Freshwater Use by U.S. Power Plants

ELECTRICITY'S THIRST FOR A PRECIOUS RESOURCE

A Report of the Energy and Water in a Warming World Initiative

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About EW3

Energy and Water in a Warming World (EW3) is a collaborative effort between the Union of Concerned Scientists (UCS) and a team of independent experts to build and synthesize policy-relevant research on the water demands of energy production in the context of climate variability and change. The initiative includes core research collaborations intended to raise the national profile of the water demands of energy, along with policy-relevant energy development scenarios and regional perspectives.

The material presented in this report is based on the research of the EW3 Baseline Assessment Team, listed below. The work discussed here is also presented in more technical detail in forthcoming scientific papers. For supporting materials (glossary, methodology appendix, and graphical appendix), go to *www.ucsusa.org/electricity-water-use*.

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Executive Summary

Take the average amount of water flowing over Niagara Falls in a minute. Now triple it. That's *almost* how much water power plants in the United States take in for cooling each minute, on average.

In 2005, the nation's thermoelectric power plants—which boil water to create steam, which in turn drives turbines to produce electricity—withdrew as much water as farms did, and more than four times as much as all U.S. residents. That means lighting rooms, powering computers and TVs, and running appliances requires more water, on average, than the total amount we use in our homes—washing dishes and clothes, showering, flushing toilets, and watering lawns and gardens.

This tremendous volume of water has to come from somewhere. Across the country, water demand from power plants is combining with pressure from growing populations and other needs and straining water resources—especially during droughts and heat waves:

- The 2011 drought in Texas created tension among farmers, cities, and power plants across the state. At least one plant had to cut its output, and some plants had to pipe in water from new sources. The state power authority warned that several thousand megawatts of electrical capacity might go offline if the drought persists into 2012.

- As drought hit the Southeast in 2007, water providers from Atlanta to Raleigh urged residents to cut their water use. Power plants felt the heat as well. In North Carolina, customers faced blackouts as water woes forced Duke Energy to cut output at its G.G. Allen and Riverbend coal plants on the Catawba River. Meanwhile the utility was scrambling to keep the water intake system for its McGuire nuclear plant underwater. In Alabama, the Browns Ferry nuclear plant had to drastically cut its output (as it has in three of the last five years) to avoid exceeding the temperature limit on discharge water and killing fish in the Tennessee River.


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- A 2006 heat wave forced nuclear plants in the Midwest to reduce their output when customers needed power most. At the Prairie Island plant in Minnesota, for example, the high temperature of the Mississippi River forced the plant to cut electricity generation by more than half.

- In the arid Southwest, power plants have been contributing to the depletion of aquifers, in some cases without even reporting their water use.

- On New York's Hudson River, the cooling water intakes of the Indian Point nuclear plant kill millions of fish annually, including endangered shortnose sturgeon. This hazard to aquatic life now threatens the plant as well. Because operators have not built a new cooling system to protect fish, state regulators have not yet approved the licenses the operators need to keep the plant's two reactors running past 2013 and 2015.

- Proposed power plants have also taken hits over water needs. Local concerns about water use have scuttled planned facilities in Arizona, Idaho, Virginia, and elsewhere. Developers of proposed water-cooled concentrating solar plants in California and Nevada have run into opposition, driving them toward dry cooling instead.

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This report—the first on power plant water use and related water stress from the Energy and Water in a Warming World initiative—is the first systematic assessment of both the effects of power plant cooling on water resources across the United States and the quality of information available to help public- and private-sector decision makers make water-smart energy choices.

Our analysis starts by profiling the water use characteristics of virtually every electricity generator in the United States. Then, applying new analytical approaches, we conservatively estimate the water use of those generators in 2008, looking across the range of fuels, power plant technologies, and cooling systems. We then use those results to assess the stress that power plant water use placed on water systems across the country. We also compare our results with those reported by power plant operators to the U.S. Energy Information Administration (EIA) for 2008.

We examine both the *withdrawal* and *consumption* of freshwater. Withdrawal is the total amount of water a power plant takes in from a source such as a river, lake, or aquifer, some of which is returned. Consumption is the amount lost to evaporation during the cooling process.

Withdrawal is important for several reasons. Water intake systems can trap fish and other aquatic wildlife. Water withdrawn for cooling but not consumed returns to the environment at a higher temperature, potentially harming fish and other wildlife. And when power plants tap groundwater for cooling, they can deplete aquifers critical for meeting many different needs. Consumption is important because it too reduces the amount of water available for other uses, including sustaining ecosystems.

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While our analysis focuses on the effects of water use by power plants today, we also consider how conditions are likely to change in the future. In the short run, our choices for what kind of power plants we build can contribute to freshwater-supply stress (by consigning an imbalanced share of the available water to power plant use) and can affect water quality (by increasing water temperatures to levels that harm local ecosystems, for example). Over a longer time frame, those choices can fuel climate change, which in turn may also affect water quantity (through drought and other extreme weather events) and quality (by raising the temperature of lakes, streams, and rivers). Population growth and rising demand for water also promise to worsen water stress in many regions of the country already under stress from power plant use and other uses.

Our findings on the **water profile of power plants** in 2008 show that:

- **Power plants are thirsty.** Every day in 2008, on average, water-cooled thermoelectric power plants in the United States withdrew 60 billion to 170 billion gallons (180,000 to 530,000 acre-feet) of freshwater from rivers, lakes, streams, and aquifers, and consumed 2.8 billion to 5.9 billion gallons (8,600 to 18,100 acre-feet) of that water. Our nation's large coal fleet alone was responsible for 67 percent of those withdrawals, and 65 percent of that consumption.
- **Where that water comes from is important.** In the Southwest, where surface water is relatively scarce, power plants withdrew an average of 125 million to 190 million gallons (380 to 590 acre-feet) of groundwater daily, tapping many aquifers already suffering from overdraft. By contrast, power plants east of the Mississippi relied overwhelmingly on surface water.
- **East is not west: water intensity varies regionally.** Power plant owners can reduce their water intensity—the amount of water plants use per unit of

electricity generated. Plants in the East generally withdrew more water for each unit of electricity produced than plants in the West, because most have not been fitted with recirculating, dry cooling, or hybrid cooling technologies. Freshwater withdrawal intensity was 41 to 55 times greater in Virginia, North Carolina, Michigan, and Missouri than in Utah, Nevada, and California. Freshwater consumption intensity was similar in those sets of states.

- **Low-carbon electricity technologies are not necessarily low-water.** On average in 2008, plants in the U.S. nuclear fleet withdrew nearly eight times more freshwater than natural gas plants per unit of electricity generated, and 11 percent more than coal plants. The water intensity of renewable energy technologies varies. Some concentrating solar power plants consume more water per unit of electricity than the average coal plant, while wind farms use essentially no water.

Water supply is said to be stressed in watersheds when demand for water—by power plants, agriculture, and municipalities, for example—exceeds a critical threshold of the available supply provided by local sources, typically surface and groundwater. Water quality can be similarly stressed when, for example, water users raise temperatures or discharge pollutants. Our findings on the **impact of power plant cooling on water stress** in 2008 show that:

- **Power plants across the country contribute to water-supply stress.** Based on our analysis, in 2008, 400 out of 2,106 watersheds across the country were experiencing water-supply stress. Power plants, by tapping this overstretched resource for cooling purposes, contributed to water-supply stress in one-fifth of those. We focused on 25 watersheds in 17 states in which power plants were the primary driver of water-supply stress based on our analysis. Several states including North Carolina, South Carolina, Missouri, and Michigan had more than one of those watersheds, including the Catawba and Seneca Rivers.
- **High-temperature water discharges are common.** Peak summer temperatures for return flows from more than 350 power plants across the country exceeded 90°F. Some 14 states prohibit such discharges, which can harm fish and other wildlife.


Wikimedia Commons/Civilengtiger

- **The mix of power plants in the nation's fleet matters.** The power plant portfolios of U.S. companies have widely varying water-use and carbon emissions profiles. Utilities with lower-water plants place less stress on local water sources. Utilities with carbon-intensive power plants contribute to long-term water stress by exacerbating climate change.

Collisions and near-misses between energy and water needs point to the importance of accurate, up-to-date information on power plant water demand. Our analysis reveals, however, a number of **gaps and apparent inaccuracies in federal data** reported for 2008. As a result, analyses based on that information would have overlooked regions facing water stress. We found:

- **Gaps add up.** Power plants that did not report their water use to the EIA accounted for 28 to 30 percent of freshwater withdrawals by the electricity sector, and at least 24 to 31 percent of freshwater consumption by the sector, according to our calculations. Gaps in the 2008 information included all water use by nuclear power plants.

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- **Discrepancies are widespread.** Reported freshwater use by power plants across the country fell outside the bounds suggested by our analysis, including plants in 22 states for withdrawal, and 38 states for consumption. The discrepancies were especially large in the Lower Colorado River and Southeast-Gulf regions, where plant operators reported consumption five times greater—and withdrawals 30 percent less—than median water-use values would suggest.
- **Discrepancies stemmed from a range of causes.** Some power plant operators are exempt from reporting their water use based on plant size or technology. Many operators appeared to report peak rates of water use rather than the requested annual average rate, leading to overestimates. Other operators reported zero water use.
- **Good analysis requires good information.** Using the available data masks existing water stress. Several of the 25 watersheds identified did not show up when we analyzed EIA-compiled information.

Averting energy-water collisions requires that power plant operators regularly report accurate information on their water use to the EIA and state agencies. The EIA has been working to improve such reporting, to better meet the needs of public- and private-sector decision makers. The agency may therefore remedy many of the problems we identified with the 2008 data shortly.

However, providing better information is only the first critical step. Decision makers must then put that information—coupled with sound analyses of water stress—to work in curbing electricity's thirst, especially in water-stressed regions. Our analysis provides a strong initial basis for **making water-smart energy choices**. Here are some ways to do so:

- **Get it right the first time.** Developing new resources for meeting electricity demand provides a critical opportunity for reducing water risks for both power plant operators and other users. Utilities and other power plant developers would be well advised to prioritize low-water or no-water cooling options, particularly in regions of current and projected high water stress.

  Some developers are already making such choices. For example, the project developer's choice of dry cooling for the 370-megawatt Ivanpah concentrating solar power (CSP) project under construction in California's Mojave Desert means that the facility will consume 90 percent less water per unit of electricity than typical wet-cooled CSP plants. Other developers and utilities are reducing the risk of energy-water collisions by choosing technologies that use essentially no water, such as wind and solar photovoltaics, and by investing in energy efficiency.
- **Retool existing plants.** Owners and operators of existing power plants with substantial effects on the supply or quality of water in water-stressed regions could consider retrofitting to low-water cooling. When the 1,250-megawatt Plant Yates near Newnan, GA, added cooling towers in 2007, it cut water withdrawals by 93 percent.

  Even greater reductions in freshwater use are sometimes essential. In much of the Southwest, even low water withdrawals can spell trouble, particularly when they come from diminishing aquifers. Water consumption, too, can pose problems. Power producers in highly water-constrained settings can make water-smart choices—as Xcel Energy, which operates the 1,080-megawatt Harrington Station in Amarillo, TX, did in 2006, when it switched to treated wastewater to meet the plant's cooling needs.

- **Set strong guidelines for power plant water use.** Public officials can draw on good information on electricity's thirst to help owners of existing and proposed power plants avert energy-water collisions. Public utility commissions, which oversee the plans of utilities and specific plant proposals, can encourage or require investments that curb adverse effects on water supply or quality, particularly in areas of current or projected water stress.

  Legislators also have a stake in averting energy-water collisions. The Colorado legislature's 2010 decision to retire more than 900 megawatts of coal plants in favor of natural gas, energy efficiency, and renewable energy will reduce water consumption by a volume roughly equivalent to that used by 50,000 people.
- **Engage diverse stakeholders.** Mayors securing water supplies for their cities, anglers concerned with sport and commercial fishing, water resource managers at all levels, and others all have a stake in averting energy-water collisions. Full public access to information on water use by existing and proposed power plants will enable these and other local stakeholders to become informed about the benefits of water-smart energy choices.
- **Reduce power plant carbon emissions.** Because human-caused climate change is worsening water stress across much of the United States, water-smart energy choices should include investing in resources that are also low-carbon. The new cooling towers for the coal-burning Plant Yates reduce its impact on water stress but not its carbon emissions.

  The coal-burning generators at Harrington Station in Amarillo, although relying on treated wastewater, still emit prodigious quantities of carbon. Of course, not all low-carbon options are water-smart. Some, such as wind power and energy efficiency, are inherently low-water. Others, such as the proposed carbon capture and storage for coal plants, are not, and could worsen energy-water collisions if used in regions with water stress.

Averting energy-water collisions means taking a long view. Power plants are designed to last for decades, and much of our existing infrastructure will continue operating for years. Our nation's precious freshwater resources will face ever more stress from growing populations, a changing climate, and other trends over the next several decades. The typically high cost of retrofitting power plants means that decisions on the water impact of today's plants should consider the risks they pose to freshwater resources and energy reliability throughout their expected lifetime.

The next report from the Energy and Water in a Warming World initiative will take up this challenge by exploring how energy choices affect the resilience of our energy sector in the face of both periodic drought and long-term changes in water availability. Zooming in on key regions of the country will yield a more robust understanding of how the energy technologies we choose to power tomorrow's world would affect water resources.

Decisions made today about which power plants to build, which to retire, and which energy or cooling technologies to deploy and develop matter greatly. Understanding how these choices affect water use and water stress will help ensure that the dependence of power plants on water does not compromise that resource, the plants themselves, or the energy we rely on them to provide.

Stephen Baird

CHAPTER 1

The Water and Power Standoff: An Introduction

As of late summer 2011, Texas had suffered the driest 10 months since record keeping began in 1895 (LCRA 2011). Some rivers, such as the Brazos, actually dried up (ClimateWatch 2011). The dry weather came with brutal heat: seven cities recorded at least 80 days above 100°F (Dolce and Erdman 2011). With air conditioners straining to keep up, the state's demand for electricity shattered records as well, topping 68,000 megawatts in early August (ERCOT 2011).

An energy-water collision wasn't far behind. One plant had to curtail nighttime operations because the drought had reduced the amount of cool water available to bring down the temperature of water discharged from the plant (O'Grady 2011; Sounder 2011). In East Texas, other plant owners had to bring in water from other rivers so they could continue to operate and meet demand for electricity. If the drought were to persist into the following year, operators of the electricity grid warned, power cuts on the scale of thousands of megawatts are possible (O'Grady 2011).

Longview News-Journal/Kevin Green

The Texas case is hardly the first example of hot weather and scarce water driving power systems to the brink of failure. In August 2007, as a triple-digit heat wave compounded months of drought on North Carolina's Catawba River, the thirst of the region's seven major power plants became incompatible with what the river had to give. That month, as demand for electricity hit an all-time high, Duke Energy had to cut power generation at its G.G. Allen and Riverbend coal-fired plants, as the temperature of discharged cooling water exceeded limits set to protect fish in the river. Blackouts rippled through the area (Beshears 2007). A month later, Duke was rushing to modify a water intake pipe on its 2,200-megawatt McGuire Nuclear Station so it could stay within reach of the dropping water level in Lake Norman (Kirkpatrick 2007a; 2007b).

More regions may experience what happened in Texas in 2011 and in North Carolina in 2007, given the nation's trajectory on a number of fronts. Population growth is worsening competition among residents, power companies, and others needing water (Hojjati and Battles 2005). Rising global water and air temperatures are disrupting rainfall patterns, curbing the amount of water available in some regions (National Research Council 2010; USGCRP 2009). Hotter weather is also pushing up summertime power demand, as air conditioning loads weigh heavier on the grid (Wilbanks et al. 2008). Compounding the problem, warmer air and water make power plants operate less efficiently, and cooling them requires even more water (NETL 2002). And as fossil-fueled power plants are

Drought, heat, and high power demand make for an energy-water collision: **Amid the Texas drought of 2011, the shores of Martin Creek Lake—the primary source of cooling water for the Luminant plant pictured here—receded to precariously low levels. To keep the plant operating, Luminant had to import water from the Sabine River. If the drought persists into 2012, operators of the electricity grid have warned that power cuts on the scale of thousands of megawatts are possible.**

forced to run longer and harder, they release even more of the climate-warming emissions that are driving up air and water temperatures and altering water resources (USGCRP 2009).

Choices about the future mix of plants used to generate electricity can ease the tension between water and energy. Renewable energy technologies such as wind turbines and photovoltaic panels use little or no water and emit no carbon pollution in producing electricity.[1] Even fossil-fueled technologies provide opportunities to reduce water demand while also addressing carbon emissions. Natural gas combined-cycle plants have lower carbon emissions than coal plants, for example, and, because of greater efficiencies, produce less waste heat. Novel cooling technologies, such as dry cooling and hybrid systems, can also reduce pressure on water systems.

Much is at stake. If power companies have trouble finding enough water to cool their power plants, blackouts can force them to purchase electricity from other sources, which can raise customers' utility bills.[2] Rising water temperatures imperil fish and other aquatic species (Hester and Doyle 2011). Struggles among power plants, cities, and farms over limited water resources can be costly, can force residents to cut water use, and can shortchange the environment.[3]

Choices about the mix of plants used to generate electricity can ease the tension between energy and water, or exacerbate it.

To make energy-water choices wisely, good information about the problem is essential: how much water power plants use, where they get that water, and how that use affects water resources. However, the most complete, publicly available set of data—that compiled by the U.S. Energy Information Administration (EIA), based on reporting by power plant operators—has contained gaps and apparent inaccuracies.[4] In 2008, for example, more than 100 water-cooled coal and natural gas power plants reported to the government that they produced millions of megawatt-hours of electricity yet used no water at all. At the same time, dozens of plant operators overreport their water use by a large margin. And the nation's fleet of nuclear power plants has been exempt from reporting to the EIA the water they use since 2002.

