

Power and Water at Risk



Photos (top to bottom): Flickr/David Joyce; Chance Kafka; Raquel Baranow; BrightSource; Texas Parks and Wildlife; J. Wes Bobbit

A CROSS THE UNITED STATES, our demand for electricity is colliding with our need for healthy and abundant freshwater. Our electricity system's dependence on water runs deep: water's role in hydropower, and the risks to hydroelectric generation when water is unavailable, are clear, but large steam-generating power plants (particularly the fossil-fuel- and nuclear-powered plants that produce the lion's share of our

COOLING POWER PLANTS requires the single largest share of U.S. freshwater withdrawals: 41 percent.² This water dependence threatens both the availability and the quality of our water resources. Power plant water withdrawals and related water consumption^{3,4} can have significant impacts on local water availability for other users and for aquatic ecosystems.* Withdrawals can also harm wildlife such as fish, turtles, and other aquatic species that are sucked into or trapped by intake mechanisms. As for water quality, coal and nuclear plants discharge water in the summer at an average temperature 17°F warmer than when it entered the plant.⁵ This warmer water can harm wildlife, as can chemicals such as chlorine, bromine, and biocides that may be introduced into the water during plant operations.⁶

The water use habits of power plants pose risks, not only to the water sources and to other users, but also to the power plants themselves. When adequate cooling water is not available to fossil fuel, nuclear, and other steam-generating plants due, for example, to prolonged drought or high water temperatures caused by a heat wave, the plants have to cut back power production or even shut down. Hydropower facilities face the same fate when water levels drop too low for power production. Even when power plants get the water they need in times of water stress or scarcity, their continued operation may come at a cost to others who rely on the same water.

The potential for this kind of collision between water users will grow wherever the demand for both energy and water

electricity)¹ also rely—often very heavily—on water for cooling purposes.

Water resources, however, are under increasing pressure and, in some instances, have been unable to meet power plant cooling needs. As our demand for electricity continues to rise, the water dependence of many power plants puts the electricity sector, water resources, and other water users at growing risk.

increases—and will be exacerbated in some regions by global warming. This is no futuristic scenario—these risks exist across the country, collisions are happening now, and the impacts are being felt by the power sector, its customers, and other water users.

When adequate cooling water is not available, plants have to cut back or even shut down.

The Threat in Your Backyard

On the following pages we describe characteristic ways in which energy-water collisions occur in each region of the country. We also highlight power companies and energy developers making choices that reduce water dependencies—and thus, water-related risks and impacts. By embracing lower-water technologies such as air cooling for power plants, or no-water options such as wind farms and energy efficiency,⁷ these companies are reducing their water-related impacts while avoiding or minimizing the risk of costly water-related power disruptions.

The U.S. electric sector's heavy water dependence represents an opportunity. Smarter energy decisions can greatly reduce the pressure that our demand for electricity places on increasingly stressed water resources, and help us improve the resilience of our electricity infrastructure.

* For an explanation of power plant water use, see the fully referenced version at www.ucsusa.org/energy-water.

Water Dependencies: Risk Taking, Impacts, and Risk Reduction across Regions



NORTHWEST

Risky business. The Northwest relies on hydropower for over 60 percent of its electricity generation.⁸ While hydropower is renewable, it depends on abundant flows in dammed rivers. Trends suggest that seasonal runoff patterns are shifting earlier and becoming more erratic: high spring flows are coming earlier in many rivers, while periods of low summer flow are starting earlier and lasting longer.⁹ By mid-century, global warming is expected to worsen periods of low streamflow by reducing snowpack and runoff.^{10,11} This could spell trouble for many large hydropower facilities,¹² users of that electricity, and coldwater fish and other species that depend on seasonal flows for survival.¹³



GREAT PLAINS

A matter of time. The high-stakes competition for access to groundwater among power plants and other Great Plains water users is intensifying even as the resource is being depleted. Today's groundwater use—17 billion gallons pumped each day from the High Plains Aquifer¹⁶—is unsustainable: the aquifer is being depleted at a rate that will take centuries to reverse.¹⁷ As cities grow and temperatures rise (between 1° and 6°F by mid-century¹⁸), demand for both water and energy in the region may increase.



SOUTHWEST

Little to go around. In the country's most arid region, water supplies are stretched thin to meet competing, and often increasing, demands from power plants, cities, farmers, and ecosystems. The region is also home to significant hydropower facilities, whose output is greatly affected by the height of the reservoirs from which they draw water (see p. 5).

Unruly rivers defy management.

Low snowpack in the Columbia and Snake River Basins in the winter of 2009–2010 is followed by unusually heavy rains in spring. As a result, the timing of peak streamflow is well out of line with projections, straining hydropower generation, power price setting, and fisheries management.¹⁴

Lake Mead water drops, power follows.

Lower water levels in Lake Mead caused by declining input from the Colorado River reduce Hoover Dam's 2010 output to 80 percent of full production.^{27,28}

Solar goes dry.

In 2010, BrightSource Energy chooses dry cooling for its 370 MW Ivanpah concentrating solar power (CSP) plant in California's Mohave Desert. While desert development requires avoidance or careful mitigation of all ecosystem impacts, Ivanpah will consume 90 percent less water per unit of electricity than typical wet-cooled CSP facilities.²⁹

Mohave plant goes dark.

In December 2005, Southern California Edison shuts its 1,580 MW Mohave coal plant in Laughlin, NV, due to lawsuits and disputes over its aquifer use and pollution.^{30,31,32,33}

Colorado says no to coal.

