Estimating Freshwater Needs to Meet 2025 Electricity Generating Capacity Forecasts

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Executive Summary

Thermoelectric generation requires large volumes of water, primarily for cooling. An analysis was conducted to estimate the demand thermoelectric power plants will have on freshwater resources through 2025. Using the Energy Information Administration's (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. The result of these case runs indicate that the amount of freshwater needed to meet forecasted increases in thermoelectric capacity over the next two decades in the United States will increase slightly or will decline to some degree in terms of withdrawal. In terms of consumption, several cases project a large increase on a percentage basis as older once-through cooling plants are replaced by new plants with recirculating cooling systems. However, the thermoelectric sector will likely continue to represent only a small faction of total freshwater consumption in the U.S in 2025. While this analysis looked at freshwater requirements on a national basis, it is recognized that there are significant regional differences in projected electricity growth and freshwater demand and availability. As such, future analyses are planned to focus on these regional differences.

Introduction

As the United States enters the 21st century, water resources will likely become an increasingly important issue, both in terms of quality and quantity. The need for adequate supplies of abundant, clean freshwater resources to meet public and agricultural demand has been identified as an area of concern both for the United States and the world.[1,2] As our population increases and economic development continues, energy demand will also grow. Energy and water are inextricably linked resources, further challenging our ability to meet increasing demands for both. Energy production, especially electricity generation, requires access to large quantities of water. As a result, water issues appear to be playing a larger role in the permitting process for new power projects. The media has recently reported several cases of permits being denied, at least in part, because of limited water availability.[3,4] Limited electricity—or the water needed

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[1] United States General Accounting Office, ***Freshwater Supply: States' Views of How Federal Agencies Could Help Them Meet the Challenges of Expected Shortages***, GAO-03-514, July 2003
[2] United Nations World Water Program, ***Water for the People Water for Life, The United Nations World Water Development Report,*** UNESCO Publishing, 2003
[3] Ernst, S., ***Fate of Idaho Plants May Impact Sumas 2,*** Utilities Notebook, July 26, 2002

for electricity generation—will constrain economic growth. In order to sustain U.S. population growth and economic development, strategies at the state, regional, and national levels are needed to more effectively manage these interrelated resources.

Electricity production requires a reliable, abundant, and predictable source of water. In terms of total U.S. water use, the thermoelectric generating industry is the largest user of the nation's water resources (i.e., fresh, surface and groundwater, saline water). Saline water use is approximately 30% of the overall thermoelectric use, and the remaining 70% is nearly all fresh surface water, making it second only to agriculture as the largest domestic user of freshwater, and accounting for 39% of all freshwater withdrawals in the United States.[5] Roughly 70% of this water is used in fossil-fuel-based electricity generation, primarily for cooling purposes.[6] Coal, our nation's most abundant fossil fuel, currently accounts for 52% of the U.S. electricity generation and, on average, each kWh of electricity generated from coal requires approximately 25 gallons of water to produce, primarily for use as cooling water.

Cooling-water intake-structure regulations promulgated by EPA will potentially reduce the demand for freshwater withdrawals by the power generation sector. However, at the same time competition for water resources among the different withdrawal sectors (i.e., agriculture, recreation, etc.) and in-stream uses will likely increase. Additionally, climate change presents many uncertainties including potential shifts in weather patterns that could exacerbate local and regional drought conditions. It would be wise to develop a better understanding of the likely future water needs of the current and near-term fleet of thermoelectric power generators. Using information available from the U.S. Department of Energy's Energy Information Agency (EIA), this study projects freshwater needs for thermoelectric power generation[7] through the year 2025. These projections are also compared to current and past water use estimates from the U.S. Geological Survey (USGS).

Background: how water is used in electricity generation

Currently, water used for power plant cooling is withdrawn primarily from large volume sources, such as lakes, rivers, oceans, and underground aquifers. Water is *withdrawn* from these sources for use at the power plant. If the power plant uses once-through cooling, nearly all of the water is returned to the source. Some minor losses of water occur through *evaporation* or leaks in the system; at most a fraction of 1% of the water withdrawn. The water not returned to the source is *consumed*. By using cooling towers and circulating the cooling water, much less water is *withdrawn* from the source but much more water is *consumed* as *evaporative loss*, typically greater than 70% and can often be as much as 90% of water withdrawn. Most often *water use* refers to the overall water supply that is directly impacted through water withdrawal. *Water consumption* is

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[4] ***Utility, State Haggle over Power Plant Water Use***, Watertech Online, February 12, 2002

[5] USGS, ***Estimated Use of Water in the United States in 2000***, USGS Circular 1268, March 2003

[6] USGS, ***Estimated Use of Water in the United States in 1995***, USGS Circular 1200, 1998

[7] Thermoelectric generation sources include fossil- and nuclear-fueled power plants that utilize a steam turbine to drive the electric generator. The thermodynamic cycle of the steam turbine requires the condensation of steam as it exits the turbine using relatively large quantities of cooling water. Fossil-fueled thermoelectric generation includes coal-, oil-, and natural gas-fired plants. Natural gas- and oil-fired combustion turbines are not sources of thermoelectric generation.

used to describe the loss of water from a water source, typically through evaporation into the air.