This report—produced by the Energy and Water in a Warming World initiative (EW3)—helps fill in many of these missing pieces. Our analysis provides a comprehensive accounting of how much water power plants withdraw and consume, and the source of all that water. The report also highlights the biggest discrepancies in federal data, and shows why inaccurate information is problematic. We also show where water use by power plants appears to be exacerbating water stress today—and point to what the future of power plant water use might hold.

The EIA has announced that it intends to address many of the information gaps on water use by power plants (EIA 2011a; 2011b). However, lasting improvements will require sustained funding for the agency, as well as a consistent commitment to closing those gaps. While the federal fix is pending, our analysis shows that collecting good data is just one step in addressing the energy-water collision. We must act on that knowledge to avoid a future in which problems like those in Texas in 2011 and on the Catawba River in 2007 are commonplace.

1 As noted below, however, low-carbon technologies do not always mean lower water use. Some renewable technologies, such as concentrating solar power, can consume as much water as coal-fired or nuclear plants.

2 This occurred with the Browns Ferry nuclear plant. See Chapter 4.

3 An example is the allocation of water rights by the Lower Colorado River Administration (LCRA) near Austin, TX. The LCRA provides water to 65 municipalities in Texas while deciding how much flow the river needs to maintain a healthy ecology. This "ecological flow" is among the first to be cut during a drought. That flow, along with residential use, sustains severe cuts before power plant operators and other commercial entities must cut their water use (LCRA 2011; 2010).

4 The EIA's annual data are, however, "the only federally collected, national data available on water use and cooling technologies at individual power plants" (GAO 2009).

How Power Plants Use Water

Thermoelectric power plants—which boil water to create steam, which in turn drives turbines—produce some 90 percent of the electricity used in the United States. These power plants use a variety of energy sources to boil the water—mainly coal, natural gas, and nuclear fission, but also wood waste (biomass), the sun's rays (concentrating solar power), and the heat energy of the earth (geothermal power).

After the steam passes through a turbine, it must be cooled so that it condenses and the water can be reused. This steam-cooling step accounts for virtually all the water used in most power plants, given that the steam itself circulates in a closed system (Figure 1).[5]

How much water a power plant uses depends mainly on which of three basic cooling technologies it uses. "Once-through" systems—which, as the name implies, use cooling water once before discharging it—withdraw much more water from sources such as lakes or rivers than other types of cooling systems.

"Recirculating" cooling systems take in a fraction of the water that once-through systems do. However, recirculating systems can consume twice as much water as once-through systems, or even more, because the former evaporate much of the cooling water to condense the steam.

Dry-cooled systems, which blow air across steam-carrying pipes to cool them, use almost no water. Most dry-cooled facilities in 2008 were natural gas plants.[6] However, dry-cooled plants become considerably less efficient when ambient air temperatures are high.

Both recirculating and dry-cooling systems require more energy than once-through systems. Because of that energy penalty, and efficiency losses at high ambient air temperatures, some power plants rely on hybrid cooling systems. These systems—some combination of the aforementioned technologies—operate in dry-cooling mode much of the time, but switch to wet-cooling mode during hot weather (Barker 2007; DOE 2006).

5 For more information on how different energy systems operate, see UCS 2011a.

6 Other such plants were fueled wtih biomass, coal, and oil. In addition, some natural gas facilities use combustion turbines, which produce electricity from exhaust gases rather than steam, and therefore do not require cooling.

EPA

Power plant water use depends on cooling technologies: **"Once-through" cooling systems, like that of the coal-fired Brayton Point Power station in Somerset, MA, withdraw much more water than "recirculating" cooling systems, but consume less. Owners of Brayton Point are building cooling towers to switch from once-through cooling to recirculating, which will cut the plant's water draw from Mt. Hope Bay by 90 percent (Dominion 2011).**

Many cooling systems—once-through or recirculating—circulate cooling water through on-site reservoirs called cooling ponds, which also lose water to evaporation.

This report tracks power plant water use in two ways: *withdrawal* and *consumption*. A plant's withdrawal is the amount it takes from a river, lake, ocean, groundwater aquifer, or municipal water system. After use, this water either evaporates or is drained back to the source. The amount lost to evaporation is a plant's water consumption.

Withdrawal volumes are important for a variety of reasons. For instance:

- For plants that draw water from a surface source such as a river or lake, withdrawal volumes influence the number of fish and other aquatic species sucked into intake structures or the plant's cooling system, or affected by warmer water returned by the plant.
- For plants that draw cooling water from an aquifer, withdrawal volumes determine how much strain the plants place on groundwater resources.
- In many states, water rights are often defined in terms of a withdrawal rate or a volume associated with a given water use.

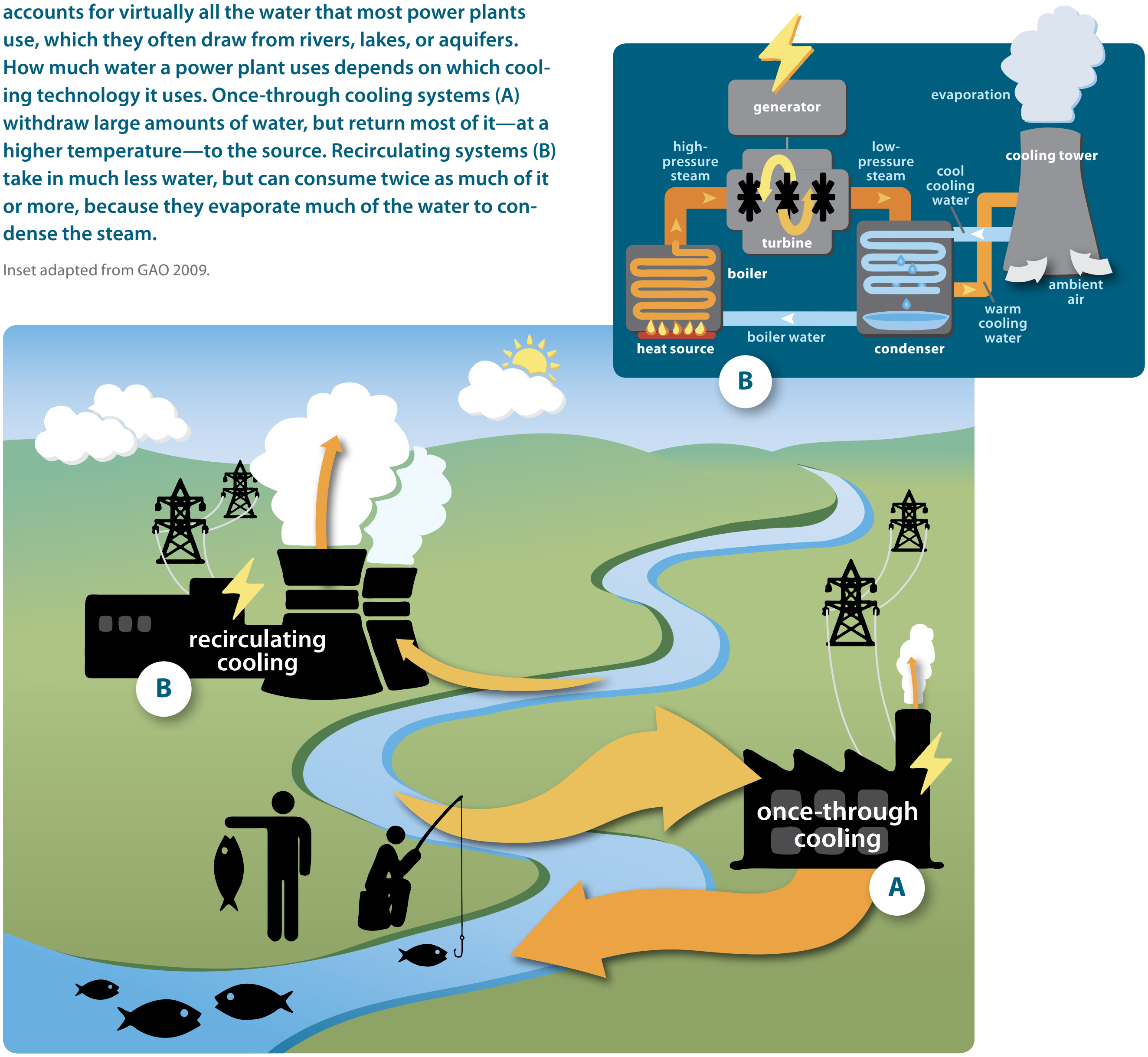
Consumption volumes matter because water that evaporates is not available for other uses. Whether withdrawal or consumption is of greater concern in a given locale depends largely on local circumstances.

In Chapter 2, we calculate the scale and geographic distribution of water use by power plants based on the

FIGURE 1. How Power Plants Use Water

Most U.S. power plants create steam to drive the turbines that generate electricity. After the steam passes through a turbine, it is cooled, condensed, and reused. Steam cooling accounts for virtually all the water that most power plants use, which they often draw from rivers, lakes, or aquifers. How much water a power plant uses depends on which cooling technology it uses. Once-through cooling systems (A) withdraw large amounts of water, but return most of it—at a higher temperature—to the source. Recirculating systems (B) take in much less water, but can consume twice as much of it or more, because they evaporate much of the water to condense the steam.

Inset adapted from GAO 2009.



type of fuel and cooling systems they use. In Chapter 3, we compare our findings with federally compiled figures on power plant water use, and examine the causes of any gaps and discrepancies.

In Chapter 4, we assess the stress that power plants place on water systems across the country, highlighting regions where power plants may contribute substantially to that stress. (For more information on our methodology, see Box 1, p. 10, and Appendix A.) Finally, in Chapter 5 we suggest steps decision makers can take to better understand and minimize the impact of the electricity sector on our water resources.

BOX 1. *The Energy and Water in a Warming World Approach*

This report presents two types of information on water use by the thermoelectric power sector: *reported* and *calculated*.

Reported information is published by the EIA, based on data on water withdrawal and consumption submitted by power plant operators for 2008. Because many operators—including those of the nation's entire nuclear fleet—did not report that information to the EIA, the reported figures contained large gaps.[7] The information that power producers did submit also included a number of errors. Some plant owners, for instance, reported that their annual water consumption was greater than their annual withdrawals.

To address the shortcomings of the 2008 reporting system, we calculated water use by electricity producers. To do so, we:

- Used federal records and other sources to identify the fuel type, cooling technology, source of cooling water, and power output of each of the 1,748 water-cooled power plants in the United States in 2008. (Power plants may include one or more generators—turbines that turn physical energy into electrical energy.)
- Calculated water use for each plant, based on the amount of water typically withdrawn and consumed per unit of electricity produced by a plant with a certain type of fuel and cooling system, according to the National Renewable Energy Laboratory (NREL) (Macknick et al. 2011). NREL provides minimum, median, and maximum values for each type of plant. Multiplying the NREL values by the plant's reported electricity production for the year yields a range of calculated figures for its water use. The NREL values are the most current published figures relating power production to water use, so we have a high degree of confidence that our calculations represent the best available information on water use by the power sector.[8]

To evaluate water stress created by each power plant, we calculated the Water Supply Stress Index (WaSSI) (Sun et al. 2008) for each of the 2,106 watersheds (or sub-basins) in the lower 48 states.[9] The WaSSI is the average annual volume of water demand divided by the average annual supply.[10] The higher a basin's WaSSI, the greater its water stress. In basins with a WaSSI exceeding 1.0, demand exceeds supply: so users are importing water from other basins to meet demand,[11] or withdrawing more surface water and groundwater than natural processes are replacing.

We calculated the WaSSI for each watershed both with and without power plant water use. Mapping the difference between the two allowed us to identify regions where power plants appear to contribute substantially to water stress.[12]

A forthcoming companion EW3 report will assess the water implications of future energy scenarios in key regions of the country, and this report includes a snapshot from that report. Using an EIA base case for growth in electricity demand, we modeled the mix of power plants in each of 134 electricity regions ("power control areas") in the continental United States through 2036, given current policies that help determine what types of power plants producers may build. We then applied the most appropriate NREL values to estimate water withdrawals and consumption in 2036, and compared those with 2008 water use in the sector.[13]

What Our Analysis Does Not Cover

Our analysis does not consider other ways electricity production affects water resources, including:

Hydropower. Hydroelectricity entails an obvious link between energy and water. However, quantifying water withdrawal and consumption for hydropower facilities is less clear-cut than for thermoelectric power plants. A dam may generate power as it releases water for downstream users and ecosystems, for example. Such facilities could be seen as not "withdrawing" any water.

Reservoirs used for hydropower increase the rate at which water is lost to evaporation. For instance, Lake Mead—the reservoir created by Hoover Dam—loses roughly 325 billion gallons (1 million acre-feet) to evaporation each year (Westernburg, DeMeo, and Tanko 2006). However, many reservoirs, including Lake Mead, provide benefits beyond hydropower, such as water supply, tourism, and recreation. In those cases, hydropower could be seen as only partly responsible for evaporative losses.

Fuel extraction and refining. This report focuses on the direct withdrawal and consumption of water by thermoelectric power plants. However, many other pieces of the energy puzzle also affect water systems. For example, U.S. coal mining uses 70 million to 260 million gallons (215 to 800 acre-feet) of water each day (DOE 2006). What's more, mountaintop removal mining has buried almost 2,000 miles of Appalachian headwater streams—some of the most biologically diverse streams in the country (EPA 2010).

Producing uranium fuel for nuclear power plants can affect water supplies as well. Uranium mining has contaminated surface or groundwater in at least 14 states (WISE 2011). Processing and enriching uranium for use in nuclear power plants also requires water.

Natural gas power plants are usually much less water-intensive than coal or nuclear plants. However, the growing use of hydraulic fracturing, or "hydrofracking," to extract natural gas has been linked with aquifer declines (Hanson and Lewis 2010) and water pollution (Urbina 2011; Lustgarten 2009; PDEP 2009; OGAP 2005). The U.S. Environmental Protection Agency (EPA) is studying the effects of hydraulic fracturing on drinking water resources (EPA 2011a).[14]

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7 In 2008, the EIA required reports only from operators of power plants that used organic fuel (coal, natural gas, biomass, and oil) and produced more than 100 megawatts of electricity (EIA 2008a; 2008b). For our purposes, we broke each plant down to the generator scale, based on 2008 information on power plant design and operations submitted to the EIA on forms 860 and 923, respectively (EIA 2008a; 2008b). We also collected location data from information reported by plant owners to the EIA and compiled by the Civil Society Institute, and used Google Earth to correct the reported data. We also collected data on CO_2 emissions as reported to the U.S. Environmental Protection Agency by a subset of plants. More details on the collection and quality-control aspects of this effort are in Appendix A.

8 Because NREL figures reflect all water used in geothermal facilities—and such water "may come from geothermal fluids, with little to no impact on local freshwater sources" (Macknick et al 2011)—we used another source to determine freshwater use by geothermal facilities (Clark et al. 2011).

9 A sub-basin, or "cataloging unit"—"a geographic area representing part or all of a surface drainage basin, a combination of drainage basins, or a distinct hydrologic feature"—is the smallest unit in the U.S. Geological Survey system (USGS 2011).

10 For each sub-basin, we calculated water supply as the average sum of a) surface water supply (five-year average 2003–2007); b) groundwater supply, based on 2005 rates of withdrawal (Kenny et al. 2009); and c) return flows from major water users, including cities and agriculture in 2005 (Kenny et al. 2009), and power plants (2008, our analysis). We calculated water demand as withdrawals by the seven major users (commercial, domestic, industrial, irrigation, livestock, and mining in 2005 (Kenny et al. 2009) along with thermoelectric power plants in 2008. For more information, see Appendix A.

11 This is the case, for instance, in the many basins in California that receive water from the Colorado River or the Sacramento-San Joaquin Delta via canals and pipelines, and in parts of Arizona served by the Central Arizona Project.

12 WaSSI measures water stress based on quantity, not quality. An assessment of the effect of power plants on water quality—such as the temperature of lakes, streams, or rivers—could reveal more basins where plants are stressing water resources.

13 The forthcoming report will include the full results of our forward-looking analysis, as well as a detailed description of our methodology.

14 For more information on water use for electricity generation beyond direct power plant cooling, see DOE 2006 or UCS 2011b.

CHAPTER 2

Electricity's Water Profile

KEY FINDINGS

- **Power plants are thirsty.** Every day in 2008, on average, water-cooled thermoelectric power plants in the United States withdrew 60 billion to 170 billion gallons (180,000 to 530,000 acre-feet) of freshwater from rivers, lakes, streams, and aquifers, and consumed 2.8 billion to 5.9 billion gallons (8,600 to 18,100 acre-feet) of that water.[15] Our nation's large coal fleet alone was responsible for 67 percent of those withdrawals, and 65 percent of that consumption.
- **Where that water comes from is important.** In the Southwest, where surface water is relatively scarce, power plants withdrew an average of 125 million to 190 million gallons (380 to 590 acre-feet) of groundwater daily, tapping many aquifers already suffering from overdraft. By contrast, power plants east of the Mississippi relied overwhelmingly on surface water.
- **East is not west: water intensity varies regionally.** Power plant owners can reduce their water intensity—the amount of water plants use per unit of electricity generated. Plants in the East generally withdrew more water for each unit of electricity produced than plants in the West, because most have not been fitted with recirculating, dry cooling, or hybrid cooling technologies. Freshwater withdrawal intensity was 41 to 55 times greater in Virginia, North Carolina, Michigan, and Missouri than in Utah, Nevada, and California.[16] Freshwater consumption intensity was similar in those sets of states.
- **Low-carbon electricity technologies are not necessarily low-water.** On average in 2008, plants in the U.S. nuclear fleet withdrew nearly eight times more freshwater than natural gas plants per unit of electricity generated, and 11 percent more than coal plants. The water intensity of renewable energy technologies varies. Some concentrating solar power plants consume more water per unit of electricity than the average coal plant, while wind farms use essentially no water.


