirable. The model IGCC coal plant, therefore, is restricted to freshwater use.

Natural Gas Combined Cycle Plants

In calculating water withdrawal and consumption quantities for combined-cycle plants, an adjustment was made to account for the fact that the gas turbine portion of the plant does not require cooling water. The design capacity of the gas turbine portion of a combined-cycle facility is typically twice that of the steam turbine portion; in other words, two-thirds of a combined-cycle plant's total output is derived from the gas turbine(s). Therefore, only about one-third of the plant output is used for steam generation, with its associated water requirements. For this analysis, water withdrawal and consumption factors were applied to only one-third of the combined-cycle capacity. Appendix E provides additional background information and justification for this assumption.

Step 3: Quality Control and Model Validation

Step 3 represents efforts designed to ensure quality control for the analysis. The water withdrawal and consumption factors that were used in the model were obtained through a rigorous statistical evaluation of data from EIA. SPSS statistical software was utilized to generate boxplots of data that were used to identify outliers. These outliers were not considered during the calculation of water withdrawal and consumption factors. The following is a detailed description of the process used to identify outliers.

For each coal, fossil non-coal, and nuclear plant identified in EIA-767, a withdrawal usage factor (gal/MWh) was calculated. The plants were then segregated into the following groups by fuel, cooling system type, and boiler type (where applicable):

- Coal Recirculating Subcritical
- Coal Recirculating Supercritical
- Coal Once-Through Subcritical
- Coal Once-Through Supercritical
- Coal Cooling Pond Subcritical
- Coal Cooling Pond Supercritical
- Fossil Non-Coal Recirculating
- Fossil Non-Coal Once-Through
- Fossil Non-Coal Cooling Pond
- Nuclear Recirculating
- Nuclear Once-Through

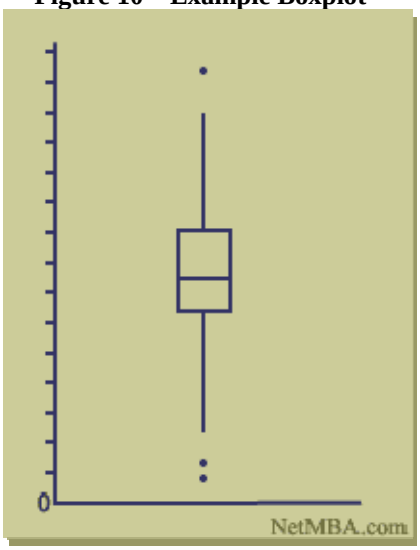
For once-through and cooling pond plants, withdrawal usage factors were multiplied by the corresponding cooling system design temperature rise to normalize the data. For recirculating plants, this step was not taken since the temperature rise would affect the size of the cooling tower, but not the amount of evaporative loss or blowdown that determine the make-up withdrawal rate.

The appropriate data (gal/MWh for recirculating plants and gal/MWh x ΔT for once-through plants) for the above categories was collected and inserted into SPSS to generate boxplots of the data in each of the above categories to identify outliers. An outlier is a data point "far away" from the rest of the data. Some of the water usage data points calculated from the EIA databases were further away from the general data population than what seems reasonable. The outliers can indicate faulty data entry, or possibly unusual operation conditions. For purposes of calculating the regional water usage factors for this study, it was decided to identify and eliminate the statistically significant outliers using the box plot technique described below.

Boxplots are a graphical tool used to identify the center, spread, extent and nature of any departure from symmetry, and outliers contained in a data set. To construct such a plot, data must be ordered in value from smallest to largest. The lower fourth and upper fourth of the data can then be identified. The lower fourth is the median of the smallest n/2 observations when n is even, and the median of the smallest (n+1)/2 observations when n is odd. The upper fourth is the median of the largest n/2 observations when n is even, and the median of the largest (n+1)/2 observations when n is odd. The fourth spread, f_s, is the difference between the upper and lower fourths. Any observation farther than $1.5f_s$ from the closest fourth is a mild outlier while those observations farther than $3f_s$ from the closest fourth are extreme outliers[26].

Figure 10 provides an example of a typical boxplot. In this plot, the upper edge of the box represents the upper fourth, while the lower edge represents the lower fourth. The horizontal line passing through the box indicates the median value of the data. The circles above and below the box indicate outliers while the vertical lines extending above and below the box represent the highest and lowest observations not considered outliers.

Figure 10 – Example Boxplot[27]



Outliers identified by SPSS boxplots were eliminated from the calculation of water usage factors. Table 6 presents the number of data points available as well as the number of outliers identified in each of the 11 categories considered.

Table 6 – Data Points and Outlier Totals for QA/QC Categories

Category	Data Points Available	Outliers Eliminated
Coal Recirculating Subcritical	199	51
Coal Recirculating Supercritical	46	7
Coal Once-Through Subcritical	400	71
Coal Once-Through Supercritical	40	3
Coal Cooling Pond Subcritical	62	0
Coal Cooling Pond Supercritical	9	4
Fossil Non-Coal Recirculating	88	34
Fossil Non-Coal Once-Through	289	55
Fossil Non-Coal Cooling Pond	6	0
Nuclear Recirculating	39	7
Nuclear Once-Through	55	9

Appendix F presents SPSS boxplots generated from the original data for each of the above categories as well as boxplots generated after outliers were eliminated from the data set.

To ensure that the estimates generated by the water needs analysis model were reasonable, the 2006 projections were compared to the 2004 analysis results. This comparison is presented in the results section. Since the 2004 projections are based on USGS data, comparing the 2006 results with those of the 2004 study serves to provide corroboration with USGS data.

Step 4: Develop Future Cases

Future water withdrawal and consumption for the U.S. thermoelectric generation sector are estimated for five cases – one reflecting status quo conditions, two reflecting varying levels of regulations regarding cooling water source, one incorporating dry cooling, and one reflecting regulatory pressures to convert existing once-through capacity to recirculating capacity. Table 7 presents the description and rationale for the five selected cases.

Table 7 – Case Descriptions for 2006 Water Needs Analysis

Case Description	Rationale
Case 1: Additions and retirements proportional to current water source and type of cooling system.	Status quo scenario case. Assumes additions and retirements follow current trends.
Case 2: All additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system.	Regulatory-driven case. Assumes 316(b) and future regulations dictate the use of recirculating systems for all new capacity. Retirement decisions hinge on age and operational costs rather than water source and type of cooling system.
Case 3: 90% of additions use freshwater and wet recirculating cooling, and 10% of additions use saline water and once-through cooling, while retirements are proportional to current water source and cooling system.	Regulatory-light case. New additions favor the use of freshwater recirculating systems, but some saline capacity is permitted. Retirement decisions remain tied to age and operational costs, tracking current source withdrawals.
Case 4: 25% of additions use dry cooling and 75% of additions use freshwater and wet recirculating cooling. Retirements are proportional to current water source and cooling system.	Dry cooling case. Regulatory and public pressures result in significant market penetration of dry cooling technology. Retirement decisions remain tied to age and operational costs, tracking current source withdrawals.
Case 5: Additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system. 5% of existing freshwater once-through cooling capacity retrofitted with wet recirculating cooling every 5 years starting in 2010.	Conversion case. Same as Case 2, except regulatory and public pressures compel state agencies to dictate the conversion of a significant amount of existing freshwater once-through cooling systems to wet recirculating.

The five cases were selected to cover the range of possible design choices for new power plants including the source of water (fresh or saline) and type of cooling system (wet recirculating or dry). In addition, Case 5 assumes that 25% of existing power plants with a once-through cooling system are retrofit with a wet recirculating system. For all five cases, it is assumed that plant retirements occur proportional to current water source and cooling system type. A comparison of these cases with those used in the 2004 Water Needs Analysis can be found in Appendix B.

Step 5: Calculate regional withdrawal and consumption to 2030

Step 5 integrates the water withdrawal and consumption factors calculated in Step 2 with the various cases defined in Step 4 to assess the regional and national impacts on water withdrawal and consumption out to 2030. The *Annual Energy Outlook* provides projections of future electricity generating capacity by year, by generation type and by NERC region. Apportioning this capacity among the chosen model plants for a given case and then applying the water withdrawal and consumption factors enabled the calculation of estimated water withdrawal and consumption trends for each of the five future cases.

Results

Water withdrawal and consumption projections for each of the five cases are presented below both nationally and regionally for total thermoelectric generation and the coal-fired generation component of thermoelectric generation.

Thermoelectric Generation - National

The analysis projects that by 2030, average daily national freshwater withdrawals required to meet the needs of U.S. thermoelectric power generation could range from 148.4 BGD to 103.7 BGD depending upon case assumptions. This compares with USGS estimates that thermoelectric power plants withdrew approximately 132 BGD of freshwater in 1995 and approximately 136 BGD of freshwater in 2000. Table 8 presents the range of average daily national freshwater withdrawal for each of the five cases from 2005 through 2030. This same data is presented graphically in Figure 11.

Table 8 – Average National Freshwater Withdrawal for Thermoelectric Power Generation (BGD)

	2005	2010	2015	2020	2025	2030
Case 1	149.2	152.7	145.6	147.6	148.8	148.4
Case 2	149.2	149.4	141.0	138.6	138.0	136.3
Case 3	149.2	149.4	140.9	138.5	137.9	136.1
Case 4	149.2	149.3	140.8	138.3	134.8	135.8
Case 5	149.2	137.7	122.7	114.2	109.4	103.7
Maximum	149.2	152.7	145.6	147.6	148.8	148.4
Minimum	149.2	137.7	122.7	114.2	109.4	103.7

The analysis projects that by 2030, average daily national freshwater consumption resulting from U.S. thermoelectric power generation could range from 7.8 BGD to 9.2 BGD depending upon case assumptions. This compares with USGS estimates that in 1995, freshwater consumption by U.S. thermoelectric power plants was approximately 3.3 BGD. Table 9 presents the range of average daily national freshwater consumption for each of the five cases from 2005 through 2030. This same data is presented graphically in Figure 12.

Figure 11 – Average Daily National Freshwater Withdrawal for Thermoelectric Power Generation

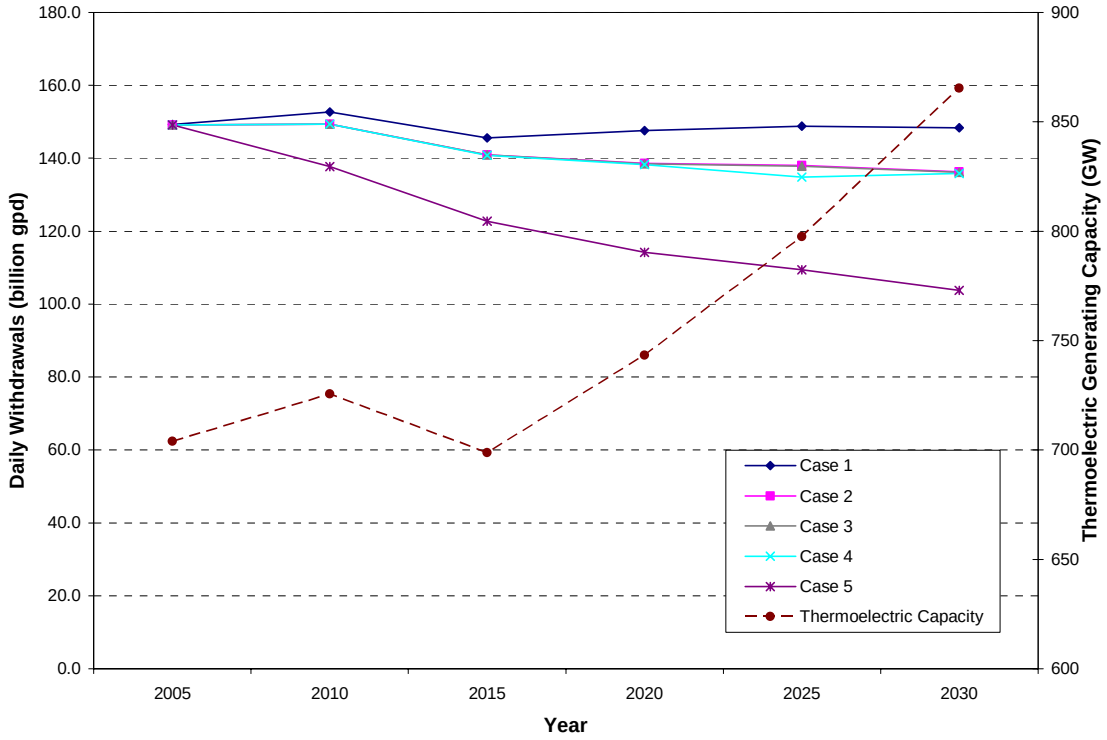


Table 9 – Average National Freshwater Consumption for Thermoelectric Power Generation (BGD)

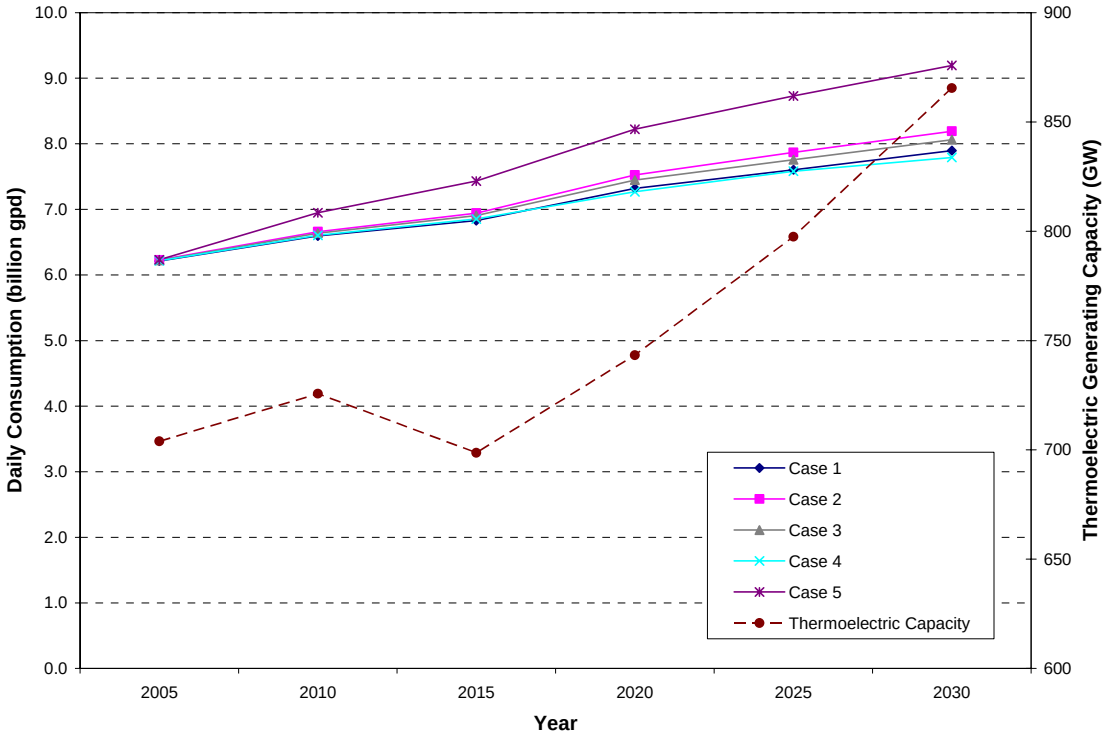
	2005	2010	2015	2020	2025	2030
Case 1	6.2	6.6	6.8	7.3	7.6	7.9
Case 2	6.2	6.7	6.9	7.5	7.9	8.2
Case 3	6.2	6.6	6.9	7.4	7.8	8.1
Case 4	6.2	6.6	6.9	7.3	7.6	7.8
Case 5	6.2	6.9	7.4	8.2	8.7	9.2
Maximum	6.2	6.9	7.4	8.2	8.7	9.2
Minimum	6.2	6.6	6.8	7.3	7.6	7.8

National Level Results

Case 1

Total thermoelectric generation freshwater withdrawal is projected to remain relatively constant from 2005 through 2030 for Case 1 – decreasing slightly from 149.2 BGD to 148.4 BGD – despite the overall 23% increase in generation capacity from 704 GW to 865 GW. At first glance this result seems inconsistent with the Case 1 status quo assumptions that additions and retirements are proportional to current water source and type of cooling water system. The explanation for this apparent inconsistency is that AEO2006 projects capacity retirements primarily from the non-FGD coal and non-coal

Figure 12 – Average Daily National Freshwater Consumption for Thermoelectric Power Generation

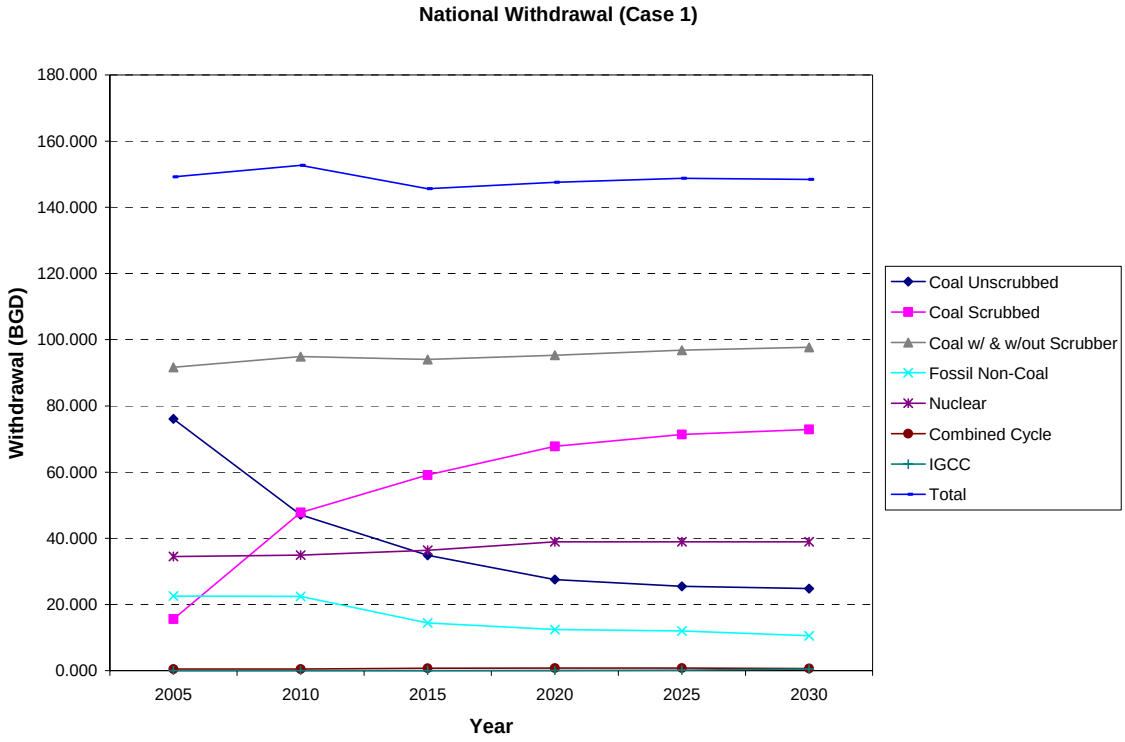


fossil generation categories, which have a relatively high proportion of once-through cooling systems, while capacity additions are primarily in the FGD coal, IGCC, and NGCC generation categories, which have a relatively high proportion of wet recirculating cooling systems. In addition, the steam cycle portion of IGCC and NGCC plants is only one-third of their total capacity. Since average freshwater withdrawal for once-through cooling is significantly higher than wet recirculating cooling – approximately 25 gal/kWh versus 0.5 gal/kWh – the net effect is no significant change in overall freshwater withdrawal over the next 25 years.

National freshwater withdrawal for each fuel type in Case 1 is presented in Figure 13. The figure shows the relatively unchanged total withdrawal, and the mirroring of scrubbed and unscrubbed coal (with scrubbed increasing over time as unscrubbed decreases). There is a slight decrease in fossil non-coal withdrawal and a slight increase in nuclear withdrawal.

Total thermoelectric generation freshwater consumption is projected to increase 27% from 2005 through 2030 for Case 1 – growing from 6.2 BGD to 7.9 BGD – consistent with the increase in generation capacity from 704 GW to 865 GW. Since once-through cooling systems have minimal water consumption, the retirement of these systems does not have the same effect on national consumption levels as they do on withdrawal levels as described above.

Figure 13 - Average Daily National Freshwater Withdrawal by Fuel for Thermoelectric Power Generation – Case 1

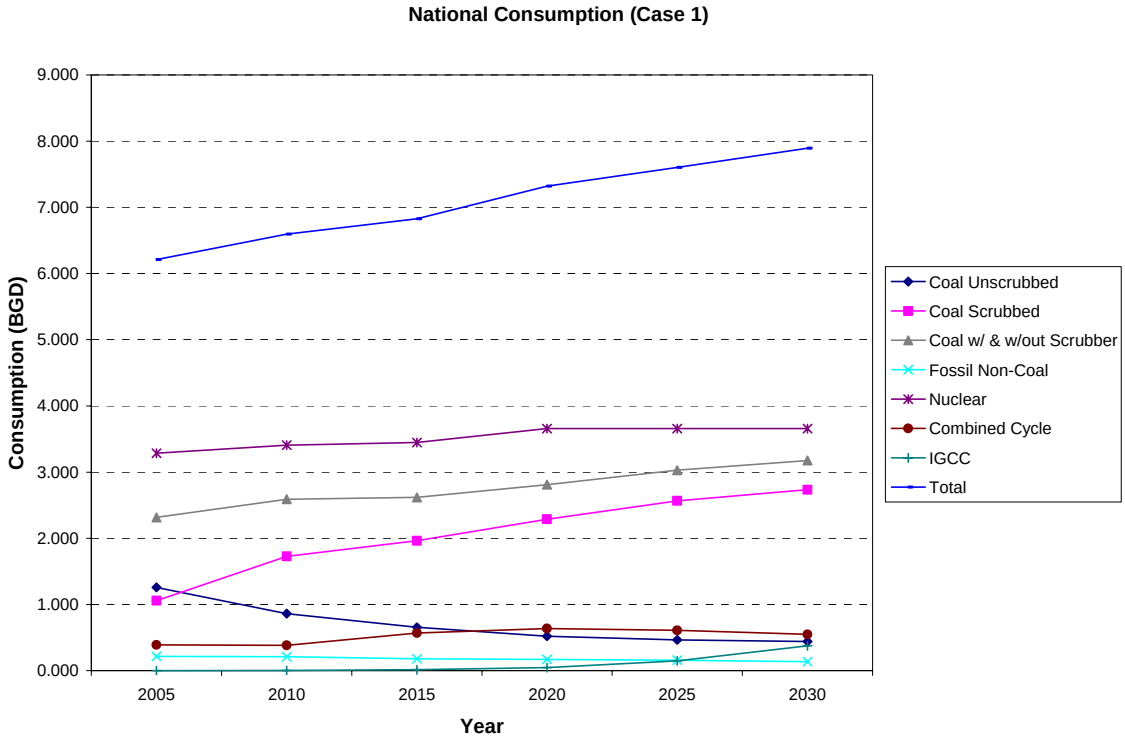


The changes in results over time reveal some interesting trends. Although total water withdrawal declines slightly between 2005 and 2030, the decline is not uniform. Between 2005 and 2010, in fact, water withdrawal increases from 149.2 BGD to 152.7 BGD, before falling off to 145.6 BGD by 2015. The initial increase is due to new coal and combined-cycle additions (more than 20 GW), while the subsequent decline is due to significant retirement of fossil non-coal capacity (more than 35 GW). This difference appears in the other cases as well, although to a lesser degree because of competing influences unique to each specific case.

The growing importance of IGCC technology is evident in the results over time. From a level of less than 500 MW in 2005, IGCC is expected to account for almost 85 GW by 2030. While this capacity impact is quite large, the water impact is remarkably small – due primarily to the assumption that all new IGCC capacity will be equipped with wet recirculating cooling. In 2030, water withdrawal for IGCC is only 0.49 BGD and water consumption is 0.374 BGD.

National freshwater consumption for each fuel type in Case 1 is presented in Figure 14. The effects of increased use of NGCC and IGCC can more clearly be seen in the consumption graph than in the previous withdrawal graph. Consumption increases for each fuel type except unscrubbed coal and fossil non-coal, which decrease.

Figure 14 - Average Daily National Freshwater Consumption by Fuel for Thermoelectric Power Generation – Case 1



Case 2

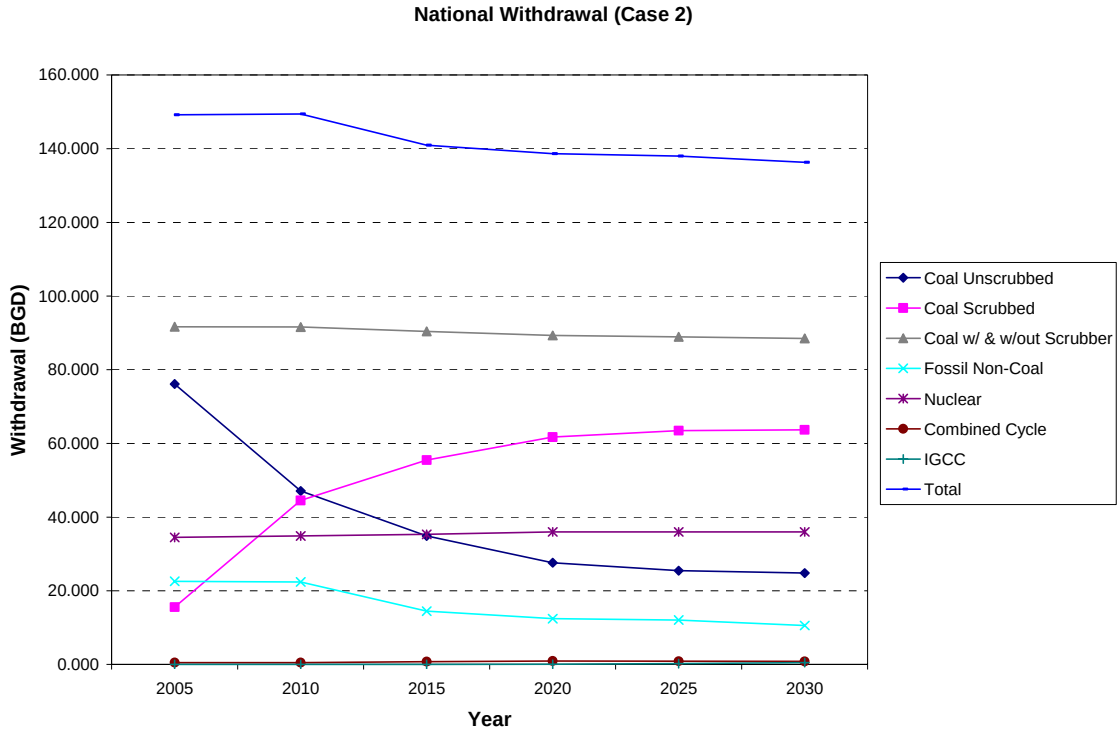
Total thermoelectric generation freshwater withdrawal is projected to decrease approximately 9% (149.2 BGD to 136.3 BGD) from 2005 through 2030 for Case 2. This trend is consistent with the assumptions that all capacity additions use freshwater and wet recirculating cooling systems, while capacity retirements are proportional to current water source and type of cooling water system.

