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Energy — Water Interdependence

James A. Tindall and Andrew A. Campbell

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Executive Summary

Energy and water security has become a national and global priority. The continued security and economic health of the United States or any country depend on a sustainable supply of both energy and water because these two critical natural resources are so closely linked. The production of energy requires large volumes of water while the treatment and distribution of water is equally dependent upon readily available, low-cost energy. In 2000, irrigated agriculture and thermoelectric generation withdrawals of fresh water were approximately equal in the U.S. Electricity production requires about 190,000 million gallons of freshwater per day, accounting for over 40percent of all daily freshwater withdrawals in the U.S. In many regions of the U.S., the indirect use of water (home lighting and electric appliances) is approximately equal to direct use (water lawns and taking showers).

Current trends of water use and availability indicate that meeting future water and energy demands to support continued economic development will require improved utilization and management of both energy and water resources. Primary concerns include:

- Increasing populations require more food and energy; this will cause direct competition between the two largest water users (energy and agriculture) for limited water resources.
- Population growth and economic expansion projections indicate the U.S. will require an additional 393,000 MW of new generating capacity (equivalent to about 1,000 new 400 MW plants) by the year 2020, which is unlikely to occur due to nuclear power plants criticism and other issues related to them.
- Potential environmental and ecological restrictions on the use of water for power generation such as the removal of hydroelectric dams, restrictions on cooling water withdrawals, and cooling water use for nuclear power plants to protect aquatic species and habitat and the environment.
- Potential terrorist attacks on power grids and water treatment and distribution systems.

The nation's ability to meet the increasing demand for affordable water and energy is being seriously challenged by these emerging issues. This is true for almost all countries.

Introduction

Energy policy and related issues are an acknowledged facet of the global community. Energy is needed to convey water; water is required to generate energy. For decades, the U.S. and other countries have failed to develop energy policies that reduce reliance on foreign energy, especially petroleum-based products, and at the same time promote a diverse supply of reliable, affordable, and environmentally sound energy. While the U.S. has often considered an energy policy, no formal policy has been implemented. Further, the BP oil leak in the Gulf of Mexico in the summer of 2010 was a serious detriment to cutting dependency on foreign oil and energy supplies. Oil has allowed the world's burgeoning population to continue to grow. When oil first became a common commodity around 1900, the world population was about two billion; today that population is over six billion. Without the use of oil for extensive monoculture agricultural production and supply through trucking and shipping, the world would have a much smaller population. Despite the growing scarcity of these resources, governments fail to develop policy that will mitigate what may become the greatest catastrophe the world has known — the failure of both energy and water systems on a large scale, which will happen for a variety of reasons.

The continued security and economic health of countries, particularly the U.S., depends on a sustainable supply of energy. More importantly, energy policy must be connected to a sustainable water policy because these two resources are inexorably linked. Energy and water are Level 1 critical infrastructures; the most important of all infrastructures.[1] These are the life-sustaining systems that drive our economies and affect every part of life, as well as individual quality of life. Current trends in global population growth, energy and water use and their availability indicate that meeting future energy and water demands to support continued economic growth in a globalization scenario will require the utilization and management in an unprecedented manner of dual resources — energy and water.

In absolute terms, neither energy nor water is in strictly short supply regionally or globally. Instead, both are disparately distributed, particularly in developing nations. What is in short supply is affordable energy and clean, affordable water. At the same time, energy is beginning to compete with agriculture as the largest user of water. A steadily increasing population will significantly increase this competition. Failure to develop sound policies for joint water and energy management and use will jeopardize homeland and national security as well as foreign policy. Both energy and water are growing security threats for the 21st century. Already, cities such as Singapore are treating waste and sewage water for use as drinking water. Cities in the U.S. such as Los Angeles, San Francisco, Las Vegas, and Phoenix are examining this same methodology for possible use.[2] On the energy side, California consistently utilizes rolling blackouts to conserve energy during peak use, a practice which has spread to other populated states such as Texas. The demand for both resources is beginning to outstrip supplies.