In 2010, Colorado's Clean Air-Clean Jobs Act mandates the retirement of more than 900 MW of coal plants (such as Denver's Cherokee plant), converting them to natural gas, or meeting demand with energy efficiency or renewable energy. The Governor's Energy Office touts the potential water benefits—an annual water savings roughly equivalent to the volume used by 50,000 people.³⁴



Wind sweeps the Northwest.

With over 4,000 MW of wind farms between them, Washington State and Oregon have the fifth- and sixth-highest levels of wind power capacity in the United States.¹⁵ Wind farms use no water in generating electricity.

An Iowa harvest without water.

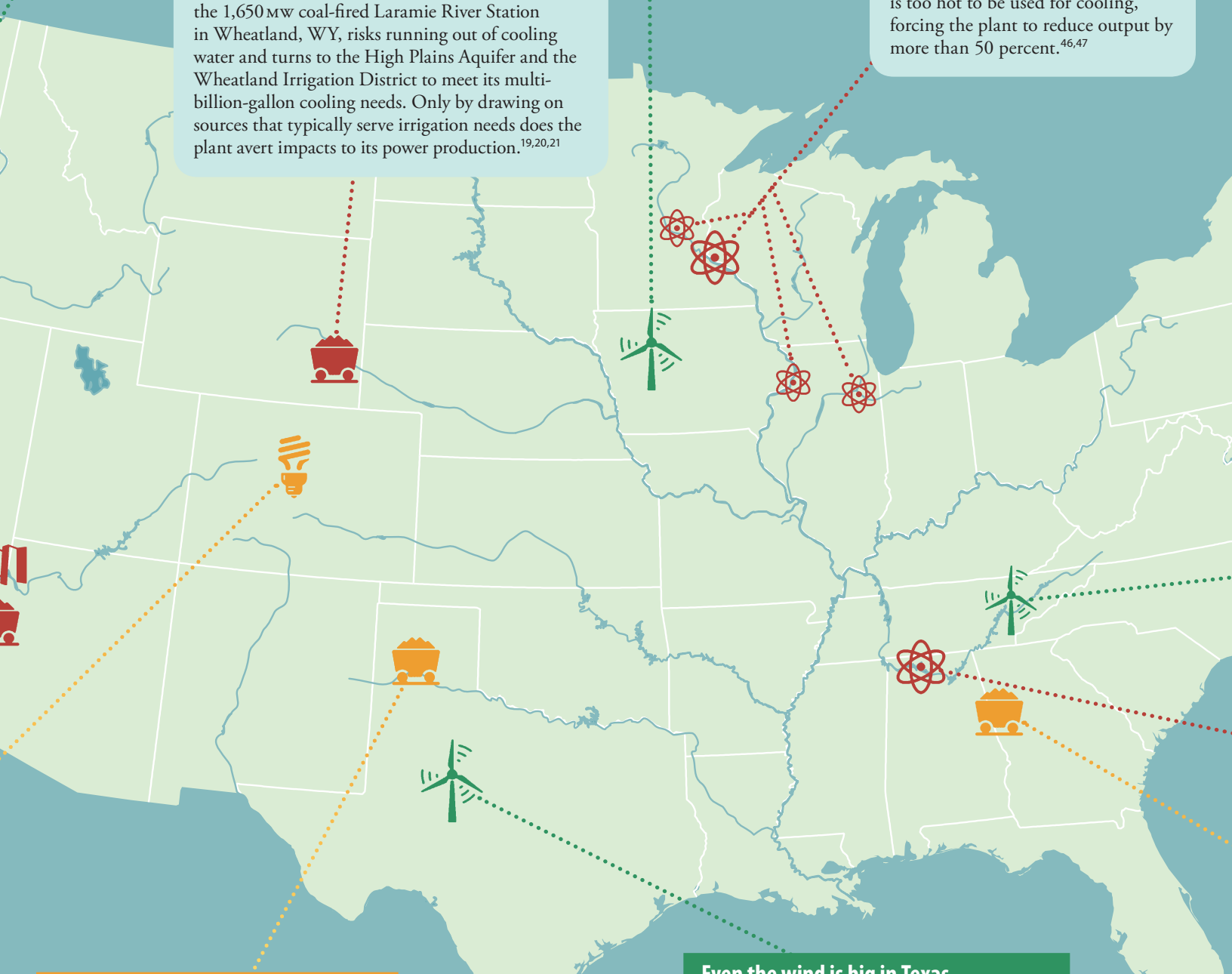
With almost 3,700 MW of wind power capacity in 2010, Iowa ranks second only to Texas.⁴⁵

Too hot for nuclear power.

During a 2006 heat wave, while electricity demand breaks records across the nation, high water temperatures force four nuclear plants in the Midwest to reduce their output when it is needed most. At the two-unit Prairie Island, MN, nuclear plant, for example, Mississippi River water is too hot to be used for cooling, forcing the plant to reduce output by more than 50 percent.^{46,47}

Thirsty plant taps crop water.

During an extended drought in 2007 and 2008, the 1,650 MW coal-fired Laramie River Station in Wheatland, WY, risks running out of cooling water and turns to the High Plains Aquifer and the Wheatland Irrigation District to meet its multi-billion-gallon cooling needs. Only by drawing on sources that typically serve irrigation needs does the plant avert impacts to its power production.^{19,20,21}



Waste not, want not.