Figure 15 displays Case 2 national withdrawal for each fuel type. The decrease in total withdrawal can be seen along with a decrease in fossil non-coal and a slight decrease on the line representing the combination of scrubbed and unscrubbed coal. Again scrubbed coal increases, while unscrubbed decreases.

Similar to Case 1, total thermoelectric generation freshwater consumption is projected to increase – growing 32% from 6.2 BGD to 8.2 BGD between 2005 and 2030 – consistent with both the 23% increase in generation capacity and increased use of wet recirculating cooling water systems.

Figure 16 displays Case 2 national consumption for each fuel type. Consumption increases are seen in every fuel type except unscrubbed coal and fossil non-coal, which decrease.

Figure 15 - Average Daily National Freshwater Withdrawal by Fuel for Thermoelectric Power Generation – Case 2



Case 3

The Case 3 assumptions are similar to Case 2, except that 90% of capacity additions use freshwater and wet recirculating cooling and 10% use saline water with once-through cooling. As might be expected, both thermoelectric generation freshwater withdrawal and consumption levels for Case 3 are slightly less than the respective values from Case 2. In 2030, freshwater withdrawal is 136.3 BGD in Case 2 compared to 136.1 in Case 3. Similarly, freshwater consumption in 2030 is 8.2 BGD and 8.1 BGD for Cases 2 and 3, respectively.

National freshwater withdrawal for each fuel type in Case 3 is presented in Figure 17. As the figure shows, total withdrawal decreases over time. Fossil non-coal and coal unscrubbed also display a noticeable decrease. National freshwater consumption for each fuel type in Case 3 is presented in Figure 18. Freshwater consumption is shown to increase over time. As with previous consumption cases, only coal unscrubbed and fossil non-coal consumption decreases from 2005 to 2030.

Figure 16 - Average Daily National Freshwater Consumption by Fuel for Thermoelectric Power Generation – Case 2

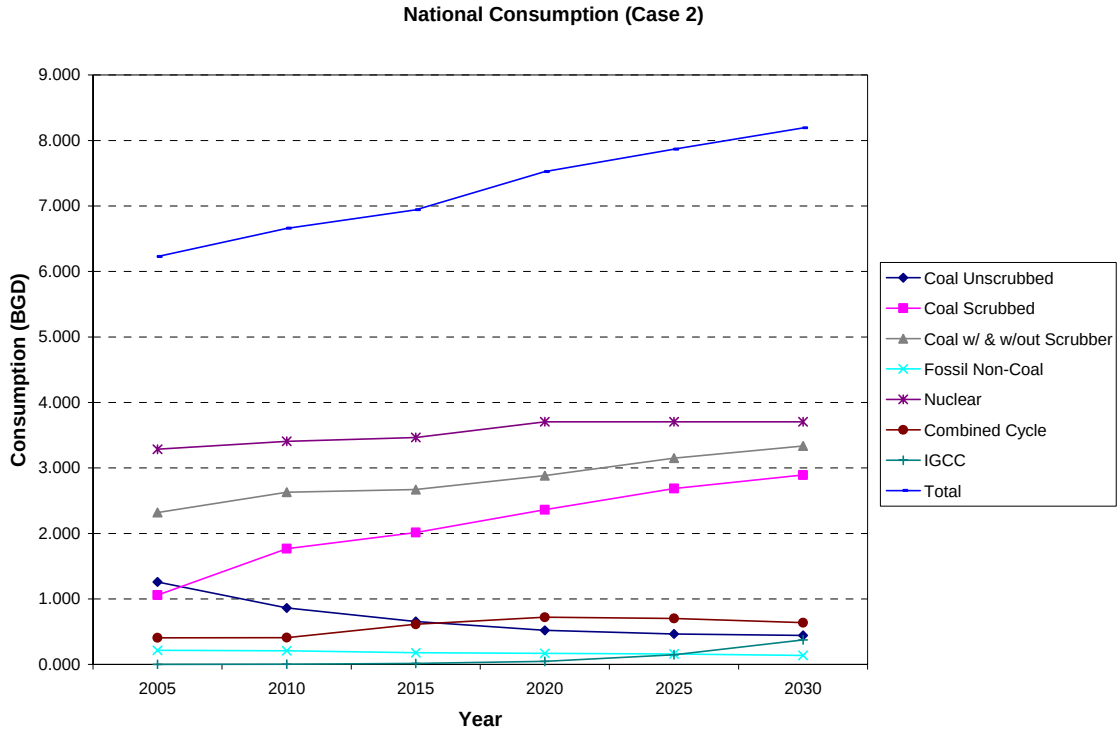


Figure 17 - Average Daily National Freshwater Withdrawal by Fuel for Thermoelectric Power Generation – Case 3

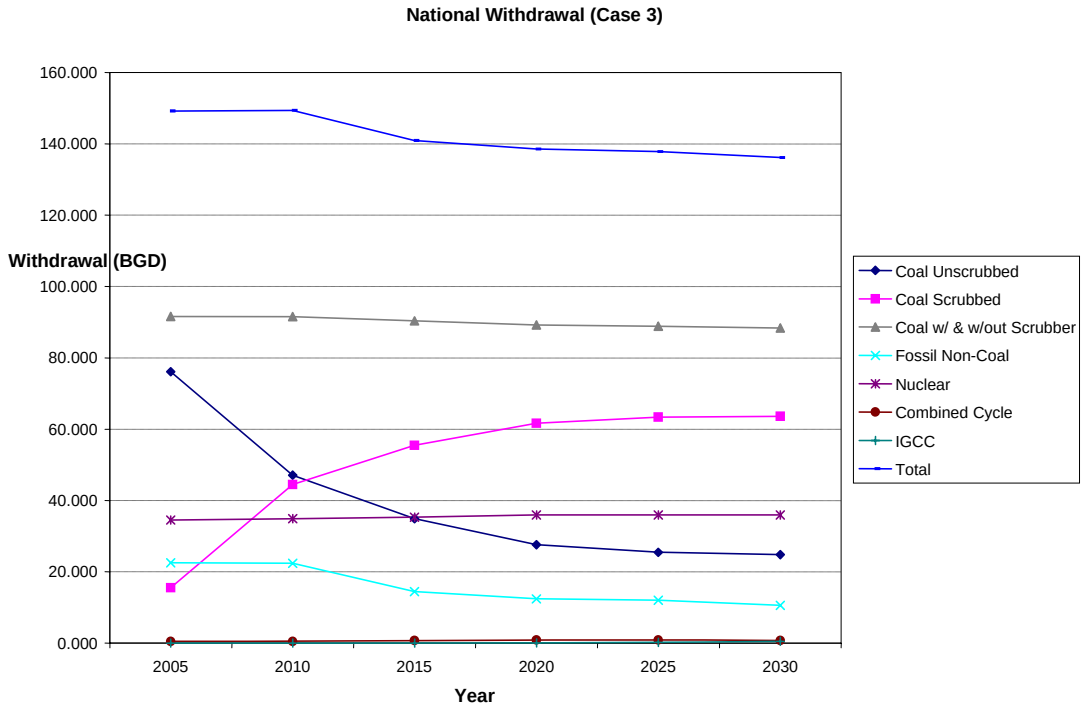
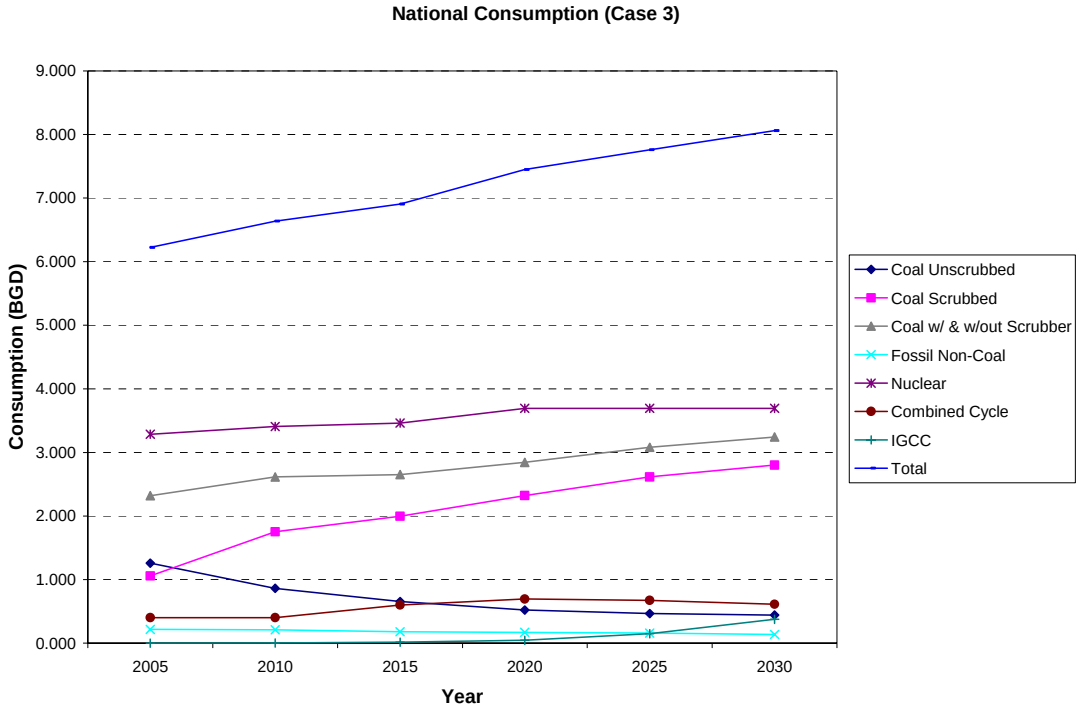


Figure 18 - Average Daily National Freshwater Consumption by Fuel for Thermoelectric Power Generation – Case 3



Case 4

The potential impact of dry cooling systems on water demand is evident in the results of Case 4, where 25% of new capacity is assumed to be equipped with dry cooling, rather than wet recirculating cooling. Thermoelectric generation freshwater withdrawal and consumption levels for Case 4 are less than the respective values from Case 2. By 2030, freshwater withdrawal is projected to be approximately 1% less in Case 4 compared to Case 2 – 135.4 BGD vs. 136.3 BGD. More significantly, freshwater consumption is projected to be approximately 9% less – 7.5 BGD in Case 4 vs. 8.2 BGD in Case 2. The results suggest that dry cooling has the potential to play a significant roll in minimizing freshwater consumption in future years if technology is developed to cost effectively build and operate dry cooling plants.

Figure 19 displays Case 4 national withdrawal for each fuel type. The total freshwater withdrawal decreases over time, as does coal unscrubbed, fossil non-coal, and the line representing the combination of scrubbed and unscrubbed coal.

Figure 20 displays Case 4 national consumption for each fuel type. Total consumption is shown to increase from 2005 to 2030, with only coal unscrubbed and fossil non-coal decreasing during that period.

Figure 19 - Average Daily National Freshwater Withdrawal by Fuel for Thermoelectric Power Generation – Case 4

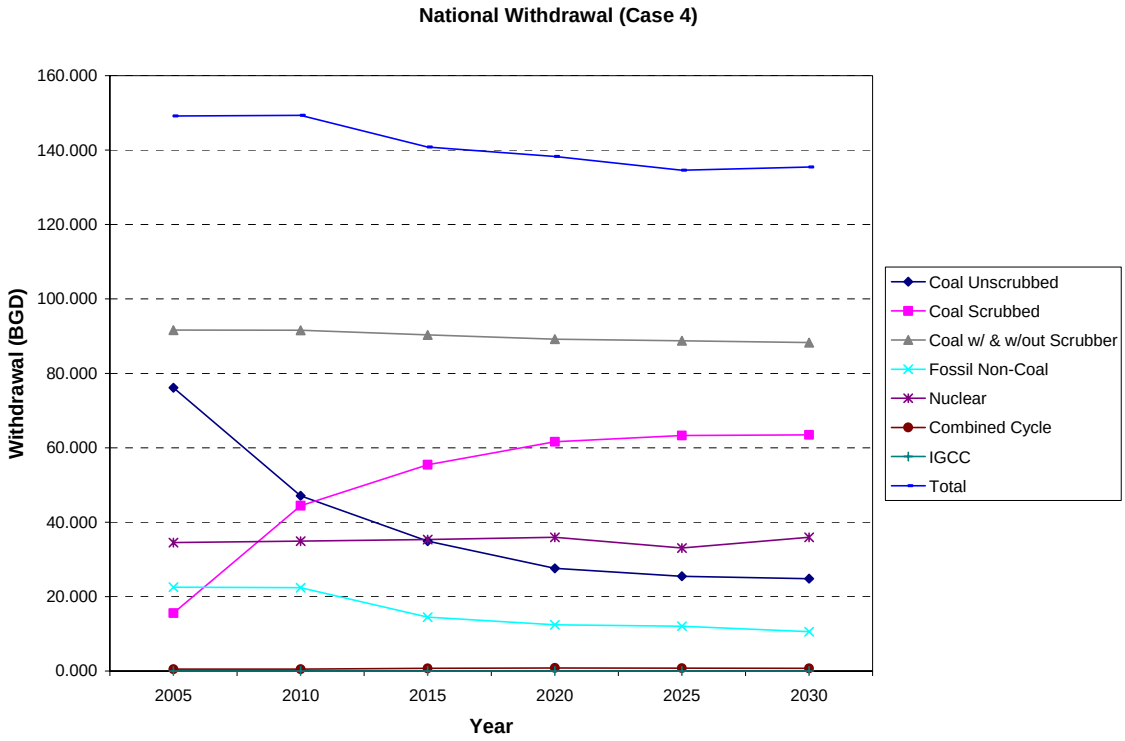
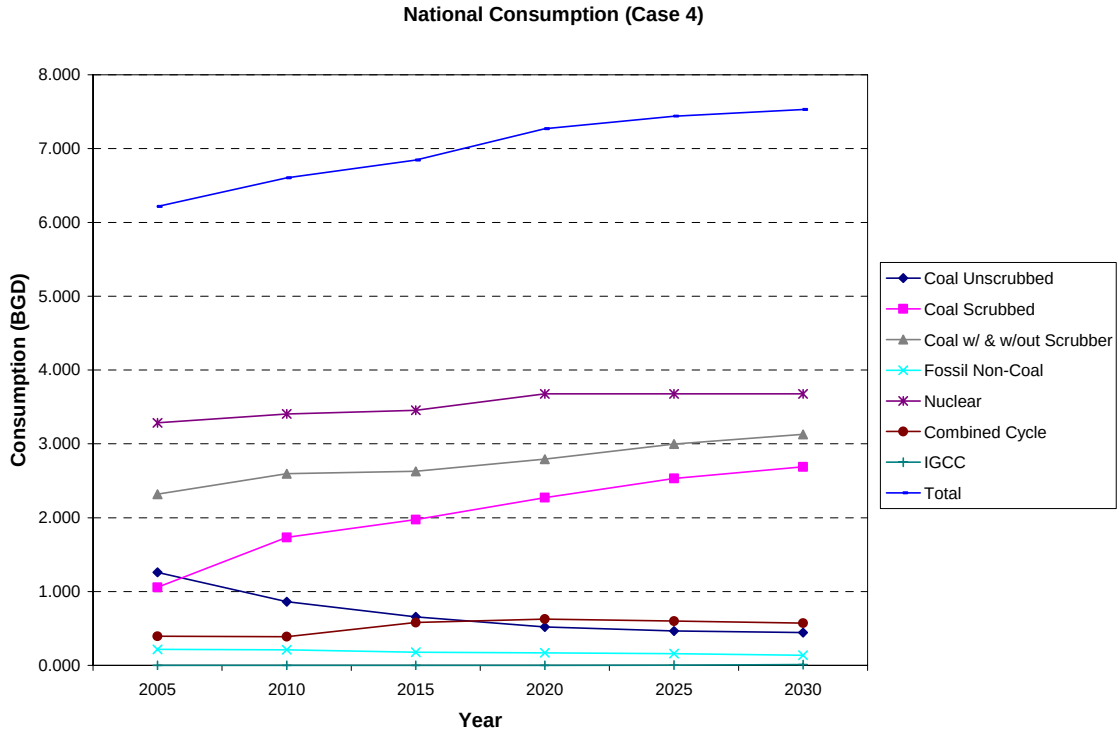


Figure 20 - Average Daily National Freshwater Consumption by Fuel for Thermoelectric Power Generation – Case 4



Case 5

The Case 5 assumptions for capacity additions and retirements are the same as Case 2. However, Case 5 also assumes that 25% of existing freshwater once-through cooling capacity is converted to wet recirculating cooling. As a result, Case 5 represents the most extreme conditions of the analysis and significantly impacts projections for both freshwater withdrawal and consumption. By 2030, total thermoelectric generation freshwater withdrawal is projected to be approximately 24% less in Case 5 compared to Case 2 – 103.7 BGD vs. 136.3 BGD – while consumption is projected to be approximately 12% more – 9.2 BGD in Case 5 vs. 8.2 BGD in Case 2.

National freshwater withdrawal for each fuel type in Case 5 is presented in Figure 21. Total freshwater withdrawal decreases over time, as does withdrawal for all fuel types except scrubbed coal (which increases as unscrubbed coal decreases). National freshwater consumption for each fuel type in Case 5 is presented in Figure 22. As with previous consumption cases, total freshwater consumption increases and unscrubbed coal and fossil non-coal are the only fuel types shown to decrease.

Thermoelectric Generation - Regional

Figures 23-27 show the results of the regional water withdrawal analysis for total U.S. thermoelectric generation comparing 2005 to 2030 for each of the five cases. The graphs show that aside from Case 1, where the water withdrawal of the SERC region increases, the ECAR, SERC, and ERCOT regions experience the largest decreases in water withdrawal in each case. Figures 28-32 show the results of the regional water consumption analysis for total U.S. thermoelectric generation comparing 2005 to 2030 for each of the five cases. Inverse to the water withdrawal regional data, the regional consumption graphs indicate that the ECAR, SERC, and ERCOT regions, along with the western regions WECC/CA, WECC/NWPP, and WECC/RM are all increasing water consumption significantly.

Case 1

As discussed previously, total thermoelectric generation freshwater withdrawal is projected to remain relatively constant from 2005 through 2030 for Case 1 – decreasing slightly from 149.2 BGD to 148.4 BGD On a regional basis, freshwater withdrawal increases in the MAIN, MAPP, SERC, FRCC, WECC/NW, and WECC/CA regions. Decreases occurred in all other regions, with the most significant decreases in the ECAR and ERCOT regions (Figure 23).

Total thermoelectric generation freshwater consumption is projected to increase 27% from 2005 through 2030 for Case 1 – growing from 6.2 BGD to 7.9 BGD. Freshwater consumption increases in all of the regions, with relatively large percentage increases occurring in the NPCC/NY (130%), FRCC (121%), WECC/RM (82%), and WECC/CA (298%) regions (Figure 28).

Figure 21 - Average Daily National Freshwater Withdrawal by Fuel for Thermoelectric Power Generation – Case 5

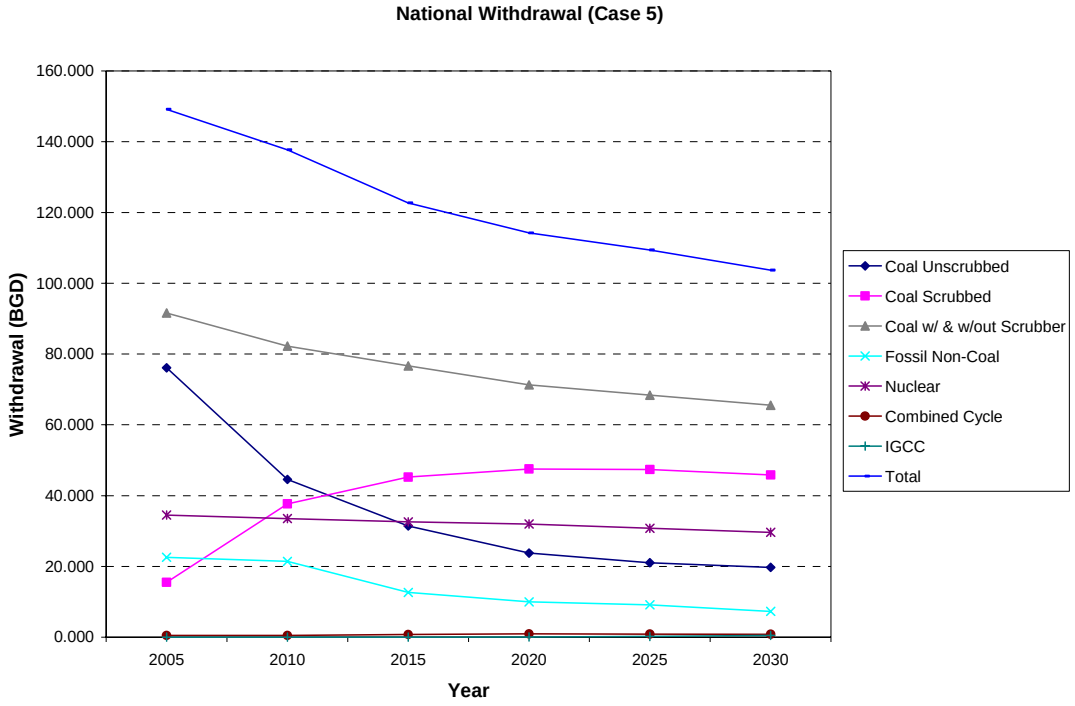


Figure 22 - Average Daily National Freshwater Consumption by Fuel for Thermoelectric Power Generation – Case 5

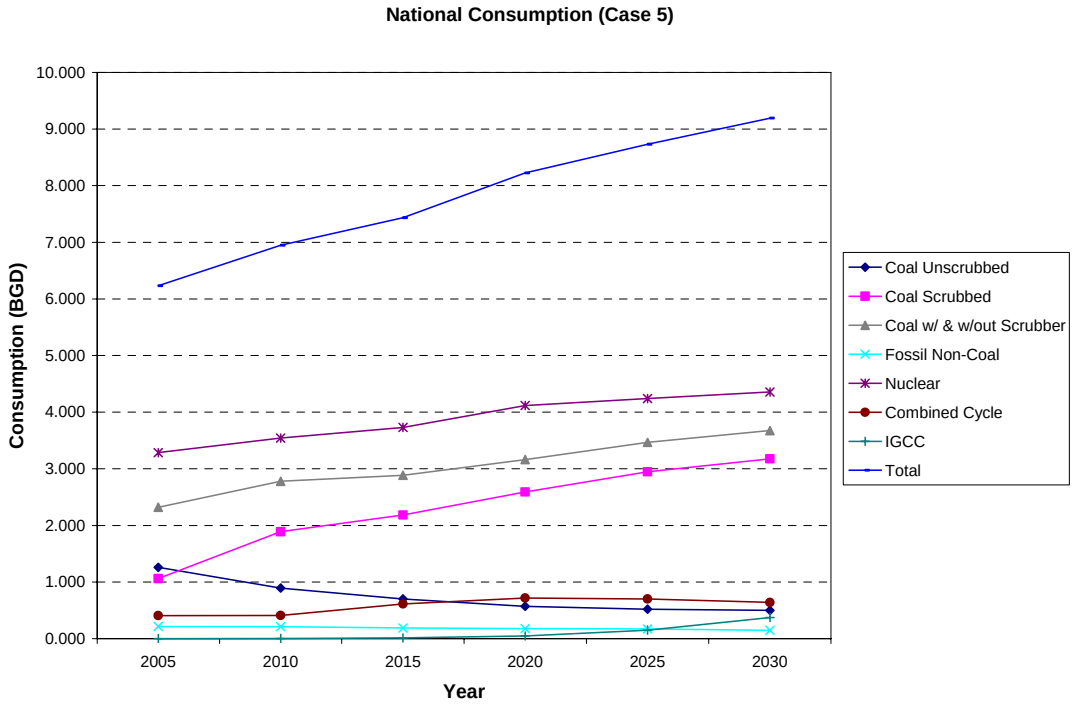


Figure 23 – Average Daily Regional Freshwater Withdrawal for Thermoelectric Power Generation – Case 1