Flickr/Siemens

Low-carbon electricity is not always low-water: **Renewable power plants have a wide range of water intensities. Wind turbines and photovoltaic panels use essentially no water. However, when geothermal, biomass, and some types of concentrating solar power plants rely on recirculating cooling systems, they can have water intensities in the range of nuclear or coal plants.**

Every day in 2008, on average, water-cooled thermoelectric power plants in the United States withdrew 60 billion to 170 billion gallons (180,000 to 530,000 acre-feet) of freshwater from rivers, lakes, streams, and aquifers, and consumed 2.8 billion to 5.9 billion gallons (8,600 to 18,100 acre-feet) of that water. The water withdrawn was enough to supply 60 to 170 cities the size of New York (NYCDEP 2009).

15 For purposes of this analysis, "freshwater" encompasses all non-ocean sources, except where otherwise noted.

16 The first four states had among the highest freshwater withdrawal intensities; the latter, among the lowest (see Figure 4).

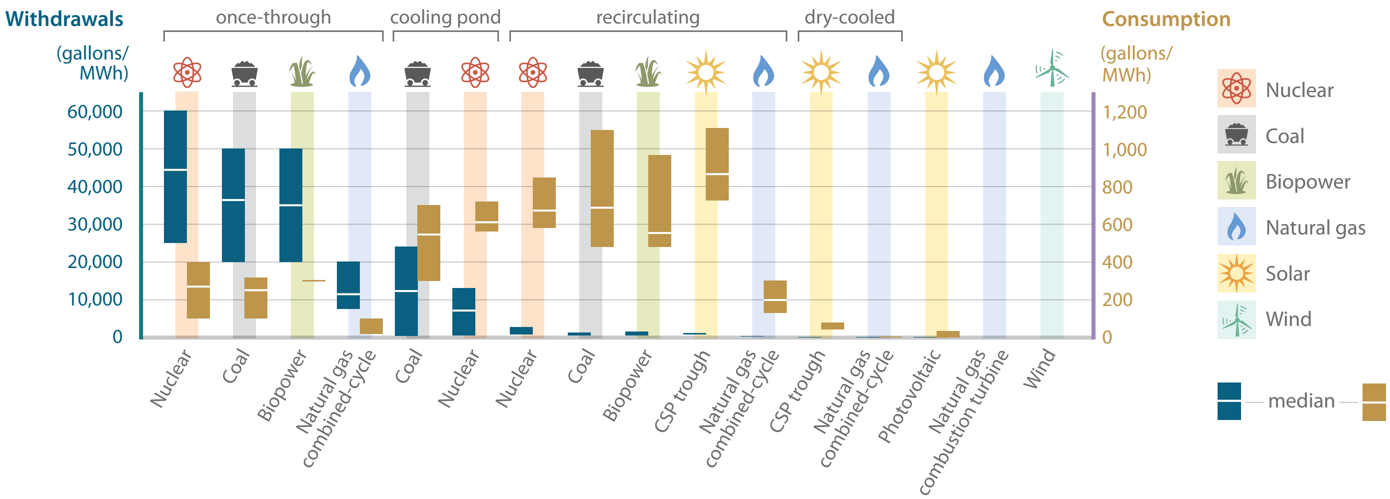


FIGURE 2. Water Use by Fuel and Cooling Technology

Water *withdrawals* per megawatt-hour (MWh) can range from almost zero for a solar photovoltaic, wind, or dry-cooled natural gas plant, to hundreds of gallons for an efficient plant using recirculating cooling, to tens of thousands of gallons for a nuclear or coal plant using once-through cooling. Water *consumption* per MWh can similarly range from almost zero for solar, wind, or gas plants using dry cooling to around 1,000 gallons for coal, oil, or concentrating solar power (CSP) with recirculating cooling. How much water a specific plant uses reflects its efficiency and age, and how much the plant is used, along with local humidity, air temperature, and water temperature.

Source: Macknick et al. 2011.

Note: Ranges reflect minimum and maximum water-use values for selected technologies from NREL. Horizontal lines within rectangles indicate median values.

This chapter presents detailed findings about where that astonishing amount of water comes from, how the power sector's water use varies across the country, and which fuel types are associated with the heaviest water use. Most of our analysis focuses on freshwater, as that limited resource is critical to our health, our economy, and our ecosystems.[17]

Water Intensity

The water demand of power plants varies widely. A nuclear power plant with once-through cooling, for instance, withdraws 25,000 to 60,000 gallons of water for each megawatt-hour of electricity it produces, but consumes 100 to 400 gallons (Macknick et al. 2011). A nuclear plant with recirculating cooling water, on the other hand, withdraws 800 to 2,600 gallons per megawatt-hour but consumes 600 to 800 gallons—roughly half the amount withdrawn (Macknick et al. 2011).

U.S. power plants withdrew enough freshwater each day in 2008 to supply 60 to 170 cities the size of New York.

According to NREL researchers, for each type of cooling technology, nuclear fission is, on average, the most water-intensive of the most commonly used fuels, followed by coal and natural gas (Figure 2) (Macknick et al. 2011).

Renewable power plants have a wide range of water intensities: low-carbon electricity is not always low-water. Wind turbines—the most widely deployed renewable electricity technology in the United States, aside from hydropower—use essentially no water. The same is true of photovoltaic panels. On the other hand, when they rely on recirculating cooling systems, geothermal, biomass,

17 Using seawater to cool power plants can also have negative effects, however, because intake pipes and warm water discharges can affect sea life.

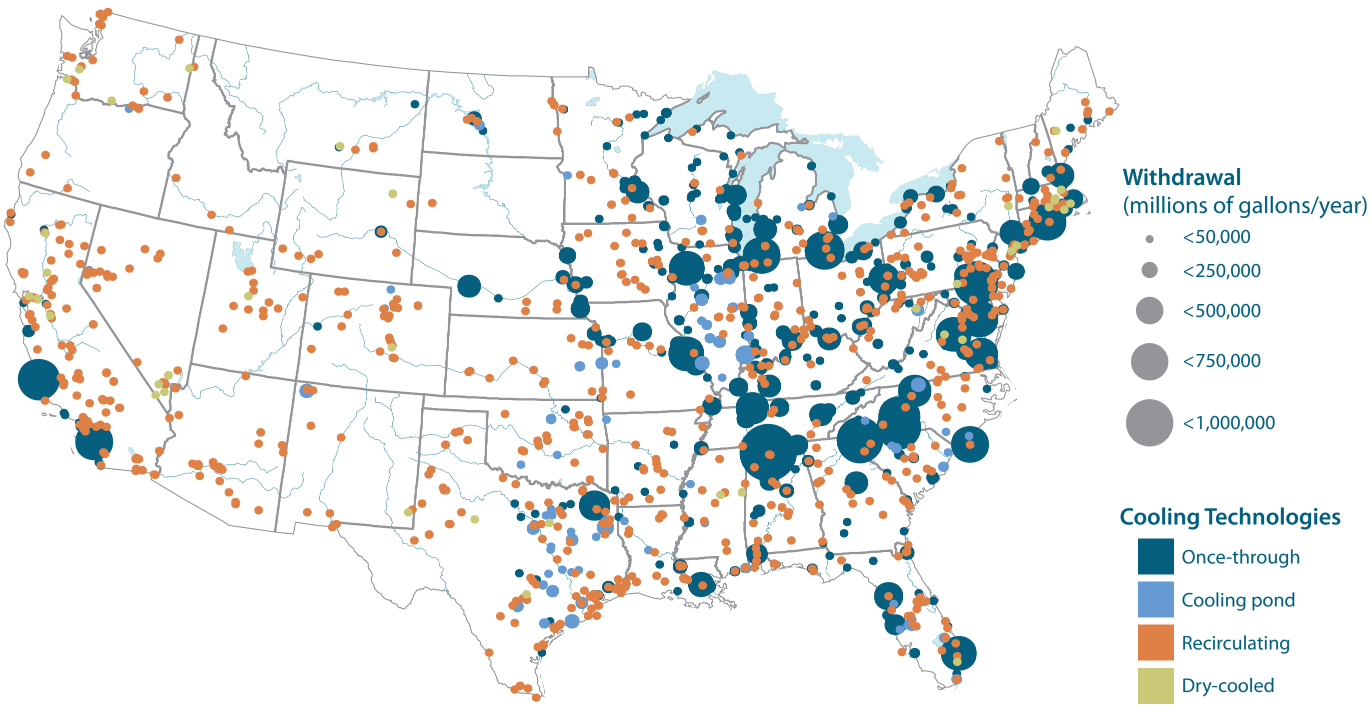
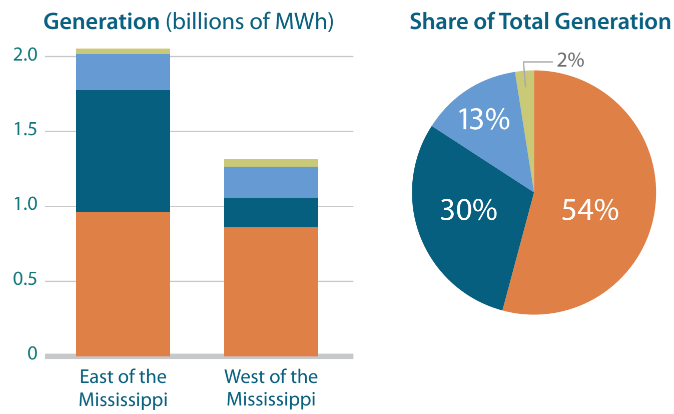


FIGURE 3. Power Plant Water Withdrawals: East versus West

Water withdrawals in 2008 were much higher east than west of the Mississippi. That is because plants with once-through cooling—which withdraw huge volumes of water—produced a much larger share of electricity in the eastern half of the country, and because overall electricity production was also higher east of the Mississippi. Plants with once-through cooling were located chiefly along the coasts, on the shores of the Great Lakes, and on large rivers and reservoirs.

Note: Based on median NREL values for the use of both freshwater and seawater. Cooling ponds may operate as once-through systems, recirculating systems, or a combination of the two.



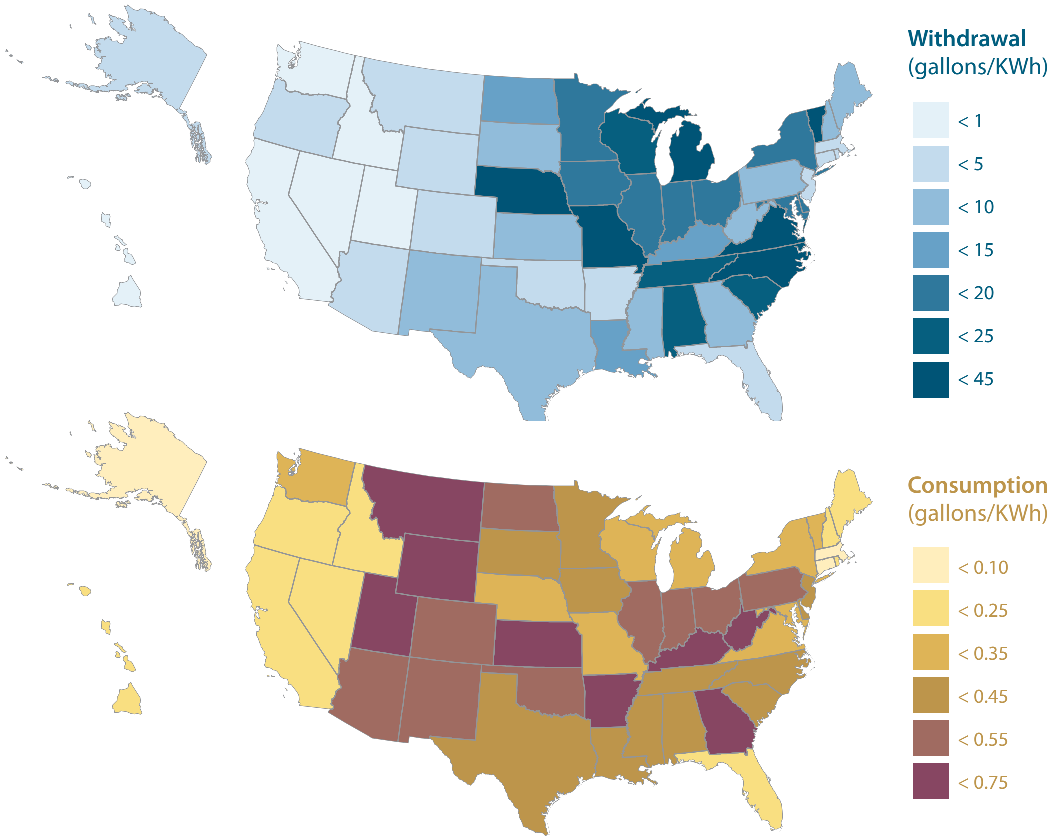
and some types of concentrating solar power plants—all of which use steam to drive turbines—have water intensities in the range of nuclear or coal. Some renewable energy power plants with turbines employ dry cooling, and those require minimal amounts of water.

Cooling Technologies across the Country

To some degree, power plant cooling systems match local water resources. We found that 86 percent of plants drawing water from the sea in 2008 used once-through cooling, taking advantage of their access to an essentially limitless resource. Most inland power plants with once-through systems were located in the eastern half of the country, where surface water is generally more plentiful (Figure 3).

Power plants in the West, in contrast, relied heavily on recirculating systems, as those withdraw much less water. Dry-cooled power plants were also more common in the West, although they accounted for only 4 percent of the region's electricity production.

Average freshwater withdrawal intensities for each state reflected these regional differences. Intensities were lowest in western states, while areas of high intensity were scattered around the East, including in the Great Lakes states, Missouri, Tennessee, Virginia, and the Carolinas (Figure 4).



Surface water sources accounted for 94 percent of power plant water withdrawals and roughly 86 percent of consumption in 2008.

Note: Based on median NREL values, divided by all non-hydro electricity generation. (Regional trends are similar when the analysis is based on the range of NREL values. See Appendix B.)

FIGURE 4. Freshwater Use for Electricity Generation

Higher freshwater withdrawal intensities in the East in 2008 reflected the fact that more power plants relied on once-through cooling. Freshwater consumption intensities were more evenly distributed across the country. Coastal states such as California and Florida had relatively low freshwater consumption intensities because their once-through plants relied mostly on seawater, not freshwater. And most thermoelectric power plants in California were highly efficient combined-cycle natural gas plants.

States with high water consumption intensities were found across most of the country, reflecting the fact that recirculating cooling systems were common throughout the United States. High freshwater consumption intensity is a particular concern in fast-growing states in the arid West, such as Utah and Arizona.

Where Does All This Water Come From?

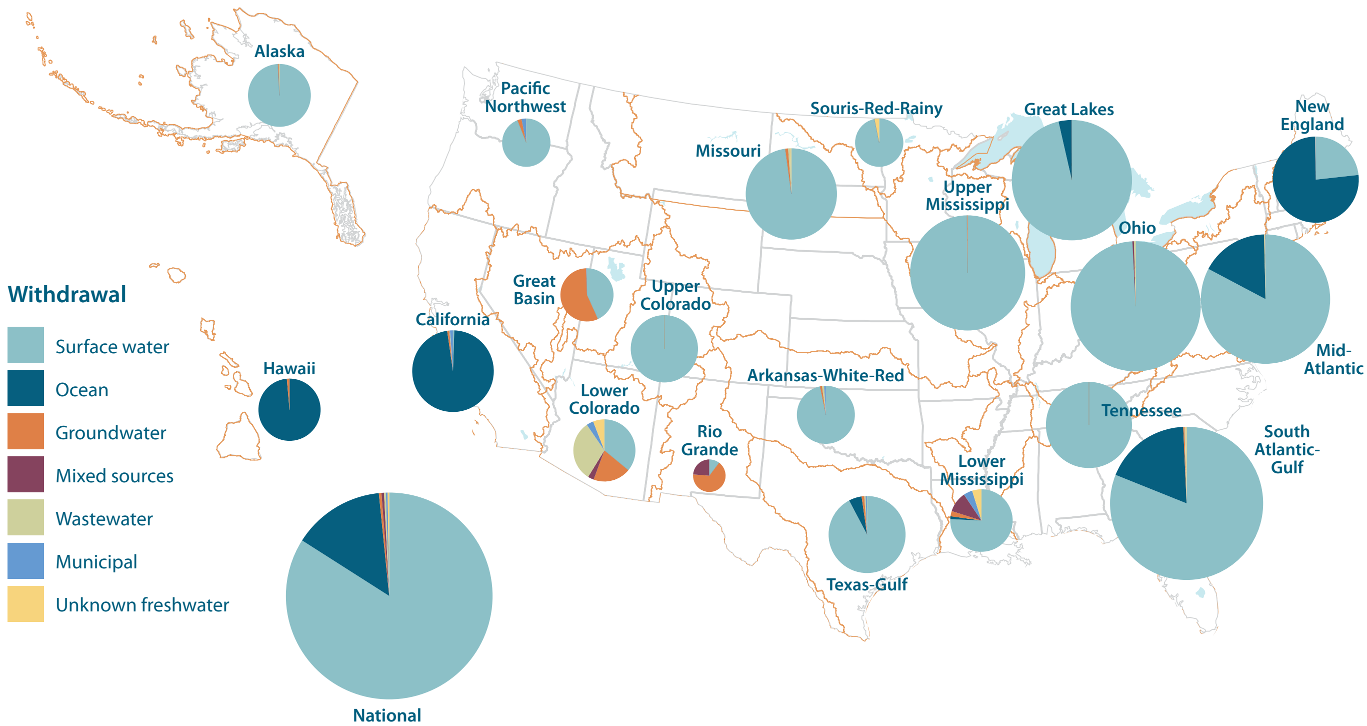
Most water-cooled power plants have been built within easy reach of a large source of surface water—a river, lake, or ocean. Nationally, we found that these sources accounted for 94 percent of water withdrawals, and roughly 86 percent of consumption, by thermoelectric power plants (Figure 5, p. 16).[18]

In many regions, however, cities, farms, and power plants, as well as recreational users and ecosystems, already have legal claims to surface water sources. When those sources are not available, utilities turn to alternatives: groundwater, treated wastewater, or other municipal sources. (Many power plants report using municipal water without specifying whether it is groundwater, surface water, or treated wastewater.)