In 2006, Harrington Station, a 1,080 MW coal plant, turns to treated wastewater from Amarillo, TX, to meet its cooling needs, saving valuable freshwater.^{22,23,24}

Even the wind is big in Texas.

The largest U.S. wind facility, the 780 MW Roscoe Wind Farm in Roscoe, TX, goes on-line in 2009.²⁵ By 2010 the state has more than 10,000 MW of installed wind capacity, much of it in arid central Texas.²⁶

Water woes beleaguer troubled plant.

As of 2011, Entergy Corporation continues to struggle to win a 20-year license extension for its Vermont Yankee nuclear plant in Vernon, VT, as water-related demands for its closure grow.³⁷ Collapsed cooling towers, radioactive water leaks, and discharge of heated water with an expired permit put its continued operation in jeopardy.^{38,39,40}

Boston takes the heat.

The Kendall Station natural gas plant in Cambridge, MA, which formerly dumped 70 million gallons of heated water into the Charles River every day, agrees in 2011 to sell its excess heat to the city of Boston instead, cutting its hot water discharge by 95 percent, creating a new source of income, and providing heat to Boston buildings without additional combustion.⁴¹

Power company gets proactive.

In 1998, American National Power voluntarily installs a dry-cooling system on its new natural-gas-fired Lake Road plant in Dayville, CT, cutting projected water consumption by 70 percent.⁴²

Oyster Creek opts for shutdown.

Exelon Corporation, the owner of the 619 MW Oyster Creek nuclear power plant in Lacey, NJ, announces in 2010 that it will shut down the plant rather than build cooling towers to reduce the impacts of its 1.4-billion-gallon daily water withdrawal habit.⁴³

Browns Ferry suffers prolonged exposure.

In the summer of 2010, amid high heat and energy demand, Tennessee River water temperatures rise above 90°F, forcing the Browns Ferry nuclear plant in Athens, AL, to drastically cut its output for nearly five consecutive weeks.^{53,54,55,56}

Georgia plant stops gulping, starts sipping.

By switching in 2007 from once-through cooling to cooling towers, the 1,250 MW coal-fired Plant Yates,⁵⁷ which previously withdrew more water per day from the Chattahoochee River than that used by all of metropolitan Atlanta, cuts its withdrawals by 93 percent.⁵⁸



NORTHEAST

A fork in the river. Nearly 70 percent of electricity generated in the Northeast comes from coal and nuclear plants—many of which rely on once-through cooling using water from rivers or the ocean.³⁵ This densely populated region's water resources have been stressed by decades of pollution and development, and electricity generation is projected to grow more than 25 percent by 2035.³⁶ How and where that power is produced could have major implications for regional water supplies and ecosystems.






MIDWEST

Looming deficits. In a typical summer, the Midwest experiences high temperatures and extended heat waves, driving increased demand for water and electricity—including the water needed to generate electricity. The region relies heavily on water-intensive coal and nuclear plants to provide power, but growth in population, electricity generation, and agricultural demand are taxing water resources.⁴⁴ When water is scarce, the region's electric sector and those dependent on it face serious risks.



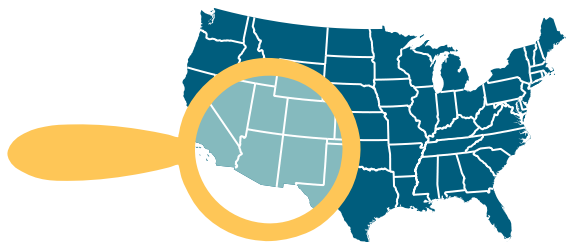
SOUTHEAST

Heated debate. Water supplies in the Southeast are periodically crippled by drought and have become the subject of legal and political battles between states.⁴⁸ Adding to this is the water-use habit of the region's power sector: fully two-thirds of water taken from freshwater bodies in the region goes toward cooling the region's power plants.^{49,50} This dependence can force plants to curtail production or shut down completely if conditions prevent them from using the cooling water they need⁵¹ (see p. 5).

-  RISK TAKING AND IMPACTS
-  RISK REDUCTION
-  WATER-SMART ENERGY

Spotlight on Key Regions

Though the energy-water collision is affecting power plants across the country, the problem is most visible in the Southwest and Southeast.



The Southwest

The U.S. Southwest is one of the world's drier regions. Most of its surface water accumulates as snow during the winter, melting into streamflow in the spring and summer. Water stored in enormous reservoirs and pumped from underground aquifers is the region's lifeblood. Droughts, already common, are projected to grow more severe in the region due to global warming.⁵⁹

Within this context, the region's power supply has been developed with comparatively greater attention paid to water use than in other regions. On balance, Southwest power plants—largely coal-fired⁶⁰—use less water for cooling than those in other regions.⁶¹ Nonetheless, water use continues to be a factor in power plant siting and operation. Large hydroelectric facilities including the Hoover and Glen Canyon Dams depend on reservoirs that

have recently had record-low water levels,^{62,63} causing some to substantially reduce their output.

Over the past 10 years, the Southwest's population has grown almost 20 percent (twice the national rate) and is expected to double by 2030,⁶⁴ placing tremendous strain on the Colorado and other rivers. In recent years, Tucson, AZ—one of a number of rapidly growing cities that depend almost exclusively on Colorado River water—has been forced during extended drought and record-breaking heat to revert to supplemental (and unsustainable) groundwater pumping in order to meet municipal water needs.⁶⁵ Power demand is likewise expected to grow: almost 30 percent by 2030.⁶⁶ In the absence of water-wise energy decisions, the power sector's water use will grow as well, increasing the burden on this stressed resource.