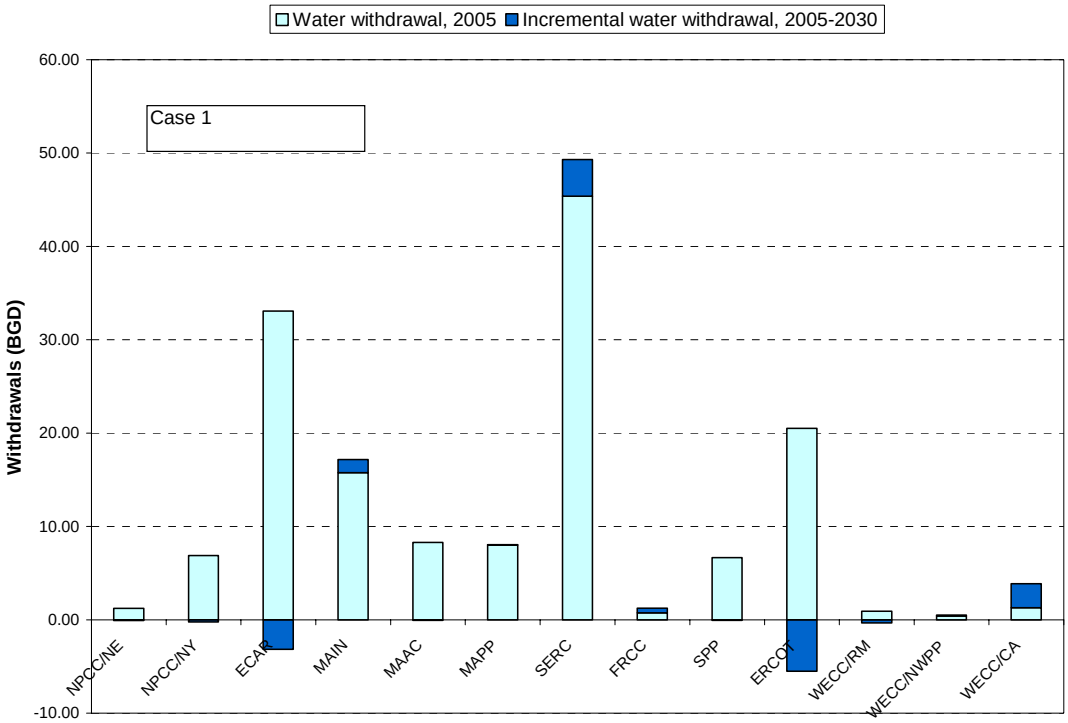


Figure 24 – Average Daily Regional Freshwater Withdrawal for Thermoelectric Power Generation – Case 2

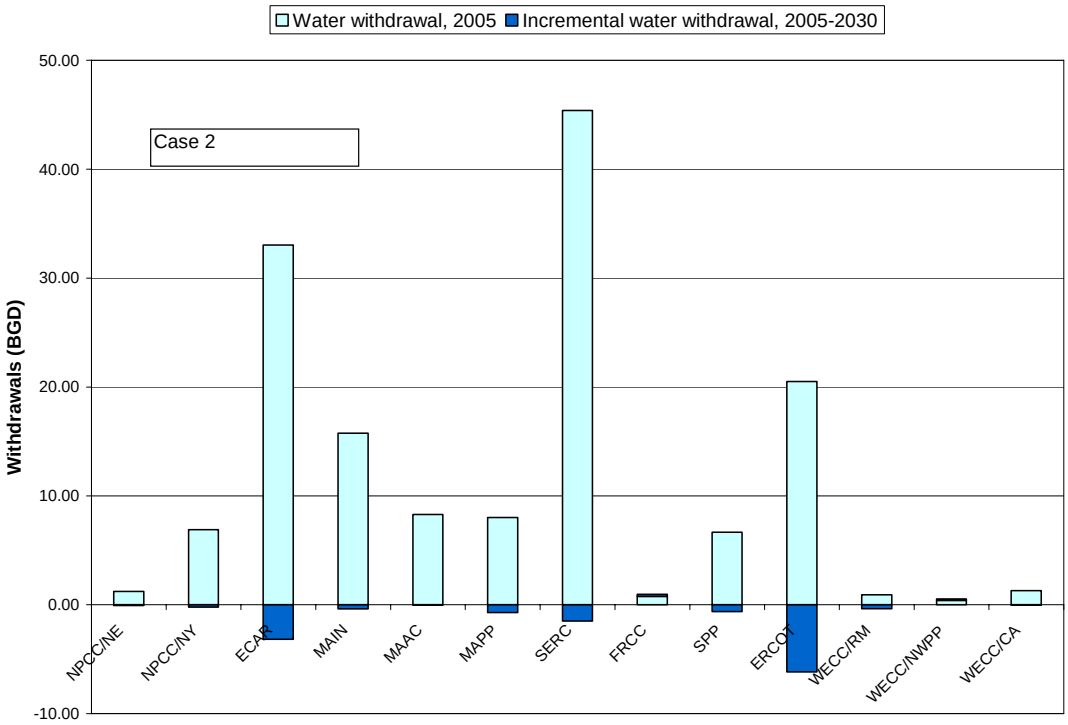


Figure 25 – Average Daily Regional Freshwater Withdrawal for Thermoelectric Power Generation – Case 3

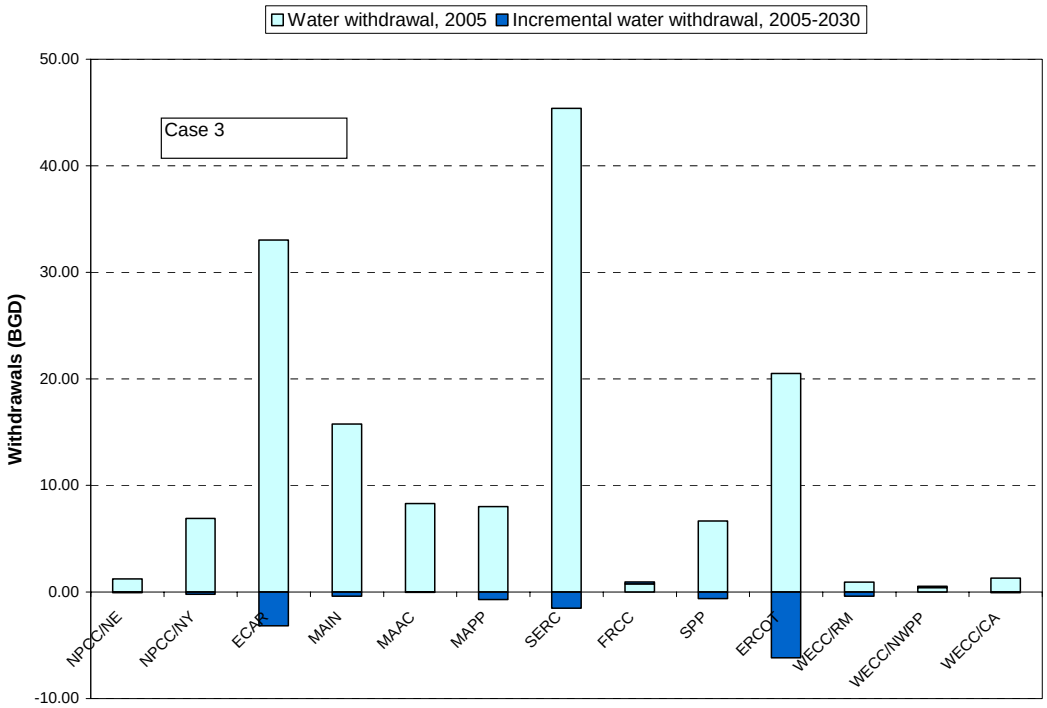


Figure 26 – Average Daily Regional Freshwater Withdrawal for Thermoelectric Power Generation – Case 4

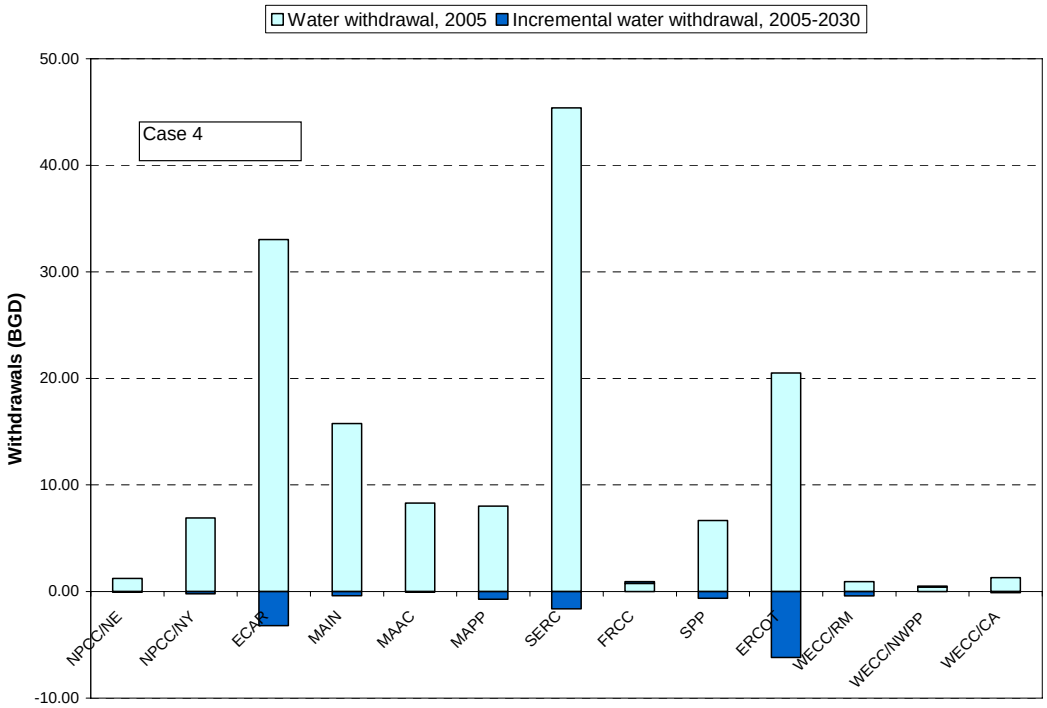


Figure 27 – Average Daily Regional Freshwater Withdrawal for Thermoelectric Power Generation – Case 5

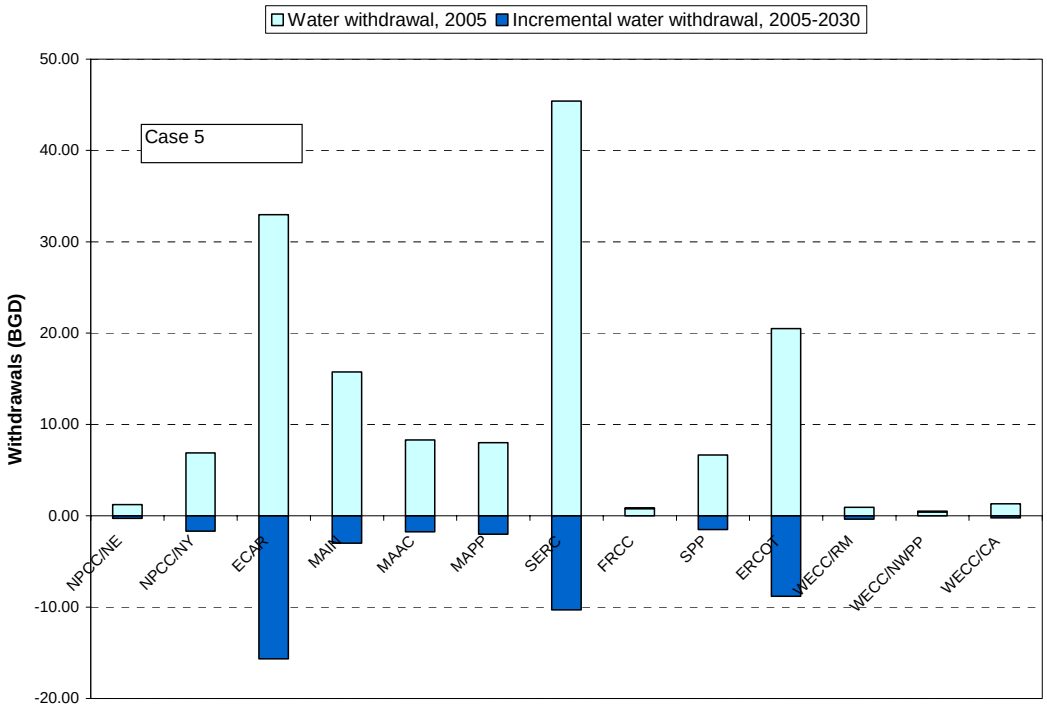


Figure 28 – Average Daily Regional Freshwater Consumption for Thermoelectric Power Generation – Case 1

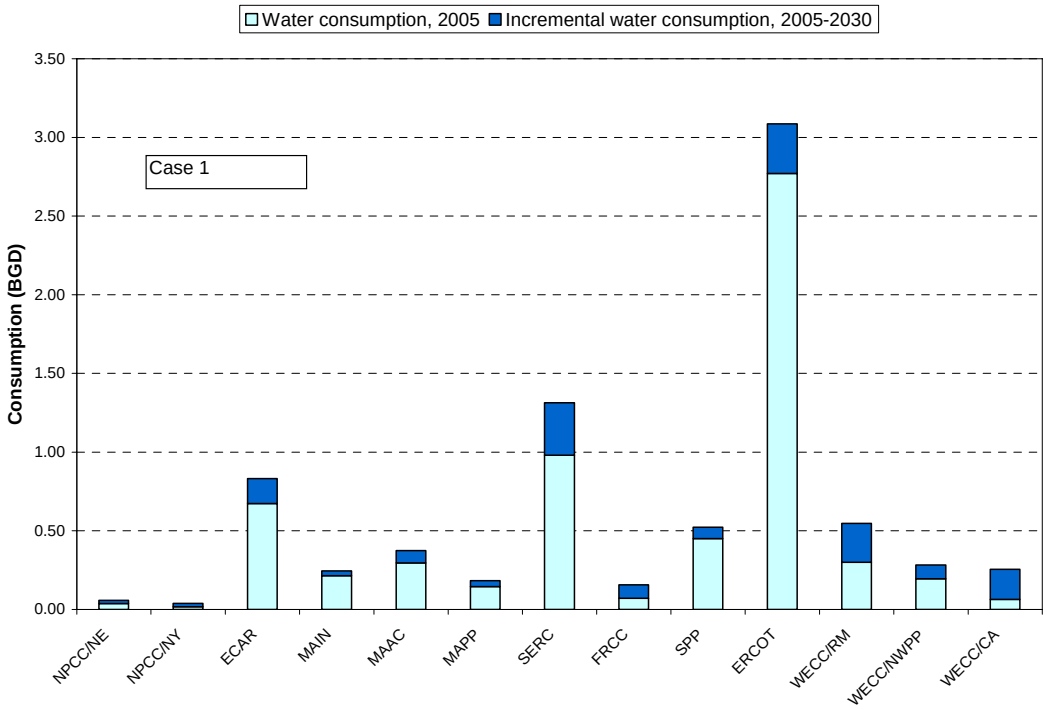


Figure 29 – Average Daily Regional Freshwater Consumption for Thermoelectric Power Generation – Case 2

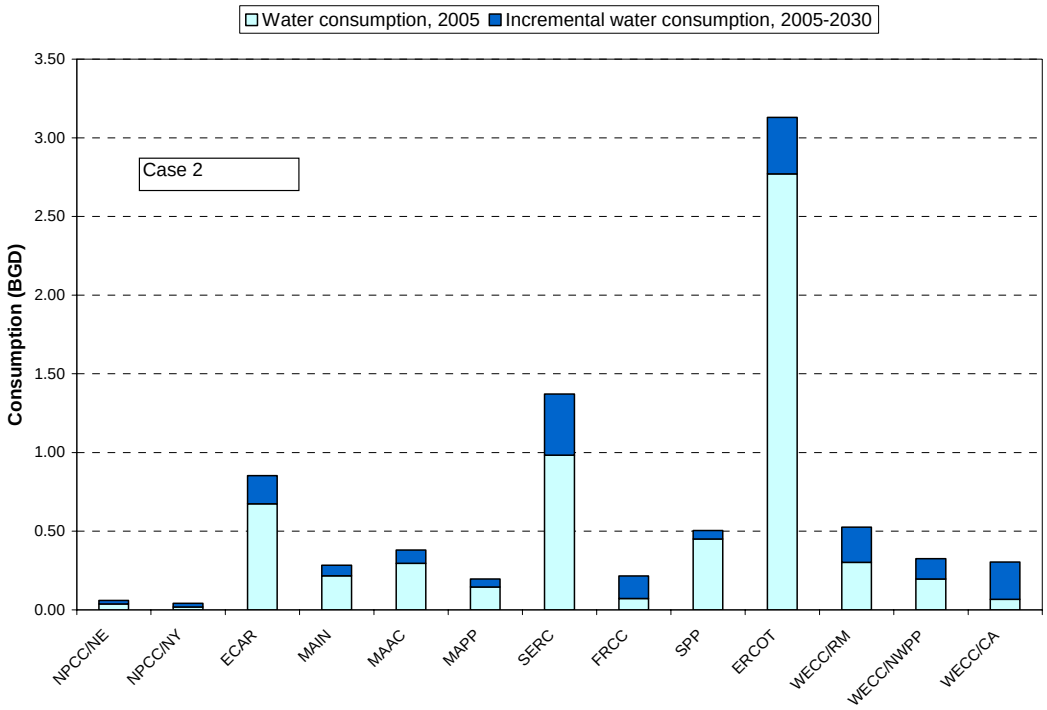


Figure 30 – Average Daily Regional Freshwater Consumption for Thermoelectric Power Generation – Case 3

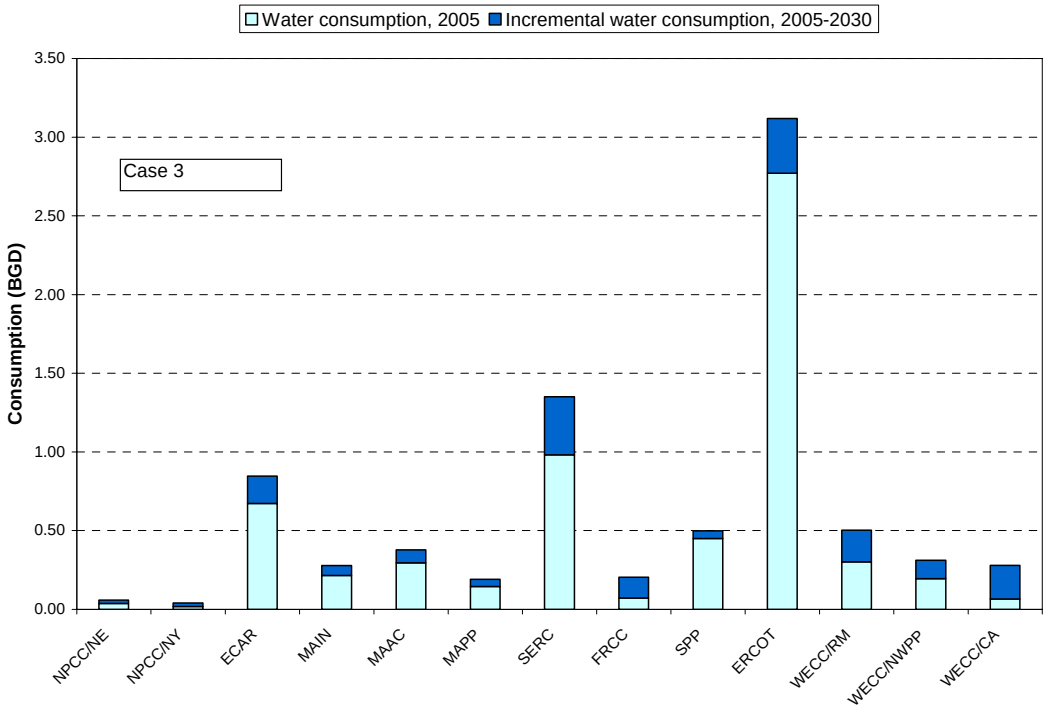


Figure 31 – Average Daily Regional Freshwater Consumption for Thermoelectric Power Generation – Case 4

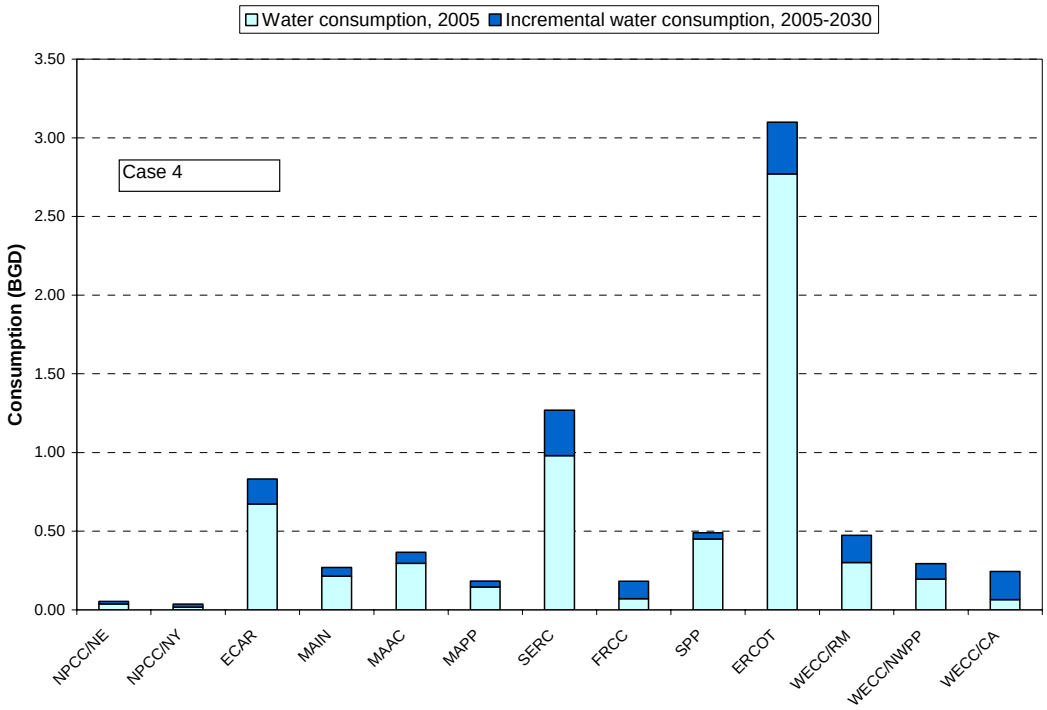
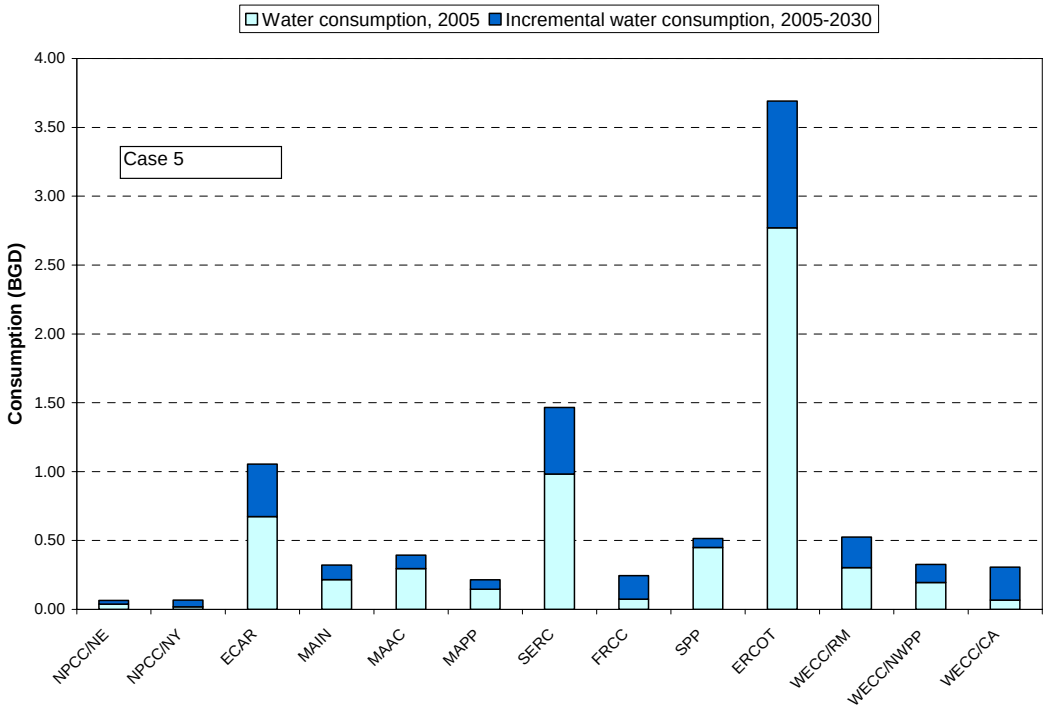


Figure 32 – Average Daily Regional Freshwater Consumption for Thermoelectric Power Generation – Case 5



Case 2

Total thermoelectric generation freshwater withdrawal is projected to decrease approximately 9% (149.2 BGD to 136.3 BGD) from 2005 through 2030 for Case 2. Similar to Case 1, total thermoelectric generation freshwater consumption is projected to increase – growing 32% from 6.2 BGD to 8.2 BGD between 2005 and 2030. On a regional basis, freshwater withdrawal increases slightly in the FRCC and WECC/NWPP regions; and decreases significantly in the ECAR, SERC, and ERCOT regions (Figure 24). Similar to Case 1, freshwater consumption increases in all of the regions, with relatively large percentage increases occurring in the NPCC/NY (132%), FRCC (199%), WECC/RM (74%), and WECC/CA (352%) regions (Figure 29).

Case 3

Both thermoelectric generation freshwater withdrawal and consumption levels for Case 3 are slightly less than the respective values from Case 2. In 2030, freshwater withdrawal is 136.3 BGD in Case 2 compared to 136.1 in Case 3. Similarly, freshwater consumption in 2030 is 8.2 BGD and 8.1 BGD for Cases 2 and 3, respectively. On a regional basis, freshwater withdrawal and consumption increases and decreases are also similar to Case 2 (Figure 25 and Figure 30).