Power plant operators usually tap these alternative sources in regions where surface water is scarce. For instance, in the Lower Colorado River region near Austin, TX, the Rio Grande region in southern Texas, and the Great Basin, which spans parts of California, Nevada, and Utah, groundwater accounted for more than half of all water consumed by thermoelectric power plants.[19]

18 For a list of rivers used most extensively to cool power plants, see Appendix B.

19 For a full analysis of water sources used to cool power plants, by region, see Appendix B.



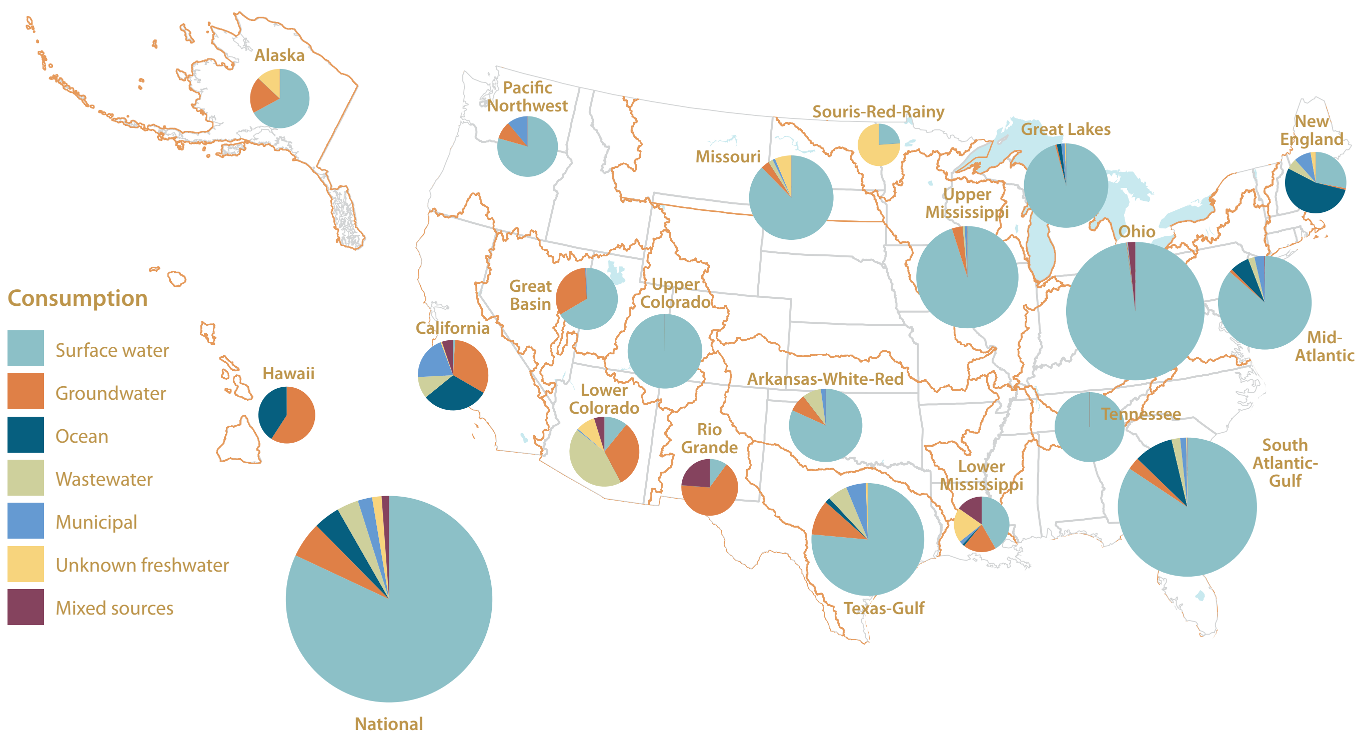


FIGURE 5. Sources of Water Used by Power Plants

In 2008, power plants withdrew 84 percent of their cooling water from rivers and lakes. The balance came mainly from the ocean in coastal regions. Most water that power plants consumed similarly came from surface sources. However, in some regions—notably the arid Southwest—cooling water came from a broader array of sources, including groundwater and wastewater.

However, these sources are not free of environmental impact. In many areas, power plant use combined with other water demands are draining aquifers at an unsustainable rate (Alley, Reilly, and Franke 1999). Power plants are major consumers of groundwater in several regions where such withdrawals have increased sharply in recent years, including the Las Vegas and Tucson areas.[20]

What's more, the extent of groundwater resources can be uncertain, so using them can be akin to drawing on a checking account without knowing whether the balance is a few hundred or many thousands of dollars (Reilly et al. 2008). Tapping groundwater can also require more electricity than using other water sources; water is heavy, so pumping it from underground takes a lot of energy. The use of municipal water and its infrastructure for cooling power plants, meanwhile, may compete with other uses (Box 2, p. 18).

Considering Freshwater Use by Fuel

Many factors influence the amount of water used by individual coal, nuclear, and natural gas plants. Different plants use different cooling systems, some are decades older than others, and operating conditions vary. However, by averaging across all plants that use each type of fuel, we found significant differences in freshwater-use profiles per unit of electricity generated (Figure 6).

For example, among plants using freshwater for cooling in 2008, we calculated that nuclear plants withdrew nearly eight times more freshwater than natural gas plants per unit of electricity generated, and about 11 percent more than coal plants. Different types of plants ranked similarly in their intensity of freshwater consumption, although the gaps were smaller. Nuclear plants consumed three times the amount of freshwater that natural gas plants did, for example, and about 4 percent more than coal plants, per unit of power produced.

Flickr/Lance and Erin

From the aquifers to the plant: **Where surface water is scarce, operators of power plants such as the Apache Generating Station, a coal- and natural-gas fired plant in southeast Arizona, usually tap alternative sources of water. In parts of the Southwest and Texas, thermoelectric power plants tapped groundwater for more than half of all the water they consumed in 2008.**

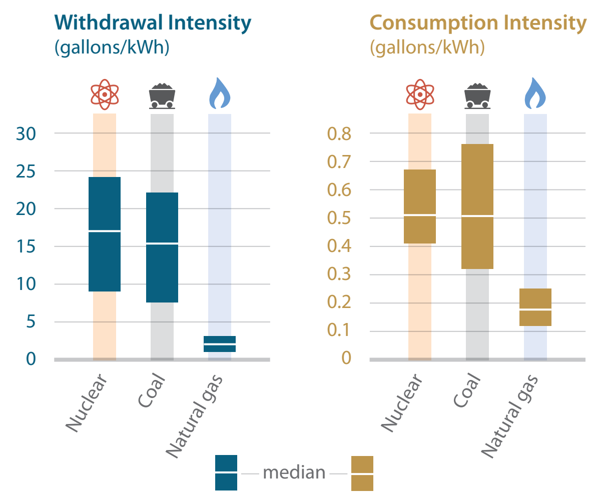


FIGURE 6. Variations in Water-Use Intensity across the Fleet

Among power plants using freshwater for cooling in 2008, nuclear power plants used more water per unit of electricity produced. The average nuclear plant withdrew nearly eight times as much freshwater as the average natural gas plant, and 11 percent more than the average coal plant. Nuclear plants also consumed three times as much freshwater as natural gas per unit of electricity produced, and about 4 percent more freshwater than coal plants.

Note: Boxes show the range of water-use values for various technologies from NREL. Comparisons are based on median water-use values.

20 For example, according to figures from the U.S. Geological Survey (Kenny et al. 2009), in 2005 power plants accounted for 28 percent of groundwater withdrawals in Storey County, NV—second only to mining, which accounted for 31 percent of those withdrawals. In Apache and Navajo counties, AZ, power plants were the largest users of groundwater, accounting for 68 percent and 28 percent of withdrawals, respectively.

Coal-fired power plants, the dominant source of U.S. electricity, accounted for 59 percent of freshwater-cooled electricity generation, according to our analysis. We found that coal plants use more than their share of freshwater: they accounted for 67 percent of all freshwater withdrawals for thermoelectric power plants, and 65 percent of consumption.

Nuclear plants, meanwhile, produced 21 percent of the nation's freshwater-cooled electricity, but accounted for 27 percent of power plant freshwater withdrawals, and 24 percent of consumption.

The natural gas fleet generates much more power for each drop of water it uses. While producing 18 percent of the nation's freshwater-cooled thermoelectric power, natural gas plants accounted for just 4 percent of power plant freshwater withdrawals and 9 percent of consumption (Appendix B).

While producing 18 percent of the nation's freshwater-cooled thermoelectric power, natural gas plants accounted for just 4 percent of power plant freshwater withdrawals and 9 percent of consumption in 2008.

BOX 2. *Alternative Water Sources: No Perfect Solutions*

Groundwater Drawdown at Laramie River

To meet the recirculating cooling needs of the coal-fired Laramie River Station in Wheatland, WY, the owners created the Grayrocks Reservoir. However, when the reservoir fell to 10 percent of capacity during an extended drought, the plant's owner had to obtain 80 percent of the plant's cooling water—more than 26 billion gallons (80,000 acre-feet)—from wells and other leased groundwater sources, most from the High Plains Aquifer, from October 2004 to May 2010. Other water sources included the Wheatland Irrigation District, which typically provides water to irrigate more than 50,000 acres of farmland (WWDC 2011).

Reusing Wastewater at Palo Verde

The Palo Verde nuclear power station, in the desert about 50 miles west of central Phoenix, is the world's only nuclear power plant not near a large body of water (Pinnacle West 2011). To meet the plant's cooling needs, Arizona Public Service buys treated wastewater from Phoenix and nearby cities (APS 2011). This system does not tap local aquifers or pump in surface water from far away. However, some 20 billion gallons (60,000 acre-feet) used at Palo Verde evaporates each year—water that might otherwise be used to recharge the area's overdrafted groundwater (APS 2011; Pinnacle West 2011).

CHAPTER 3

Gaps and Errors in Information on Power Plant Water Use

KEY FINDINGS

- **Gaps add up.** Power plants that did not report their water use to the EIA accounted for 28 to 30 percent of freshwater withdrawals by the electricity sector, and at least 24 to 31 percent of freshwater consumption by the sector, according to our calculations. Gaps in the 2008 information included all water use by nuclear power plants.
- **Discrepancies are widespread.** Reported freshwater use by power plants across the country fell outside the bounds suggested by our analysis, including plants in 22 states for withdrawal, and 38 states for consumption. The discrepancies were especially large in the Lower Colorado River and Southeast-Gulf regions, where plant operators reported consumption five times greater—and withdrawals 30 percent less—than the median NREL values would suggest.
- **Discrepancies stemmed from a range of causes.** Some power plant operators are exempt from reporting their water use based on plant size or technology. Many operators appeared to report peak rates of water use rather than the requested annual average rate, leading to overestimates. Other operators reported zero water use.

To shed light on shortcomings in public information on water use by power plants, we compared our findings with data reported to and published by the EIA, and found serious discrepancies between our calculations and the information from the agency.

In states such as Arizona, for example, the EIA process produced total water withdrawals for power plants that were below the range indicated by calculations based on minimum NREL values—while consumption totals were above calculations based on maximum NREL values. In other states, such as Tennessee, reported withdrawals were within the range of our calculations, while consumption was dramatically underreported. Then there is Texas, where power plant owners overreported both withdrawals and consumption, according to our analyses. South Carolina provides one of the most extreme cases of underreporting: we calculated that power plants withdrew some 1.2 trillion to 3.2 trillion gallons (3.7 million to 9.8 million acre-feet) of water each year—5 to 12 times the EIA-compiled figure of 262 billion gallons (800,000 acre-feet) (Figure 7, p. 20).

Breaking down the numbers by fuel, we found a consistent pattern of overreporting of water use by operators of all major types of power plants except nuclear (Table 1, p. 20). As noted, owners of those power plants did not report on water use at all.

The discrepancies between our calculated water use and reported water use are especially notable in the case of oil-fired power plants. Those plants generate less than 1.5 percent of the nation's freshwater-cooled power but account for more than 26 percent of reported water consumption. We found that their owners overreport water consumption by a factor of 40 to 76.

South Carolina provides one of the most extreme cases of underreporting: power plants withdrew 5 to 12 times the reported figure of 262 billion gallons in 2008.

What's Going on Here?

Some of the inaccuracies in the EIA-compiled data are easy to explain. To start, several categories of power plants were exempt from reporting under EIA policy. The most significant exemption was for the nation's 66 nuclear power plants, as noted. In 2002, the agency stopped

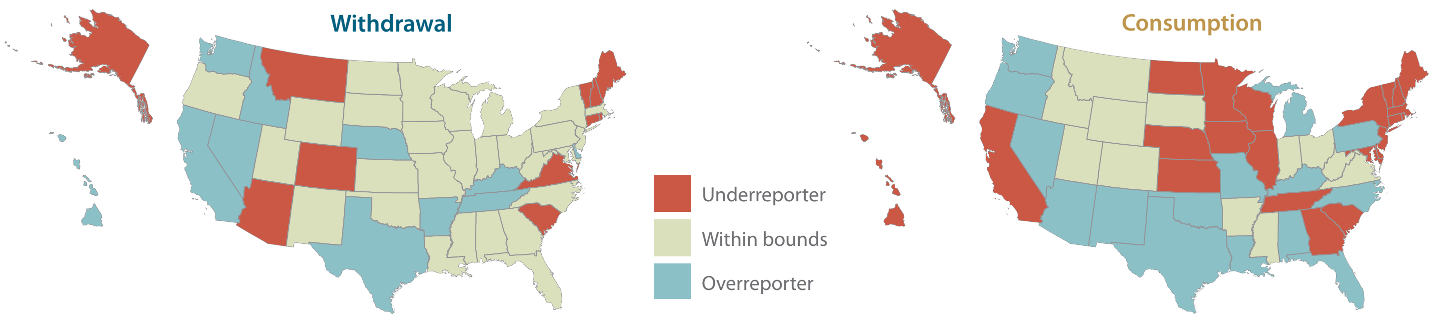


FIGURE 7. Reported versus Calculated Power Plant Water Use: Discrepancies across the Country

The relationship between reported and calculated water withdrawal and consumption varies widely across states. In Arizona, for example, reported withdrawals are much lower than calculated withdrawals, yet reported consumption is much higher than calculated consumption. In Tennessee, reported withdrawals are close to calculated withdrawals, while reported consumption is much lower than calculated consumption. And in Texas, reported withdrawals and consumption are both higher than calculated amounts.

Note: The figure is based on reported use by power plants of all water sources—both freshwater and seawater—compared with water use calculated using the full range of NREL values.

requiring owners of those plants to report on their cooling technology and water use (because of budget limitations at the EIA, according to the U.S. Government Accountability Office) (GAO 2009). Yet that left 6.3 trillion to 16.7 trillion gallons (19 million to 51 million acre-feet) of freshwater withdrawals and 280 billion to 460 billion gallons (870,000 to 1.4 million acre-feet) of freshwater consumption unaccounted for, representing 27 percent of all freshwater withdrawals, and 24 percent of all freshwater consumption.

Another 322 freshwater plants were exempt for other reasons. These included all plants rated at less than 100 megawatts of capacity, as well as all geothermal and concentrating solar plants regardless of capacity. The unreported water use of these plants represented 1.2 percent of all freshwater withdrawals, and 2.0 percent of consumption, by the power sector in 2008, according to our calculations.[21]

The source of other reporting problems is less clear. For example, 201 freshwater-cooled coal and natural

	Freshwater use, in millions of gallons per day				
Fuel	Reported Withdrawal	Calculated Withdrawal	Reported Consumption	Calculated Consumption	Electricity Generation (MWh/day)
Coal	100,000	40,000–120,000	4,500	1,700–4,000	5,425,000
Nuclear	0	17,000–46,000	0	780–1,300	2,201,000
Natural gas	19,000	2,200–6,700	3,500	260–530	2,270,000
Oil	6,000	640–3,200	1,700	22–42	162,000
Biomass	220	360-920	55	29–54	92,300
Geothermal	0	31	0	31	41,400
Solar	0	0.16–0.26	0	0.16–0.26	450
Wind	0	0–0.15	0	0–0.15	152,000
Total	**125,220**	**60,000–170,000**	**9,755**	**2,800–6,000**	**10,300,000**

red: underreported
blue: overreported

Note: The table is based on minimum and maximum water-use values for various technologies from NREL.

TABLE 1. Reported versus Calculated Power Plant Water Use, by Fuel

Operators of coal, natural gas, and oil power plants reported water withdrawals that were considerably higher than calculated withdrawals, on average. Operators of nuclear plants were not required to report water use to the EIA at all in 2008. And although oil-fired power plants generated less than 1.5 percent of the nation's electricity from freshwater-cooled plants, they accounted for more than 26 percent of reported consumption. Our analysis suggests that they overreported by a factor of 40 to 76.