Power Plant Cooling Technologies

In steam-generating power plants, mechanisms are needed to cool the steam exiting a turbine.^{68,69} The typical options are:

Once-through systems, which take water from nearby bodies of water, circulate it through pipes to absorb heat from the steam, and discharge it back to the source at a higher temperature.⁷⁰

Recirculating or closed-loop systems, which reuse cooling water rather than immediately releasing it back to the source. Such systems withdraw comparatively small amounts of water but lose most of it to evaporation.⁷¹

Dry-cooling systems, which use air instead of water. Dry-cooled systems can decrease a power plant's water needs by up to 90 percent, but these systems cost more and make the plant less efficient.⁷²



The Southeast

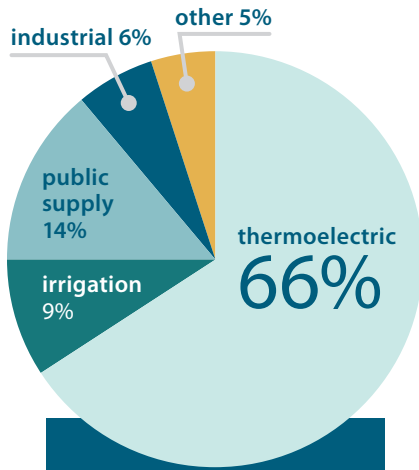
The Southeast's power plant fleet is dominated by coal and nuclear plants, almost half of which are older facilities that use once-through cooling and withdraw two orders of magnitude more water than their newer counterparts (see figure, p. 6).⁷³ When the required volumes of cooling water cannot be withdrawn from lakes and rivers (e.g., during drought or extended heat), such water-intensive power plants can become unreliable. Water levels can become too low for withdrawal, the water can become too warm to cool the plant, or the water that is returned can become so warm that it harms the ecosystem (e.g., by killing fish). These constraints can force plants to reduce their output or shut down altogether.

Hot, dry conditions, reduced streamflows, and warm river temperatures are a feature of many Southeast summers.⁷⁴ When these conditions occur, people often respond by using more water (e.g., for watering lawns) and electricity (e.g., for air conditioning), which requires more cooling water at the power plant, increasing stress on local water supplies.



SandiaLabs

In the Southwest, where surface water resources are stretched thin, there is little available to meet growing demand, including new power sector needs. Even without factoring in the exacerbating role of climate change, water supply conflicts involving several major Southwest cities—including Denver, Albuquerque (pictured here), Las Vegas, and Salt Lake City—are considered highly likely by 2025.⁶⁷



Southeastern U.S. freshwater withdrawals

Power plants account for two-thirds of all Southeast freshwater withdrawals.⁷⁵

The region's population is projected to grow 40 percent by 2030, and its conventional power plant capacity is projected to rise almost 20 percent.^{76,77}

In the absence of water-wise energy decisions, the power sector's water use will grow.

With current patterns of use, more people and more power mean greater demands on water supply, in a region where access to water is already highly contentious.^{78,79} In a similar time frame, both extreme heat and the severity of summer drought are expected to increase.⁸⁰ This means that even if the Southeast could meet its increased energy demand through greater energy efficiency, energy-water crises could still increase in frequency.⁸¹

Looking Ahead

Over many decades, we have built an electricity system that is highly water-dependent, posing risks to itself and other water users. These risks may grow considerably over the coming years, in proportion to increasing power demand in some regions, mounting water stresses around the nation, and, in many places, continuing changes in climate. Though global warming may lead to more abundant water in some parts of the country (at least temporarily), in many other areas it is expected to increase climate extremes including drought and heat waves, exacerbating the energy-water collision.⁸²

Water-smart energy choices would reduce the electricity sector's drain on water resources and the associated risks. Some power companies are making retrofits to existing plants or changes in plant designs that lower water use—either voluntarily or at the behest of state regulators. In other cases, power plant proposals are being denied, or existing plants are facing the prospect of closure, due to their water-related impacts.⁸³

Water-smart energy choices would reduce the electricity sector's drain on water resources and the associated risks.

A more forward-looking approach to this problem, already being employed by leading developers and utilities, involves using low- or no-water technology for producing electricity, or meeting electricity demand through energy efficiency. In many cases, these technologies also address other issues, such as the need to reduce heat-trapping emissions and other pollutants. Examples of low-water and low-carbon options include wind, solar photovoltaic, some types of concentrating solar, certain dry-cooled steam-based plants, and a range of efficiency approaches.

The choice is simple: continue with business as usual and hope we avoid energy-water collisions (and the costs associated with them), or build a water-smart energy system that can provide us with energy security while protecting our precious water supplies.



Duke Energy

Wind farms and some other renewable energy technologies offer ready options for generating electricity with little or no water.

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This fact sheet, which draws from a growing body of research, is part of our Energy and Water Collision series that explores the ways in which energy choices affect water resources in the United States, and how these will change in the face of global warming. To download a fully referenced version, visit the UCS website at www.ucsusa.org/energy-water.