The largest demand for water in thermoelectric plants is cooling water for condensing steam. There are three basic types of cooling systems: once-through, recirculating wet, and dry cooling. In a once-through system, cool water is withdrawn from the water source, used to remove heat and condense the process steam, and then returned to the water source. A recirculating wet system employs large cooling towers, and in some cases, ponds and canals, to recycle the cooling water and reduce the amount of water withdrawn from the water source. Indirect dry cooling systems, with very low water requirements, have been considered for power plant cooling applications, but have high parasitic power needs, high capital costs, and also require a larger footprint relative to other cooling options.

In terms of withdrawals, a once-through cooling system uses significantly more water; however, a recirculating system can *consume* 10 times more water than a once-through system. Cooling system water needs will vary depending on a number of factors, including local climate, stream characteristics and other parameters. For this analysis, the cooling system water needs were considered approximate and did not vary depending on location or source water-body characteristics, including whether the source was fresh or saline water. Table 1 provides the cooling system water needs used for this analysis.

Table 1 -- Cooling System Water Needs[8]

Fuel Source	**Technology**	**Withdrawal (gal/kWh)**	**Consumption[9] (gal/kWh)**
Fossil	Once-Through	37.7	0.1
	Recirc (Wet Tower)	1.2	1.1
Nuclear	Once-Through	46.2	0.1
	Recirc (Wet Tower)	1.5	1.5

In addition to water for cooling, power plants use water for blowdown (purging) of boilers and flue gas desulfurization (FGD) units, washing of stacks, plant and employee sanitation, and water and wastewater treatment. Waste water from non-cooling uses typically goes to a public wastewater treatment facility or the plant's onsite wastewater treatment facility. Stormwater from roof drains and area storm sewers also may be treated at the wastewater facility.

[8] Estimates for fossil-powered units were obtained from work done for NETL by Science Applications International Corporation (SAIC) and based on data obtained from EIA Form 767, Steam-Electric Plant Operation and Design Report. For combined cycle plants, the steam cycle was assumed to be equivalent to 1/3 of the total generating capacity. Estimates of water needs for cooling systems at nuclear facilities were obtained from EPRI; ***Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production, The Next Half Century***,TR-1006786, March 2002.

[9] Consumptive values are considered "on-site" water consumption and do not include losses for once-through systems from downstream evaporation that may result from discharge of water at a higher temperature than the receiving water body.

Projecting water needs through 2025

By 2025, the Energy Information Administration (EIA) projects significant increases in coal steam and combined-cycle power plants—both in terms of generation capacity and the number of plants.[10] Table 2 summarizes these projections and also includes projected additions of new units and retirement of older units including other fossil steam and nuclear. For this study, it is assumed that future generating facilities will employ a closed loop recirculating cooling system (i.e., wet cooling towers), while all retired facilities employ once-through cooling systems. This assumption follows current trends in choice of cooling systems, driven primarily by state and federal regulatory requirements.

Table 2 -- Projected Changes in Power Generating Capacity, GW[11]

	1995	2001	2002	2010	2015	2020	2025
U.S. Electric Power Generating Capacity							
Net Generating Capacity							
Coal Steam	304.9	310.7	310.9	310.2	321.5	353.5	412.3
Other Fossil Steam[12]	139.6	134.9	133.6	106.1	102.7	101.1	96.5
Combined Cycle	14.7	65.5	110.4	160	191.7	217.3	235.2
Nuclear Power	99.2	98.2	98.7	100.6	102.1	102.6	102.6
Total	558.4	609.3	653.6	676.9	718	774.5	846.6
Cumulative Power Capacity Additions (Planned and Unplanned) - 1995 Baseline							
Coal Steam	0.0	5.8	6.0	12.8	24.6	57.8	117.7
Other Fossil Steam	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Combined Cycle	0.0	50.8	95.7	145.3	177.0	202.7	220.6
Nuclear Power	0.0	0.0	0.5	2.4	3.9	4.4	4.4
Total	0.0	56.6	102.2	160.5	205.5	264.9	342.7
Cumulative Power Retirements - 1995 Baseline							
Coal Steam	0.0	0.0	0.0	7.5	8.0	9.2	10.3
Other Fossil Steam	0.0	4.7	6.0	33.5	36.9	38.5	43.1
Combined Cycle	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Nuclear Power	0.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	0.0	5.7	7.0	42.0	45.9	48.8	54.5