Case 4

Thermoelectric generation freshwater withdrawal and consumption levels for Case 4 are less than the respective values from Case 2. By 2030, freshwater withdrawal is projected to be approximately 1% less in Case 4 compared to Case 2 – 135.4 BGD vs. 136.3 BGD. More significantly, freshwater consumption is projected to be approximately 9% less – 7.5 BGD in Case 4 vs. 8.2 BGD in Case 2. On a regional basis, freshwater withdrawal and consumption increases and decreases are also similar to Case 2 (Figure 26 and Figure 31).

Case 5

The Case 5 assumptions for capacity additions and retirements are the same as Case 2, but Case 5 also assumes that 25% of existing freshwater once-through cooling capacity is converted to wet recirculating cooling. By 2030, total thermoelectric generation freshwater withdrawal is projected to be approximately 24% less in Case 5 compared to Case 2 – 103.7 BGD vs. 136.3 BGD – while consumption is projected to be approximately 12% more – 9.2 BGD in Case 5 vs. 8.2 BGD in Case 2. On a regional basis, freshwater withdrawal increases in the FRCC (9%) and WECC/NWPP (21%) regions; and decreases in all other regions, with significant decreases in the NPCC/NY (24%), ECAR (48%), MAIN (19%), MAAC (21%), MAPP (25%), SERC (23%), SPP (23%), ERCOT (43%), and WECC/RM (39%) regions (Figure 27). Freshwater consumption increases in all of the regions, with relatively large percentage increases occurring in the NPCC/NE (72%), NPCC/NY (271%), ECAR (56%), SERC (49%), FRCC (231%), WECC/RM (74%), and WECC/CA (356%) regions (Figure 32).

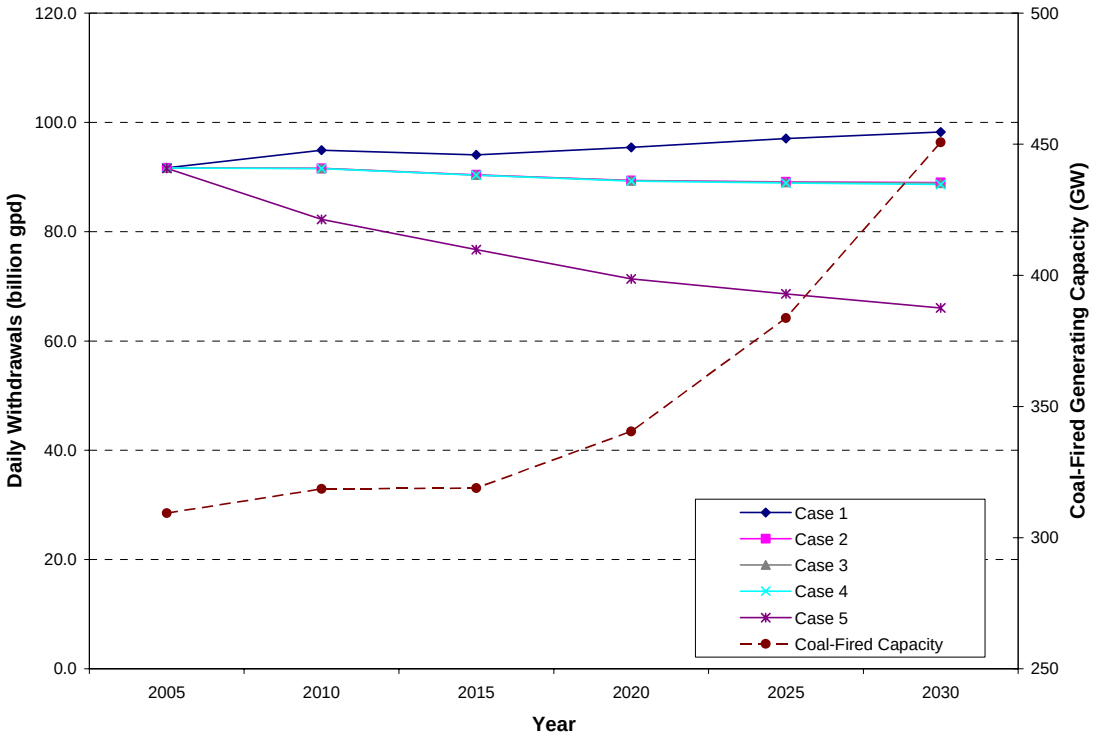
Coal-Fired Generation - National

Coal-fired generating capacity is projected to increase by 148 GW from 2005 to 2030. The analysis projects that by 2030, average daily national freshwater withdrawals required to meet the needs of the U.S. coal-fired generation component of thermoelectric generation may decrease to 66.0 BGD (28%) or increase to 98.2 BGD (7%) depending upon case assumptions. Table 10 presents the range of average daily national freshwater withdrawal for each of the five cases from 2005 through 2030. This same data is presented graphically in Figure 33.

Table 10 –Average National Freshwater Withdrawal for Coal-Fired Power Generation (BGD)

	2005	2010	2015	2020	2025	2030
Case 1	91.7	94.9	94.1	95.4	97.0	98.2
Case 2	91.6	91.6	90.4	89.4	89.1	89.0
Case 3	91.6	91.6	90.4	89.3	89.0	88.9
Case 4	91.6	91.5	90.3	89.2	88.9	88.6
Case 5	91.6	82.3	76.7	71.3	68.6	66.0
Maximum	91.7	94.9	94.1	95.4	97.0	98.2
Minimum	91.6	82.3	76.7	71.3	68.6	66.0

Figure 33 –Average Daily National Freshwater Withdrawal for Coal-Fired Power Generation



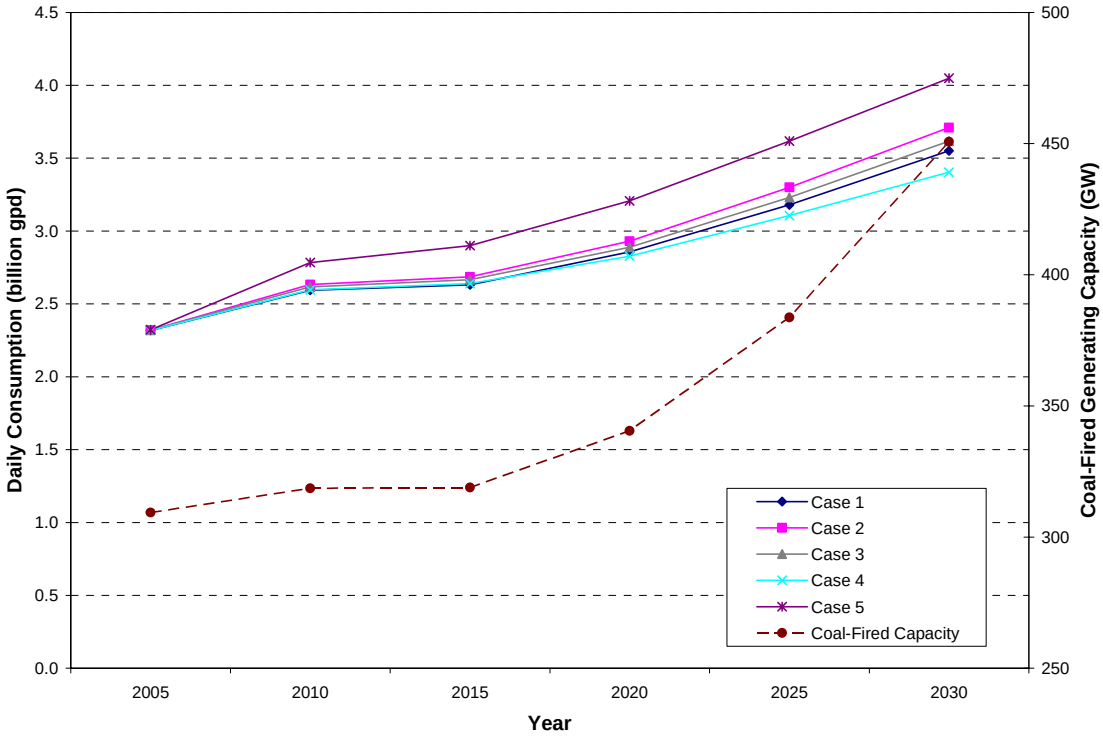
The analysis projects that by 2030, average daily national freshwater consumption resulting from U.S. coal-fired power generation could range from 3.4 BGD to 4.0 BGD depending upon case assumptions. This represents an increase of 48% and 74%

respectively. Table 11 presents the range of average daily national freshwater consumption for each of the five cases from 2005 through 2030. This same data is presented graphically in Figure 34.

Table 11 – Average National Freshwater Consumption for Coal-Fired Power Generation (BGD)

	2005	2010	2015	2020	2025	2030
Case 1	2.3	2.6	2.6	2.9	3.2	3.6
Case 2	2.3	2.6	2.7	2.9	3.3	3.7
Case 3	2.3	2.6	2.7	2.9	3.2	3.6
Case 4	2.3	2.6	2.6	2.8	3.1	3.4
Case 5	2.3	2.8	2.9	3.2	3.6	4.0
Maximum	2.3	2.8	2.9	3.2	3.6	4.0
Minimum	2.3	2.6	2.6	2.8	3.1	3.4

Figure 34 – Average Daily National Freshwater Consumption for Coal-Fired Power Generation



National Conventional Coal Results

Case 1

The conventional coal (not including IGCC) portion of thermoelectric generation freshwater withdrawal is projected to increase approximately 7% from 2005 through 2030 for Case 1 – from 91.7 BGD to 97.7 BGD – consistent with the overall 18% increase in generation capacity from 309 GW to 366 GW and roughly equal distribution of once-through and wet recirculating cooling water systems. More significantly,

conventional coal generation freshwater consumption is projected to increase 39% from 2005 through 2030 for Case 1 – growing from 2.3 BGD to 3.2 BGD. See Figure 13 and Figure 14 for plots of coal withdrawal and consumption from 2005-2030.

Case 2

Conventional coal generation freshwater withdrawal is projected to decrease approximately 3% (91.6 BGD to 88.5 BGD) from 2005 through 2030 for Case 2. This trend is consistent with the assumptions that all capacity additions use freshwater and wet recirculating cooling systems, while capacity retirements are proportional to current water source and type of cooling water system.

Similar to Case 1, conventional coal generation freshwater consumption is projected to increase in Case 2 – growing 43% from 2.3 BGD to 3.3 BGD between 2005 and 2030 – consistent with both the 18% increase in generation capacity and increased use of wet recirculating cooling water systems. See Figure 15 and Figure 16 for plots of coal withdrawal and consumption from 2005-2030.

Case 3

The Case 3 assumptions are similar to Case 2, except that 90% of capacity additions use freshwater and wet recirculating cooling and 10% use saline water with once-through cooling. As might be expected, both conventional coal generation freshwater withdrawal and consumption levels for Case 3 are slightly less than the respective values from Case 2. In 2030, freshwater withdrawal is 88.5 BGD in Case 2 compared to 88.4 in Case 3. Similarly, freshwater consumption in 2030 is 3.3 BGD and 3.2 BGD for Cases 2 and 3, respectively. See Figure 17 and Figure 18 for plots of coal withdrawal and consumption from 2005-2030.

Case 4

The potential impact of dry cooling systems on water demand is evident in the results of Case 4, where 25% of new conventional coal capacity is assumed to be equipped with dry cooling, rather than wet recirculating cooling. Conventional coal generation freshwater withdrawal and consumption levels for Case 4 are less than the respective values from Case 2. By 2030, freshwater withdrawal is projected to be slightly less in Case 4 compared to Case 2 – 88.3 BGD vs. 88.5 BGD. Freshwater consumption is projected to be approximately 6% less – 3.1 BGD in Case 4 vs. 3.3 BGD in Case 2. See Figure 19 and

Figure 20 for plots of coal withdrawal and consumption from 2005-2030.

Case 5

The Case 5 assumptions for conventional coal capacity additions and retirements are the same as Case 2. However, Case 5 also assumes that 25% of existing freshwater once-through cooling capacity is converted to wet recirculating cooling. As a result, Case 5 represents the most extreme conditions of the analysis and significantly impacts projections for both freshwater withdrawal and consumption. By 2030, total conventional coal generation freshwater withdrawal is projected to be approximately 26% less in Case 5 compared to Case 2 – 65.5 BGD vs. 88.5 BGD – while consumption is projected to be approximately 12% more – 3.7 BGD in Case 5 vs. 3.3 BGD in Case 2.

See Figure 21 and Figure 22 for plots of coal withdrawal and consumption from 2005-2030.

Coal-Fired Generation - Regional

Figures 35-39 shows the results of the regional water withdrawal analysis for total U.S. coal-fired generation comparing 2005 to 2030 for each of the five cases. With each successive case, the water withdrawal of the regions displays greater decreases, with Case 5 showing the largest overall decrease in water withdrawal. Figures 40-44 show the results of the regional water consumption analysis for total U.S. coal-fired generation comparing 2005 to 2030 for each of the five cases. Aside from Case 5, where water consumption increases more than other cases, the water consumption regionally stays rather consistent.

Case 1

Conventional coal generation freshwater withdrawal is projected to increase approximately 7% from 2005 through 2030 for Case 1 – from 91.7 BGD to 97.7 BGD. Conventional coal freshwater consumption is projected to increase 39% from 2005 through 2030 for Case 1 – growing from 2.3 BGD to 3.2 BGD. On a regional basis, freshwater withdrawal increases in the MAIN, SERC, FRCC, SPP, ERCOT, WECC/RM, and WECC/CA regions; and decreases in the NPCC/NE (3%), NPCC/NY (1%), and ECAR (3%) regions (Figure 35). Freshwater consumption increases in all of the regions, with relatively large percentage increases occurring in the NPCC/NE (1,000%), NPCC/NY (587%), FRCC (173%), WECC/RM (132%), and WECC/CA (540%) regions (Figure 40).

Case 2

Conventional coal generation freshwater withdrawal is projected to decrease approximately 3% (91.6 BGD to 88.5 BGD) from 2005 through 2030 for Case 2. Similar to Case 1, conventional coal generation freshwater consumption is projected to increase in Case 2 – growing 43% from 2.3 BGD to 3.3 BGD between 2005 and 2030. On a regional basis, freshwater withdrawal increases slightly in the FRCC, WECC/RM, WECC/NWPP, and WECC/CA regions; and decreases slightly in the ECAR, MAIN, MAPP, SERC, and SPP regions (Figure 36). Similar to Case 1, freshwater consumption increases in all of the regions, with relatively large percentage increases occurring in the NPCC/NE (1,000%), NPCC/NY (587%), MAIN (86%), FRCC (298%), ERCOT (88%), WECC/RM (120%), WECC/NWPP (81%), and WECC/CA (665%) regions (Figure 41).

Case 3

Both conventional coal generation freshwater withdrawal and consumption levels for Case 3 are slightly less than the respective values from Case 2. In 2030, freshwater withdrawal is 88.5 BGD in Case 2 compared to 88.4 in Case 3 (Figure 37). Similarly, freshwater consumption in 2030 is 3.3 BGD and 3.2 BGD for Cases 2 and 3, respectively (Figure 42). On a regional basis, freshwater withdrawal and consumption increases and decreases are also similar to Case 2.

Figure 35 – Average Daily Regional Freshwater Withdrawal for Coal-Fired Power Generation – Case 1

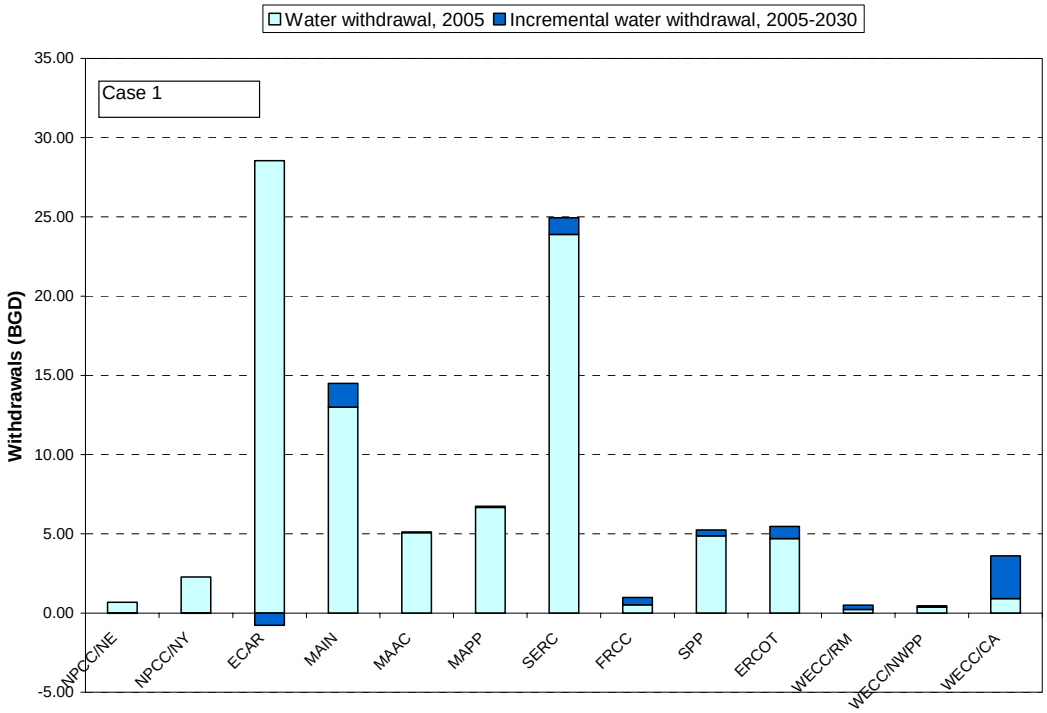


Figure 36 – Average Daily Regional Freshwater Withdrawal for Coal-Fired Power Generation – Case 2

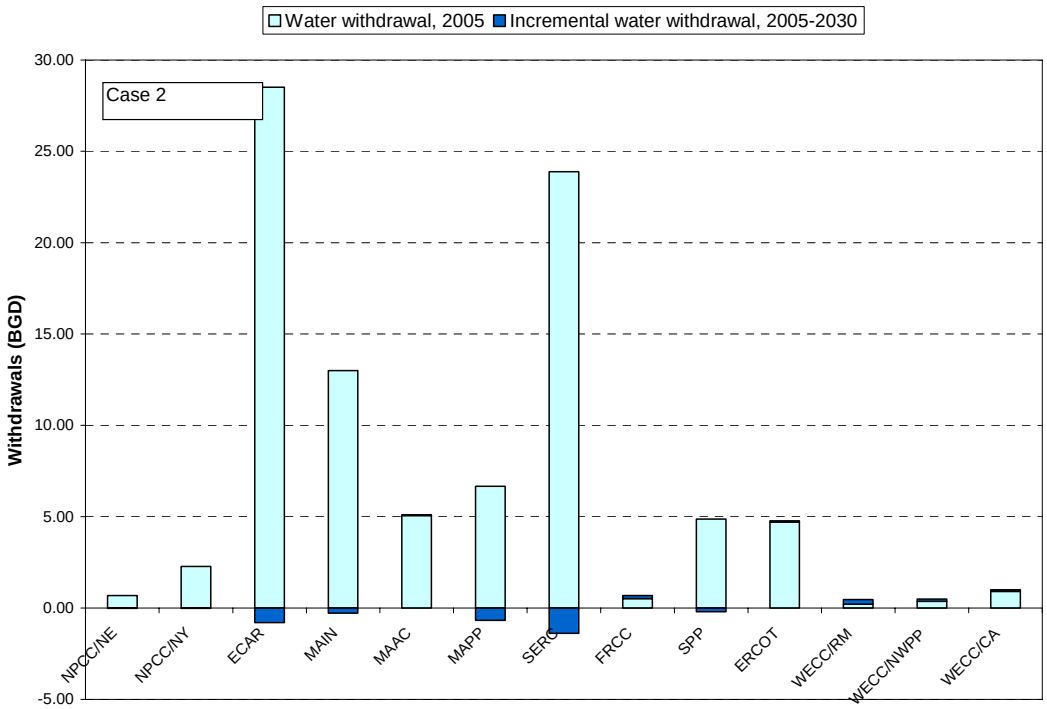


Figure 37 – Average Daily Regional Freshwater Withdrawal for Coal-Fired Power Generation – Case 3

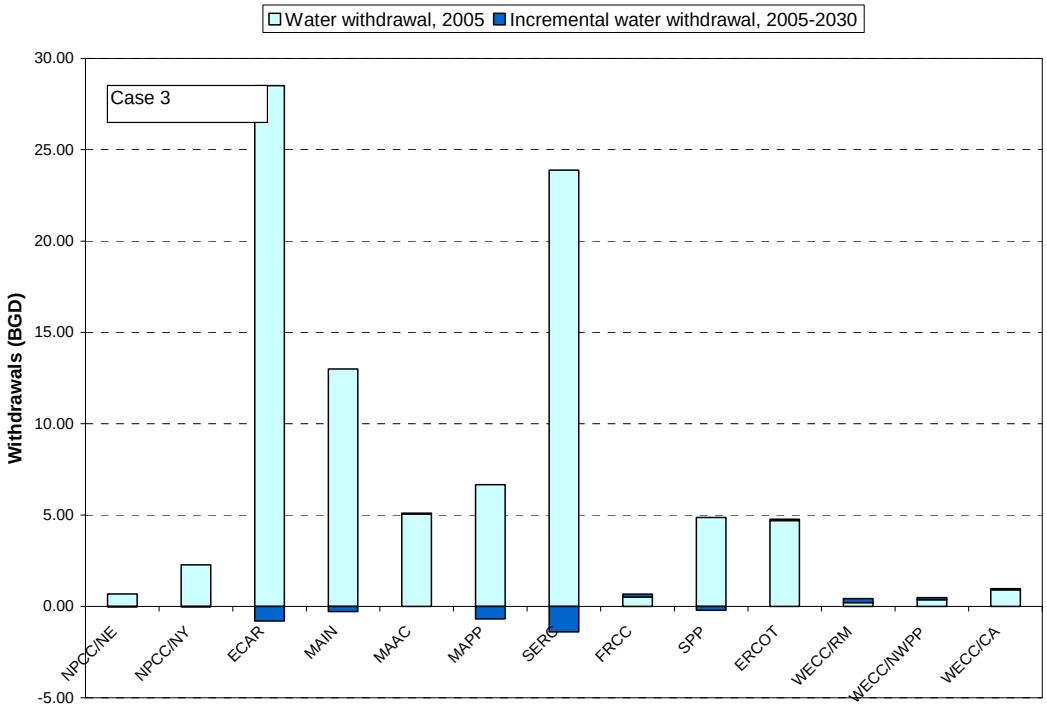


Figure 38 – Average Daily Regional Freshwater Withdrawal for Coal-Fired Power Generation – Case 4

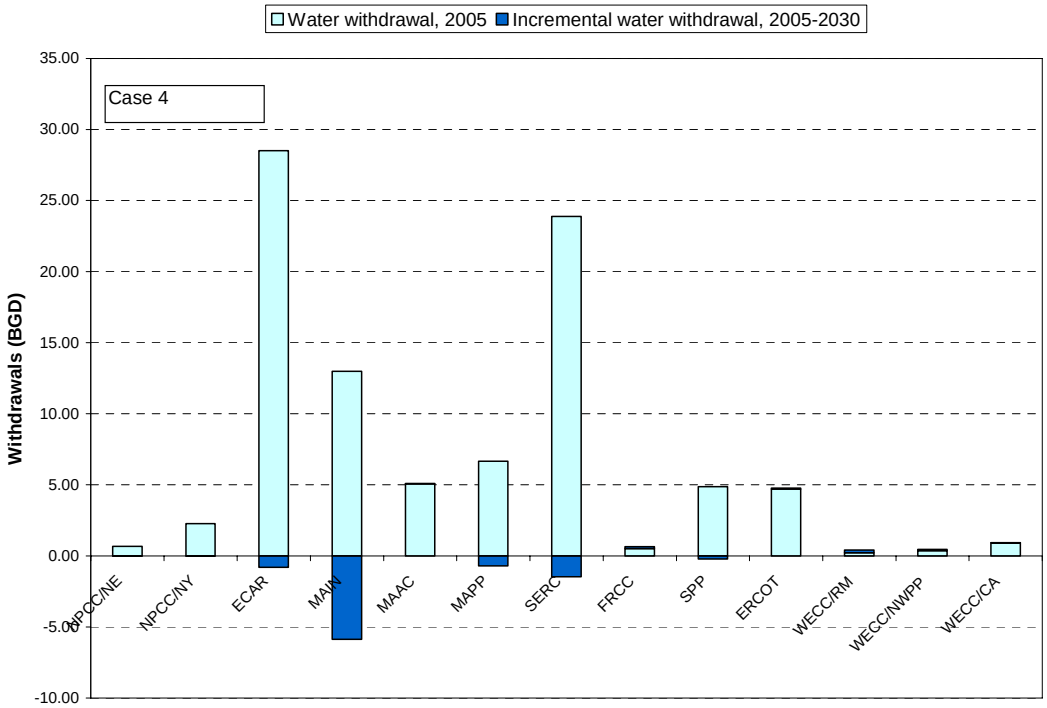


Figure 39 – Average Daily Regional Freshwater Withdrawal for Coal-Fired Power Generation – Case 5