Although a dual resource, tensions related to water are increasing and have significant implications for U.S. national security. For example, the Indus River System is in a state of heightened tensions between India and Pakistan. There are those who claim that armed conflict over water

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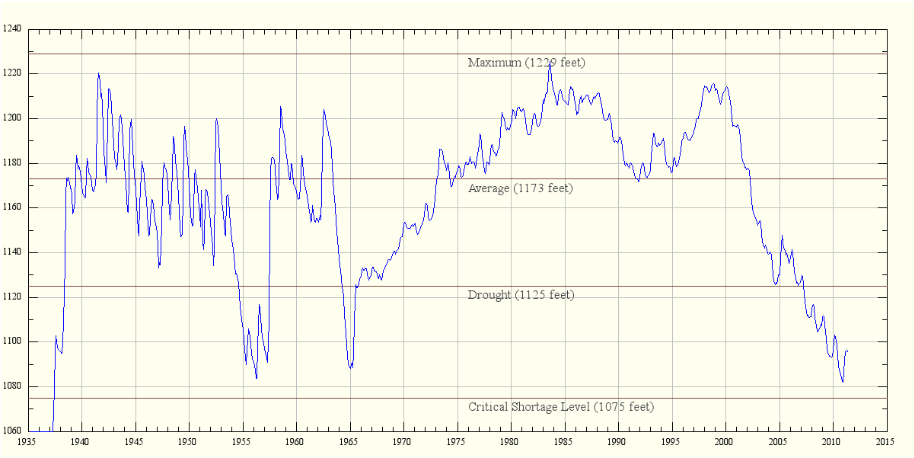
[1] J. Tindall, and Campbell, A., "Water Security: Conflicts, Threats, Policies," 2010, DTP Publishing, Denver, 452 p.

[2] Tindall, J.A., and Campbell, A.A., 2010, Water security—National and global issues: U.S. Geological Survey Fact Sheet 2010–3106, 6 p.

resources has never and will never happen. However, this was exactly the cause of the 1967 war between Israel and Syria — the water dispute between the two countries for control over the Jordan River triggered that conflict. The instability in the Middle East lingers as a result of this issue. Furthermore, a continuation of these conflicts could subject the U.S. and its allies to energy blackmail from the rich oil producers of the Middle East and the major corporations who hold the majority of oil rights in those areas.

A steadily increasing global population is placing greater demand on energy and water resources. In turn, this will necessitate the need for increased agricultural outputs on a global scale, which will increase competition for energy and water resources. If this happens, regional stability and national security will be decreased. As an example, in terms of dual use, the water levels of Lake Mead, which is controlled by Hoover Dam, are only 15 feet above critical shortage levels (1,075 feet) at the time of this writing. If the use rate continues, that critical level will be reached by summer 2012 (see **Figure 1**).

Figure 1: Lake Mead water level - 1937 to May 18, 2011 (Source: U.S. Bureau of Reclamation - The database is located at http://www.usbr.gov/lc/region/g4000/hourly/mead-elv.html).



When the critical shortage level is reached, water flow through the dam will cease, as will hydroelectric output. The water from Lake Mead, which is supplied by the Colorado River System, represents half of the water used by metro Los Angeles. The water of Lake Mead is used by 22 million people; seven million people use the hydroelectric energy produced by Hoover Dam turbines. If this critical shortage level is reached, severe consequences will result for the U.S. as a whole, especially economically. In recent years, water levels in Lake Mead, which is fed by the Colorado River, have been about 100 feet lower than historic levels. This drop is primarily a consequence of increasing populations in Los Angeles and Las Vegas, reduced flows in the Colorado River due to a sustained 12-year drought in the Southwest, and other competing uses such as agriculture. It would therefore appear we face a conundrum. Building more power plants will further strain and affect freshwater supplies; constructing larger delivery systems to meet the needs of growing populations will increase energy demands. Further, Hoover Dam could be particularly vulnerable to a bio-terrorist attack or an earthquake.