This study focuses on freshwater use. However, because in their most recent report the USGS indicates that approximately 30% of all water withdrawals by thermoelectric power plants were from saline water sources, a series of different cases were considered, with different allocation (saline versus freshwater withdrawals) of capacity additions and retirements. Because generation capacity additions and retirements were not geographically identified (coastal or inland) by EIA, a range of projected changes in freshwater needs were developed by considering the following potential scenarios:

[10] EIA, ***Annual Energy Outlook 2004 With Projections to 2025***, DOE/EIA-0383(2004), Reference Case Forecast, January 2004

[11] 1995 Data: EIA, ***Annual Energy Outlook 1997 With Projections to 2015***, DOE/EIA-0383(97), December 1996, 2001 – 2025 Data, EIA, ***Annual Energy Outlook 2004 With Projections to 2025***, DOE/EIA-0383(2004), January 2004

[12] Includes oil-, gas- and dual-fired capability.

- 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 in Table 2 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 in Table 2 are reduced by the repowered units.

The analysis projects that by 2025 daily freshwater withdrawals required to meet the needs of U.S. thermoelectric power generation may decrease to 113 billion gpd or increase to 138 billion gpd depending upon the assumptions made about source of cooling water and type of cooling technology employed for new and retired capacity. This compares with USGS estimates that thermoelectric power plants withdrew approximately 132 billion gallons per day (gpd) of freshwater in 1995[13] and approximately 136 billion gpd of freshwater in 2000[14] -- an approximate 3% increase from their 1995 estimate.

Table 3 presents the range of potential daily freshwater withdrawal based on the cases described above.

Table 3 -- Projected Power Sector Freshwater Withdrawals

	1995	2001	2002	2010	2015	2020	2025
Freshwater Withdrawals - Billion gallons/day							
Case 1	132.1	131.0	131.1	120.0	119.8	119.6	119.2
Case 2	132.1	131.3	131.4	123.6	123.5	123.3	123.1
Case 3	132.1	132.1	132.1	132.1	132.1	132.1	132.1
Case 4	132.1	132.5	133.0	134.2	135.2	136.4	137.9
Case 5	132.1	130.6	130.2	117.9	116.6	115.3	113.4
Case 6	132.1	132.4	132.7	133.3	134.6	135.6	136.8
Maximum	132.1	132.5	133.0	134.2	135.2	136.4	137.9
Minimum	132.1	130.6	130.2	117.9	116.6	115.3	113.4

Because a significant fraction of water withdrawn for use in an evaporative cooling tower is lost through evaporative consumption (see Table 1) projected change in consumptive use was also estimated. The USGS estimates that in 1995, freshwater consumption by U.S. thermoelectric power plants was approximately 2.5% of withdrawals, or 3.3 billion gpd.[15] This study projects that by 2025, 3.3 to 8.7 billion gpd may be consumed. Table

[13] Ibid Ref. 6
[14] Ibid Ref. 5
[15] USGS discontinued estimates of water consumption for its 2000 estimates

4 presents the range of potential daily freshwater consumption based on the cases described above.

Table 4 -- Projected Power Sector Freshwater Consumption

	1995	2001	2002	2010	2015	2020	2025
Freshwater Consumption - Billion gallons/day							
Case 1	3.3	3.7	4.1	5.2	6.2	7.3	8.7
Case 2	3.3	3.6	3.9	4.7	5.4	6.1	7.1
Case 3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Case 4	3.3	3.7	4.1	5.3	6.3	7.4	8.8
Case 5	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Case 6	3.3	3.6	3.9	4.5	5.8	6.7	7.8
Maximum	3.3	3.7	4.1	5.3	6.3	7.4	8.8
Minimum	3.3	3.3	3.3	3.3	3.3	3.3	3.3

Projections of withdrawal and consumption through 2025 based on the various cases are presented graphically in Figures 1 and 2. Figure 1 also includes projected increase in thermoelectric capacity through 2025.

Figure 1 -- Average Daily Freshwater Withdrawal for Thermoelectric Power Generation.