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Endnotes

- 1 Two-thirds of electricity generated in the United States comes from coal, oil, and nuclear power plants; natural gas electricity generation, which accounts for more than 20 percent, also often involves water for cooling. Online at www.eia.doe.gov/cneaf/electricity/epm/table1_1.html, accessed April 22, 2011.
- 2 Kenny, J.F., N.L. Barber, S.S. Hutson, K.S. Linsey, J.K. Lovelace, and M.A. Maupin. 2009. Estimated use of water in the United States in 2005. U.S. Geological Survey Circular 1344.
- 3 WATER WITHDRAWAL: The total amount of water taken from a surface- or groundwater source. In most cases, some fraction of that water will be returned to the water source and available for other withdrawals (Kenny et al. 2009). Water withdrawal can become a large problem during drought and heat waves: water can be too warm, or levels too low, to cool the power plant, or the cooling water used by the plant can be made too warm to safely discharge.

WATER CONSUMPTION: That part of withdrawn water that is not readily available for re-use because it is evaporated in power plants. The amount of water consumed by power plants is a particular concern in water-constrained regions (including large parts of the western United States).
- 4 Detailed information on the water impacts of power plants can be found online at www.ucsusa.org/clean_energy/technology_and_impacts/energy_technologies/water-energy-electricity-overview.html.
- 5 Median summer peak temperature increases. See: NETL. 2007. NETL coal power plant database. Online at www.netl.doe.gov/energy-analyses/hold/technology.html, accessed July 27, 2010.
- 6 Buecker, B., and R. Aull. 2010. Cooling tower heat transfer 201. *Power Engineering* 114(11): November.
- 7 Avoiding additional electricity generation by meeting electricity demand with more efficient motors, appliances, and lighting, for example, also does away with the water impacts associated with that generation.
- 8 Much of this electricity is sent to California to meet its peak power demands in the summer. Online at www.eia.doe.gov/cneaf/electricity/epm/table1_1.html, accessed April 22, 2011.
- 9 United States Global Change Research Program (USGCRP). 2009. Global climate change impacts in the United States. Edited by T. R. Karl, J. M. Melillo, and T. C. Peterson. Cambridge, UK: Cambridge University Press.
- 10 Hamlet, A.F., P.W. Mote, M.P. Clark, and D.P. Lettenmaier. Effects of temperature and precipitation variability on snowpack trends in the western United States. *Journal of Climate* 18(21):4545–4561.
- 11 Mote, P., A. Hamlet, and E. Salathe. Has spring snowpack declined in the Washington Cascades? *Hydrology and Earth System Sciences* 12 (1):193–206.
- 12 The region's three dozen facilities larger than 100 MW include the Grand Coulee Dam on the Columbia River, which is one of the world's largest, with a capacity of nearly 6,500 MW.
- 13 USGCRP 2009.
- 14 Recent experience in these two basins exhibits how a lack of consistency and predictability in streamflow makes it harder to efficiently manage electricity-generating options and effectively protect river species. Based on projected losses, Bonneville Power Administration (BPA) sought and was awarded a large increase in electricity rates for customers. Unusually heavy rains in late spring that year dramatically reversed these projections, causing BPA to sell electricity at low to no cost and open spillways to release excess water, an action that can kill salmon and steelheads. See: Bonneville Power Administration. 2009. 2010 wholesale power and transmission rate adjustment proceeding (BPA-10) administrator's record of decision. WP-10-A-02. Portland, OR. And: Wald, M. 2010. Sudden surplus calls for quick thinking. *New York Times* blog, July 7. Online at green.blogs.nytimes.com/2010/07/07/sudden-surplus-calls-for-quick-thinking, accessed March 31, 2011.
- 15 American Wind Energy Association (AWEA). 2011. U.S. wind industry year-end 2010 market report. Online at www.awea.org/learnabout/publications/loader.cfm?csModule=security/getfile&PageID=5083, accessed March 31, 2011.
- 16 Maupin, M.A., and N.L. Barber. 2005. Estimated withdrawals from principal aquifers in the United States, 2000. U.S. Geological Survey Circular 1279. Reston, VA: USGS.
- 17 McGuire, V.L. 2007. *Water-level changes in the High Plains aquifer, predevelopment to 2005 and 2003 to 2005*. U.S. Geological Survey Scientific Investigations Report 2006–5324. Reston, VA: USGS.
- 18 USGCRP 2009.
- 19 The Grayrocks Reservoir, supplied by the Laramie River, was constructed 30 years prior to meet the plant's recirculating cooling needs. It fell to 10 percent capacity by mid-2008, forcing the plant to obtain 80 percent of its cooling water from wells and other leased sources. More than 26 billion gallons of water—most of it from the High Plains Aquifer—was delivered to the Laramie River plant from leased sources between October 2004 and May 2010. Other sources include the Wheatland Irrigation District, which typically provides water to more than 50,000 irrigated acres. Online at waterplan.state.wy.us/plan/platte/atlas/lower/lower_agricultural_irrigation_districts.htm, accessed April 11, 2011.
- 20 National Energy Technology Laboratory (NETL). 2009. *An analysis of the effects of drought conditions on electric power generation in the western United States*. DOE/NETL-2009/1365. Washington, DC: DOE.
- 21 Though the Grayrocks Reservoir was back to full capacity as of July 2010, the groundwater withdrawals cannot be replaced as readily and a similar situation could recur with future droughts. See: Basin Electric Power Cooperative. 2010. Grayrocks Reservoir fully recovers. News release, June 3. Online at www.basinelectric.com/News_Center/Publications/News_Briefs/Grayrocks_Reservoir_fully_recovers.html, accessed April 11, 2011.
- 22 Xcel Energy. Harrington Station. Minneapolis, MN. Online at www.xcelenergy.com/Minnesota/Company/About_Energy_and_Rates/Power%20Generation/TexasPlants/Pages/HarringtonStation.aspx, accessed April 11, 2011.
- 23 McBride, J. 2006. Xcel Energy completes wastewater project: Plan could save 1 billion gallons of water a year. *Amarillo Globe News*, April 22. Online at amarillo.com/stories/042206/bus_4445680.shtml, accessed April 20, 2011.
- 24 While this approach takes some pressure off of local freshwater supplies, it does mean that the treated effluent is not available for other water demands. It also does not address other impacts of coal plant operations, including carbon emissions.