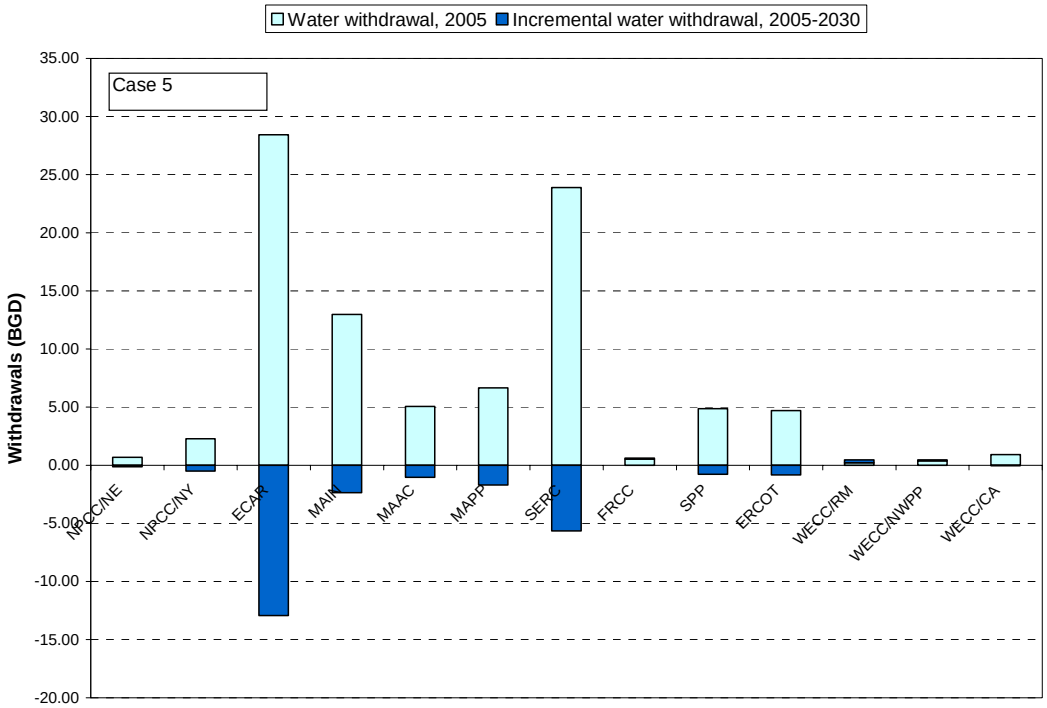


Figure 40 – Average Daily Regional Freshwater Consumption for Coal-Fired Power Generation – Case 1

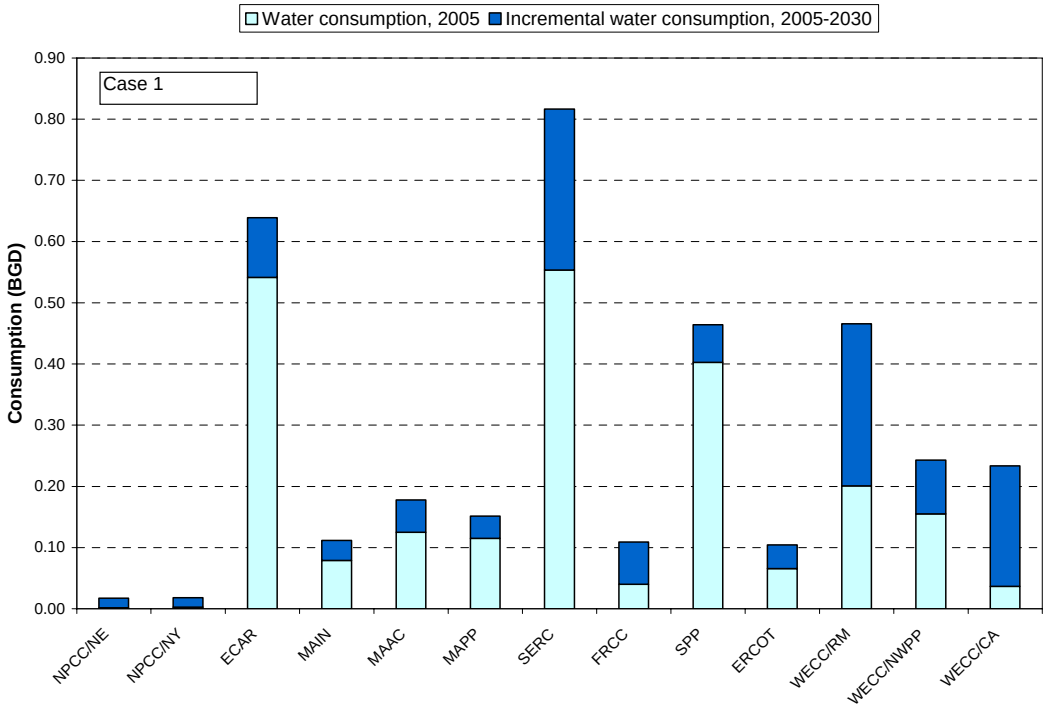


Figure 41 – Average Daily Regional Freshwater Consumption for Coal-Fired Power Generation – Case 2

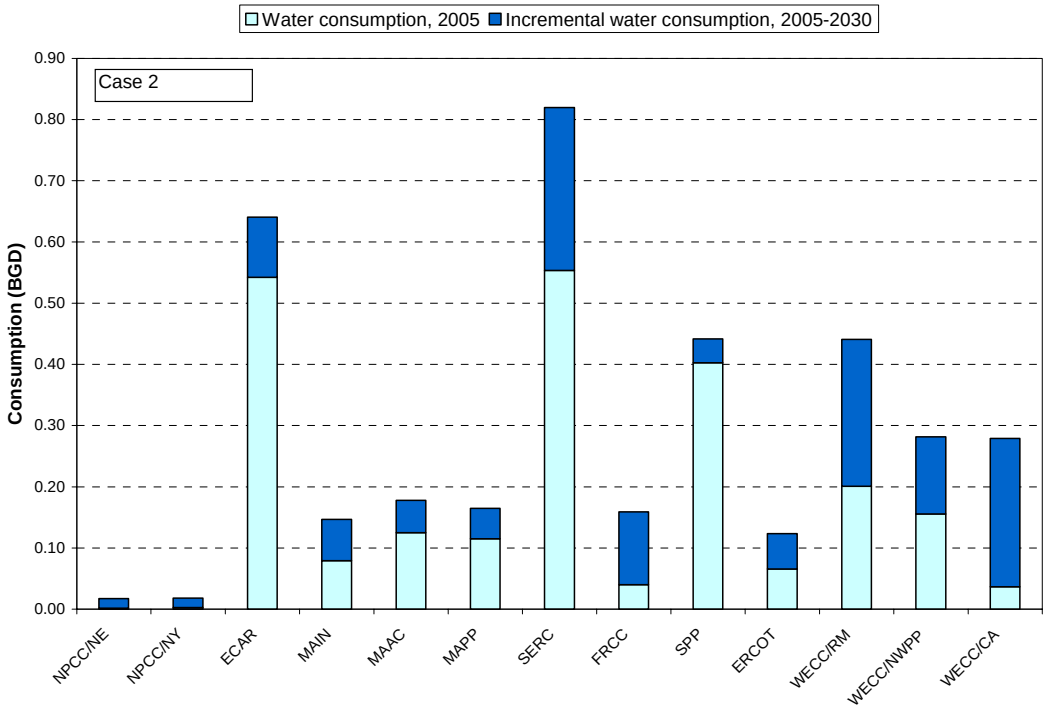


Figure 42 – Average Daily Regional Freshwater Consumption for Coal-Fired Power Generation – Case 3

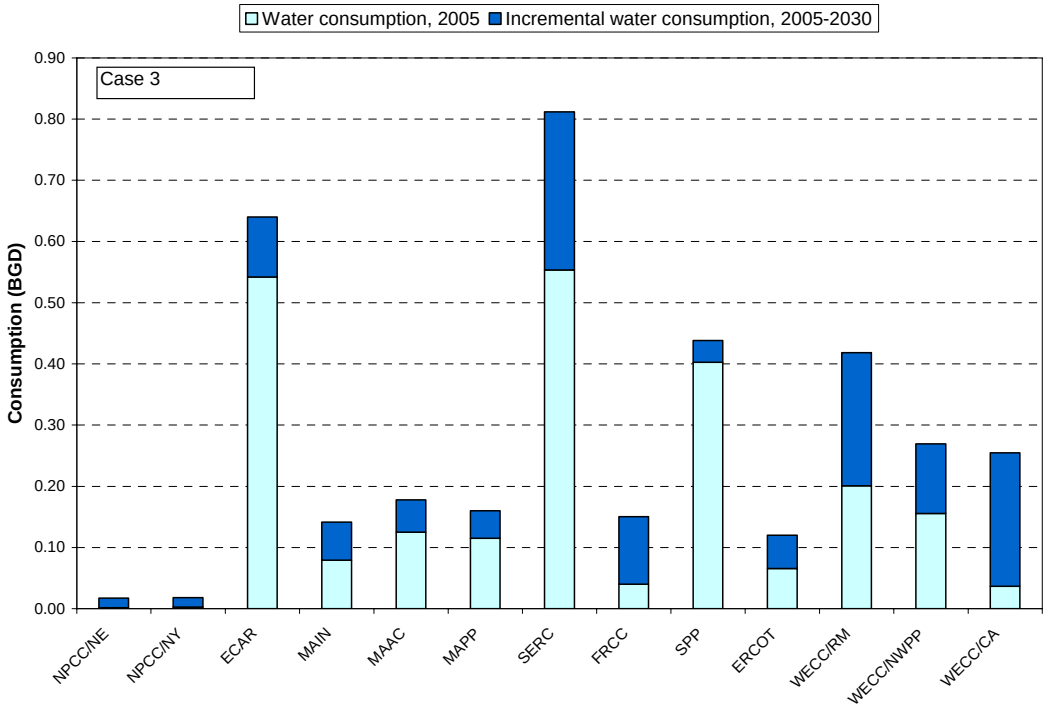


Figure 43 – Average Daily Regional Freshwater Consumption for Coal-Fired Power Generation – Case 4

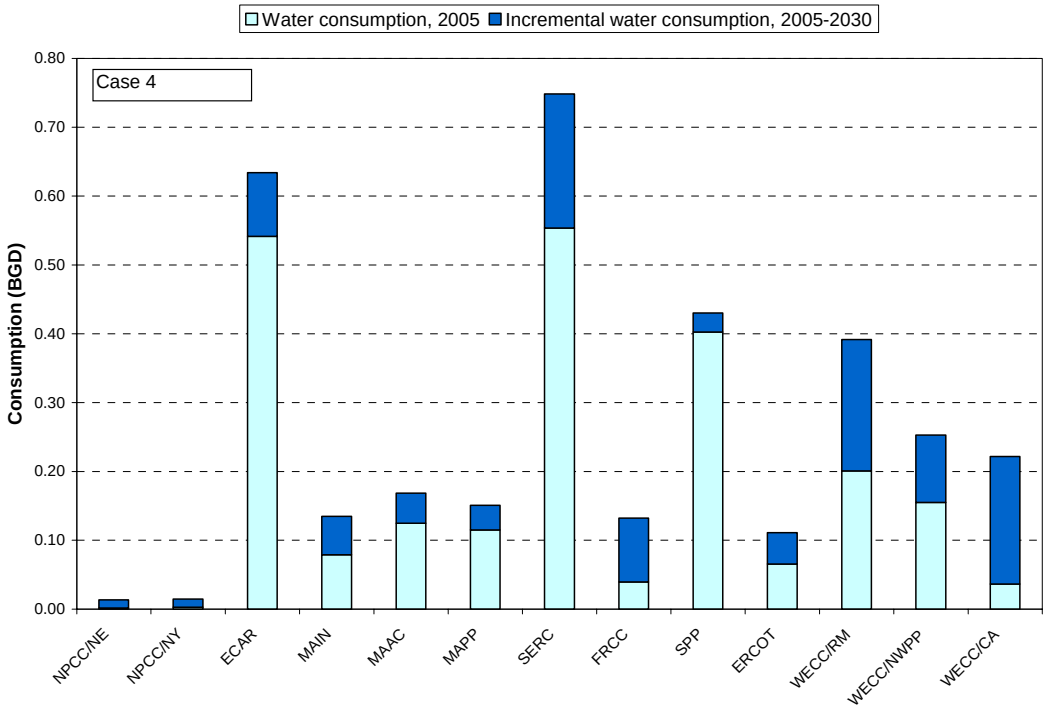
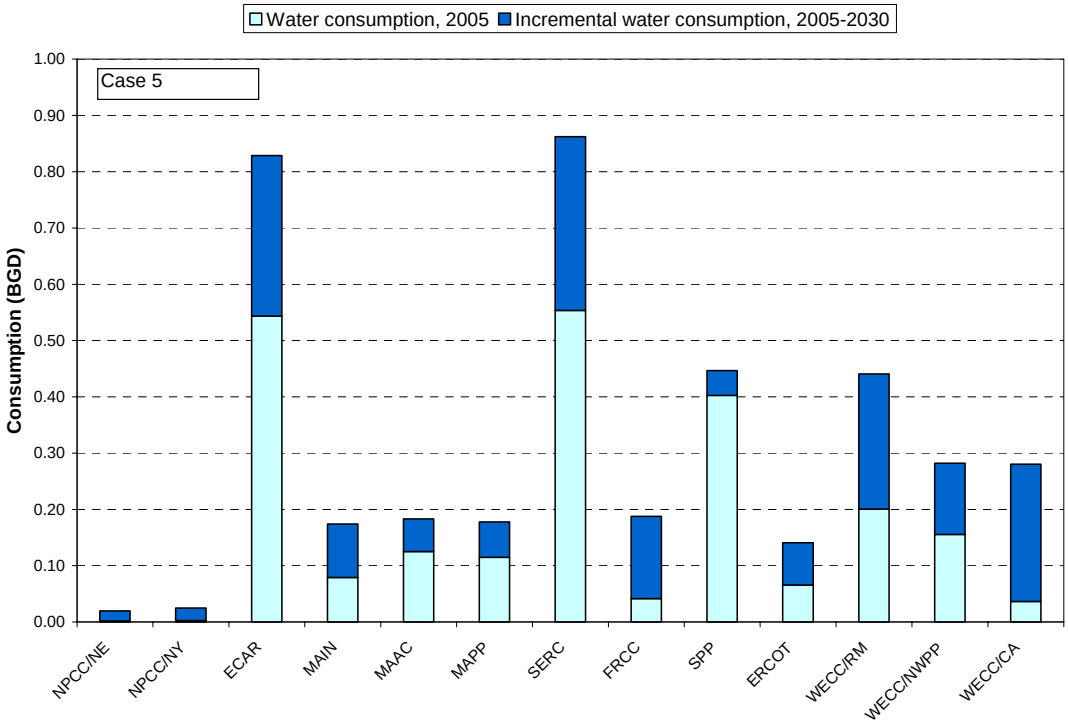


Figure 44 – Average Daily Regional Freshwater Consumption for Coal-Fired Power Generation – Case 5



Case 4

Conventional coal generation freshwater withdrawal and consumption levels for Case 4 are less than the respective values from Case 2. By 2030, freshwater withdrawal is projected to be slightly less in Case 4 compared to Case 2 – 88.3 BGD vs. 88.5 BGD (Figure 38). Freshwater consumption is projected to be approximately 6% less – 3.1 BGD in Case 4 vs. 3.3 BGD in Case 2 (Figure 43). On a regional basis, freshwater withdrawal and consumption increases and decreases are also similar to Case 2.

Case 5

By 2030, total conventional coal generation freshwater withdrawal is projected to be approximately 26% less in Case 5 compared to Case 2 – 65.5 BGD vs. 88.5 BGD – while consumption is projected to be approximately 12% more – 3.7 BGD in Case 5 vs. 3.3 BGD in Case 2. On a regional basis, freshwater withdrawal increases in the WECC/RM (113%) region; and decreases significantly in the NPCC/NY (22%), ECAR (45%), MAIN (18%), MAAC (21%), MAPP (25%), SERC (24%), SPP (16%), and ERCOT (18%) regions (Figure 39). Freshwater consumption increases in all of the regions, with relatively large percentage increases occurring in the NPCC/NE (1,136%), NPCC/NY (838%), ECAR (53%), MAIN (120%), SERC (56%), FRCC (352%), ERCOT (115%), WECC/RM (120%), WECC/NWPP (81%), and WECC/CA (669%) regions (Figure 44).

Comparison of 2004 & 2006 study projections

Comparing the results of the 2004 water needs analysis with the results of the updated 2006 water needs analysis must begin with a discussion of the different methodologies used for each analysis. Because the two studies used fundamentally different analytical approaches, the results must be examined in terms of general agreement and consistent trends, not in terms of close numerical similarity.

As a broad generalization of the two methodologies employed, the 2004 study provided a top-down analysis, while the 2006 study provided a bottoms-up analysis. The 2004 analysis used as its starting point the thermoelectric water withdrawal estimated by the U.S. Geologic Survey in its 1995 survey. In other words, the estimated total thermoelectric withdrawal, 132.1 BGD, represented the baseline withdrawal for all six cases considered (a description of the cases used in the 2004 analysis can be found in the Introduction section of this paper). Changes in withdrawal and consumption over time were calculated from this base for each case using the capacity additions and retirements projected by the *Annual Energy Outlook 2004* out to 2025; single-point national average withdrawal and consumption factors for fossil and nuclear power plants (recirculating and once-through); and AEO 2004's capacity factor projections.

The 2006 analysis, on the other hand, used as its starting point the water withdrawal and consumption quantities associated with specific power plant configurations in a particular region. In other words, water withdrawal and consumption factors were calculated from plant data (see Table 5 for data sources) for a number of different power plant types; these factors were then applied to the capacity of each plant type in each region to calculate regional water withdrawal and consumption amounts. The regional quantities could be summed to assess national impacts. Changes in withdrawal and consumption

over time were calculated for each case using the capacity additions and retirements projected by the *Annual Energy Outlook 2006* out to 2030; the plant type-specific and region-specific withdrawal and consumption factors described above; and AEO 2006's capacity factor projections.

Although the 2004 water needs analyses evaluated six cases, and the 2006 water needs analysis evaluated five cases, only one was the same (Case 2 in the 2004 analysis and Case 1 in the 2006 analysis), in which additions and retirements are proportional to current source withdrawals. Table 12 presents the results of these two cases over equivalent 25-year periods. For the 2004 analysis, the baseline thermoelectric water withdrawal, as noted above, was 132.1 BGD in 1995. For the 2006 analysis, the baseline thermoelectric water withdrawal was 149.2 BGD in 2005. The 13% difference in the baseline estimate is relatively small considering the 10-year time lag and the difference in the analytical methodologies between the two studies. As another point of comparison, USGS estimated thermoelectric water withdrawal for the year 2000 as 136 BGD, indicating a 3% increase in water withdrawal from 1995 to 2000. Extrapolating this 3% increase to 2005 results in a thermoelectric water withdrawal estimate of 140 BGD in 2005, or about 6% less than the 2005 withdrawal value calculated in the 2006 analysis. It should be pointed out, however, that about 200 GW of new capacity came on-line between 2000 and 2005 – a large fraction of which was combined-cycle capacity. Combined-cycle plants have lower water requirements than conventional fossil steam plants because only about one-third of the plant capacity operates on the Rankine steam cycle, but the water requirements are not insignificant, particularly across 100+ GW.

Table 12 - Results Comparison, 2004 vs. 2006 Water Needs Analysis

	Year	**1995**	**2001**	**2002**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
2004 Analysis, Case 2	Withdrawal (BGD)	132.1	131.3	131.4		123.6	123.5	123.3	123.1	
	Consumption (BGD)	3.3	3.6	3.9		4.7	5.4	6.1	7.1	
2006 Analysis, Case 1	Withdrawal (BGD)				149.2	152.7	145.6	147.6	148.8	148.4
	Consumption (BGD)				6.2	6.6	6.8	7.3	7.6	7.9

Case 2 from the 2004 analysis projected a 6.6% decline in water withdrawal over a 25-year period from 1995 to 2020, from 132.1 BGD to 123.3 BGD. The corresponding Case 1 from the 2006 analysis projected a 0.5% decline in water withdrawal over a 25-year period from 2005 to 2030, from 149.2 BGD to 148.4 BGD. The 2004 study reports a much larger decline in withdrawal because all retirements in the 2004 analysis are assumed to be from plants equipped with once-through cooling systems (with their higher water withdrawal requirements), while the 2006 analysis assumes retirements are divided among once-through and recirculating systems according to their relative percentage in 2005.

In terms of consumption, comparing values between the 2004 and 2006 analyses is less meaningful than comparing trends. The baseline thermoelectric consumption from the

2004 water needs analysis, 3.3 BGD, came from USGS's 1995 estimate, and equals 2.5% of withdrawal. For the 2006 analysis, consumption was computed from the individual plant and regional calculations. The baseline thermoelectric water consumption for Case 1 in the 2006 analysis was 6.2 BGD, which represents about 4% of withdrawal.

Consumption trends across equivalent 25-year time periods are in the same direction and of similar magnitude between the 2004 and 2006 analyses. Case 2 of the 2004 water needs analysis projected an increase in consumption from 1995 to 2020 of 85%, from 3.3 BGD to 6.1 BGD. Case 1 of the 2006 water needs analysis projected an increase in consumption from 2005 to 2030 of 27%, from 6.2 BGD to 7.9 BGD. The greater numerical increase in consumption for the 2004 analysis is due to the 2004 assumption that all new plants would use freshwater recirculating systems and to the higher water consumption factors used for recirculating systems.

Conclusions

Population shifts, increasing power demand, and greater competition for water resources has heightened interest in the link between energy and water. The EIA projects about a 24% increase in total generating capacity by 2030 compared to 2005. Of the 312 GW of new capacity, more than 233 GW will be thermoelectric generation.

On a national basis, this analysis indicates that the potential impacts on future freshwater withdrawals to meet forecasted increases in electricity generating capacity would be relatively low, with most cases exhibiting a decrease in daily withdrawals. The national freshwater withdrawal requirements to operate the 233 GW of new thermoelectric generating capacity in 2030 will range from a 1% to a 30% decrease compared to freshwater withdrawals in 2005. Conversely, many of the cases project a significant increase in freshwater consumption by 2030 on a percentage basis. Changes in freshwater consumption in 2030 will range from a 21% to as much as a 48% increase compared to 2005. Similar trends in freshwater withdrawal and consumption are projected for the additional coal-based generating capacity that will come on line by 2030, with withdrawal ranging from a 28% decrease to a 7% increase and consumption ranging from a 48% to a 74% increase.

The regional component of the 2006 water needs analysis revealed some significant differences from the national averages, reflecting recent U.S. population shifts. Regions with strong population growth, such as the southeast and southwest, exhibit high growth in water consumption requirements, while regions with minimal to modest population growth, such as the midwest and mid-Atlantic, exhibit modest growth in water consumption requirements. EIA projects a 66% increase in thermoelectric capacity by 2030 for the western United States and a 61% increase in the southeast compared to the 24% increase nationally. These increases in projected capacity will occur in regions of the United States that are challenged in terms of both current and future availability of freshwater. For example, consider Case 2, a plausible future cooling system scenario that assumes all capacity additions use freshwater and wet recirculating cooling. The national percent changes indicate that water withdrawal will fall by 8.6% and that water

consumption will rise by 32.3% between 2005 and 2030. On a regional basis, however, water withdrawal ranges from a 25% increase in Florida to a 30% decline in Texas; and while freshwater consumption increases in all regions, the biggest gains come in California (352%), Florida (199%), New York (132%) and the Rocky Mountain/desert southwest region (74%).

The thermoelectric power generation sector will remain a significant water consumer for the foreseeable future. While national water withdrawals are projected to decline slightly over the 25-year time period evaluated in this analysis, the amount of water withdrawal is huge, on the order of 135 to 140 billion gallons per day. On a consumption basis, although the magnitude is much less than that for withdrawal, the trend is steadily upward, regardless of the case considered. National water consumption is expected to grow from 6.2 billion gallons per day in 2005 to 8 or 9 billion gallons per day by 2030. In the face of growing competition for water resources – particularly in the arid West and Southwest, and in the expanding Southeast – regional and national efforts to reduce water withdrawal and consumption for thermoelectric power plants are expected to intensify.

Appendix A
Energy-Water Issues
Supplemental Information

Water Availability

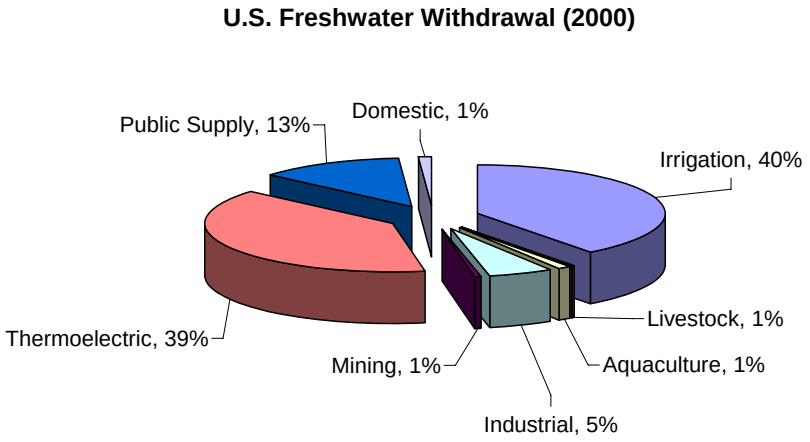
In 2006, RDS contacted state government water monitoring agencies inquiring if water availability in general is a concern in their state. Of the 33 states that responded, 58% of states said that yes, water availability is a concern. An additional 15% said that water availability varies within the state, with only some regions having water supply issues. Another 12% responded that water availability had not been of great concern in the past, but has recently been becoming more critical.

Water availability issues are not limited to the western United States. State government water monitoring contacts in Alabama, Florida, Hawaii, Illinois, Louisiana, Missouri, South Carolina, and Virginia indicated that water availability is generally a concern in their state or has become more of a concern in recent years. A February 2006 article in the Baltimore Sun[14] describes the difficulties of several communities in Maryland facing water shortages, where "growing towns in Carroll and Frederick counties have been forced to curtail development – either voluntarily or under orders from the state – because their growth was outstripping water supplies." In addition, the article states that in "Southern Maryland, the state's fastest-growing region, groundwater levels are dropping an average of 1 to 2 feet a year."

Competing Water Uses

Concerns over limited water quantities are not restricted to thermoelectric generation. According to USGS, 346 *billion* gallons of freshwater were withdrawn *per day* in the United States in the year 2000. The largest use, agricultural irrigation, accounted for 40% of freshwater withdrawn (see Figure A-1).