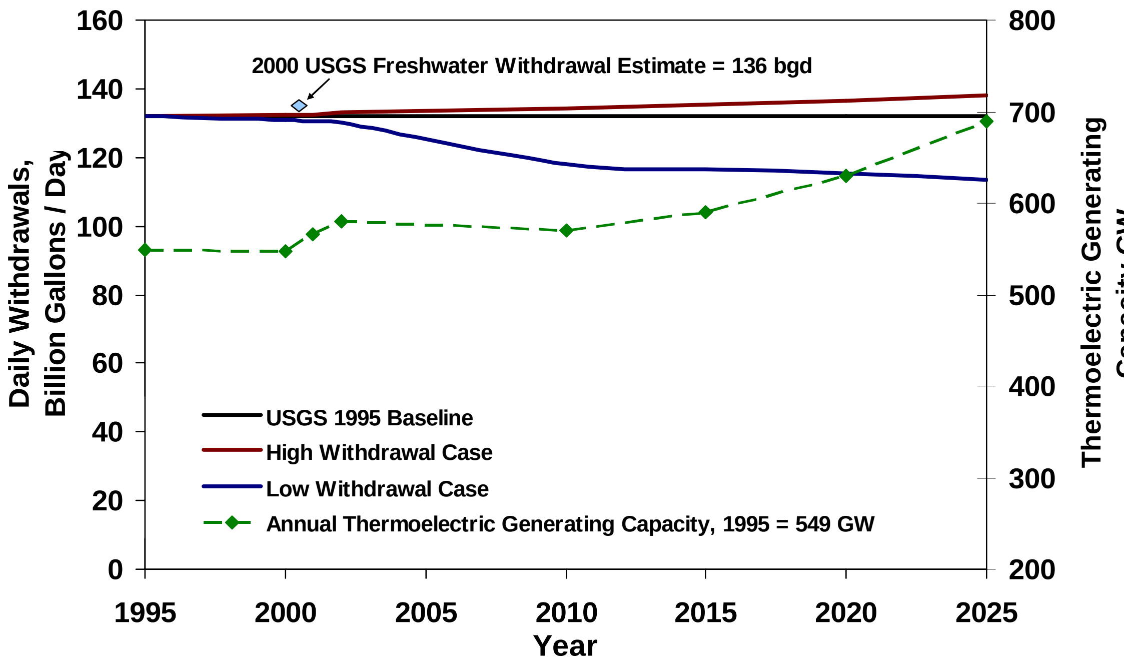
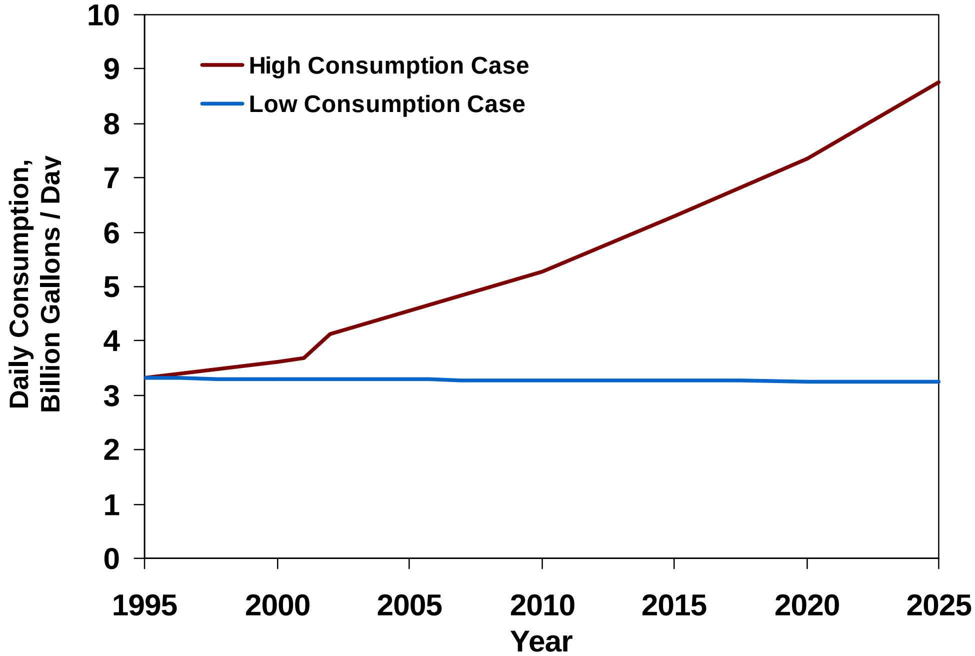


Figure 2 -- Average Freshwater Consumption for Thermoelectric Power Generation



It should be noted that the low-consumption case (Case 5) in Figure 2 shows a slight decrease over time due to the retirement of approximately 54 GW of coal-steam and other fossil-steam units. While this decrease is not shown in Table 4 due to rounding, it is reflected in Table 5 below. Table 5 provides a comparison of changes in daily freshwater withdrawal and consumption by thermoelectric power plants for 2025 relative to the 1995 baseline for each of the six cases described above.