21 Based on median NREL values.

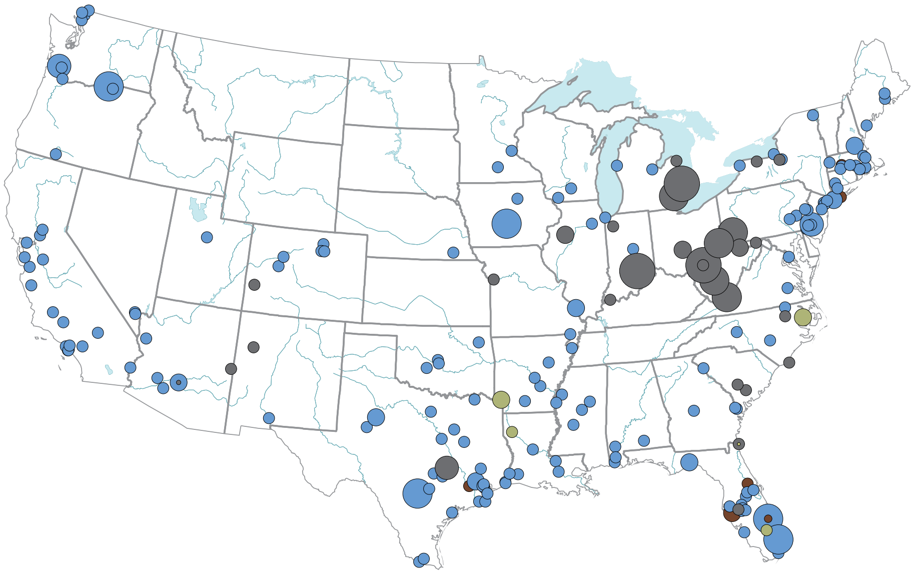


FIGURE 8. Water Withdrawals by Power Plants That Reported No Water Use

More than 200 power plants that required cooling water (and were required to report to the EIA) reported zero withdrawal and consumption in 2008. That shortcoming helps account for discrepancies between reported and calculated water use.

gas plants nominally reported water use to the EIA but claimed to withdraw and consume no water at all (Figure 8). Such reporting is obviously in error: these plants could not run without water. We identified 29 coal plants and 161 natural gas plants in this category, with calculated 2008 withdrawals of 1.1 trillion to 2.6 trillion gallons (3.4 million to 8.0 million acre-feet), and consumption of 62 billion to 133 billion gallons (190,000 to 410,000 acre-feet), according to our calculations. Why the owners of these plants reported zero water use is unclear.[22]

We spotted another 381 freshwater plants with other types of misreporting. Twenty-two plants reported water consumption greater than water withdrawals, even though a power plant cannot consume more water than it withdraws. Our analysis suggests that these plants withdrew 150 billion to 500 billion gallons (470,000 to 1.5 million acre-feet) in 2008, compared with 316 billion gallons (970,000 acre-feet) reported, and consumed 18 billion to 38 billion gallons (55,000 to 120,000 acre-feet), rather than the 1.3 trillion gallons (4.0 million acre-feet) reported.

Another 91 plants claimed to withdraw and consume identical amounts of water.[23] While plants with


U.S. Nuclear Regulatory Commission

Water users that were exempt from reporting: **Among power plants not required to report water use under EIA policy in 2008, the most significant were the nation's 66 nuclear power plants, such as Georgia's Plant Vogtle, on the Savannah River shared with South Carolina. The omission of nuclear plants means 6 trillion to 17 trillion gallons of freshwater withdrawals and 280 billion to 460 billion gallons of freshwater consumption went unaccounted.**

22 The U.S. Government Accountability Office has pointed out that these reports are subject to little oversight (GAO 2009).

23 These plants do not include those that reported zero for both consumption and withdrawal.

Catawba River Keepers

Power plants that underreported water use: **Drought and rising demand for water have stressed the Catawba River, the source of cooling water for Duke Energy's Marshall Steam Station and several other plants. These power plants underreported the amount of river water they used in 2008, according to our analysis. In its 2009 report on energy and water, the U.S. Government Accountability Office (GAO) explicitly recognized the importance of providing better information on power plant water use, to improve planning and management.**

recirculating cooling systems evaporate most of the water they withdraw, operators must discharge water periodically to prevent the buildup of minerals.[24] Operators overstated freshwater withdrawals at these plants in 2008 by 40 percent, according to median NREL values.

Finally, we found 267 plants—including 128 coal plants and 126 natural gas plants—that had reported withdrawals or consumption 50 percent above those suggested by the median NREL values.

Why so many errors? One reason appears to be that many operators estimated annual water use rather than measuring it.[25] Operators also appear to have based some estimates of annual water use on a high-demand period, leading to large overestimates for an entire year.[26] However, it is impossible to know for sure because operators did not have to report whether they measured or estimated water use.[27] Some operators may also have reported withdrawal amounts as consumption, or vice versa.

Other Reporting Problems

Beyond gaps regarding the volume of water used by the power sector, important details on the nature of that water use were often missing as well. For example, plant owners often did not provide detailed information to the EIA about where they obtained their cooling water.

In 2008, plants accounting for 12 percent of the nation's thermoelectric capacity did not report a specific cooling water source, instead listing only "lake" or "river." These plants accounted for 13 percent of freshwater consumption and 2 percent of withdrawals, according to our calculations. And of 498 plants using groundwater, only six identified the aquifer and nine identified the wells.[28] This lack of detailed information is of particular concern in the Southwest, where groundwater is a leading source of cooling water, and where water levels in many aquifers are declining.[29]

24 This process is known as blowdown.

25 As the EIA allowed: "If actual data are not available, provide an estimated value" (EIA 2008a).

26 The EIA required plant operators to report their average annual intake and discharge in cubic feet per second. If a cooling system operated only 10 percent of the year, the operator must have calculated the average intake and discharge as if the plant had operated throughout the year (EIA 2008a; EIA 2008b).

27 The EIA will track this distinction beginning in 2011 (EIA 2011a).

28 Five of the six plants used the same aquifer.

29 Some—but not all—state or local water managers have this information. In Texas and Arizona, for example, plant operators in specific groundwater management areas must provide more detailed information on their water use. However, operators in other areas of those states must indicate only the location of their well—not how much water they withdraw.

"[W]ithout this comprehensive information [on power plant water use], policy makers have an incomplete picture of the impact that thermoelectric power plants will have on water resources." —GAO

EIA data also did not reflect variations in power plant water use throughout the year. Yet weekly or monthly information is critical to assessing the stress a plant's water use places on local resources and ecosystems. A plant that withdraws little water from a river most of the year but needs a great deal in late summer, when river flows may be both low and warm, can create more water stress than its annual water demand would suggest.

Why Accurate Information Matters

Imagine if the U.S. Census were as problem-ridden as the system for reporting and compiling data on power plant water use in 2008. Perhaps 75 million people would be ignored. Some 50 million people might be counted twice, or five times. Another 30 million would write in saying they do not exist, and the government would not have the resources to correct the errors.

The resulting figures would throw the nation into disarray. Official state populations might be double, or half, the real count. Federal funding for schools and other programs would be misallocated. Local governments would have to launch their own counting efforts. Planners would not know whether to prepare for population growth or loss.

That scenario sounds far-fetched. But the lack of high-quality federal data on water use by thermoelectric power plants also has serious consequences. At the national level, low-quality data hinder the creation of well-informed federal policies to guide the sustainable development of water and energy resources (GAO 2009). Poor information also complicates analyses of trends in water use by the power sector.[30] Assessing the water use of plants using different cooling technologies or fuels, for instance, becomes a major undertaking.

At state and local levels, the lack of reliable federal numbers on water use by power plants has forced water and energy planners to create their own data—and these are known to be of uneven quality, particularly for groundwater. In water-short states such as California and Arizona, assembling data on the power sector's water use is standard procedure (ADWR 2011; California Department of Water Resources 2009). However, other states and stakeholders may lack the resources or foresight to invest in understanding the potential tension between power production and water resources until a drought occurs.

What's more, modifying power plants to adapt to limits on the amount of available water is not simple or cheap (GAO 2003; NDWP 1999). Altering intake structures, for example, takes months (Weiss 2008). Other changes, such as building auxiliary cooling towers or shifting from recirculating cooling to dry cooling, take even longer.[31]

In a 2009 report, the U.S. Government Accountability Office (GAO) explicitly recognized the importance of providing better information on power plant water use. According to the GAO, problems in collecting and reporting such information "[limit] the ability of federal agencies and industry analysts to assess important trends in water use by power plants, compare them to other sectors, and identify the adoption of new technologies that can reduce freshwater use."

The agency added that "without this comprehensive information, policy makers have an incomplete picture of the impact that thermoelectric power plants will have on water resources … and will be less able to determine what additional activities they should encourage for water conservation" (GAO 2009).

30 Several published papers have used data from either the U.S. Geological Survey or the EIA to determine where future water stress will occur (e.g., Yang and Lant 2011; Brown 1999). However, if these analyses are based on poorly reported data, they may overlook areas that are actually under stress.

31 Permitting and constructing cooling towers or dry-cooling systems can take months to years. However, a plant does not normally have to shut down during that process, as it can occur during regularly scheduled maintenance (Havey 2008).

Changes Coming

Although the EIA reporting system has had shortcomings, the agency is taking steps to collect more—and more accurate—information on water use by thermoelectric power plants (EIA 2011a; 2011b; 2008a; 2008b). Beginning in 2011, for example, plant operators—including those of nuclear and thermoelectric concentrating solar facilities—must report their water use on a monthly basis. The reporting system will recognize hybrid cooling systems as a distinct type.

Operators must specify the type of water used for cooling and the source—whether a water body, groundwater, or a cooling pond. Operators must also report the method they use to determine water withdrawals and consumption. And they must report the maximum and average monthly temperatures of water they discharge, and the method they use to measure those temperatures.

However, some problems appear likely to persist. The EIA will still allow plant owners to estimate their water use—and estimates may be inaccurate, as we have found. Further, owners do not have to report modifications they make to comply with environmental regulations, such as adding cooling towers to reduce the temperature of water flowing out of plants with once-through cooling systems. These modifications may cause significant new evaporative losses.

Whether the new reporting will yield needed information on water sources is also unclear. Such information includes the names of groundwater aquifers, and, for power plants drawing on tributaries, the river system of which they are a part.

Finally, compliance stands to be a problem unless the EIA can devote enough resources to oversight. For instance, power plant operators have universally ignored rules requiring them to specify groundwater sources used for cooling. The agency's success in improving information on water use by the power sector will ultimately depend on both its budget and its priorities.

CHAPTER 4

Under Pressure: Stress on Water Systems

KEY FINDINGS

- **Power plants across the country contribute to water-supply stress.** Based on our analysis, in 2008, 400 out of 2,106 watersheds across the country were experiencing water-supply stress. Power plants, by tapping this overstretched resource for cooling purposes, contributed to water-supply stress in one-fifth of those. We focused on 25 watersheds in 17 states in which power plants were the primary driver of water-supply stress based on our analysis. Several states including North Carolina, South Carolina, Missouri, and Michigan had more than one of those watersheds, including the Catawba and Seneca Rivers.
- **Good analysis requires good information.** Using the available data masks existing water stress. Several of the 25 watersheds identified did not show up when we analyzed EIA-compiled information.
- **High-temperature water discharges are common.** Peak summer temperatures for return flows from more than 350 power plants across the country exceeded 90°F. Some 14 states prohibit such discharges, which can harm fish and other wildlife.
- **The mix of power plants in the nation's fleet matters.** The power plant portfolios of U.S. companies have widely varying water-use and carbon emissions profiles. Utilities with lower-water plants place less stress on local water sources. Utilities with carbon-intensive power plants contribute to long-term water stress by exacerbating climate change.

The combination of hot weather, drought, peak power demand, and power plant water use can quickly bring on an energy and environmental collision. Some parts of the United States have been unable to weather these storms (Box 3, p. 26) (Sovacool 2009). Assessing a region's vulnerability to such stress requires evaluating many factors, from the intensity of power plant development and competing demands for freshwater to a watershed's susceptibility to drought and the sensitivity of local ecosystems.[32]

This chapter evaluates stress at the energy-water interface in three ways. First, we identify locations across the country where the amount of water used by power plants in 2008 appears to have substantially affected the balance of water supply and demand. Next, we examine how power plant water use can affect ecosystems by heating up rivers and lakes and drawing in large numbers of fish and other aquatic species. Last, we see how stress at the nexus of energy and water can jeopardize power plant operations—and thus the reliability of the electricity supply.

As the U.S. population grows, the electricity infrastructure evolves, water and energy policies change, and the climate changes, the conditions that cause energy-water stress will shift as well. The chapter closes with a projection of how the water and carbon profiles of the nation's electricity sector may change over the next 25 years, and considers strategies for ensuring a lower-stress future.

Stress: Water Supply and Demand

Water supply in many parts of the United States is under stress from multiple users (*Economist* 2011; Dziegielewski and Kiefer 2006; GAO 2003). Our analysis using the WaSSI[33] suggests that the largest locations with water stress are, predictably, the nation's more arid areas: the Colorado River region, the Great Basin, and California. However, our analysis also points to a number of watersheds in the eastern half

32 We define vulnerability as the degree to which a person, system, or unit is likely to experience harm from exposure to perturbations or stresses (Kasperson et al. 2002), and consider demand to include both human and ecosystems and encompass both withdrawals and consumption.

33 As outlined in Box 1, we based our analysis on a five-year average of surface water supply, and single-year data on groundwater, return flows, power plant water use, and demands.

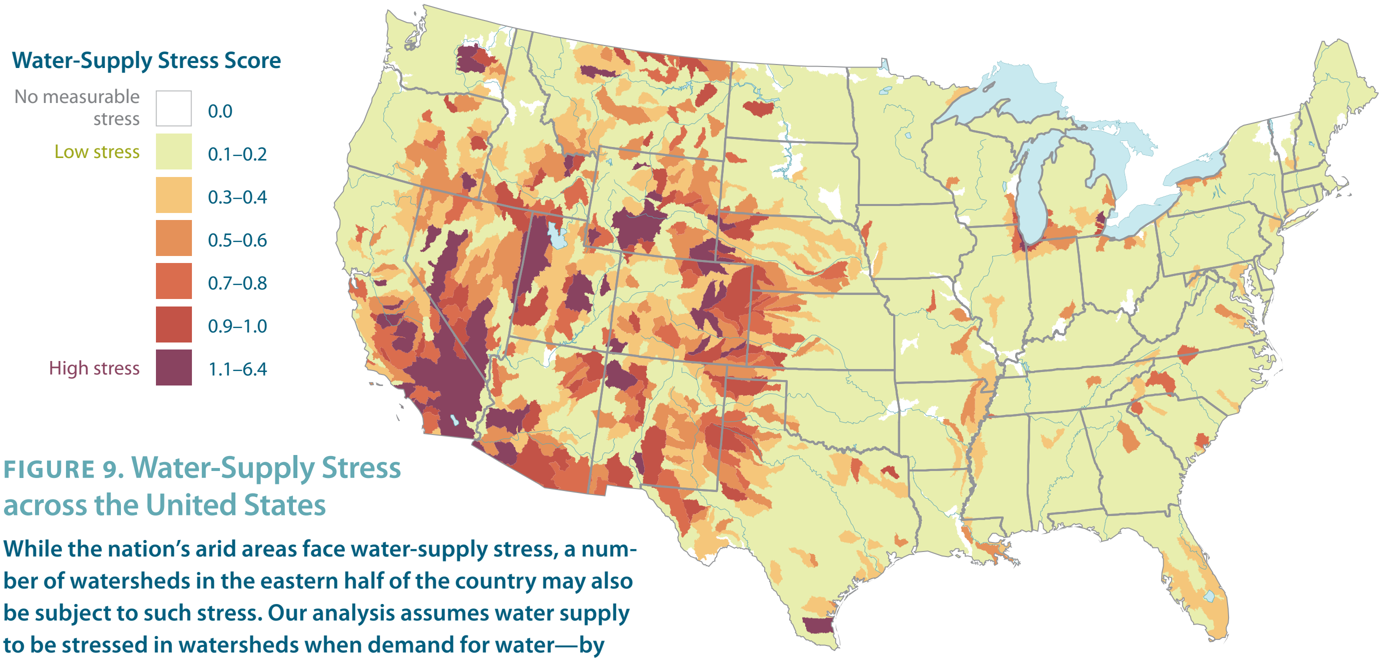


FIGURE 9. Water-Supply Stress across the United States

While the nation's arid areas face water-supply stress, a number of watersheds in the eastern half of the country may also be subject to such stress. Our analysis assumes water supply to be stressed in watersheds when demand for water—by power plants, agriculture, and municipalities, for example—exceeds a threshold of 40 percent of the available average annual supply provided by local sources (typically surface and groundwater).[34]

BOX 3. *Stress on the Chattahoochee*

Atlanta has long used Lake Lanier, a reservoir on the Chattahoochee River, as a source of freshwater. But many downstream users count on water released from the reservoir, including the Joseph M. Farley nuclear power plant in southeastern Alabama, and the Herbert Scholz coal-fired power plant in the Florida panhandle (Feldman, Slough, and Garrett 2008).

In 2007, severe drought dropped Lake Lanier to record-low levels, threatening Atlanta's water supply. These low water levels also threatened downstream ecosystems, which included the gulf sturgeon and three types of mussels, all endangered (Carter et al. 2008; Haag and Warren 2008; Shapley 2007). These competing demands prompted a legal battle among Alabama, Florida, and Georgia.[35]

The crisis affected the power supply. For both its generators to run at full capacity, the Farley nuclear plant needs flows of 2,000 cubic feet per second (cfs). In September 2007 Southern Company, the plant's owner, took one of the generators offline for maintenance. The overburdened river gave the utility little choice: flows past the Farley plant dropped below 2,000 cfs in October, and by late November had reached a low of 1,048 cfs (Carter et al. 2008).

of the country that are under high or moderate levels of water-supply stress as well (Figure 9).[36] Our analysis assumes water supply to be stressed in watersheds when demand for water—by power plants, agriculture, and municipalities, for example—exceeds a threshold of 40 percent of the available supply provided by local sources (typically surface and groundwater). According to our analysis, approximately 20 percent of the watersheds were experiencing water-supply stress.

Where are power plants contributing to that stress? To answer that question, we repeated our WaSSI calculations for 2,106 watersheds in the lower 48 states, but subtracted power plant water use. Of the watersheds experiencing water-supply stress, power plants, by tapping this overstretched resource for cooling purposes, contributed to that stress in 78, or 20 percent (Figure 10). By comparing the WaSSI calculations with and without water use by power plants, we were able to

34 WaSSI measures stress associated with water availability and demand. It does not explicitly account for transfers of water between basins, except through return flows. In regions where such transfers play a large role in water supply, the analysis can be used as an indicator of where water stress warrants further investigation.