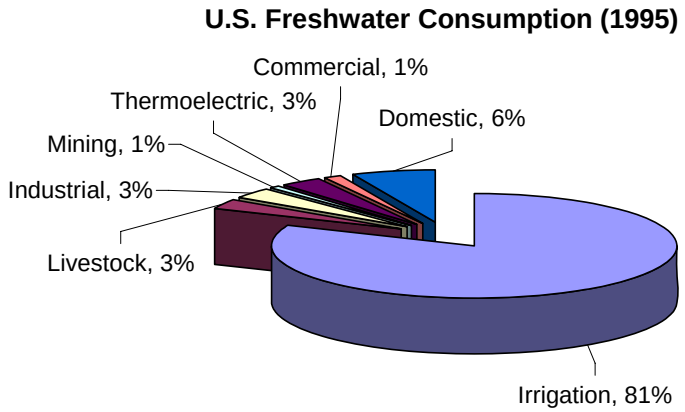
Figure A-1 - Percent of freshwater withdrawal by use category



The second largest use, thermoelectric generation, withdrew 136 billion gallons per day (BGD), followed by public supply, industrial uses, aquaculture, domestic use, mining, and livestock. Interestingly, thermoelectric generation withdrew the largest amount of saline water, 60 BGD (96% of all saline withdrawn). Withdrawal of saline water (and other non-traditional waters) reduces the strain on freshwater supplies and is one research area facilitated by the IEP program.

USGS estimates for freshwater consumption for the year 1995 (the most recent year for which this data is available) is presented in Figure A-2. Freshwater consumption for thermoelectric purposes appears low (only 3%) when compared to other use categories (irrigation was responsible for 81% of water consumed). However, even at 3% consumption, over 3 BGD were consumed. As a result of growing public pressures to withdraw less water, coupled with requirements under Section 316(b) of the Clean Water Act, consumption will likely increase significantly due to greater use of closed-loop cooling systems that consumes far more water than once-through cooling systems due to evaporation losses.

Figure A-2 - Percent of freshwater consumption by use category



In addition to the water uses described above, increased value is being placed on in-stream freshwater uses, consisting mainly of habitat/species protection and recreational uses. In-stream uses will require a minimum flow rate or depth to be maintained in water bodies.

Because freshwater supply is limited, choices will have to be made regarding withdrawal and consumption of this natural resource. Water availability and its withdrawal and consumption are top priorities on the public agenda in many nations throughout the world. It is likely that the issue will also filter to the top of the U.S. public agenda in the near future. In water-stressed areas of the country, power plants will increasingly compete with other water users. Agriculture and public supply will most likely be the greatest competitors due to their large water withdrawal. As with all resources, tradeoffs will occur, and concerns will increasingly be raised over which use is more important: water for drinking and personal use, growing food, or energy production.

Regulatory Impacts on Water Withdrawal and Consumption

The power industry must comply with a variety of local, state and federal regulations pertaining to water acquisition, use, and quality. In considering long-term water withdrawal and consumption patterns in the power sector, the cooling water intake structure regulations established under the Clean Water Act, Section 316(b) will likely have the greatest impact. Designed to protect aquatic life from inadvertently being killed by intake structures at power stations and certain manufacturing facilities, Section 316(b) requires EPA to ensure that the "location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact."

EPA divided its 316(b) rulemaking into three phases: Phase I, completed in late 2001, applies to new facilities; Phase II, completed in early 2004, applies to large existing power facilities; and Phase III, due to be finalized in 2006, applies to existing manufacturing facilities. The regulations establish performance standards for cooling water intake structures based on impingement mortality and entrainment (IM&E) impacts. A minimum level of IM&E reduction is required based on the type of water body a given facility accesses for cooling water. Compliance with 316(b) is coordinated through the individual states' NPDES (National Pollutant Discharge Elimination System) permitting program.

The largest design impact of 316(b) compliance is that most new power plants will have to use closed-loop, recirculating cooling systems or dry (air-cooled) systems. Open-loop systems are strongly discouraged unless the permit applicant can demonstrate that alternative IM&E measures can provide a reduction level comparable to that achieved through closed-loop cooling or that the compliance costs, air quality impacts, and/or energy generation impacts would outweigh the IM&E benefits and justify an open-loop system. Because 316(b) portends a greater reliance on closed-loop cooling systems, water withdrawal and consumption patterns for the thermoelectric power sector are destined to change over time. Even accounting for significant thermoelectric capacity additions, water withdrawal levels will likely remain relatively constant. Water consumption, on the other hand, is expected to increase substantially since closed-loop cooling systems consume more water, due to evaporation, than open-loop systems.

Existing and future air quality regulations will also affect water withdrawal and consumption patterns, although to a lesser extent than cooling water regulations. Tighter emission levels for sulfur dioxide, for example, have sparked a mini-boom in the flue gas desulfurization (FGD) market. The size of the U.S. FGD market is expected to increase by more than 100,000 megawatts (MW) over the next 10 years. Although FGD water requirements are a fraction of those required for cooling purposes, FGD units require a significant amount of water to produce and handle the various process streams (limestone slurry, scrubber sludge, etc.). Makeup water requirements for the FGD island at a nominal 550 MW subcritical coal-fired power plant are about 570 gpm, versus about 9,500 gpm for cooling water makeup.[15] Nonetheless, the additional FGD systems coming online within the next decade will place a greater strain on water supplies.

Notably, semi-dry flue gas desulfurization systems are available that substantially reduce water requirements for SO_2 control, and these systems are in commercial application at numerous plants, many in arid environments.

Several other regulatory actions warrant attention because of their potential impact on water withdrawal and consumption. Under section 303(d) of the 1972 Clean Water Act, states, territories, and authorized tribes are required to develop a list of impaired waters not meeting water quality standards and then establish total maximum daily loads (TMDL) for these waters. A TMDL specifies the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and allocates pollutant loadings among point and nonpoint pollutant sources. TMDL requirements could potentially constrain a power plant's ability to discharge cooling water, as well as trace metals and other pollutants from flue-gas cleanup byproducts, into a water body if the water body is impaired. The power plant may then be required to seek an alternate water source or install additional water treatment equipment.

The current debate over global climate change and carbon dioxide (CO_2) emissions could also potentially impact the water resource situation. If power plants are ultimately required to implement carbon separation and sequestration technologies to comply with future regulations, additional water may be needed for certain process steps and groundwater could be impacted by CO_2 sequestration (in a manner similar to produced water from oil and gas recovery applications). On the other hand, water could potentially be recovered from the CO_2 stream prior to dry pumping for sequestration or reclaimed from produced waters due to underground displacement. A detailed analysis would be required to delineate the net water withdrawal and consumption associated with CO_2 separation and sequestration and is outside the scope of this study.

Legislative Activities

The Energy Policy Act of 2005 (Title IX, Subtitle G − Science, Section 979) directs the DOE to address energy-water nexus issues and assess the effectiveness of existing Federal programs to address energy-water related issues. The direction is for a program of research, development, demonstration, and commercial application to: 1) address energy-related issues associated with provision of adequate management, and efficient use of water; 2) address water-related issues associated with the provision of adequate supplies, optimal management, and efficient use of energy; and 3) assess the effectiveness of existing programs within the Department and other Federal agencies to address these energy and water related issues.

An amendment to the Energy Policy Act, the Energy-Water Efficiency and Supply Technology Bill, was originally introduced in 2004 and has gone through two revisions. The current version of the bill would allocate $5 million for the first year and "such sums as are necessary for each fiscal year thereafter." The bill would instruct the Secretary of Energy to "establish a national program for the research, development, demonstration, and commercial application of economically viable and cost-effective water supply technologies."

Drought Conditions

A Government Accountability Office (GAO) report[16] prepared in 2003 addressed the issue of freshwater supply at the state level. The report indicated that under normal rainfall conditions, state water managers in 36 states anticipated shortages in localities, regions, or even statewide in the next 10 years (2003 – 2013). The report goes on to say that "drought conditions will exacerbate shortage impacts."

During the summer of 2005, a joint effort between the Department of the Interior (DOI) and the Department of Agriculture (USDA) created Interagency Drought Action Teams to coordinate relief efforts in communities in western states facing droughts. A DOI report[17] about the action teams quotes Secretary (of the Interior) Norton, "Much of the Pacific Northwest has been hard hit by drought this year."

Power Generation Facility Siting

Power generation facilities will have increasing difficulties siting new plants due to water concerns. Concurrently, existing plants will be under increasing pressure to reduce their water withdrawal and consumption. In 2006, RDS contacted state government water monitoring agencies inquiring if there is a limit to freshwater withdrawal and/or consumption by thermoelectric plants in their state. Of the 33 states that responded, 24% indicated that plants must either have a senior water right, or purchase such a water right from an entity willing to sell it. Another 18% indicated that limitations are imposed when water levels fall below the protect flow level and/or in times of water shortage. An additional 18% of states responded that water withdrawal and consumption varies regionally across the state, with some areas having no limit but other areas that are water sparse or over-allocated requiring water rights or special permits. The number of states with over-allocated water resources is expected to increase over time.

Concern about water supply, expressed by state regulators, local decision-makers, and the general public, is already impacting power projects across the United States. For example, in March 2006, an Idaho state House committee unanimously approved a two-year moratorium on construction of coal-fired power plants in the state based on environmental and water supply concerns.[18] Arizona recently rejected permitting for a proposed power plant because of concerns about how much water it would withdraw from a local aquifer.[19] In early 2005, Governor Mike Rounds of South Dakota called for a summit to discuss drought-induced low flows on the Missouri River and the impacts on irrigation, drinking-water systems, and power plants.[20] A coal-fired power plant to be built in Wisconsin on Lake Michigan has been under attack from environmental groups because of potential effects of the facility's cooling-water-intake structures on aquatic life.[21] In February 2006, Diné Power Authority reached an agreement with the Navajo Nation to pay $1,000 per acre foot and a guaranteed minimum total of $3 million for water for its proposed Desert Rock Energy Project.[22] In an article discussing a 1,200 MW proposed plant in Nevada, opposition to the plant stated, "There's no way Washoe County has the luxury anymore to have a fossil-fuel plant site in the county with the water issues we now have. It's too important for the county's economic health to allow water to be blown up in the air in a cooling tower."[23]

Appendix A
Water Needs Analysis Methodology

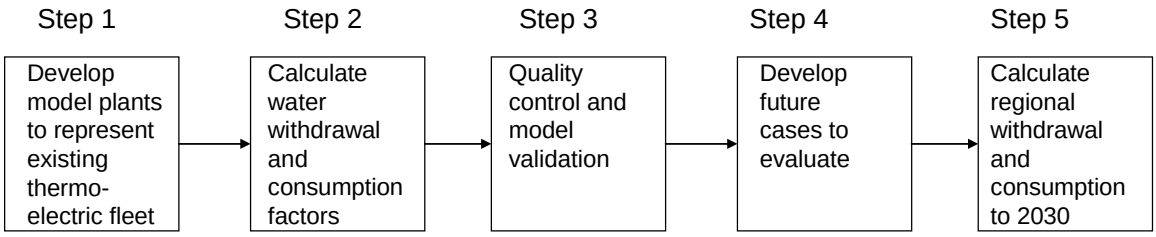
The purpose of this analysis is to update a 2004 National Energy Technology Laboratory (NETL) study to estimate freshwater needs to meet future year thermoelectric generation capacity requirements. This analysis uses a more detailed analytical approach and incorporates data and projections from the Energy Information Administration's *Annual Energy Outlook 2006*. Table B-1 summarizes the specific items that are updated in the 2006 Water Needs Analysis. The additional level of detail and resolution included in the 2006 analysis required a modified methodology from that used in the 2004 analysis.

Table B-1 - U.S. Power Generation Industry Water Withdrawal and Use Analysis – Comparison of Assumptions and Methodologies

Item	2004 Analysis	2006 Analysis
Capacity/Generation Projections	AEO2004	AEO2006
Geographical Breakdown	National	National and NERC region
Cooling Water Source Breakdown	Freshwater and Saline	Freshwater and Saline
Cooling Water System Type	Once-through and wet recirculating	Once-through, recirculating, and cooling pond
Boiler Type	Not included	Subcritical and supercritical
FGD Type	Not included	Wet, Dry, and None
Final Year of Projection	2025	2030
Cases	Six cases with upper and lower bounds	Five cases with conservative assumptions
Water Use Scaling Factors	National	NERC region with adjustment for capacity factor increase

Figure B-1 provides a flowchart depiction of the methodology used to conduct the analysis. The five-step approach represents a refined and more robust methodology than that used in the 2004 Water Needs Analysis. Each step in the process is described below.

Figure B-1 - Methodology for the 2006 Water Needs Analysis



Step 1: Develop model plants

To obtain the resolution desired for this analysis, water withdrawal and consumption factors were determined for a large number of plant configurations, based on location, generation type, cooling water source, cooling system type, and where applicable, boiler type and type of flue gas desulfurization (FGD) system. The existing thermoelectric fleet was segregated into numerous configurations, called "model plants" using data contained in several sources: the NETL Coal Plant Database, EIA-767, and EIA-860. Water withdrawal and consumption factors were calculated for each model plant using the available data and then used in conjunction with projections from AEO 2006 to provide an estimate of future water withdrawal and consumption for various cases.

The model plant derivation process is detailed below.

NERC Regions

Cooling water needs will vary by region due to climatic variations and availability of cooling water. Performing the water needs analysis on a regional level, therefore, provides a more accurate estimate of cooling water trends than a higher-level analysis. To accomplish this, the 13 NERC regions (excluding Alaska and Hawaii) were integrated into the *NETL Coal Plant Database* from the EIA-860 database.

Thermoelectric Generation Type

Water withdrawal and consumption factors were determined for thermoelectric power plants: coal, nuclear, oil, natural gas and the steam portion of gas-fired combined cycles. However, more detailed effort was expended in determining water factors for coal-fired power plants. The analysis doe not include non-thermoelectric plants such as combustion turbines, renewable generations, etc.

Individual water use estimates were developed for the following thermoelectric generation types:

i. Coal
ii. Nuclear
iii. Non-Coal Fossil
iv. Combined Cycle

Model plants for coal in each NERC region were developed using the following hierarchy:

Cooling Water Type (Freshwater/Saline)

↓

Cooling Water System Type (Once-Through, Wet Recirculating, Dry Recirculating, Cooling Ponds)

↓

Boiler Type (Subcritical, Supercritical)

↓

FGD Type (Wet, Dry, None)

Using this hierarchy, a total of 30 model plants are possible for coal in each region[e]:

1. Freshwater, once-through, subcritical, wet FGD
2. Freshwater, once-through, subcritical, dry FGD
3. Freshwater, once-through, subcritical, no FGD
4. Freshwater, once-through, supercritical, wet FGD
5. Freshwater, once-through, supercritical, dry FGD
6. Freshwater, once-through, supercritical, no FGD
7. Freshwater, recirculating, subcritical, wet FGD
8. Freshwater, recirculating, subcritical, dry FGD
9. Freshwater, recirculating, subcritical, no FGD
10. Freshwater, recirculating, supercritical, wet FGD
11. Freshwater, recirculating, supercritical, dry FGD
12. Freshwater, recirculating, supercritical, no FGD
13. Freshwater, cooling pond, subcritical, wet FGD
14. Freshwater, cooling pond, subcritical, dry FGD
15. Freshwater, cooling pond, subcritical, no FGD
16. Freshwater, cooling pond, supercritical, wet FGD
17. Freshwater, cooling pond, supercritical, dry FGD
18. Freshwater, cooling pond, supercritical, no FGD
19. Saline, once-through, subcritical, wet FGD
20. Saline, once-through, subcritical, dry FGD

[e] According to the hierarchy presented, 36 model plant combinations are possible. Six of these combinations would be configured with saline cooling ponds. Such a cooling water source is technically impractical and, therefore, not included in this analysis.

21. Saline, once-through, subcritical, no FGD
22. Saline, once-through, supercritical, wet FGD
23. Saline, once-through, supercritical, dry FGD
24. Saline, once-through, supercritical, no FGD
25. Saline, recirculating, subcritical, wet FGD
26. Saline, recirculating, subcritical, dry FGD
27. Saline, recirculating, subcritical, no FGD
28. Saline, recirculating, supercritical, wet FGD
29. Saline, recirculating, supercritical, dry FGD
30. Saline, recirculating, supercritical, no FGD

Similar model plants were developed for nuclear, non-coal fossil, and combined cycle, but only broken down by cooling water type (freshwater vs. saline) and cooling water system type (once-through, recirculating, cooling pond).

Step 2: Calculate water withdrawal and consumption factors
For each model plant defined in Step 1, water withdrawal and consumption factors were calculated using the data sources outlined above.

Coal
For coal, the water withdrawal and consumption factors were based on the sum of three components: 1) boiler make-up water; 2) FGD make-up water; and 3) cooling water.

The boiler make-up water component at a coal plant depends on the type of boiler – either subcritical or supercritical. The boiler make-up water factors were calculated using water balance data contained in Parsons' "Power Plant Water Consumption Study" conducted for NETL in August 2005. Separate values were determined for subcritical and supercritical plant configurations, but the values were fixed for all regions, water source, cooling type, and FGD type.

The FGD make-up water component depends on the type of FGD system – either wet or dry. Dry FGD systems require much less water than wet FGD systems, for example, so different factors must be used. The FGD make-up water factors were calculated using material balance data contained in Carnegie Mellon University's Integrated Environmental Control Model (IECM). Separate values were determined for subcritical and supercritical plant configurations, but the values were fixed for all regions, water source, and cooling type.

The cooling water component for each model plant was calculated by compiling data from the *NETL Coal Power Plant Database* and EIA-860 for water withdrawal, water consumption, and summer capacity. Average water withdrawal (gal/hr), average water consumption (gal/hr), and summer capacity were used to calculate average withdrawal and consumption scaling factors (gal/kWh) for each model plant in each of the NERC regions. The power plant capacity data contained in the NETL database consists of

nameplate MW capacity taken from the EIA-767 report. However, the AEO projections are based on summer capacity. Therefore, summer capacity (MW) data was obtained from the EIA-860 report to calculate the scaling factors. The following methodology was used to calculate the average cooling water withdrawal and consumption factors for each type of cooling water system:

- *Once-through systems:* To maximize plant efficiency during partial load operation, power plant operators normally maintain cooling water flow through the condenser at full load design rates. Therefore, the cooling water withdrawal rate for a once-through cooling water system is dependent on plant capacity (kW) and independent of plant electrical generation (kWh). For this reason, the water usage factors for once-through systems were determined by dividing the sum of the average withdrawal or consumption rate by the sum of the generator summer capacity.

  Withdrawal Factor (gal/kWh) = ΣAverage Withdrawal (gal/h) / ΣCapacity (kW) (1a)

  Consumption Factor (gal/kWh) = ΣAverage Consumption (gal/h) / ΣCapacity (kW) (1b)

- *Wet Recirculating Systems:* Similar to once-through systems, to maximize plant efficiency during partial load operation, power plant operators normally maintain cooling water flow through the condenser and across the cooling tower at full load design rates. However, as more power is produced, the heat load to the cooling tower increases, resulting in greater evaporative losses and blowdown and consequently, higher water withdrawal requirements. Therefore, water withdrawal and consumption are independent of plant capacity (kW) and dependent on plant electrical generation (kWh) in wet recirculating systems. For this reason, the water usage factors for wet recirculating cooling systems were adjusted for each year of the analysis by applying a capacity factor ratio, F, to account for the growth in generation.

  Withdrawal Factor (gal/kWh) = F x ΣAverage Withdrawal (gal/h) / ΣCapacity (kW) (2a)

  Consumption Factor (gal/kWh) = F x ΣAverage Consumption (gal/h) / ΣCapacity (kW) (2b)

  Where:

  F = Ratio of capacity factor in year X to capacity factor in baseline year 2003

- *Cooling Ponds*: EIA-767 considers cooling ponds to be a type of wet recirculating cooling system since heat loss occurs through evaporative loss. However, cooling water flow rates for a cooling pond are more similar to once-through than wet recirculating systems. Therefore, for this study, water usage factors were calculated using the same formula as for once-through systems.

- *Dry Recirculating Systems*: For dry recirculating systems, the cooling water withdrawal and consumption factors are both assumed to be zero.

Non-Coal Plants

Nuclear, oil steam, gas steam, and natural gas combined-cycle plants were classified according to NERC region, cooling water source (fresh or saline), and cooling water system (recirculating or once-through). Water usage factors for each plant classification were determined using equations 1a, 1b, 2a, and 2b, depending on type of cooling water system.

In calculating water withdrawal and consumption quantities for combined-cycle plants, an adjustment was made to account for the fact that the gas turbine portion of the plant does not require cooling water. The design capacity of the gas turbine portion of a combined-cycle facility is typically twice that of the steam turbine portion; in other words, two-thirds of a combined-cycle plant's total output is derived from the gas turbine(s). Therefore, only about one-third of the plant output is used for steam generation, with its associated water requirements. For this analysis, water withdrawal and consumption factors were applied to only one-third of the combined-cycle capacity.

Step 3: Quality Control and Model Validation

Step 3 represents just one of several efforts designed to ensure quality control for the analysis. Because models, by definition, are simplified representations of reality, absolute model accuracy is impossible to guarantee in any situation. It is important, however, to have procedures in place to ensure that output from a given analysis is consistent with reality and reasonable expectations. Several steps were taken for the water needs analysis to achieve this objective.

The water withdrawal and consumption factors that were used in the model were obtained through a rigorous evaluation of data collected by the Energy Information Administration, primarily forms EIA-767 and EIA-860. Data presented on these forms is assumed to accurately represent conditions at a particular power plant. A variety of reasons, however, could account for errors and discrepancies in the data: lack of understanding of the form's directions, data entered in the wrong places, inaccurate data entry, improperly aggregated data, and others.

The calculated water withdrawal and consumption factors for a given categorical breakdown (e.g., NERC region) should fall within a limited range based on generation type and cooling type. If the dataset in that categorical breakdown was too small, data outliers could have disproportionately impacted the results. While it is impossible to eliminate all such errors, the data was carefully vetted to ensure quality data points were used. Certain entries were modified or discarded based on accompanying information and engineering judgment. For example, if a power plant was designated as a once-through facility, but reported cooling water withdrawal and consumption quantities that clearly identify it as a recirculating facility, the plant was re-classified as a recirculating facility.

To ensure that the estimates generated by the water needs analysis model were reasonable, power generation data from 1995 was obtained and inserted into the model. The calculated water withdrawal and consumption values for thermoelectric generation were then compared with U.S. Geologic Service estimates for water withdrawal and consumption for 1995.

Step 4: Develop Future Cases

Table B-2 summarizes the cases evaluated in the original 2004 analysis and the 2006 analysis. The effects of emerging issues, particularly the impact of the Clean Water Act 316(b) regulations,[f] were incorporated into the selection of the 2006 cases. Comments are provided with each of the cases to assess their likelihood and justify the chosen cases. Five cases were included in the 2006 Water Needs Analysis, one reflecting status quo conditions, two reflecting varying levels of regulations regarding cooling water source, one incorporating dry cooling, and one reflecting regulatory pressures to convert existing once-through capacity to recirculating capacity.

To determine total water withdrawal and consumption requirements for thermoelectric generation in future years, new capacity additions and existing capacity retirements were factored into the analysis. As noted in the table, retirements were modeled based on current source withdrawals; in other words, freshwater and saline units were retired from service in proportion to their current contributions to total installed capacity, which is thought to more accurately reflect industry behavior. Units recently retired and/or placed in cold reserve have been removed from service due to age and operational cost constraints; cooling water source has played a minimal or nonexistent role. Future capacity retirement decisions, therefore, will likely remain more dependent on age and operational costs than cooling water source, and should reflect current proportions of freshwater and saline water facilities.

Retired capacity in a given NERC region was broken down by generation type, water source, cooling type, and, where applicable, boiler and FGD type, based on the current proportion of capacity for each specific combination. The corresponding water withdrawal and consumption factors were then applied to the retired capacity to determine how much water must be deducted from the withdrawal and consumption totals.

In modeling capacity additions, it was necessary to consider the different thermoelectric generation types. A variety of model plants were added based on the case assumptions. Expected capacity additions in a given region in a given year, as projected by AEO 2006, were apportioned into these model plant categories. Each model plant will have an

[f] The Clean Water Act's 316(b) regulations require the U.S. Environmental Protection Agency to ensure that cooling water intake structures at power plants and other manufacturing facilities reflect the best technology available for minimizing adverse environmental impact. The practical impact of these regulations is that most new power plants will have to incorporate closed-loop, recirculating cooling systems, which overwhelmingly rely on freshwater.

associated water withdrawal and consumption factor. The corresponding capacity (kW) for each model plant category was used with the withdrawal and consumption factors to calculate incremental water withdrawal and consumption.

The model plants for the five cases are listed in Table B-3. Because of the resolution provided in this analysis for coal-fired power plants, more model plants were developed for coal than for the other generation types. Several notes are in order regarding the coal model plants:

- For pulverized coal plants, new additions are expected to favor supercritical boiler technology. Nationwide, the current split between subcritical and supercritical boiler technology capacity is 73% subcritical/27% supercritical, reflecting greater industry experience and familiarity with subcritical technology. Pressure from several sources – environmental entities, state utility commissions, the threat of CO_2 regulations – is increasing utility interest in supercritical boiler technology. A majority of the coal-fired power plants currently under construction or planned will rely on supercritical boiler technology. In selecting model coal plants for new additions, therefore, a 70% supercritical/30% subcritical split was employed. See Appendix B for further information.
- For coal-fired power plants equipped with flue gas desulfurization equipment, water withdrawal and consumption rates can exhibit relatively significant differences based on whether the FGD is a wet or dry system. Since all new pulverized coal-fired power plants will need FGD systems to comply with emission regulations, future capacity additions must be apportioned by FGD type. Since emission regulations do not dictate technology selection, the analysis apportions FGD type to new capacity additions based on the existing split in the coal-fired power fleet (by summer capacity), which is 90% wet/10% dry.
- The *Annual Energy Outlook* assumes that a portion of new coal-fired capacity will utilize integrated gasification combined-cycle (IGCC) technology. The water requirements for IGCC facilities differ from those at pulverized coal facilities. While both require cooling water, IGCC requires substantially less since a large fraction of the output from an IGCC plant is produced from the combustion turbines, which require minimal water. Moreover, since IGCC relies on water for significant process (non-cooling) use, it is unlikely that a saline water source would be desirable. The model IGCC coal plant, therefore, is restricted to freshwater use.