Table 5 -- Change in Daily Freshwater Withdrawal And Consumption By Thermoelectric Power Plants, 1995—2025

	1995	2025	Delta, 10^9 gpd	Delta, %
Freshwater Withdrawals - Billion gallons/day (gpd)				
Case 1	132.1	119.2	-12.9	-10%
Case 2	132.1	123.1	-9.0	-7%
Case 3	132.1	132.1	0.0	0%
Case 4	132.1	137.9	5.8	4%
Case 5	132.1	113.4	-18.7	-14%
Case 6	132.1	136.8	4.7	4%
Maximum	132.1	137.9	5.8	4%
Minimum	132.1	113.4	-18.7	-14%
Freshwater Consumption - Billion gallons/day (gpd)				
Case 1	3.3	8.7	5.4	163%
Case 2	3.3	7.1	3.8	114%
Case 3	3.3	3.3	0.0	0%
Case 4	3.3	8.8	5.5	165%
Case 5	3.3	3.3	-0.1	-2%
Case 6	3.3	7.8	4.5	135%
Maximum	3.3	8.8	5.5	165%
Minimum	3.3	3.3	-0.1	-2%

When compared with freshwater withdrawal estimates for 1995, the daily requirements for 2025 range from a 14% decrease to as much as a 4% increase for freshwater withdrawals. For freshwater consumption, daily requirements for 2025 range from a 2% decrease to as much as a 165% increase relative to 1995 estimates.

Coal-fired power plants

As can be seen in Table 2, EIA projects that in terms of overall capacity, the largest increase through 2025 will be combined-cycle power plants, with more than 220 GW of capacity additions from the 1995 baseline. Second to combined-cycle additions, EIA projects that more than 117 GW of new coal-fired thermoelectric capacity will be added and approximately 10 GW of the existing fleet will be retired. Overall, EIA projects that total coal steam capacity will increase by more than 35% compared to 1995. The same cases described above were also used to estimate the change in water withdrawals for the coal-fired fleet exclusive of the rest of the fleet. Because 1995 baseline water withdrawal data for coal-fired power plants was not provided by USGS, Table 6 presents *change* in projected freshwater withdrawal for coal steam electric generators.

Table 6 -- Projected Changes in Coal Steam Freshwater Withdrawals

	1995	2001	2002	2010	2015	2020	2025
Freshwater Withdrawals - Billion gallons/day							
Case 1	0	0.1	0.1	-5.3	-5.5	-5.6	-4.9
Case 2	0	0.1	0.1	-3.7	-3.8	-3.9	-3.5
Case 3	0	0.0	0.0	0.0	0.0	0.0	0.0
Case 4	0	0.1	0.1	0.3	0.6	1.4	2.8
Case 5	0	0.0	0.0	-5.6	-6.0	-7.0	-7.8
Case 6	0	0.1	0.1	0.1	0.4	1.2	2.6
Maximum	0	0.1	0.1	0.3	0.6	1.4	2.8
Minimum	0	0.0	0.0	-5.6	-6.0	-7.0	-7.8

Table 7 presents *change* in projected freshwater consumption for coal steam electric generators.

Table 7 -- Projected Changes in Coal Steam Freshwater Consumption

	1995	2001	2002	2010	2015	2020	2025
Freshwater Consumption - Billion gallons/day							
Case 1	0	0.1	0.1	0.3	0.5	1.3	2.6
Case 2	0	0.1	0.1	0.2	0.4	0.9	1.8
Case 3	0	0.0	0.0	0.0	0.0	0.0	0.0
Case 4	0	0.1	0.1	0.3	0.5	1.3	2.6
Case 5	0	0.0	0.0	0.0	0.0	0.0	0.0
Case 6	0	0.1	0.1	0.1	0.4	1.1	2.4
Maximum	0	0.1	0.1	0.3	0.5	1.3	2.6
Minimum	0	0.0	0.0	0.0	0.0	0.0	0.0

Projections of change in average daily freshwater withdrawal and consumption for coal-steam power plants are presented graphically in Figures 3 and 4. Figure 3 also includes projected increase in coal-fired capacity through 2025.