- 25 O'Grady, E. 2009. E.ON completes world's largest wind farm in Texas. Reuters, October 1. Online at www.reuters.com/article/2009/10/01/wind-texas-idUSN3023624320091001, accessed April 11, 2011.
- 26 AWEA 2011.
- 27 Online at www.usbr.gov/lc/region/g4000/hourly/rivops.html, accessed April 20, 2011.
- 28 Carleton, J. 2011. Wet winter can't slake west's thirst. *Wall Street Journal*, March 31.
- 29 Bureau of Land Management (BLM). 2010. Record of decision for the Ivanpah Solar Electric Generating System Project and associated amendment to the California Desert Conservation Area Plan. Needles, CA: U.S. Department of the Interior.
- 30 Online at www.sce.com/powerandenvironment/powergeneration/mohavegenerationstation, accessed March 31, 2011.
- 31 To power Mohave, coal slurry (pulverized coal mixed with water) was piped 273 miles from the Black Mesa Mine in Arizona, requiring the annual use of 1.3 billion gallons of water from an aquifer on tribal lands. See: U.S. Geological Survey (USGS). 1999. *Monitoring the effects of ground-water withdrawals from the N Aquifer in the Black Mesa area, northeastern Arizona*. USGS fact sheet 064-99. Tuscon, AZ: USGS. March.
- 32 Including this slurry water, Mohave withdrew and consumed 4.9 billion gallons annually for cooling (the equivalent annual water use of more than 100,000 people), taking additional water from the Colorado River. See: California Public Utilities Commission (CPUC). 2001. Mohave Generating Station (A.99-10-023). San Francisco, CA.
- 33 The Hopi and Navajo tribes demanded that an aquifer on tribal land not be used for the creation of coal slurry, effectively shutting down the supply of coal to the Mohave plant. Together, Mohave's lack of pollution controls for sulfur dioxide and nitrogen oxides, and its loss of a water source for slurry, led to the decision to shut the plant. See: *Power Magazine*. 2006. Environmental quandary shuts Mohave Plant. March 15.
- 34 State of Colorado. 2010. Clean Air-Clean Jobs Act. House Bill 10-136. Online at www.leg.state.co.us/clics/clics2010a/csl.nsf/fsbillcont/0CA296732C8CEF4D872576E400641B74?Open&file=1365_ren.pdf, accessed April 25, 2011. And: Colorado Governor's Energy Office. 2010. Colorado's Clean Air-Clean Jobs Act. Fact sheet. Online at www.rechargecolorado.com/images/uploads/pdfs/Colorado_Clean_Air_Clean_Jobs_Act_GEO_WhitePaper.pdf, accessed April 25, 2011. And: WRA testimony with estimate. Online at www.dora.state.co.us/pls/efi/efi_p2_v2_demo.show_document?p_dms_document_id=86272.
- 35 The states of Connecticut, Massachusetts, Maine, New Hampshire, New York, Pennsylvania, Rhode Island, and West Virginia generated 7,557 TWh of electric power from coal and nuclear plants, out of a total 10,799 TWh of electricity generated in 2009. See: EIA. 2010. State historical tables for 2009. Online at eia.doe.gov/cneaf/electricity/epa/generation_state.xls, accessed May 16, 2011.
- 36 Energy Information Administration (EIA). 2011. Annual energy outlook 2011. Reference case table 63: Electricity generation by electricity market module region and source. Washington, DC: U.S. Department of Energy. Online at www.eia.doe.gov/forecasts/aeo/MT_electric.cfm, accessed May 4, 2011.
- 37 Wald, M. 2010. Vermont Senate votes to close nuclear plant. *New York Times*, February 24.
- 38 Welch, P. 2007. Cong. delegation requests thorough investigation into Vermont Yankee cooling tower collapse. August 22. Online at welch.house.gov/index.php?option=com_content&task=view&id=186&Itemid=61.
- 39 DiSavino, S. 2011. Entergy again finds tritium at Vermont Yankee. Reuters, January 21.
- 40 Vermont Law School. 2011. Petition filed asking state to update Vermont Yankee's water permit. February 17. Online at www.vermontlaw.edu/x12538.xml.
- 41 Daley, B. 2011. Agreement to cut power plant discharge, send steam heat to Boston. *Boston Globe*, March 2. Online at www.boston.com/news/science/articles/2011/02/02/power_plant_plan_to_cut_discharge_send_heat_to_boston, accessed April 25, 2011.
- 42 In 1997, ANP sought to construct two 580 MW natural-gas-fired power plants in Massachusetts' Blackstone River Valley. The Charles River Watershed Association helped convince the company to install dry-cooling systems at both plants, reducing their projected water consumption by 70 percent and saving between 30,000 and 580,000 gallons per day per plant. When ANP proposed building a similar natural-gas-fired plant the following year in nearby Dayville, CT, it decided from the outset to use dry cooling. The Dayville Siting Council commended ANP for the decision, stating that the use of low-water cooling technology had "made a tremendous difference" in the public's reaction to the plant. See: Gaffney, J. 2000. What blight through yonder window breaks? A survey of the environmental implications of electric utility deregulation in Connecticut. *Connecticut Law Review* 32:1443.
- 43 New Jersey Department of Environmental Protection (NJDEP). 2010. Administrative consent order to close Oyster Creek. Trenton, NJ. Online at www.state.nj.us/dep/barnegatbay/docs/aco_oyster.creek.pdf, accessed April 11, 2011.
- 44 Hightower, M., C. Cameron, D. Macuga, K. Wilson, and J. Hoffman. 2006. Defining research and development needs at the energy-water nexus. In UCOWR/NIWR Conference: Increasing freshwater supplies. July 18-20, 2006. Santa Fe, NM. Online at opensiu.lib.siu.edu/ucowrconfs_2006/14/, accessed May 5, 2011.
- 45 AWEA 2011.
- 46 In addition to the Prairie Island Nuclear Facility, located near Welch, MN, the Quad Cities Reactors near Cordova, IL, the Dresden Nuclear Plant near Morris, IL, and the Monticello Nuclear Plant in Monticello, MN, all reported that they had reduced power production to moderate water discharge temperatures. Through five scorching days (July 29 through August 2), Prairie Island (1,137 MW) was compelled to reduce its output as much as 54 percent. See: NRC power reactor status reports for July 28 through August 3, 2006. Online at www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/2006, accessed March 31, 2011.
- 47 From July 31 through August 1, the regional electricity grid coordinator, PJM, issued a "maximum emergency generation alert" requesting all possible generation in order to deal with record-breaking demand. See: PJM OASIS. 2010. Online at www.pjm.com/~media/documents/reports/2010-load-forecast-report.ashx, accessed April 11, 2011.