As discussed above, model plants for the non-coal thermoelectric generation capacity – nuclear, oil steam, gas steam, and natural gas combined cycle – were broken down by water source (fresh or saline) and cooling water type (once-through or wet recirculating) based on data from the EIA-767 and EIA-860 databases. Two model plants account for all likely new non-coal thermoelectric additions: a plant using a freshwater recirculating system and a plant using a saline once-through system. For Case 4, an additional model plant with dry cooling is included for both coal and non-coal generation types.

Table B-2 - Case Selection, 2004 vs. 2006

2004 Water Needs Analysis	
Case description	Comments
Case 1: All additions and retirements occur at facilities using freshwater.	Reasonable. While the vast majority of new additions will use freshwater due to 316(b) regulations, it is unlikely that the majority of retirements will be from freshwater facilities. Retirement decisions will depend more on age and operational costs than on cooling water source.
Case 2: Additions and retirements are proportional to current source withdrawals (70% freshwater/30% saline).	Reasonable. As discussed for Case 1, retirement decisions will depend on age and operational costs, which will likely mirror the proportional split between freshwater and saline. For additions, however, 316(b) regulations will likely lead to a higher proportion of freshwater facilities since saline water is incompatible with wet recirculation systems..
Case 3: All additions and retirements occur at facilities using saline water.	Unlikely. Due to 316(b) regulations, saline water will likely account for a significantly smaller percentage of new additions. Retirements may slightly favor saline, but decision will depend more on age and operational costs.
Case 4: Additions occur at freshwater facilities, while retirements occur at saline facilities.	Reasonable. Although retirements are likely to be more proportional to current source withdrawals, as discussed above.
Case 5: Additions occur at saline facilities, while retirements occur at freshwater facilities.	Extremely unlikely. 316(b) regulations will make saline a difficult choice for additions. No regulatory or operational trends indicate that retirements would favor freshwater.
Case 6: All retired coal units use once-through cooling and are repowered using the existing once-through system. Additions reduced by the repowered units.	Unlikely. Via repowering, units would be subject to new source regulations, which favor recirculating systems and the use of freshwater.
2006 Water Needs Analysis	
Case Description	**Rationale**
Case 1: Additions and retirements proportional to current water source and type of cooling system.	Status quo scenario case. Assumes additions and retirements follow current trends.
Case 2: All additions use freshwater and wet recirculating cooling, while retirements are proportional to current water source and cooling system.	Regulatory-driven case. Assumes 316(b) and future regulations dictate the use of recirculating systems for all new capacity. Retirement decisions hinge on age and operational costs rather than water source and type of cooling system.
Case 3: 90% of additions use freshwater and wet recirculating cooling, and 10% of additions use saline water and once-through cooling, while retirements are proportional to current water source and cooling system.	Regulatory-light case. New additions favor the use of freshwater recirculating systems, but some saline capacity is permitted. Retirement decisions remain tied to age and operational costs, tracking current source withdrawals.
Case 4: 25% of additions use dry cooling and 75% of additions use freshwater and wet recirculating cooling. Retirements are proportional to current water source and cooling system.	Dry cooling case. Regulatory and public pressures result in significant market penetration of dry cooling technology. Retirement decisions remain tied to age and operational costs, tracking current source withdrawals.
Case 5: Additions use freshwater and wet recirculating cooling, while	Conversion case. Same as Case 2, except regulatory and public pressures compel state agencies to dictate the conversion of a

retirements are proportional to current water source and cooling system. 5% of existing freshwater once-through cooling capacity retrofitted with wet recirculating cooling every 5 years starting in 2010.	significant amount of existing freshwater once-through cooling systems to wet recirculating.

Table B-3 - Model Plants for New Capacity Additions

Case 1	

Coal	• Pulverized coal, freshwater, recirculating cooling system
	  o 75% supercritical/25% subcritical
	  o Wet FGD/dry FGD based on existing split
	• Pulverized coal, saline water, once-through cooling system
	  o 75% supercritical/25% subcritical
	  o Wet FGD/dry FGD based on existing split
	• Integrated gasification combined-cycle, freshwater, recirculating

Nuclear	• Freshwater, recirculating cooling system • Saline water, once-through cooling system
Non-coal fossil	• Freshwater, recirculating cooling system • Saline water, once-through cooling system
Case 2	

Coal	• Pulverized coal, freshwater, recirculating cooling system
	  o 75% supercritical/25% subcritical
	  o Wet FGD/dry FGD based on existing split
	• Integrated gasification combined-cycle, freshwater, recirculating

Nuclear	• Freshwater, recirculating cooling system
Non-coal fossil	• Freshwater, recirculating cooling system
Case 3	

Coal	• Pulverized coal, freshwater, recirculating cooling system
	  o 75% supercritical/25% subcritical
	  o Wet FGD/dry FGD based on existing split
	• Pulverized coal, saline water, once-through cooling system
	  o 75% supercritical/25% subcritical
	  o Wet FGD/dry FGD based on existing split
	• Integrated gasification combined-cycle, freshwater, recirculating

Nuclear	• Freshwater, recirculating cooling system • Saline water, once-through cooling system
Non-coal fossil	• Freshwater, recirculating cooling system • Saline water, once-through cooling system
Case 4	

Coal	• Pulverized coal, freshwater, recirculating cooling system
	  o 75% supercritical/25% subcritical
	  o Wet FGD/dry FGD based on existing split
	• Pulverized coal, freshwater, dry cooling system
	  o 75% supercritical/25% subcritical
	  o Wet FGD/dry FGD based on existing split
	• Integrated gasification combined-cycle, freshwater, recirculating
	• Integrated gasification combined-cycle, dry cooling system

Nuclear	• Freshwater, recirculating cooling system • Dry cooling system

Non-coal fossil	• Freshwater, recirculating cooling system • Dry cooling system
Case 5	

Coal	• Pulverized coal, freshwater, recirculating cooling system
	  o 75% supercritical/25% subcritical
	  o Wet FGD/dry FGD based on existing split
	• Integrated gasification combined-cycle, freshwater, recirculating

Nuclear	• Freshwater, recirculating cooling system
Non-coal fossil	• Freshwater, recirculating cooling system

Step 5: Calculate regional withdrawal and consumption to 2030

Step 5 integrates the water withdrawal and consumption factors calculated in Step 2 with the various cases defined in Step 4 to assess the regional and national impacts on water withdrawal and consumption out to 2030.

The *Annual Energy Outlook* provides projections of future electricity generating capacity by year, by generation type and by NERC region. Apportioning this capacity among the chosen model plants for a given case and then applying the water withdrawal and consumption factors enables one to estimate water withdrawal and consumption trends.

For a given case in a given region, the capacity additions and retirements projected by AEO 2006 were first divided between freshwater and saline water based on the source withdrawal split for each technology type (coal, nuclear, non-coal fossil), as determined using existing fleet data. The additions and retirements were further apportioned among cooling water system type (once-through, recirculating), again using existing fleet splits. For nuclear and non-coal fossil, the water withdrawal and consumption factors determined in Step 2 were then applied to the resulting capacity amounts to calculate water withdrawal and consumption totals.

For coal, further segregation was necessary before performing the calculations. The additions and retirements were further apportioned by technology type (supercritical and subcritical boilers). Retirements were divided based on the existing fleet split between supercritical and subcritical technology. Additions were divided between supercritical and subcritical boilers at a 70/30 ratio to reflect a growing preference for supercritical technology, as described above in Step 4 and in Appendix C. The additions also must accommodate new IGCC plants; AEO projections for IGCC were used to apportion capacity amounts by region. Finally, coal retirements and additions were apportioned by FGD type (wet, dry, none) using existing fleet data. The water withdrawal and consumption values determined in Step 2 were applied to the segregated capacity quantities determined in Step 5 to calculate water withdrawal and consumption totals.

The calculations were a result of summing the results for each model plant in each region. The following is an example formula to calculate water withdrawal that was used for a model plant:

Water Withdrawal (gal/hr) = A x B x C (3)

Where:
A = Total regional capacity, kW
B = Proportion of capacity assigned to model plant, %/100
C = Capacity factor-weighted water use scaling factor for model plant, gal/kWh

Appendix C
Future Coal-Fired Power Plant Boiler Type
Supercritical versus Subcritical

The water analysis uses different water use scaling factors for coal-fired power plants based on boiler type. A supercritical boiler – operating at steam conditions above the critical point – is more efficient and therefore requires less cooling water flow than a subcritical boiler for an equivalent amount of electrical generation output. The critical point represents the highest temperature and pressure at which a substance can exist as a vapor and liquid in equilibrium. The critical point for water is 3200 psia and 705°F. Today's supercritical boilers operate at steam conditions of approximately 3500 psia and 1000°F compared to subcritical boilers that operate at approximately 2400 psia or less and 1000°F.

Table C-1 presents a summary of the breakdown by boiler type for currently operating U.S. coal-fired power plants according to data taken from Platt's UDI Power Plant Database. The current boiler type breakdown by MW capacity is 27% supercritical and 73% subcritical. It should also be noted that supercritical boilers tend to be significantly larger in capacity. The average size of supercritical boilers is 743 MW compared to 234 MW for subcritical boilers.

Table C-1 – Boiler Type for Existing Plants

Operating Plants	Total	Super-critical	Sub-critical
No. Units	1,136	117	1,019
Total Capacity, MW	325,651	86,903	238,748
Average Unit Capacity, MW	287	743	234
% Total Capacity	Base	27%	73%

Table C-2 presents a similar summary by boiler type for coal-fired power plants either under construction or planned also taken from Platt's UDI Power Plant Database. However, not all of the plants reported boiler type. For those plants that boiler type is reported, the breakdown by capacity is 55% supercritical and 45% subcritical. Similar to the currently operating plants, the average size of supercritical plants is 719 MW compared to 312 MW for subcritical plants. Since it appears that plant capacity correlates fairly well with boiler type, the unreported plants are segregated into two plant sizes – greater than or equal to 500 MW (87%) and less than 500 MW (13%).

Table C-2 – Boiler Type for Future Plants – As Reported

Plants Under Construction or Planned	Total	Boiler Type Reported			Boiler Type Not Reported		
		Total	Super-critical	Sub-critical	Total	≥ 500 MW	< 500 MW
No. Units	86	49	17	32	37	26	11
Total Capacity, MW	42,835	22,203	12,225	9,978	20,632	17,887	2,745
Average Capacity, MW	498	453	719	312	558	688	250
% Total Capacity			55%	45%		87%	13%

Based on the boiler type data in Table C-1 and reported boiler type data in Table C-2, it is apparent that plant capacity correlates fairly well with boiler type. As a result, the unreported plants in Table C-2 that were segregated by plant capacity can also be categorized by boiler type. Plants with a capacity greater than or equal to 500 MW are assumed to be supercritical and those with a capacity less than 500 MW are assumed to be subcritical. Table C-3 presents the result of this categorization by combining the reported and unreported plant data from Table C-2. Therefore, future coal-fired plant capacity is assumed to be split as 70% supercritical and 30% subcritical for the water analysis.

Table C-3 – Boiler Type for Future Plants - Combined

Plants Under Construction or Planned	Total	Super-critical	Sub-critical
No. Units	86	43	43
Total Capacity, MW	42,835	30,112	12,723
Average Capacity, MW	498	700	296
% Total Capacity		70%	30%

Appendix D
Water Withdrawal and Consumption Factors

Table D-1 – National Average Withdrawal and Consumption Factors for Model Coal Plants

Model Plant	Withdrawal Factor (gal/kWh)	Consumption Factor (gal/kWh)
Freshwater, Once-Through, Subcritical, Wet FGD	27.113	0.138
Freshwater, Once-Through, Subcritical, Dry FGD	27.088	0.113
Freshwater, Once-Through, Subcritical, No FGD	27.046	0.071
Freshwater, Once-Through, Supercritical, Wet FGD	22.611	0.124
Freshwater, Once-Through, Supercritical, Dry FGD	22.590	0.103
Freshwater, Once-Through, Supercritical, No FGD	22.551	0.064
Freshwater, Recirculating, Subcritical, Wet FGD	0.531	0.462
Freshwater, Recirculating, Subcritical, Dry FGD	0.506	0.437
Freshwater, Recirculating, Subcritical, No FGD	0.463	0.394
Freshwater, Recirculating, Supercritical, Wet FGD	0.669	0.518
Freshwater, Recirculating, Supercritical, Dry FGD	0.648	0.496
Freshwater, Recirculating, Supercritical, No FGD	0.609	0.458
Freshwater, Cooling Pond, Subcritical, Wet FGD	17.927	0.804
Freshwater, Cooling Pond, Subcritical, Dry FGD	17.902	0.779
Freshwater, Cooling Pond, Subcritical, No FGD	17.859	0.737
Freshwater, Cooling Pond, Supercritical, Wet FGD	15.057	0.064
Freshwater, Cooling Pond, Supercritical, Dry FGD	15.035	0.042
Freshwater, Cooling Pond, Supercritical, No FGD	14.996	0.004

Table D-2 – National Average Withdrawal and Consumption Factors for Model Nuclear Plants

Model Plant	Withdrawal Factor (gal/kWh)	Consumption Factor (gal/kWh)
Freshwater, Once-Through	31.497	0.137
Freshwater, Recirculating	1.101	0.624

Table D-3 – National Average Withdrawal and Consumption Factors for Model Fossil Non-Coal Plants

Model Plant	Withdrawal Factor (gal/kWh)	Consumption Factor (gal/kWh)
Freshwater, Once-Through	22.74	0.09
Freshwater, Recirculating	0.25	0.16
Freshwater, Cooling Pond	7.89	0.11

Table D-4 – National Average Withdrawal and Consumption Factors for Model IGCC/NGCC Plants

Model Plant	Withdrawal Factor (gal/kWh)	Consumption Factor (gal/kWh)
NGCC, Freshwater, Once-Through	9.01	0.02
NGCC, Freshwater, Recirculating	0.15	0.13
NGCC, Freshwater, Cooling Pond	5.95	0.24
NGCC Air Cooled	0.004	0.004
IGCC, Freshwater, Recirculating	0.226	0.173

Appendix E
Combined-Cycle Power Plants:
Relative Contributions from Gas and Steam Turbines

Combined-cycle power plants integrate the power generating capabilities of gas turbines and steam turbines in a highly efficient manner. The waste heat generated by fuel combustion in the gas turbine is recovered in a heat recovery steam generator, producing steam that is then used to generate additional power in the steam turbine. A common rule of thumb for combined-cycle design is that the gas turbine capacity is about twice that of the steam turbine (i.e., steam turbine output represents about one-third of total plant output).

The water needs analysis incorporates this rule of thumb by applying the water withdrawal and consumption factors to only one-third of the combined-cycle capacity. To justify this assumption, the Platts *World Electric Power Plants Database* was analyzed. For those plants reporting gas turbine and steam turbine capacity in a combined-cycle configuration, the database produced the numbers shown in the table below.

Table E-1 - Gas and Steam Turbine Contribution

	Capacity (MW)	Percentage	Number of units	Percentage
Gas turbines in combined-cycle configuration	93,526	62.1%	846	63.2%
Steam turbines in combined-cycle configuration	57,068	37.9%	493	36.8%
Total	150,594	100.0%	1339	100.0%

Steam turbine capacity represents about 38% of total combined-cycle capacity. While the data do not precisely equal the 2:1 ratio posited by the rule of thumb, the agreement is fairly close. Industry product evolution and individual plant design data also support the 2:1 ratio. Siemens Power Generation recently expanded its product portfolio with the SGT5-8000H gas turbine, featuring advanced H-class efficiency.[24] This turbine will be capable of producing about 340 MW in simple-cycle configuration, and about 530 MW in combined-cycle configuration, resulting in a steam turbine percentage of 35.8%. In the forthcoming NETL report, "2006 Cost and Performance Comparison of Fossil Energy Power Plants," the steam turbine in the natural gas-fired combined-cycle design represents 29.2% of total plant output.[25]

Based on this information, assuming that the water scaling factors should only be applied to one-third of the generating capacity for combined-cycle plants appears quite reasonable.

Appendix F
Results from Statistical Analysis of Water Usage Factor Data

Figure F-1 – Boxplot for All Water Usage Factor Data for Coal Recirculating Subcritical Category

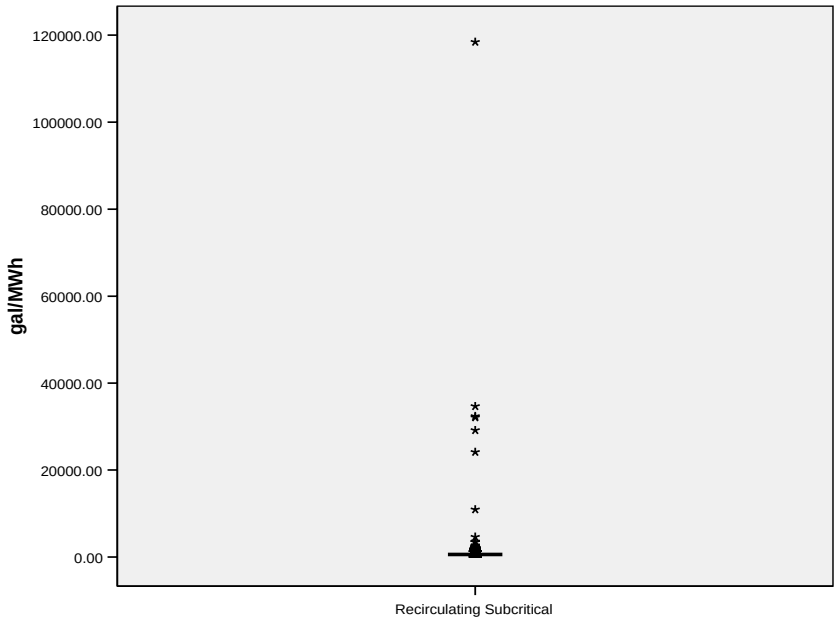


Figure F-2 - Boxplot for Water Usage Factor Data for Coal Recirculating Subcritical Category with Outliers Eliminated

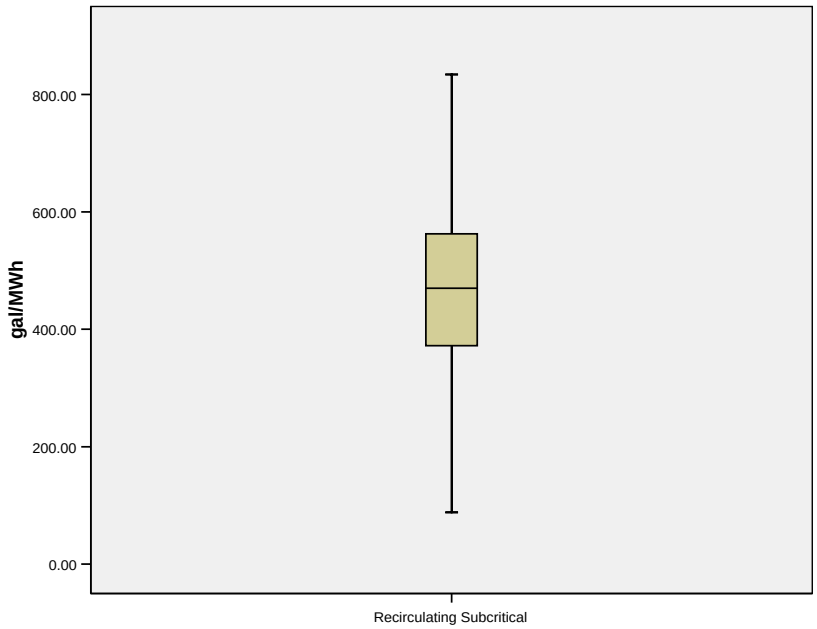


Figure F-3 – Boxplot for All Water Usage Factor Data for Coal Recirculating Supercritical Category

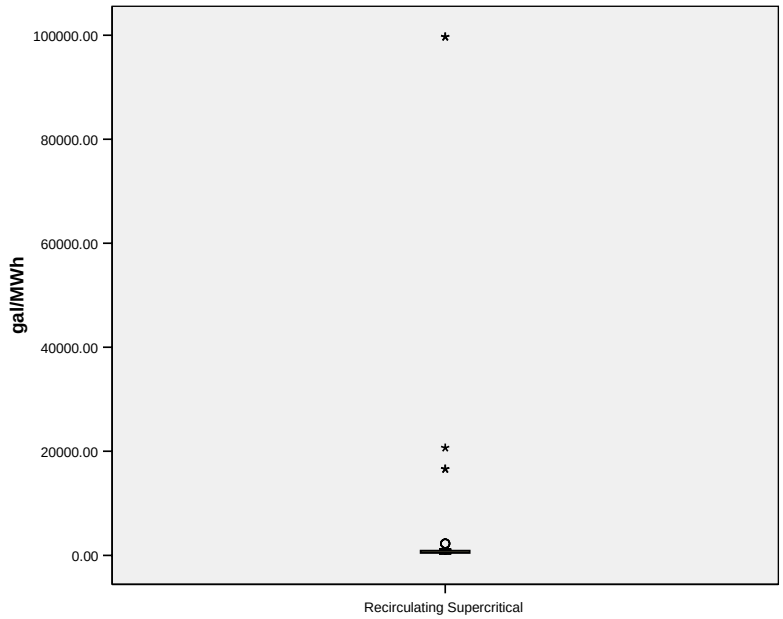


Figure F-4 - Boxplot for Water Usage Factor Data for Coal Recirculating Supercritical Category with Outliers Eliminated

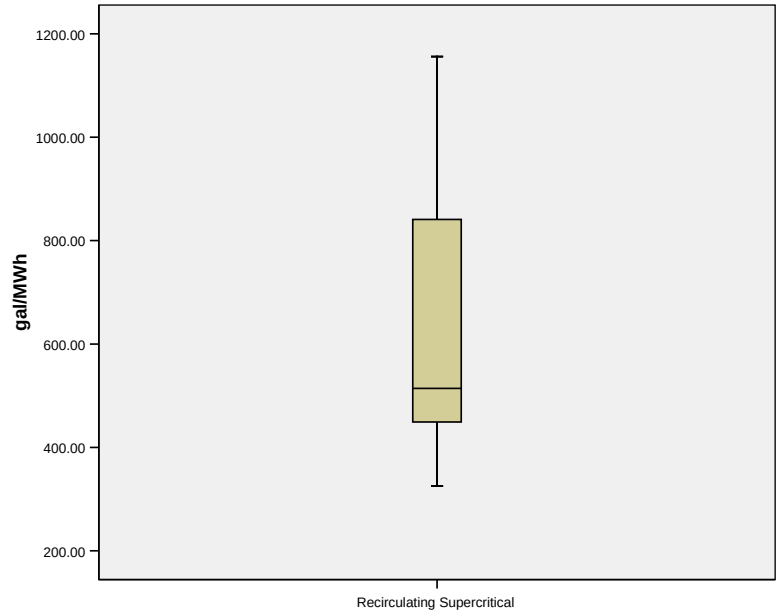


Figure F-5 – Boxplot for All Water Usage Factor Data for Coal Once-Through Subcritical Category

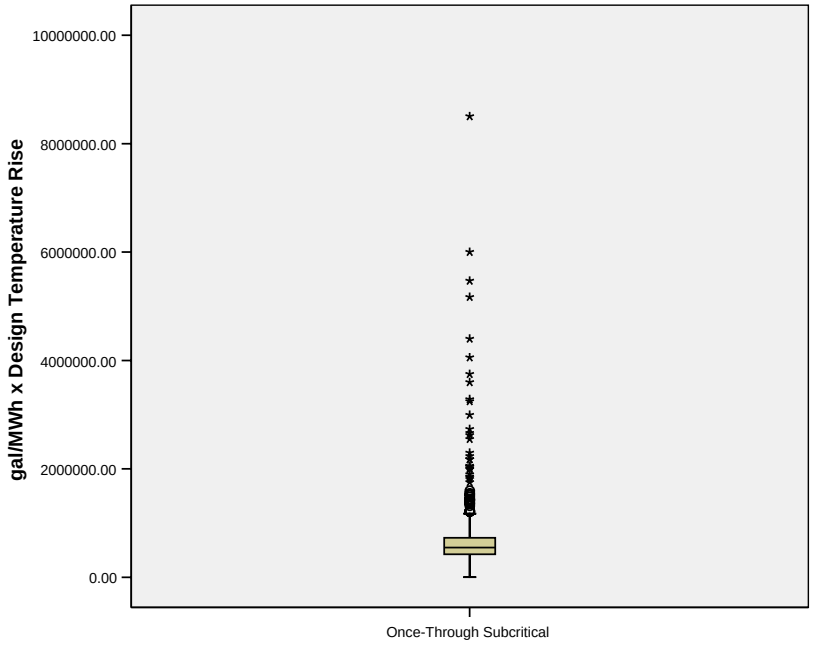


Figure F-6 - Boxplot for Water Usage Factor Data for Coal Once-Through Subcritical Category with Outliers Eliminated