35 A federal district judge determined division of the water in 2009 (U.S. District Court Middle District of Florida 2009).

36 We used WaSSI to calculate withdrawal and consumption for 2,106 small-scale watersheds in the lower 48 states. This section refers to freshwater only; it omits stress on ocean ecosystems.

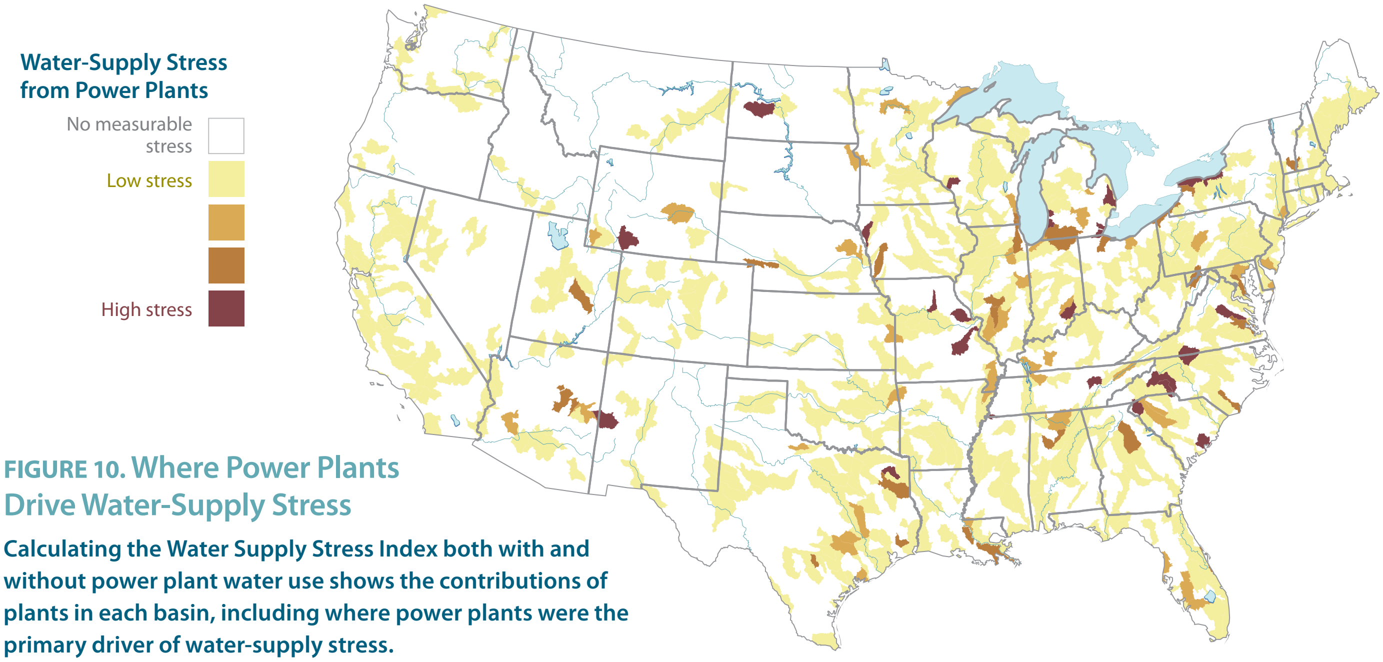


FIGURE 10. Where Power Plants Drive Water-Supply Stress

Calculating the Water Supply Stress Index both with and without power plant water use shows the contributions of plants in each basin, including where power plants were the primary driver of water-supply stress.

focus on watersheds in which power plants were the primary drivers of water-supply stress.

The 25 watersheds our analysis identified as having the highest contributions to water-supply stress from power plants appeared in 17 states[37, 38] and were not confined to the arid West. Many of the nation's largest utilities operating in other parts of the country, including American Electric Power, Dominion Resources, Duke Energy, and the Tennessee Valley Authority, owned at least one plant that used freshwater in these watersheds. In fact, although the Southwest is a region of high water stress, much of the supply stress associated with water use by thermoelectric power plants appeared to occur in places such as Appalachia, eastern Texas, the Corn Belt, and even the Great Lakes.[39] Several states including North Carolina, South Carolina, Missouri, and Michigan had more than one of the watersheds.

Some of these watersheds, like the Catawba, are experiencing highly visible consequences of water-supply stress today. In other cases where, for example, freshwater is supplied from other basins or released from reservoirs (the dynamics of which were not captured in our analysis), these watersheds may in fact not face the level of water-supply stress we identified. In others, signs of stress are simply less visible. And by not integrating


Flickr/Andy Shapiro

Habitat and hot water: **Rivers and lakes used for power plant cooling can also be prime habitat for prized sportfishing species, including cold-water species such as trout. Yet in 2008 power plant operators reported discharging water to rivers at peak temperatures above 110°F. Those temperatures can be lethal to wildlife, and are far in excess of limits set by many states (EPA 2011b).**

37 These watersheds were ones in which power plants increased WaSSI scores by at least 0.4 and contributed more than half the stress, based on analyses using median NREL values. The states were Arizona, Georgia, Indiana, Iowa, Michigan, Mississippi, Missouri, New York, North Carolina, North Dakota, Ohio, South Carolina, Tennessee, Texas, Virginia, Wisconsin, and Wyoming.

38 Of those watersheds, 17 increased WaSSI scores by at least 0.4 even when we used the most conservative criteria for power plant water use (i.e., when the analyses were based on the minimum, median, and maximum NREL values).

39 See Appendix A for discussion of the analytical treatment of watersheds bordering the Great Lakes.

the exacerbating role of temperature and drought directly into this analysis, we understate stress in still other places. Each of these watersheds warrants closer scrutiny to assess and minimize the risk of future energy-water collisions.

- In Georgia, the Upper Oconee River basin is already home to four power plants, and operators are seeking to add another. The proposed coal-fired Plant Washington is projected to withdraw 14 million gallons of water (43 acre-feet) per day, and return just 1 million. During times of drought, when the Oconee runs low, the plant would rely instead on groundwater (GAEPD 2010).
- In North Carolina and Virginia, the upper reaches of the Dan River provide cooling water to two power plants, as well as prime habitat for native brook trout and other prized sport-fishing species. We found that power plants in this hot spot were the dominant driver of water stress. Operators reported releasing cooling water to the river at peak temperatures above 110°F. Those temperatures can be lethal to wildlife and far in excess of the limits set by many states (EPA 2011b).
- In northeastern Texas, the Big Cypress and Sabine River areas, which faced high overall water stress, support 10 power plants.[40] Record-breaking drought in 2011 dropped water levels in reservoirs created to store water for these plants. Several plants sustained their reservoirs by bringing in water from the Sabine and other rivers, and faced curtailment or shutdown if the drought continued (Evans 2011; O'Grady 2011).

BOX 4. *Water-Supply Stress, Availability, and Legal Rights*

In the West, legal rights determine who has priority access to water.[41] An upstream water user with senior water rights has access to water even during droughts. For example, in Wyoming's Bitter River Basin—a watershed of interest because of water use by power plants, according to our analysis—local power plants have senior rights to draw from the river, backstopped by access to reservoirs. So while power plant water use may affect downstream water users, operators of specific power plants may be more insulated from supply stress since they are among the first in line—in this case, for Bitter River water.

The Texas Water Development Board has identified this region as one where water supply falls short of demand for power plant cooling, and projects that shortages will become more severe. Officials estimate that creating the infrastructure to meet power plant cooling needs will cost more than $2 billion statewide.[42]

To accurately identify these and other watersheds stressed by power plants—and plan for potential crises—reliable information on their water use is essential. However, several of the 25 watersheds we focused on when we analyzed water-supply stress disappeared when we used EIA data. Those watersheds include the Seneca River in South Carolina and the Pamunkey River near Richmond, VA. Power plants appeared to be the dominant contributors to water-supply stress in those areas. However, operators of power plants drawing on those rivers greatly understated their water use to the EIA.

40 The Cypress River was a hot spot, according to our analysis. As Figure 10 depicts, the Sabine River was subject to slightly lower water stress, with a WaSSI score of 0.3 based on median NREL values.

41 Water rights to the Colorado River, for example, are governed by a collection of interstate compacts and other legal agreements known as the Law of the River. However, the agreements have allocated a total of 16.5 million acre-feet of water, while the average annual flow since 1906 has been 15.1 million acre-feet, and studies suggest a longer-term average closer to 14 million acre-feet (Western Water Assessment n.d.). Actual basinwide water use now exceeds supply on a 10-year running basis. Water shortages have been avoided only because of the basin's huge reservoir capacity (some four times annual water flow). Agriculture accounts for 78 percent of water use basinwide. However, if states that do not now use their full allocation make new withdrawals to meet growing municipal demand, urban areas such as Phoenix and Denver will shoulder the risk of future shortages—even if they do not increase their own use—because of the complex priority system embedded in the Law of the River.

42 According to the Texas State Water Plan, thermoelectric power plants in the North East region already have unmet water needs of 8,690 acre-feet (2.8 billion gallons). Officials project that amount to increase almost 10-fold, to 77,000 acre-feet (25 billion gallons), in 2060 (TWDB 2012).

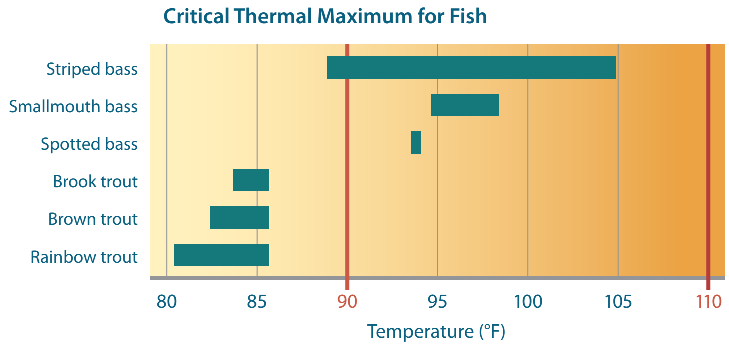


FIGURE 11. Fish in Hot Water

In 2008, more than 350 power plants reported discharging water above 90°F—the threshold set by 14 states, but still far above optimal for many fish species. Some power plants reported discharging water above 110°F. Even species that show a tolerance to high temperatures in laboratory settings can nonetheless be affected in rivers; discharge of hot water from power plants on the Catawba River was linked to mass die-offs of striped bass in 2004, 2005, and 2010.

Sources: EPA 2011b; Beitinger et al. 1999.

Note: Critical thermal maximum represents the temperature at which fish begin to display neurological symptoms of distress under laboratory conditions.

Stress on Ecosystems

A large coal or nuclear power station with once-through cooling can easily withdraw more than 500 million gallons (1,500 acre-feet) per day. Such huge flows can have two main consequences for species living in the rivers and lakes that provide cooling water and receive power plant discharges.

First, the suction pipes that draw water into a plant, or their screens, can trap creatures swimming nearby. And second, as water passes through a once-through cooling system, it gets about 17°F warmer than the source water in summer, on average. Introducing warm water to a river or lake can lead to a dangerous "temperature squeeze" for fish (Figure 11). Warm water holds less oxygen than cold water and elevates the metabolic rate of fish such that they need more oxygen and food. Warm water can also disrupt aquatic food chains.[43]

Warmer water decreases the efficiency of power plants, making them uncompetitive. And the environmental threats posed by hot water discharges can force operators to dial back or shut down.

Both effects have led to documented kills of large numbers of fish and other aquatic species. The dozens of power stations that use water from the Great Lakes for cooling, for example, kill an estimated 100 million fish annually through impingement (trapping against a screen), and 1.28 billion larval fish annually through entrainment (pulling through the cooling process) (Kelso and Milburn 1979; also see EPA 2001).

Lake Norman, NC, a reservoir on the Catawba River, provides cooling water for two plants—one coal and one nuclear—with once-through cooling and a combined capacity of 4,200 megawatts. Discharge of hot water from the power plants was linked to mass die-offs of striped bass in 2004, 2005, and 2010 (NCDWQ 2010; Weeks 2010; Waters 2005). At the Lake Sinclair

SACE

Wildlife threats: **Operators of power plants with once-through cooling systems discharge water that is 17°F warmer than the source water, on average. At the Lake Sinclair reservoir on Georgia's Oconee River, extensive fish die-offs were common until Georgia Power retrofitted its Plant Harllee Branch coal-fired power station (shown here) with a cooling tower in 2002.**

43 We compiled the peak intake and discharge temperatures of water from power plants, including nuclear plants, based on information reported to the EIA from 1996 to 2000 (609 plants) and 2001 to 2005 (551 plants) (EIA n.d.). We found that operators discharged water at peak summer temperatures averaging 99°F—17° higher than average peak intake temperatures (see Madden 2010).

reservoir on the Oconee River in Georgia, extensive fish die-offs were common until Georgia Power retrofitted its Plant Harllee Branch coal-fired power station with a cooling tower in 2002 (Schwarzen 2000).[44]

In our analysis of EIA information in 2008, we found that more than 350 power plants had reported peak water discharges exceeding 90°F—a maximum threshold for discharges in 14 states.[45] These discharges occurred across the country, including in 11 states that have adopted the 90°F standard.[46] The nation's largest utilities own many of these plants, including Ameren, FirstEnergy, Southern Company, and the Tennessee Valley Authority, each of which owns at least three of the plants. Because less than 10 percent of power plants reported temperature data to the EIA in 2008, and no nuclear plants reported this information, these numbers are undoubtedly a conservative estimate of the true thermal impact of the electricity sector.

Water Stress and Power Plant Reliability

The temperature squeeze can also squeeze power plants themselves. Warmer water decreases their efficiency, making the plants uncompetitive. And the environmental threats posed by hot water discharges, and the temperature limits set to protect rivers and lakes, can force operators to dial back a plant's output, or even to temporarily shut a plant down.

Temperature problems for power plants most often arise during heat waves, when the temperature of intake water is elevated and electricity loads (largely for air conditioning) are high (Wilbanks et al. 2008).[47] Water shortages can pinch power plants as well. Drought can drop water levels in lakes and reservoirs out of reach of power plant intake structures. Conflicts with other

Nuclear Regulatory Commission

***Perennial risk:* In 2007, and again in 2010 and 2011, the Tennessee River rose above 90°F, ensuring that the temperature of water discharged from the Tennessee Valley Authority's 3,400-megawatt Browns Ferry nuclear power station would exceed permitted limits, and forcing extended cuts in power output from the plant.**

users can also restrict the amount of water power plants can withdraw.

All these pressures—high water temperatures, declining water levels, warmer air temperatures, and larger air conditioning loads—tend to arise during extended periods of heat and drought. Together these factors can create a "perfect storm" that puts the reliability of the electricity grid in question, as in Texas in 2011.

However, while the Texas drought drew national attention to water's role in energy production, such a crisis is nothing new. In 2007, and again in 2010 and 2011, for example, the temperature of the Tennessee River rose above the 90°F threshold. That ensured that discharge temperatures from the Tennessee Valley Authority's 3,400-megawatt Browns Ferry nuclear power station would exceed permitted limits, and forced extended reductions in power output from the plant (Nuclear Regulatory Commission 2011; 2010; 2007). These cutbacks forced the authority to purchase electricity at high cost, which it passed on to consumers (Amons 2007). The 2010 slowdown cost ratepayers

44 Sudden drops in the temperature of discharged water because of a power plant shutdown can also kill fish. A shutdown in 2000 at the Oyster Creek Nuclear Generating Station in Ocean County, NJ, for example, killed nearly 3,000 striped bass, as the temperature of water flows into Barnegat Bay plunged. In 2002 a similar shutdown killed more than 5,800 fish. Finally, after another 5,000 fish perished for the same reason in 2006 and 2007, the EPA stepped in and fined the plant more than $65,000 (Clean Ocean Action 2008).

45 Those states are California, Florida, Georgia, Idaho, Illinois, Indiana, Michigan, Mississippi, Oregon, Pennsylvania, South Carolina, Tennessee, Washington, and Wisconsin (EPA 2011b).

46 Those states are California, Florida, Georgia, Illinois, Indiana, Michigan, Pennsylvania, South Carolina, Tennessee, Washington, and Wisconsin.

47 We found that limits on the temperature of discharge water have prompted utilities in at least six states to add downstream cooling towers to plants with once-through cooling systems. By cooling the plant's effluent before it is released to the environment, such towers allow older plants in temperature-constrained areas to continue to operate. However, running these auxiliary cooling systems consumes more water (as more is lost to evaporation) and electricity, increasing a plant's water use and potentially its carbon emissions.

With projected increases in water demand from a growing population, and changes in water supply from climate change, the water demands of power plants could continue to worsen water-supply stress in many areas.

more than $50 million in higher electricity bills (Associated Press 2007; Kenward 2011).

Similar events occurred at nuclear reactors in the Midwest during a 2006 heat wave. While demand for electricity broke records across the nation, high water temperatures forced four nuclear plants in Minnesota and Illinois to reduce their output when users needed it most. At the two-unit Prairie Island nuclear plant in Minnesota, for example, Mississippi River water was too hot to be used for cooling, forcing the plant to reduce output by more than 50 percent (Nuclear Regulatory Commission 2006).[48]

Events like these prompted the U.S. Department of Energy's National Energy Technology Laboratory to conclude, "Because of shallow intake depth, some power plants nationwide may be at risk of having to curtail or shut down operations in case of moderate or severe drought. Elevated temperature of the intake water may cause disruptions, however, prior to the water falling below the level of the intake" (NETL 2009).

Such episodes, now endemic in the United States, have had devastating consequences abroad as well. The 2006 European heat wave forced blackouts throughout parts of the United Kingdom (Jowit and Espinoza 2006). Another European heat wave from June to August 2003 forced rolling blackouts across most of the continent. Nuclear reactors in France were hit especially hard by the elevated water temperatures (De Bono et al. 2004).