Figure 3 -- Change in Average Daily Freshwater Withdrawal for Coal-Steam Power Generation

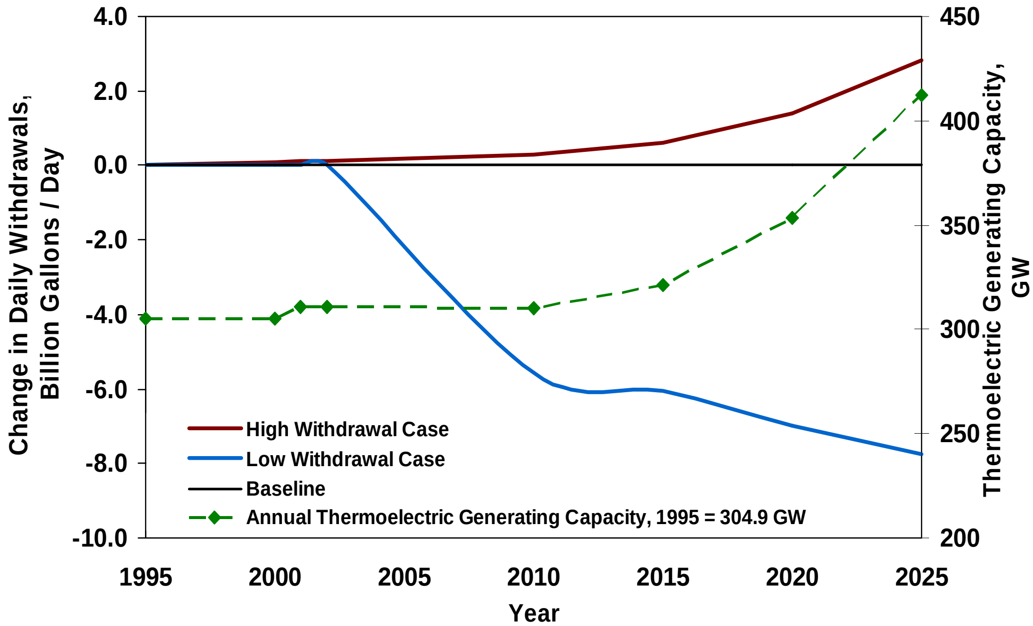
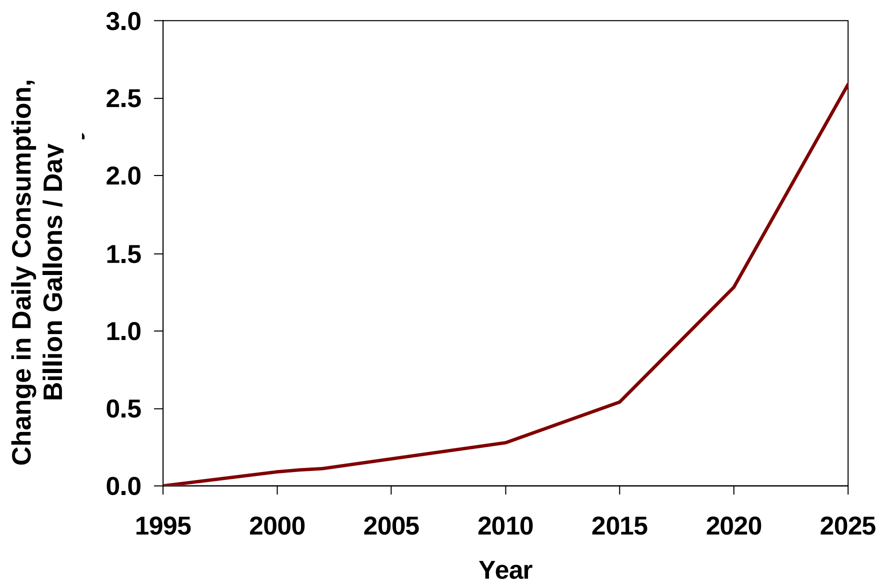


Figure 4 -- Change in Average Daily Freshwater Consumption for Coal-Steam Power Generation