- 48 For example: "In June [2008] the state of Florida made an unusual announcement: it would sue the U.S. Army Corps of Engineers over the corps's plan to reduce water flow from reservoirs in Georgia into the Apalachicola River, which runs through Florida from the Georgia-Alabama border. Florida was concerned that the restricted flow would threaten certain endangered species. Alabama also objected, worried about another species: nuclear power plants, which use enormous quantities of water, usually drawn from rivers and lakes, to cool their big reactors. The reduced flow raised the specter that the Farley Nuclear Plant near Dothan, Ala., would need to shut down." See: Webber, M.E. 2008. Energy versus water: Solving both crises together. *Scientific American* 18(4):6–11.
- 49 USGS. 2009. Estimated use of water in the United States in 2005. *U.S. Geological Survey Circular* 1344: 52.
- 50 Most withdrawn water is returned to the water body from which it came, albeit at higher temperature.
- 51 Water can be too warm, or levels too low, to cool the power plant, or the cooling water used by the plant can be made too warm to safely discharge back into the local water body.
- 52 Online at www.tva.gov/greenpowerswitch/wind_faq.htm, accessed April 20, 2011.
- 53 According to the Nuclear Resource Council (NRC), between July 24 and August 27, 2010, the average power production of all three reactors at Browns Ferry was less than 60 percent of capacity. See: Nuclear Regulatory Commission (NRC). 2010. Power reactor status reports for 2010. Online at www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/2010/index.html, accessed August 30, 2010.
- 54 An EPA permit requires that the Browns Ferry plant reduce power generation or shut down altogether rather than discharge water that is too hot into the Tennessee River and potentially harm fish and other aquatic life. The permit limits discharge water temperatures to 90°F over 24 hours or 93°F over one hour. See: Tennessee Valley Authority (TVA). 2003. *Browns Ferry Nuclear Plant Units 2 and 3 extended power uprate project*. Final environmental assessment. Knoxville, TN.
- 55 In 2007, under similar conditions, the Tennessee Valley Authority (TVA), which owns the plant, shut down one reactor "due to river discharge temperature limit" for five days in August. See: Nuclear Regulatory Commission (NRC). 2007. Power reactor status reports for August 16–20, 2007.
- 56 The plant's two other reactors were forced to reduce power due to water temperature limitations as well. TVA's customers, hungry for electricity for air conditioning, saw increased electricity prices to cover the purchase of enough power to make up for the closed plants, as well as for lower hydroelectric power production due to low water levels. See: Associated Press. 2007. TVA reactor shut down; cooling water from river too hot. *Houston Chronicle*, August 16. Online at www.chron.com/disp/story.mpl/business/energy/5061439.html, accessed April 25, 2011. And: Amons, N. 2007. Power plants affected by drought, temps. *WSMV Nashville*, August 22. Online at www.wsmv.com/money/13952333/detail.html, accessed April 25, 2011.
- 57 United States Geological Survey. Thermoelectric-power water use in Georgia, 2005. Online at ga.water.usgs.gov/infodata/wateruse/thermoelectric.html, accessed May 4, 2011.
- 58 After switching to cooling towers, Plant Yates' water withdrawals dropped to roughly 32 million gallons per day. While this is a positive development in an area that has recently experienced crippling drought, the new cooling system means that the plant actually loses roughly half its withdrawn water to evaporation. The loss of water to evaporation and "blowdown" (flushing water from the system to remove buildup) results in only 16 million gallons being returned to the river daily. The plant also continues to burn coal, with all of that fuel's attendant environmental implications. See: Foskett, K., M. Newkirk, and S. Shelton. 2007. Electricity demand guzzling state's water. *Atlanta Journal Constitution*, November 18.
- 59 USGCRP 2009.
- 60 In 2009, coal-fired plants supplied 51 percent of the electricity in Nevada, Arizona, New Mexico, Utah, and Colorado. See: EIA. Electric power annual 2009 state data tables. Online at www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html, accessed April 20, 2011.
- 61 The majority of steam-based plants in Arizona, Colorado, Nevada, New Mexico, and Utah use recirculating cooling systems to reduce their water needs: 85 percent use recirculating systems; 2 percent use dry cooling. See: Energy Information Administration (EIA). 2008. Form EIA-860 annual electric generator report. Online at www.eia.doe.gov/cneaf/electricity/page/eia860.html, accessed April 25, 2011.
- 62 U.S. Bureau of Reclamation. Lake Mead at Hoover Dam, elevation (feet). Online at www.usbr.gov/lc/region/g4000/hourly/mead-elv.html, accessed April 11, 2011.
- 63 U.S. Bureau of Reclamation. Upper Colorado Region water operations: Current status: Lake Powell. Online at: www.usbr.gov/uc/water/crsp/cs/gcd.html, accessed May 16, 2011.
- 64 The combined populations of Arizona, Colorado, Nevada, New Mexico, and Utah are expected to grow from 3 million to more than 7 million between 2010 and 2030. See: U.S. Census Bureau. 2004. U.S. population projections. Table 6: Total population for regions, divisions, and states: 2000 to 2030. Online at www.census.gov/population/www/projections/projectionsagesex.html, accessed April 11, 2011.
- 65 Hutchins-Cabibi, T., B. Miller, and A. Schwartz. 2006. *Water in the urban Southwest: An updated analysis of water use in Albuquerque, Las Vegas and Tucson*. Boulder, CO: Western Resource Advocates. Boulder, CO.
- 66 EIA 2011.
- 67 The probability of conflicts is based on a combination of factors including population growth and the water requirements of endangered species. Multiple locations throughout the Southwest were considered "substantially likely" or "highly likely" to experience water conflict by 2025, without factoring in the highly relevant projected effects of climate change. See: Bureau of Reclamation. 2003. *Water 2025: Preventing crises and conflict in the West*. And: USGCRP 2009.
- 68 Kenny et al. 2009.
- 69 Union of Concerned Scientists (UCS). 2010. How it works: Water for power plant cooling. Online at www.ucsusa.org/clean_energy/technology_and_impacts/energy_technologies/water-energy-electricity-cooling-power-plant.html, accessed March 30, 2011.