Declining water levels left some power plants high and dry—water intakes could no longer reach water sources. Other plants had cooling water that was too hot to discharge, forcing operators to curb power capacity by an amount equal to the output of four nuclear plants (Hightower and Pierce 2008). With air conditioning loads overtaxing the system and public well-being at stake, French officials lifted restrictions on high-temperature water discharges at several power plants (Godoy 2005). Even then, more than 14,000 deaths in France—of a Europe-wide total of 30,000—were attributed to the heat wave (De Bono et al. 2004).

What Climate Change Brings

Growing populations may increase demand for both water and power, while climate change is projected to make droughts and floods in many regions more severe, affecting water quality by driving up the temperatures of lakes, streams, and rivers (USGCRP 2009). With a growing population and a changing climate, the tension between supply and demand stands to rise (Vorosmarty 2000).

Average annual precipitation in a given location—and thus water availability—often seems relatively fixed. However, evidence of precipitation levels going back thousands years shows that "average" rainfall can meander over time. The Pacific Northwest, for instance, has been wetter in the last century than at any point in the last 6,000 years (Nelson et al. 2011), while the Southwest has at times experienced decades-long droughts worse than any seen in the region in the last few centuries (Woodhouse et al. 2010).

With rapid, human-induced global warming under way, scientists project changes in many regions to the weather we take for granted, adding climate change to climate variability. These shifts are expected to affect long-term average conditions, and the intensity of acute weather events such as droughts (USGCRP 2009).

By the middle of the twenty-first century, periods of severe drought—a combination of reduced precipitation

48 During five scorching days (July 29 through August 2), Prairie Island (1,137 megawatts) was compelled to reduce its output by as much as 54 percent. The Quad Cities Reactors, near Cordova, IL, the Dresden Nuclear Plant, near Morris, IL, and the Monticello Nuclear Plant, in Monticello, MN, also reported that they had cut power production to moderate water discharge temperatures (Nuclear Regulatory Commission 2006).

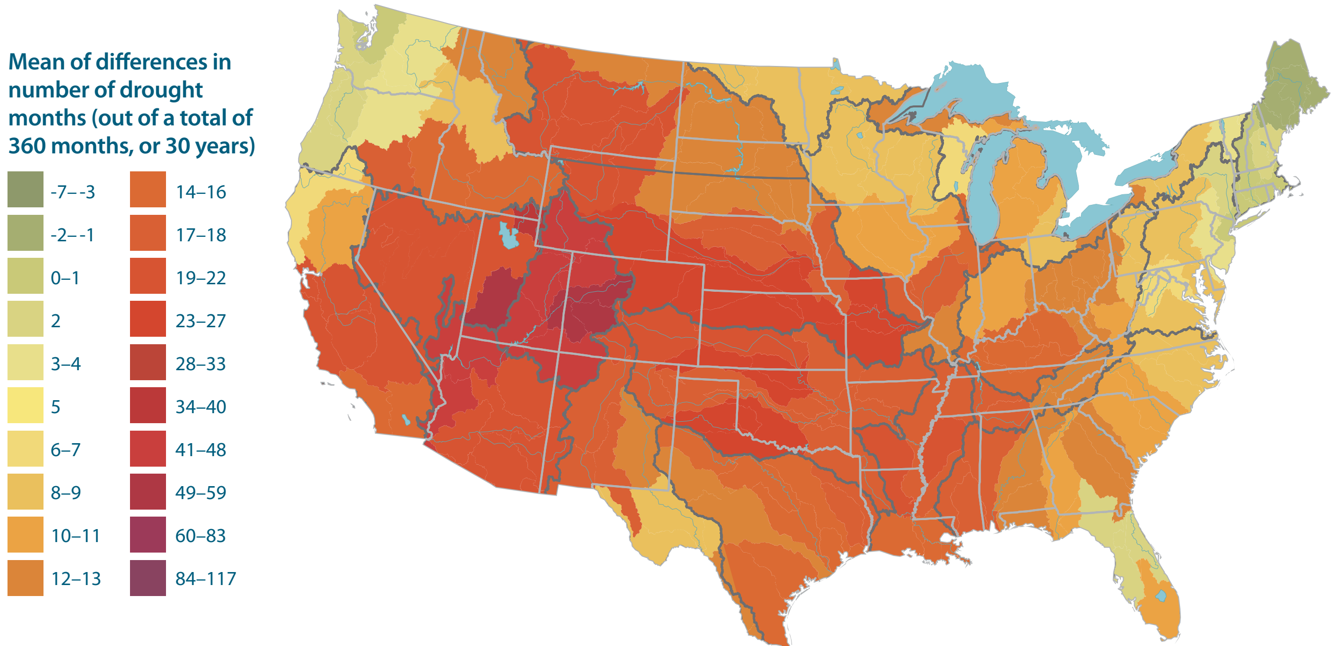


FIGURE 12. A Dry Future Source: Strzepek et al. 2010.

Droughts are projected to be more frequent and severe in most of the continental United States by 2050 as a result of climate change. The Southwest and the Rocky Mountain states are projected to see the largest increases in drought frequency.

Note: The map shows projections of the mean changes in the extreme Palmer Drought Severity Index (PDSI) for the 30-year period centered on 2050. The results—from the average of 22 general circulation models—are based on the A1B emissions scenario from the Intergovernmental Panel on Climate Change. See Strzepek et al. 2010 for more information.

With rapid, human-induced global warming under way, scientists project changes in many regions to the weather we take for granted, adding climate change to climate variability.

and elevated temperature, which speeds evaporation—are expected to be substantially longer than those in the twentieth century (Figure 12). Weather patterns may also continue to change, shifting the locations where rain and snow fall. Higher temperatures—specifically warmer winters, which yield reduced snowpack—are already compounding the effects of changing precipitation levels in parts of the United States. One expected net result is a reduction in water runoff across most of the western half of the nation, where surface water is already scarce.

How Power Plant Water Use Might Change

Just as the water supply will change over time, so too will water demand, including from power plants. For plant operators, their neighbors, and their customers, the magnitude of water stress in each basin and region will depend on factors affecting supply and demand, including decisions about how we produce and use energy. The power sector is continually changing as new plants are built, older ones are retired, new technologies come to market, and new policies drive decision making.

The EIA projects a 25 percent increase in electricity demand over the next quarter-century (EIA 2011c). The "base case" from our forthcoming companion report on the water implications of future energy scenarios offers insights into one possible path for the electricity sector. Under this case, which assumes no new electricity-related policies, traditional water-using plants—chiefly natural gas combined-cycle and more-water-efficient coal plants—would meet 60 percent of the projected increase in demand. Low-water renewable technologies would provide most of the rest of the added generation.

Retiring numerous old coal plants could drop water withdrawals in the electricity sector by 25 percent, and water consumption by 5 percent, if plants use the median amounts of water suggested by NREL. At the regional level, our analysis shows that those changes could reduce power plant water withdrawals in the Southeast by 25 percent, as once-through plants are replaced. However, such changes would not reduce water consumption in that region. And water withdrawals and consumption in the Southwest would remain virtually unchanged.

With potential increases in water demand from a growing population, and changes in water supply owing to climate variability or climate change, the water needs of power plants could continue to worsen water stress in particular areas even if the electricity sector makes minor cuts in water use. Expanding the electricity sector to meet rising demand for power as outlined above could also lead to a 6 percent increase in carbon emissions from power plants, contributing to climate change (Box 5, p. 34).

The Texas Case: Are We Prepared for the Future?

The Texas experience in the summer of 2011 showed how heat and drought can quickly expose the energy sector's dependence on potentially scarce water resources. But what may be most worrisome about the Texas case is that the state is actually better prepared to cope with an energy-water collision than many other states.

The Texas power plant fleet is not among the nation's heaviest water users, as measured by either withdrawal or consumption intensity, owing partly to the state's large natural gas and wind portfolios. Texas is also relatively accustomed to coping with drought. In regions where extremely dry weather is rare and the power sector is thirstier, the consequences of a similar drought could be much worse.

What could Texas and other states do to prepare for future droughts and heat waves? A recent analysis from the University of Texas–Austin showed that changing power plant cooling systems from once-through to recirculating could increase the availability of water resources during drought. Such a shift would reduce water diversions in the state by 30 billion to 100 billion gallons (90,000 to 300,000 acre-feet) or more per year (Stillwell, Clayton, and Webber 2011).

The state's power sector could also continue to shift away from water dependence. Texas leads the nation in installed wind power capacity, but it could do more with low- or no-water renewables, including wind

The Texas experience in the summer of 2011 showed how heat and drought can quickly expose the energy sector's dependence on potentially scarce water resources.

and solar photovoltaics. Texas also has much room to improve energy efficiency. While the state was the first (beginning in 1999) to require utilities to meet energy efficiency goals, it ranks in the bottom half of states in overall energy efficiency policies (ACEEE 2011).

Decisions in these arenas, made today, may help minimize future problems. However, as this report shows and the forthcoming EW3 report will emphasize, the links among water, energy, and climate mean that we must remain vigilant about planning with both water and power in mind.

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A river runs dry: **During the Texas drought of 2011, some rivers, such as the Brazos (shown here), ran dry. Among its many effects, this drought exposed the energy sector's dependence on potentially scarce water resources.**

BOX 5. *Climate Change: Challenging the Carbon-Water Balancing Act*

Today's carbon emissions affect tomorrow's water availability. Heat-trapping emissions from human activity are driving up global average temperatures. As the atmosphere warms, it can hold more water, altering the hydrologic cycle (Held and Soden 2006). This has led to an observed shift in precipitation patterns that affects water resources in parts of the United States (USGCRP 2009).

Moreover, as air temperatures rise, so does the temperature of many streams, lakes, and rivers (National Research Council 2010; USGCRP 2009). The combination of warmer air and warmer cooling water makes power plants run less efficiently, increasing the cost of electricity and the amount of water required to produce a unit of power (NETL 2002).

The climate-water connection affects the power sector, but that sector is also a major source of heat-trapping emissions. U.S. electric utilities accounted for one-third of the country's total in 2009 (EPA 2011c).

The mix of fuel types and cooling technologies in a utility's power plant portfolio determines both its water requirements and its carbon emissions. For example, a utility with a large proportion of nuclear plants with once-through cooling has high water withdrawal intensity but low carbon intensity. A utility with a large proportion of wind or photovoltaic plants in its fleet would have both low water intensity and low carbon intensity (Figure 13).

The research and development community is actively engaged in reducing energy-related carbon emissions by improving fuel efficiency. National investments are also under way in carbon capture and storage (CCS), which involves capturing carbon produced in fossil-fueled plants and injecting it underground, so that it does not contribute to global warming. This technology is a potential option for curbing heat-trapping emissions. However, adding CCS to a new or existing coal plant could increase water consumption 35 to 95 percent or more (Woods et al. 2007). CCS may not be an optimal choice for water-stressed areas.

As technologies and policies that affect utilities' power plant portfolios continue to emerge, the carbon-water balancing act will continue.

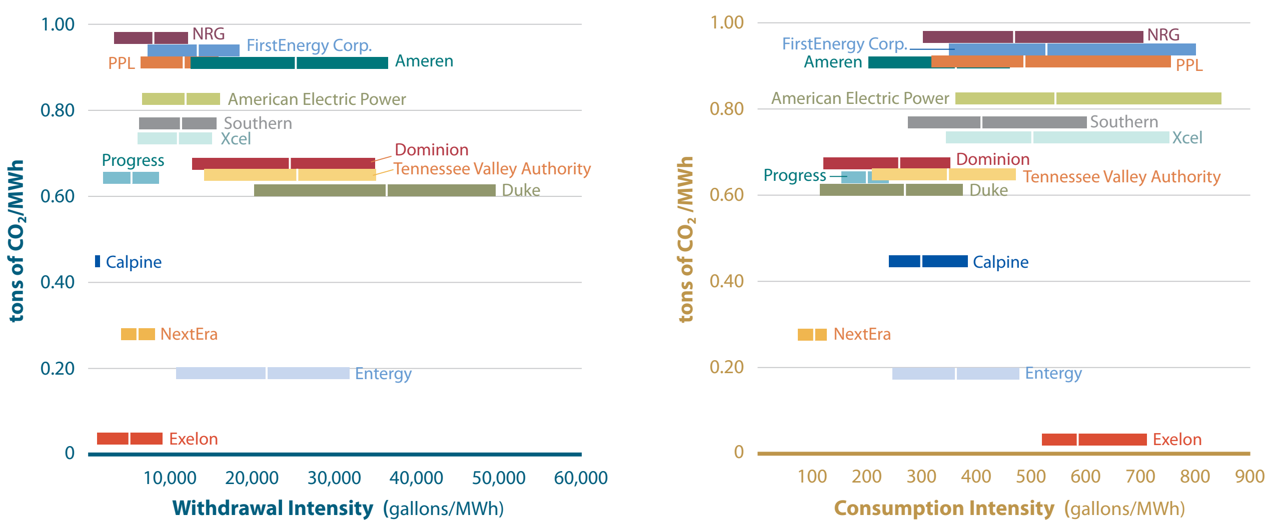

FIGURE 13. Power Companies, Freshwater, and Carbon

The nation's 15 largest electricity producers—which accounted for 50 percent of all U.S. power generated in 2008—varied widely in their water use and carbon emissions. Producers with a large proportion of nuclear plants that used freshwater for once-through cooling had high freshwater withdrawal intensities but low carbon intensities. Producers using seawater to cool nuclear facilities had low freshwater and carbon intensities. Producers with a large proportion of wind or solar photovoltaic plants had low water and carbon intensities.

Note: Based on minimum and maximum water-use values from NREL. Excludes electricity produced by the U.S. government.

CHAPTER 5

Toward a Water-Smart Energy Future

Electricity's thirst for water, along with pressure from growing populations, is putting freshwater resources and the reliability of our energy supply in jeopardy. From Arizona to Alabama, from North Carolina to New York, the use of water to cool many of today's power plants is contributing to the stress we are placing on water resources.

Pressure on both the energy and water sectors stands to rise as populations continue to grow. The effects of climate change—including regional fluctuations in freshwater supplies, higher water temperatures, and more frequent and intense droughts—have the potential to compound these demands (USGCRP 2009). These effects mean that the choices we make today regarding our power plants—their fuel sources, cooling technologies, and carbon emissions—will affect our water resources through mid-century and beyond.

Some principles and steps to consider to help ensure a sustainable energy and water future:

Good information on the links between energy and water matters. The first step in making informed decisions about power and water is to ensure that decision makers in the public and private sectors have accurate, timely, and readily available information on water supply and demand. The National Research Council has outlined the need for better-quality information to improve the management of water resources (National Research Council 2002). The U.S. Government Accountability Office has pointed specifically to the importance of good information on water use by power plants (GAO 2009). And documenting water use by power plants is one critical piece of the energy-water nexus that is among the easiest to remedy, as the EIA already collects this information.

The analysis summarized here suggests both problems and opportunities. The EW3 approach to calculating water use by power plants offers important insights, but is a major undertaking with inherent uncertainties. Far more efficient would be for key agencies to ensure that power plant operators report their water use accurately and consistently, and make the compiled information broadly accessible.

From Arizona to Alabama, from North Carolina to New York, the use of water to cool many of today's power plants is contributing to the stress we are placing on water resources.

The EIA is well positioned to be the authoritative source of information on power plant water use for federal, state, and local planners. Although our analysis highlights the need to strengthen the agency's efforts, the EIA has already made critical improvements since 2008, such as requiring operators of nuclear power plants to report their water use, and applying more oversight to reported information.

However, to sustain these changes and establish and maintain a system for making information on power

Fernando Arce-Larreta

Low-water conventional power: **Efficient natural gas facilities that use dry cooling, such as the Front Range power plant in Colorado Springs, CO, require essentially no water.**

BrightSource Energy

Flickr/Pixor

Water-smart renewables: **Some developers and utilities are reducing risk by choosing technologies that use essentially no water, such as wind and solar photovoltaics (right), and by investing in energy efficiency. Other developers are choosing low-water approaches for plants that need cooling. For example, the 370-megawatt Ivanpah concentrating solar power (CSP) project under construction in California's Mojave Desert (left) will rely on dry cooling—and consume 90 percent less water per unit of electricity than typical wet-cooled CSP plants (BLM 2010).**

plant water use readily available, the agency will require sufficient and consistent support for both its budget and its authority from Congress and the White House. Independent verification of EIA data, as this report provides, will also be a valuable tool for quality assurance.

Indicators of water stress show where we need to look deeper. Applying information on power plant water use to analyze water stress is another area deserving robust attention. Improvements in data quality will allow for more accurate assessment of water stress. That assessment can allow national, regional, state, and local officials to plan for sustainable water demand.

We can avert energy-water collisions, but doing so will require a balancing act. Averting such collisions requires sustained reporting of accurate information on power plant water use to the EIA and state agencies. Avoiding such collisions also requires putting sound information on water stress to work to reduce electricity's thirst—especially in water-stressed regions.

The information in this report provides a strong initial basis for making water-smart energy choices. Here are some ways to do so:

- **Get it right the first time.** Developing new resources for meeting electricity demand provides a critical opportunity for reducing water risks for both power plant operators and other users. Utilities and other power plant developers would be well advised to prioritize low-water or no-water cooling options, particularly in regions of current and projected high water stress.

  Some developers are already making such choices. For example, the project developer's choice of dry cooling for the 370-megawatt Ivanpah concentrating solar power (CSP) project under construction in California's Mojave Desert means that the facility will consume 90 percent less water per unit of electricity than typical wet-cooled CSP plants (BLM 2010). Other developers and utilities are reducing the risk of energy-water collisions by choosing technologies that use essentially no water, such as wind and solar photovoltaics, and by investing in energy efficiency.