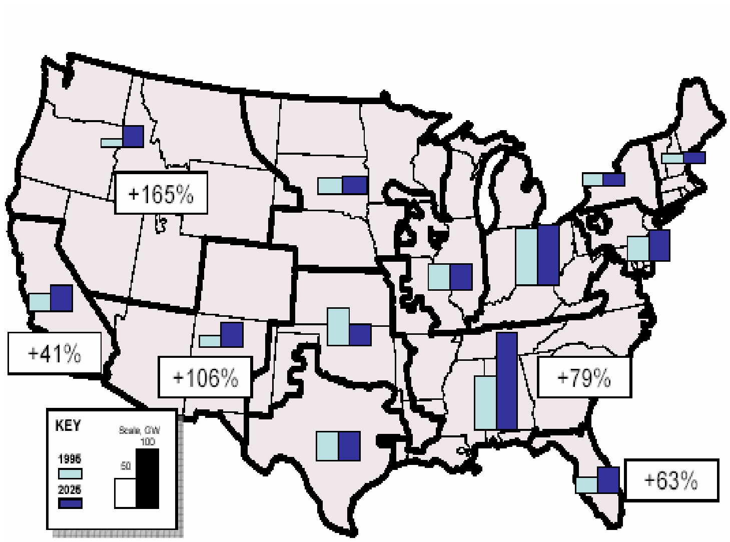
Conclusion

The EIA projects about a 52% increase in generating capacity by 2025 compared to 1995. Nearly 196 GW of the more than 342 GW of new capacity will be thermoelectric generation. This analysis indicates that the withdrawal of freshwater to operate the 196 GW of new thermoelectric generating capacity in 2025 will range from a 14% decrease to a 4% increase compared to freshwater withdrawals in 1995[16]. Changes in freshwater consumption in 2025 will range from a 2% decrease to as much as a 165% increase compared to 1995. Similar trends in freshwater withdrawal and consumption are projected for the additional coal-based generating capacity that will come on line by 2025.

Overall, potential impacts on future freshwater withdrawals to meet forecasted increases in electricity generating capacity would appear to be relatively low, with most cases indicating a decrease in daily withdrawals. And while several of the consumptive cases project a significant increase in freshwater consumption by 2025 on a percentage basis, thermoelectric power plants would still likely represent only a small fraction of total U.S. freshwater consumption compared to irrigation and agriculture. However, it is very important to point out that this study only considered changes in water withdrawal and consumption on a national level and not on a regional level.

On a regional basis, EIA projects a 41% to 165% increase in thermoelectric capacity by 2025 for the western U.S. and a 63% to 79% increase in the southeast (Figure 5). These

Figure 5 -- Comparison of Regional Thermoelectric[17] Generation Capacity by North American Electric Reliability Council Region, 1995—2025[18]



[16] In comparison, the USGS estimates that freshwater withdrawals for thermoelectric have increased by 3% between 1995 and 2000.

[17] For combined-cycle capacity, thermoelectric capacity is assumed 1/3 of generation capacity.

[18] Regional data from Energy Information Agency, AEO 1997 and AEO 2004, http://www.eia.doe.gov/oiaf/archive.html#aeo, February 2004.

increases in projected capacity will occur in regions of the U.S. that are challenged in terms of both current and future availability of freshwater.

Figure 6 below is a map from NOAA's Climate Prediction Service[19] that shows drought forecasts for the U.S. As can be seen, abnormally dry to exceptional drought conditions are predicted for the west and parts of the southeast – the same regions where EIA is projecting significant growth in generating capacity over the next two decades.