- 70 Once-through cooling systems have historically been the most popular because of their relative simplicity, low cost, and ease of siting power plants in places with abundant supplies of cooling water. They are now rarely implemented, however, due to disruptions to local ecosystems and heightened difficulty in siting power plants near available water sources.
- 71 Most commonly, wet-recirculating systems use cooling towers to expose water to ambient air, and allow evaporation as the water cools back to an appropriate temperature. The water is then recirculated back to the condenser in the power plant. Because wet-recirculating systems only require water withdrawals to replace water lost in the cooling tower, these systems have much lower withdrawals than once-through systems.
- 72 Though no water is required for dry-cooling systems, power plants using dry-cooling systems also require water for system maintenance and cleaning. Less efficient power plants require more fuel per unit of electricity, which in turn leads to higher heat-trapping emissions. In 2000, 92 percent of all U.S. dry-cooling installations were in smaller power plants, most commonly in natural gas combined-cycle power plants. Small power plants are defined as having an electric generating capacity less than 300 MW.
- 73 EIA 2008.
- 74 Kaushal, S., G. Likens, N. Jaworski, M. Pace, A. Sides, D. Seekell, K. Belt, S. Secor, and R. Wingate. 2010. Rising stream and river temperatures in the United States. *Frontiers in Ecology and the Environment*: 100323112848094.
- 75 Calculated based on the following states: Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. See: Kenny et al. 2009.
- 76 U.S. Census Bureau 2004.
- 77 National Energy Technology Laboratory (NETL). 2009. Estimating freshwater needs to meet future thermoelectric generation requirements. Washington, DC: U.S. Department of Energy.
- 78 A dispute between North and South Carolina over sharing Catawba River water went all the way to the U.S. Supreme Court before settlement; the case was settled with a decision to use the previously negotiated FERC relicensing agreement as the basis for water allocation between the states and users of water from the Catawba reservoirs. (US Supreme Court. 2010. *South Carolina v. North Carolina*, 130, U.S., 2010.) Meanwhile, the states of Georgia, Alabama, and Florida have been involved in legal battles over shared water resources for the past 20 years. (USGCRP 2009. And: Ruhl, J.B. 2005. Water wars, eastern style: Divvying up the Apalachicola-Chattahoochee-Flint River Basin. *Journal of Contemporary Water Research & Education* 131:47–54.) (See also endnote 49.)
- 79 Sovacool, B. K., and K. E. Sovacool. 2009. Preventing national electricity-water crisis areas in the United States. *Columbia Journal of Environmental Law* 34: 333.
- 80 USGCRP 2009.
- 81 Against a backdrop of increased climate-driven water stress (see USGCRP 2009), a rise in energy-water conflicts would be expected if the region were to continue to rely on plants that require substantial amounts of cooling water.
- 82 USGCRP 2009.
- 83 Examples presented here include Oyster Creek in Lacey, NJ, and Vermont Yankee in Vernon, VT.