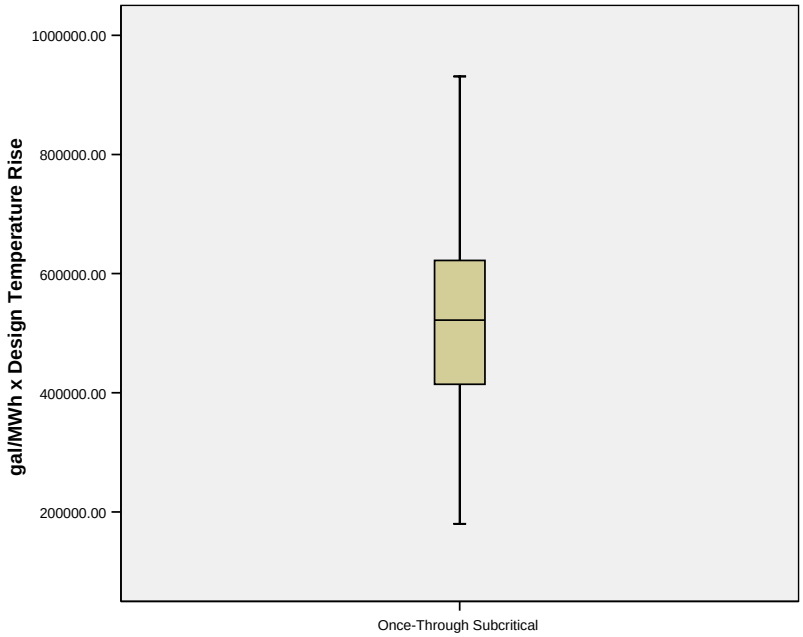


Figure F-7 – Boxplot for All Water Usage Factor Data for Coal Once-Through Supercritical Category

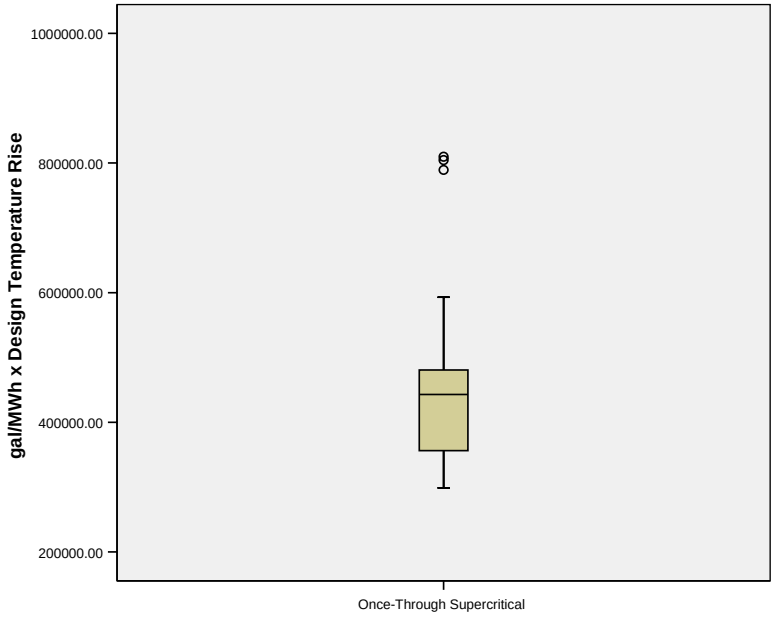


Figure F-8 - Boxplot for Water Usage Factor Data for Coal Once-Through Supercritical Category with Outliers Eliminated

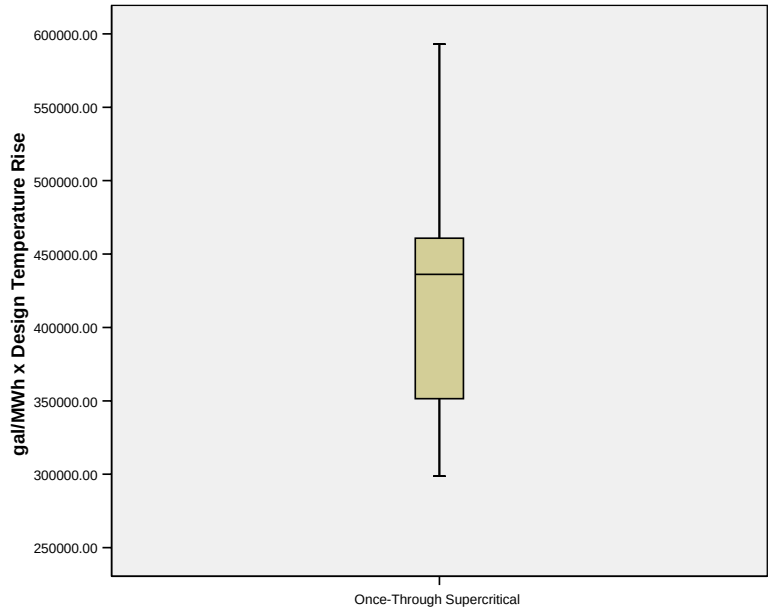


Figure F-9 – Boxplot for All Water Usage Factor Data for Coal Cooling Pond Subcritical Category

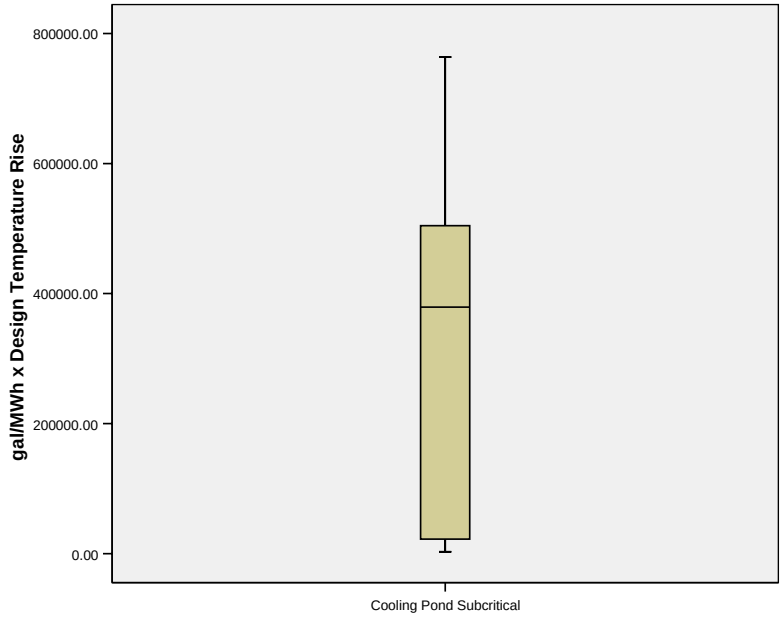


Figure F-10 – Boxplot for All Water Usage Factor Data for Coal Cooling Pond Supercritical Category

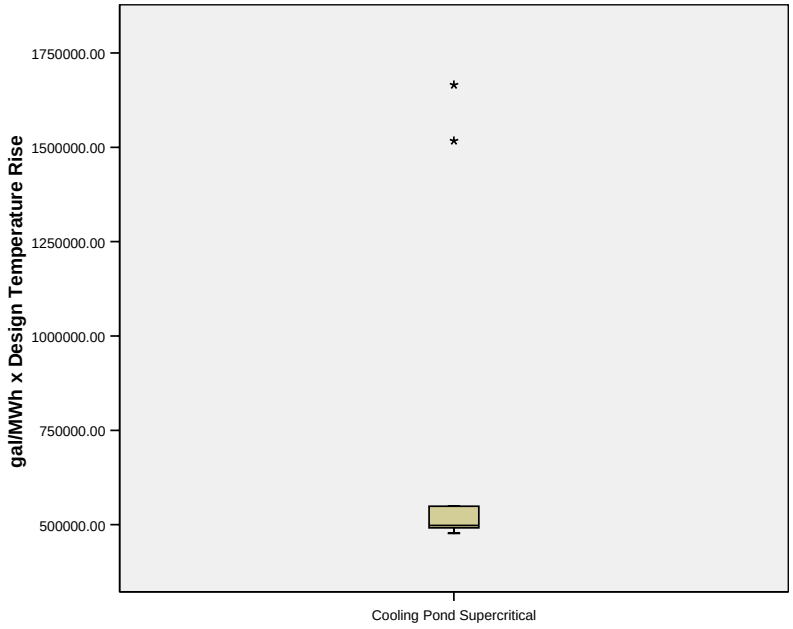


Figure F-11 - Boxplot for Water Usage Factor Data for Coal Cooling Pond Supercritical Category with Outliers Eliminated

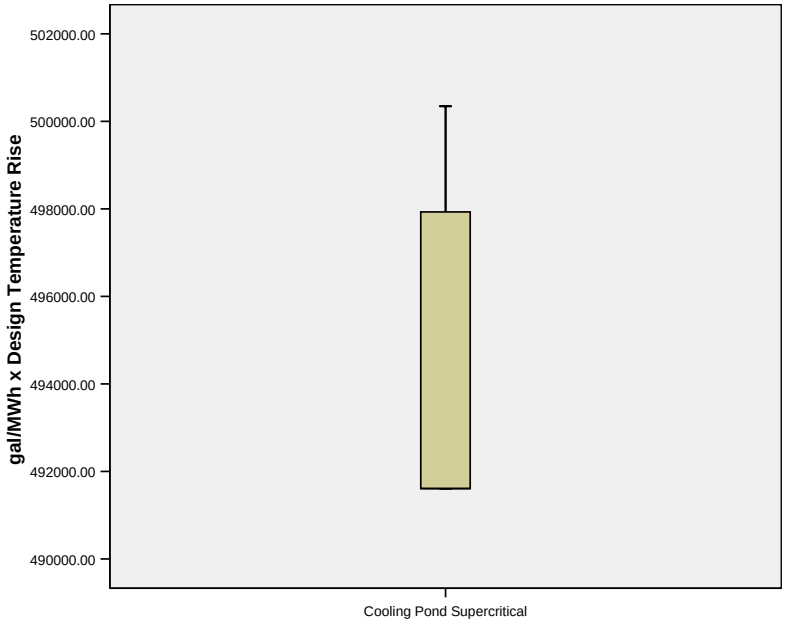


Figure F-12 – Boxplot for All Water Usage Factor Data for Fossil Non-Coal Recirculating Category

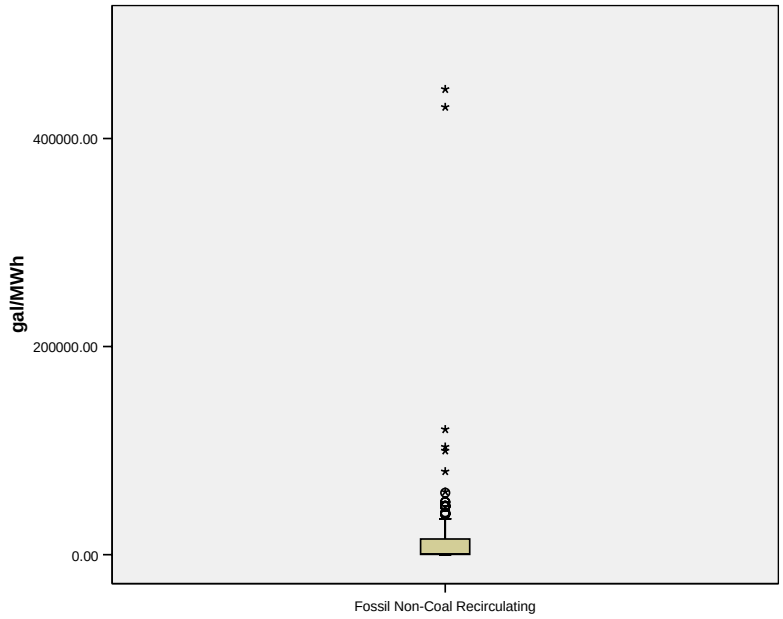


Figure F-13 - Boxplot for Water Usage Factor Data for Fossil Non-Coal Recirculating Category with Outliers Eliminated

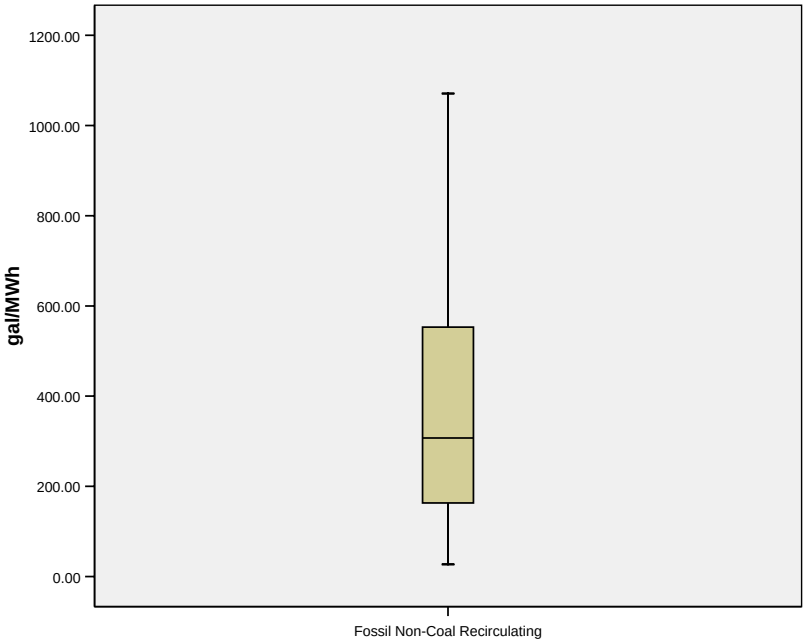


Figure F-14 – Boxplot for All Water Usage Factor Data for Fossil Non-Coal Once-Through Category

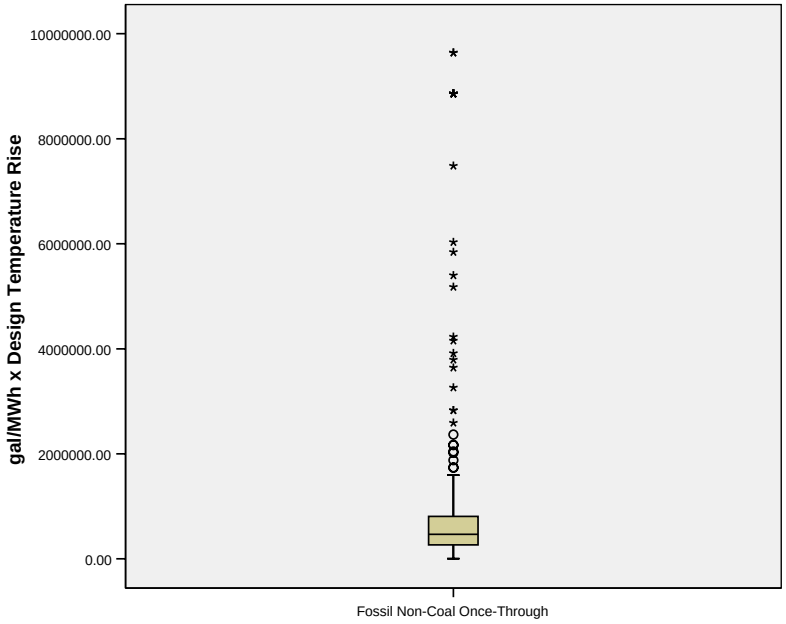


Figure F-15 - Boxplot for Water Usage Factor Data for Fossil Non-Coal Once-Through Category with Outliers Eliminated

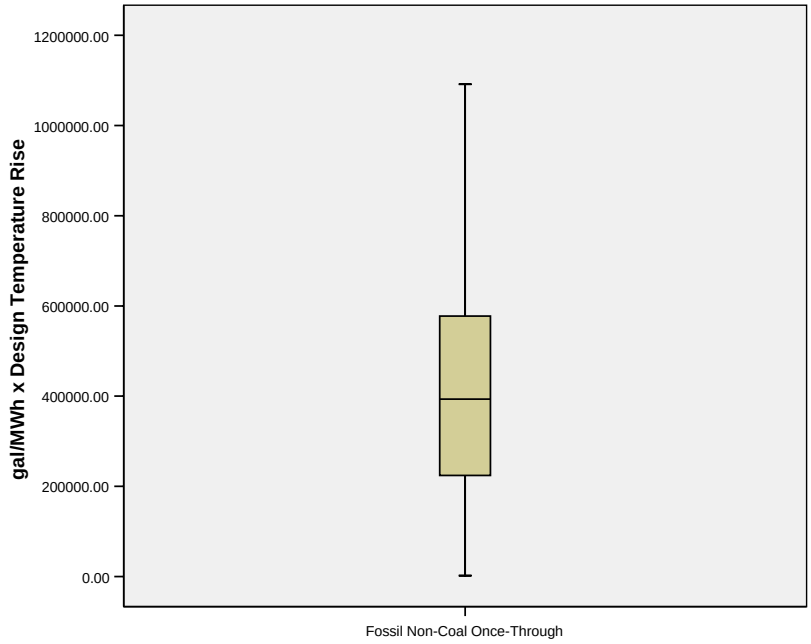


Figure F-16 – Boxplot for All Water Usage Factor Data for Fossil Non-Coal Cooling Pond Category

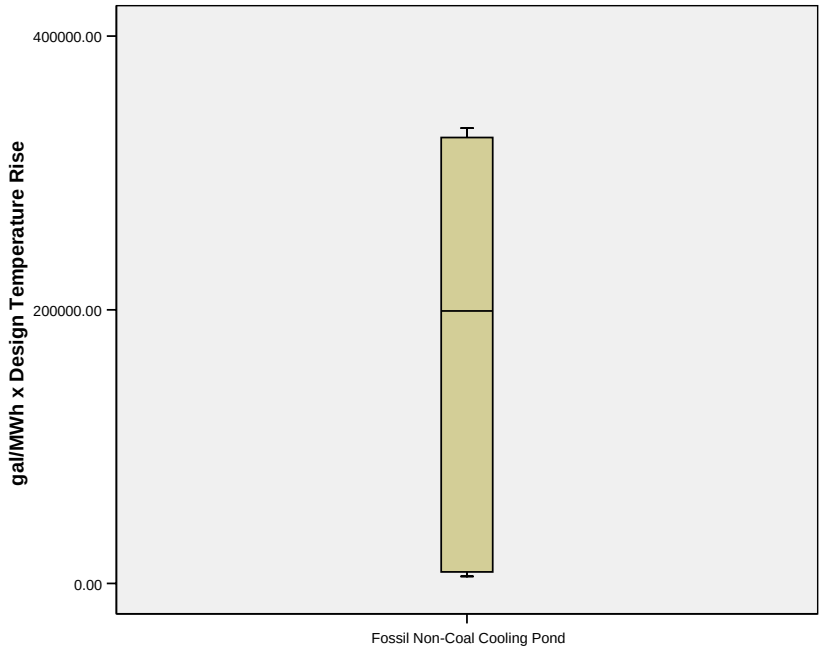


Figure F-17 – Boxplot for All Water Usage Factor Data for Nuclear Recirculating Category

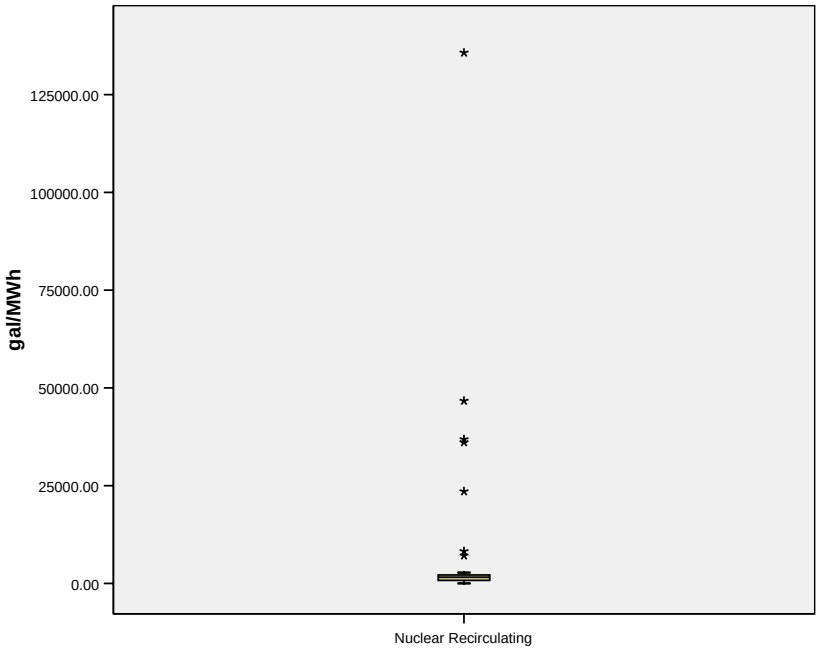


Figure F-18 - Boxplot for Water Usage Factor Data for Nuclear Recirculating Category with Outliers Eliminated

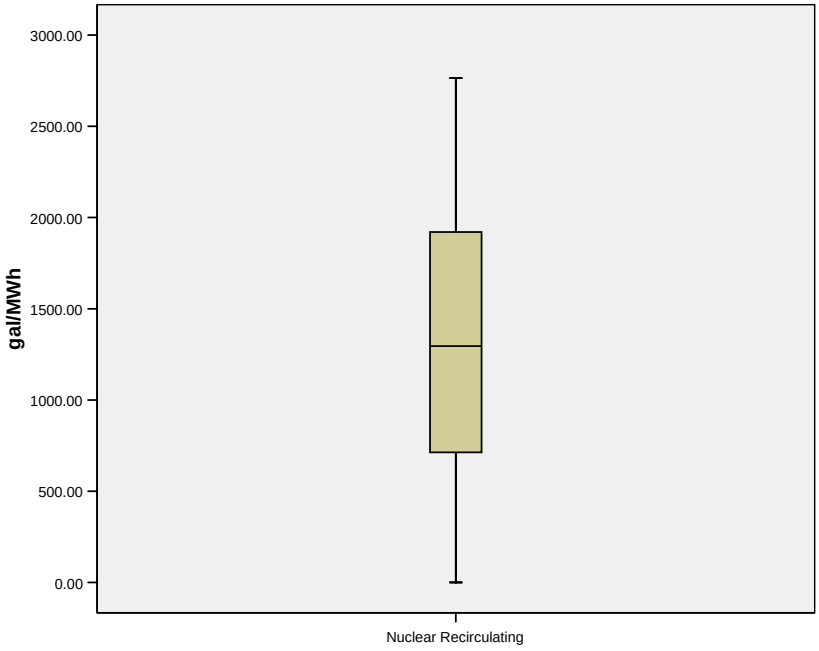


Figure F-19 – Boxplot for All Water Usage Factor Data for Nuclear Once-Through Category

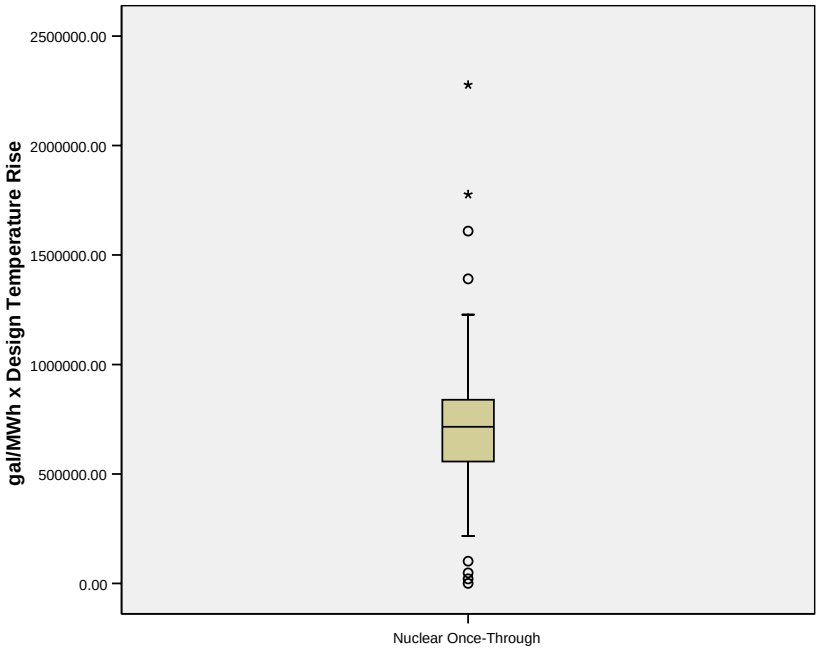
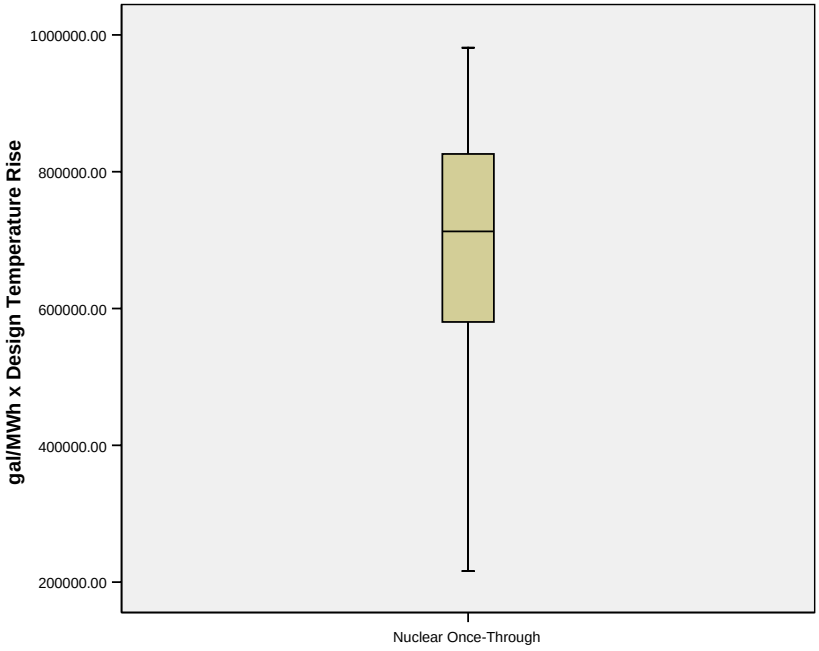


Figure F-20 - Boxplot for Water Usage Factor Data for Nuclear Once-Through Category with Outliers Eliminated



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