- **Retool existing plants.** Owners and operators of existing power plants with substantial effects on the supply or quality of water in water-stressed regions could consider retrofitting to low-water cooling. When the 1,250-megawatt Plant Yates near Newnan, GA, added cooling towers in 2007, it cut water withdrawals by 93 percent (Foskett, Newkirk, and Shelton 2007).

Water-smart energy choices should include investing in resources that are also low-carbon.

Even greater reductions in freshwater use are sometimes essential. In much of the Southwest, even low water withdrawals can spell trouble, particularly when they come from diminishing aquifers. Water consumption, too, can pose problems. Power producers in highly water-constrained settings can make water-smart choices—as Xcel Energy, which operates the 1,080-megawatt Harrington Station in Amarillo, TX, did in 2006, when it switched to treated wastewater to meet the plant's cooling needs (Xcel Energy 2011; McBride 2006).

- **Set strong guidelines for power plant water use.** Public officials can draw on good information on electricity's thirst to help owners of existing and proposed power plants avert energy-water collisions. Public utility commissions, which oversee the plans of utilities and specific plant proposals, can encourage or require investments that curb adverse effects on water supply or quality, particularly in areas of current or projected water stress.

  Legislators also have a stake in averting energy-water collisions. The Colorado legislature's 2010 decision to retire more than 900 megawatts of coal plants in favor of natural gas, energy efficiency, and renewable energy will reduce water consumption by a volume roughly equivalent to that used by 50,000 people (Tellinghuisen 2010; State of Colorado 2010).

- **Engage diverse stakeholders.** Mayors securing water supplies for their cities, anglers concerned with sport and commercial fishing, water resource managers at all levels, and others all have a stake in averting energy-water collisions. Full public access to information on water use by existing and proposed power plants will enable these and other local stakeholders to become informed about the benefits of water-smart energy choices.

- **Reduce power plant carbon emissions.** Because human-caused climate change is worsening water stress across much of the United States, water-smart energy choices should include investing in resources that are also low-carbon. The new cooling towers for the coal-burning Plant Yates reduce its impact on water stress but not its carbon emissions. The coal-burning generators at Harrington Station in Amarillo, although relying on treated wastewater, still emit prodigious quantities of carbon.

  Of course, not all low-carbon options are water-smart. Some, such as wind power and energy efficiency, are inherently low-water. Others, such as the proposed carbon capture and storage for coal plants, are not, and could worsen energy-water collisions if used in regions with water stress.

Averting energy-water collisions means taking a long view. Power plants are designed to last for decades, and much of our existing infrastructure will continue operating for years. Our nation's precious freshwater resources will face ever more stress from growing

Texas Parks and Wildlife

Everyone is an energy-water stakeholder: **Local officials, water resource managers, recreation and conservation groups, and others all have a stake in averting energy-water collisions. Full public access to information on water use by existing and proposed power plants will enable stakeholders to become informed about the benefits of water-smart energy choices.**

Averting energy-water collisions means taking a long view.

populations, a changing climate, and other trends over the next several decades. The typically high cost of retrofitting power plants means that decisions on the water impact of today's plants should consider the risks they pose to freshwater resources and energy reliability throughout their expected lifetime.

The next report from the Energy and Water in a Warming World initiative will take up this challenge by exploring how energy choices affect the resilience of our energy sector in the face of periodic drought and changes in water availability. Zooming in on key regions of the country will yield a more robust understanding of how the energy technologies we choose to power tomorrow's world would affect water resources.

Decisions made today about which power plants to build, which to retire, and which energy or cooling technologies to deploy and develop matter greatly. Understanding how these choices affect water use and water stress will help ensure that the dependence of power plants on water does not compromise that resource, the plants themselves, or the energy we rely on them to provide.

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Water-smart energy choices can ensure reliable electricity while protecting our freshwater resources.

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Appendices

For more information, see the following appendices at *www.ucsusa.org/electricity-water-use:*

GLOSSARY

APPENDIX A: Detailed Methodology

APPENDIX B: Graphical Appendix

Energy and Water in a Warming World Baseline Team

EW3 Baseline Assessment Team

KRISTEN AVERYT is deputy director of the Western Water Assessment at the University of Colorado–Boulder, a program sponsored by the National Oceanic and Atmospheric Administration (NOAA) designed to connect climate science with decision making across the western United States. Before joining the University of Colorado in 2008, Dr. Averyt was a staff scientist for the Nobel Prize–winning Intergovernmental Panel on Climate Change. In 2005 she was a NOAA congressional fellow, where she worked as a legislative aid in the U.S. Senate. Dr. Averyt trained as a geochemist specializing in paleoclimatology, and received her Ph.D. from Stanford University. Her current research includes investigations of the intersection of energy, water, and climate in the West, and evaluations of strategies for adapting to climate change.

JEREMY FISHER is a scientist with Synapse Energy Economics, an energy consulting firm. He brings a background in global ecosystem modeling and climate impact science to energy system planning and analysis. Before joining Synapse, he researched feedback cycles between the climate and carbon exchange in ecosystems, including determining the footprint of Hurricane Katrina. At Synapse, Dr. Fisher has pursued applied research on policy decisions regarding electrical generation and source emissions, and the social and environmental implications of current and future power sources. Dr. Fisher holds a B.S. in geology and a B.A. in geography from the University of Maryland, and an M.S. and Ph.D. in geological sciences from Brown University.

ANNETTE HUBER-LEE is a research assistant professor and lecturer in the Department of Civil and Environmental Engineering at Tufts University. Dr. Huber-Lee has more than 20 years of experience in international and domestic planning and management of environmental and water resources. She focuses on integrating economic, engineering, and ecological approaches to solve environmental and social problems in a comprehensive and sustainable manner, as well as on developing innovative approaches to environmental policy and natural resource conflict management. Dr. Huber-Lee holds a B.S. in agricultural engineering from Cornell University, an M.S. in civil engineering from the Massachusetts Institute of Technology, and a Ph.D. in engineering sciences from Harvard University.

AURANA LEWIS is a master's candidate in environmental management at Duke University's Nicholas School of the Environment, graduating in 2012. Her focus is on water quality and quantity management, with an emphasis on water needs for energy production. For her master's thesis, she is looking at reuse and recycling of water produced from hydraulic fracturing. Before attending Duke, Ms. Lewis worked for Brooks Rand Labs, LLC, in Seattle, WA, as a mercury chemist and trace metals analyst. She has also worked in the geobiology and astrobiology lab at the Massachusetts Institute of Technology, and lived in Japan under the Japan Exchange and Teaching Program. Ms. Lewis holds a B.A. from Wesleyan University, and a certificate in environmental law and policy from the University of Washington–Seattle.

JORDAN MACKNICK is an energy and environmental analyst at the Strategic Energy Analysis Center at the National Renewable Energy Laboratory. He focuses on analyzing the environmental effects of energy technologies and future energy scenarios. Much of his work centers on the energy-water nexus, analyzing the effects on water of the energy industry, and the energy implications of the water industry. He holds a B.A. in mathematics and environmental studies from Hamline University, and an M.S. in environmental science from Yale University School of Forestry and Environmental Studies.

NADIA MADDEN is the energy-water project associate at the Union of Concerned Scientists. Before joining UCS, Nadia worked in business development for algae biofuels technologies at GreenFuel Technologies, as a project manager building clean water systems for rural communities at WaterHealth International in Sri Lanka and India, and as a field assistant mapping aquatic biodiversity for the Massachusetts Division of Fisheries and Wildlife. She is a cofounder and board member of WatSan Action, a nonprofit dedicated to providing access to safe water and a healthy environment in Jakarta's most underserved communities, and chairs the Conservation Commission in Groton, MA. Ms. Madden holds a B.S. in ocean and atmospheric physics from MIT, as well as a master's degree in water resources from the University of New Hampshire, and a master's in energy and resources from the University of California–Berkeley.

JOHN ROGERS, a senior analyst in the Climate and Energy Program at the Union of Concerned Scientists, co-manages the Energy and Water in a Warming World initiative. Mr. Rogers formerly managed the organization's Northeast Clean Energy Project, working to implement a range of clean energy and climate policies. He serves on the board of directors of the U.S. Offshore Wind Collaborative and of Renewable Energy New England, and on the advisory boards of nonprofit organizations promoting U.S. renewable energy and global energy access. Mr. Rogers joined UCS in 2006 after working for 15 years on private and public clean energy initiatives, including as a cofounder of Soluz, Inc., a leading developer of clean energy solutions for rural markets, and as a Peace Corps volunteer in Honduras. He earned an A.B. at Princeton University and a master's degree in mechanical engineering at the University of Michigan.

STACY TELLINGHUISEN is a senior energy and water policy analyst for Western Resource Advocates (WRA), a nonprofit dedicated to protecting the West's water, land, and air. Stacy works on both sides of the energy-water nexus, researching the effects of energy development on water resources, and of new and existing water supplies on energy resources. She has published numerous reports and testified before utilities and the Colorado Public Utilities Commission on water savings from clean energy choices. Before joining WRA, Stacy worked on water issues for the California Sustainability Alliance and the city of Moab, UT, and taught natural history to school groups in parks throughout California and Utah. She received a bachelor's degree from Carleton College, and a master's in environmental science and management from the University of California–Santa Barbara.

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PETER C. FRUMHOFF is the director of science and policy at the Union of Concerned Scientists, and chief scientist of the UCS Climate Campaign. A global change ecologist, he has published and lectured widely on the effects of climate change, climate science and policy, tropical forest conservation and management, and biodiversity. He was a lead author of the 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change, and the 2000 IPCC *Special Report on Land Use, Land-Use Change and Forestry*. He serves on the board of the American Wind Wildlife Institute and is a member of Harvard University's Center for the Environment. Dr. Frumhoff has taught at the Fletcher School of Law and Diplomacy at Tufts University, Harvard University, and the University of Maryland. He also served as an AAAS science and diplomacy fellow at the U.S. Agency for International Development, where he designed and led conservation and rural development programs in Latin America and East Africa. He holds a B.A. in psychology from the University of California–San Diego, and an M.A. in zoology and a Ph.D. in ecology from the University of California–Davis.

GEORGE M. HORNBERGER is distinguished university professor at Vanderbilt University, where he is the Craig E. Philip professor of engineering and professor of earth & environmental sciences. He directs Vanderbilt's Institute for Energy and Environment. Dr. Hornberger is a member of the U.S. National Academy of Engineering and a fellow of the American Geophysical Union (AGU), the

Association for Women in Science, and the Geological Society of America. He received the Robert E. Horton Award (Hydrology Section, AGU), the Biennial Medal for Natural Systems (Modelling and Simulation Society of Australia), the John Wesley Powell Award for Citizen's Achievement (U.S. Geological Survey), the Excellence in Geophysical Education Award (AGU), the William Kauala Award (AGU), and the 2007 Outstanding Scientist in Virginia Award. He has a Ph.D. in hydrology from Stanford University.

ROBERT B. JACKSON holds the Nicholas chair in global environmental change at Duke University, where he is a professor in the biology department. His research examines how people affect the earth, including the global carbon and water cycles, land and energy use, and global change. After receiving a B.S. in chemical engineering from Rice University, he worked for Dow Chemical Co. for four years before obtaining M.S. degrees in ecology and statistics and a Ph.D. in ecology from Utah State University. He directs Duke's Center on Global Change, its Stable Isotope Mass Spectrometry Laboratory, and the National Institute for Climate Change Research for the southeastern United States, funded by the U.S. Department of Energy. Dr. Jackson has received numerous awards, including the Murray F. Buell Award from the Ecological Society of America, and a 1999 Presidential Early Career Award in Science and Engineering from the National Science Foundation. He is also a fellow of the American Geophysical Union, and among the top 0.5 percent most-cited scientific researchers, according to the Institute for Scientific Information.

ROBIN L. NEWMARK directs the Strategic Energy Analysis Center at the National Renewable Energy Laboratory. Before joining NREL, Dr. Newmark was at Lawrence Livermore National Laboratory, where she focused on energy, environment, and national security. She has led or contributed to research on the interdependence of energy, climate, and water, including the effects of climate change on water resources, the denitrification of agricultural regions, and the development of energy-efficient water treatment technologies. Dr. Newmark is a member of the multinational Energy-Water Nexus working group, the World Resources Institute's Carbon Capture and Sequestration (CCS) Stakeholder Group, and the U.S.-China Expert CCS Steering Committee. She is an author of more than 50 papers, reports, and patents, and a fellow of the Renewable and Sustainable Energy Institute at the University of Colorado–Boulder and the Center for Integrated Water Research at the University of California–Santa Cruz. Dr. Newmark holds a B.S. from MIT, where she was selected Phi Beta Kappa, an M.S. from the University of California–Santa Cruz, and an M.Phil. and a Ph.D. from Columbia University.

JONATHAN OVERPECK is professor of geosciences and atmospheric sciences at the University of Arizona, where he is a founding co-director of the Institute of the Environment. He is principal investigator for the Climate Assessment for the Southwest Project and the Southwest Climate Science Center. He has active research programs in North America, South America, Africa, and monsoon Asia, most focused on providing insights from Earth's deep past into how the climate system may change in the future. Dr. Overpeck has written more than 150 papers on climate and the environmental sciences, and recently served as a coordinating lead author for the 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change. He was honored with the American Meteorological Society's Walter Orr Roberts Award for his interdisciplinary research, and won bronze and gold medals from the Department of Commerce for his climate research. He has served as a Guggenheim fellow, and is a fellow of the American Association for the Advancement of Science. Dr. Overpeck holds an A.B. in geology from Hamilton College, and a master's and Ph.D. in geological sciences from Brown University.

BRAD UDALL is on the research faculty at the University of Colorado, where he serves as director and principal investigator of the Western Water Assessment, one of 11 Regional Integrated Sciences and Assessments of the National Oceanic and Atmospheric Administration. Mr. Udall is also a co-principal investigator of the

Southwest and the North Central Climate Science Centers, funded by the U.S. Department of the Interior. Mr. Udall's expertise includes hydrology and related policy issues of the American West, and he has written extensively on the effects of climate change on water resources. Mr. Udall was lead author of the water sector chapter of the 2009 *Global Climate Change Impacts in the United States* from the United States Global Change Research Program, and an author of climate change reports in 2008 and 2011 for the state of Colorado. He has provided testimony to Congress and input to several National Academy of Science panels, and given hundreds of talks on the connection between climate change and the water cycle.

MICHAEL WEBBER is associate director of the Center for International Energy and Environmental Policy, co-director of the Clean Energy Incubator at the Austin Technology Incubator, and assistant professor of mechanical engineering at the University of Texas–Austin, where he trains a new generation of energy leaders through research and education at the intersection of engineering, policy, and commercialization. He has authored more than 150 scientific articles, columns, books, and book chapters, including *Changing the Way America Thinks about Energy* (2009). Dr. Webber is on the board of advisors of *Scientific American*, holds four patents, and is an originator of the Pecan Street Project, a $30 million public-private partnership for smart grid innovation and deployment. Before joining the University of Texas, Dr. Webber studied energy, innovation, manufacturing, and national security at RAND Corp. He was also a senior scientist at Pranalytica, where he invented sensors for homeland security, industrial analysis, and environmental monitoring. Dr. Webber holds a B.A. in liberal arts and a B.S. in aerospace engineering from the University of Texas, and an M.S. and a Ph.D. in mechanical engineering from Stanford University, where he was a National Science Foundation fellow from 1995 to 1998.

About UCS

The Union of Concerned Scientists is a nonprofit partnership of scientists and citizens combining rigorous scientific analysis, innovative policy development, and effective citizen advocacy to achieve practical environmental solutions. Established in 1969, UCS seeks to ensure that all people have clean air, energy, and transportation, as well as food that is produced in a safe and sustainable manner. We strive for a future that is free from the threats of global warming and nuclear war, and a planet that supports a rich diversity of life. Sound science guides our efforts to secure changes in government policy, corporate practices, and consumer choices that will protect and improve the health of our environment globally, nationally, and in communities throughout the United States. In short, UCS seeks a great change in humanity's stewardship of the earth.

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Freshwater Use by U.S. Power Plants

ELECTRICITY'S THIRST FOR A PRECIOUS RESOURCE

Every day, water-cooled power plants in the United States withdraw 60 billion to 170 billion gallons (180,000 to 530,000 acre-feet) of freshwater from rivers, lakes, streams, and aquifers, and consume 2.8 billion to 5.9 billion gallons (8,600 to 18,100 acre-feet) of that water. Understanding where such volumes come from—and how that use conflicts with both the amount of water available and demand from other users—is essential for water users, water resource managers, and planners at the energy-water nexus. Yet even basic information about power plant water use across the country has been difficult to obtain.

In this report, the first on power plant water use and related water stress from the Energy and Water in a Warming World initiative, the authors present the first systematic assessment of both power plants' effects on water resources across the United States and the quality of information available to help public- and private-sector decision makers make water-smart energy choices.

Flickr/Williams_Jt

Decisions made today about which power plants to build, which to retire, and which energy and cooling technologies to deploy and develop matter greatly. Understanding how these choices affect water use and water stress will help ensure that the electricity sector's current dependence on freshwater resources does not compromise those resources, the plants themselves, or the energy we rely on them to provide.

For more information on freshwater use by U.S. power plants visit *www.ucsusa.org/electricity-water-use.*

Energy and Water in a Warming World (EW3) is a collaborative effort between the Union of Concerned Scientists and a team of independent experts to build and synthesize policy-relevant research on the water demands of energy production in the context of climate variability and change. The initiative includes core research collaborations intended to raise the national profile of the water demands of energy, along with policy-relevant energy development scenarios and regional perspectives. The material presented in this report is based on the research of the EW3 Baseline Assessment Team. The work discussed here will also be presented in more technical detail in forthcoming scientific papers and a Web-accessible database. For supporting materials (including glossary, methodology appendix, and graphical appendix) go to *www.ucsusa.org/electricity-water-use.*

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