Figure 6 – Projected Drought Conditions in the U.S. for March 30, 2004

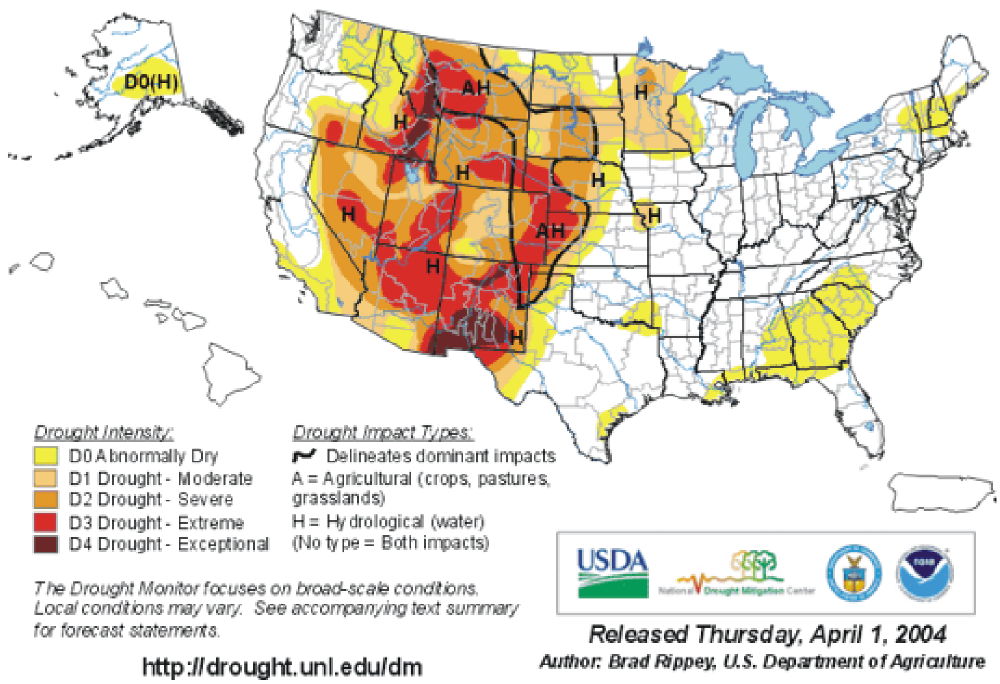


Figure 7 shows projected state-by-state changes in population through 2020 based on U.S. census data together with qualitative groundwater availability information. Similar to growth in generating capacity, the largest increases in population will also occur in the water-challenged states in the west and southeast. Therefore, to meet the increasing demand for electricity in these regions, thermoelectric power plants will have to compete with a growing population for a limited supply of freshwater. This will be coupled with increasing competition for freshwater from other use sectors such as agriculture, mining, industrial and in-stream use -- further stressing an already scarce resource. The potential for emerging regional conflicts over freshwater have been recognized by the U. S. Department of Interior (DOI). The DOI has identified the west as the fastest growing region of the country and has initiated a program to attempt to head-off a freshwater supply crisis that could occur in several western cities by 2025.[20]

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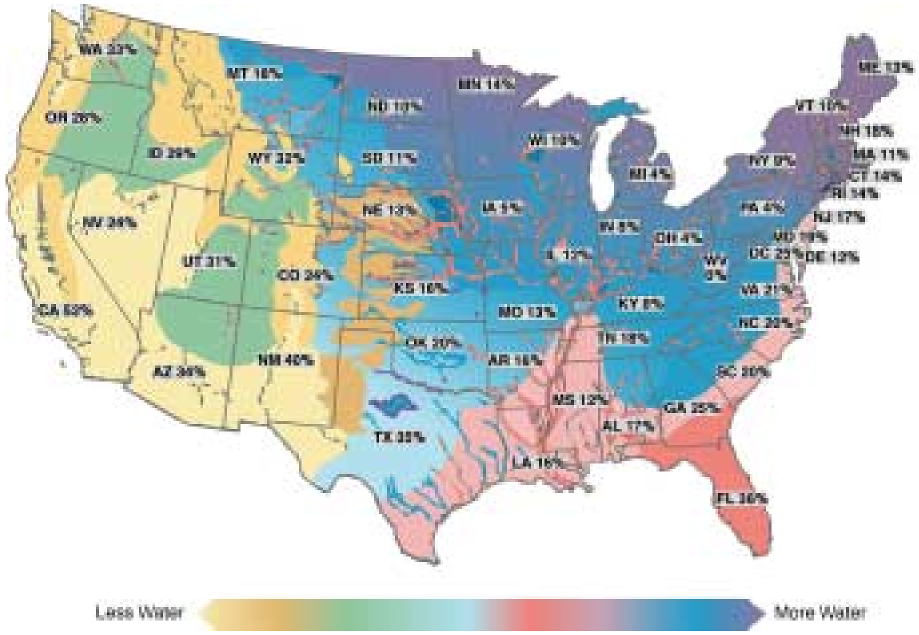
[19] NOAA National Weather Service Climate Prediction Center, "U.S. Seasonal Drought Outlook Archive"

[20] U. S. Department of the Interior, *Water 2025: Preventing Crisis and Conflict in the West*, May 2003.

Figure 7 -- Relative Groundwater Availability and Population Change, 2000—2020[21]



Next Steps

Follow on analyses will be carried out to assess the regional impact of future growth in thermoelectric generation capacity on freshwater withdrawal and consumption.

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[21] This graphic depicts the estimated change in population per state, 2000 through 2020, as well as the water supply per that region. The scale below the map indicates areas of least water concentration to greatest water concentration, yellow being the lightest (desert) and purple being the greatest, with high groundwater availability. Note that the colors are for relative comparison, not to indicate distinct water levels, current use patterns, nor weather pattern changes which may affect water availability. Source: NETL analysis of USGS and U.S. Census data.