There is no redundant supply for this system or for many similar systems around the world, and factually, terrorists already possess the necessary chemicals that require minimal logistics to poison this and other large systems. Although many experts have stated the logistics required to carry out such an attack are virtually impossible, they are in error — depending on the bio-agent used logistics are far less sophisticated and extensive than have been suggested. As an example, it would require only 22.5 pounds of one specific agent to achieve success; this small amount could be easily carried in a backpack or other innocuous container.

Colorado is not the only state in the U.S. facing linked energy and water problems. In June 2008, the state of Florida announced it would sue the U.S. Army Corps of Engineers in regard to the Corps' plan to reduce water flows from reservoirs in Georgia that flowed into the Apalachicola River; this river runs through Florida from the Georgia-Alabama border. Florida's concerns were environmental, that the restricted flow would threaten a variety of endangered species. However, Alabama also objected because they feared that reduced flows might force the Farley Nuclear Plant near Dothan, Alabama, to shut down. Nuclear plants require large quantities of water to cool their reactors (to be discussed later). The state of Georgia had been hit hard by a sustained drought, causing a drop in water levels of rivers around the state, which could have also forced Georgia to shut down its own nuclear power plants. Tensions between these states became much heightened. At one point, a Georgia state legislator suggested that Georgia move its northern border one mile further into Tennessee, citing a problematic land survey dating back to 1818.

This is a firsthand example of the competitive use among water, energy, and the environment — excluding agriculture, which uses vast quantities of water — and how calamitous circumstances could become for large numbers of people and the consequential need for sound policy implementation. Water and energy are required for modern societies to sustain growth. Water is the most important resource since is it necessary to sustain life, but without energy, food cannot be grown, homes, offices, or schools powered, nor can communications work effectively. A growing population will create demands on these resources at a faster pace than in the past and with consequences that will likely be both unanticipated and disastrous. And, without back-up for most of these systems, various economic, health, and other effects could linger for years.

While these strains between energy and water require sound management and policy development at the local level, especially in water-stressed areas such as the Southwest U.S., relations across boundaries of countries (termed transboundary issues) become ever more important and may likely become the key to preventing potential armed conflict. Water quality concerns, availability and sustainability, border issues, climate change, increasing populations, and growing demands for these resources are creating tough challenges. If, for example, the U.S. and its allies are determined to sever dependence on foreign oil for energy and security concerns, what will this imply for water resources?

Currently there is no cohesive approach since the Department of Energy is concerned more about energy issues than water, assuming there will be sufficient water resources for energy needs; and other agencies, such as NOAA and NASA, only collect water data and are not involved in policy, while the Environmental Protection Agency regulates its quality. The latter looks primarily at water and not at energy and thus, for the most part, all three work separately and discontinuously in closely related areas of these problems; failure to link the criticality of these resources and develop joint policy will likely lead to sustainability issues. Perhaps it will be necessary to form a Department of Water within the U.S. Government, which would be far better economically than nationalization of the U.S.

water infrastructure. And, continued failure to develop a national energy policy will likely cause a backlash of results that cannot be escaped. Since other energy sources lag far behind the use of oil and are too expensive for the general population to afford, when oil becomes too costly or in critically short supply, the U.S. lifestyle and that of the world will necessarily shift dramatically and irreversibly.

The energy-water link creates many problems, whether looking at carbon emissions from transportation and their reduction, plug-in cars and their increased energy requirements, or biofuels and the large quantities of water required to grow them, and scaling these issues nationally and globally becomes a complex strategic issue. The choice for one energy use versus another will require an abundant, dependable, and affordable water supply — oil is not a substitute for drinking water. This report will focus on energy-water interdependencies and the primary requirements of the energy industry for water resources and how energy processes affect them.

Energy — Water Interdependencies

Water is a vital and integral element for the development of U.S. and global energy resources and utilization. It is used in energy-resource extraction, refining and processing, and transportation. All of these are vitally interdependent because of their relation to critical infrastructure.[3] For example, water plays an integral role in electric-power generation, where it is used directly in hydroelectric generation and extensively for cooling and emissions scrubbing in thermoelectric generation. In calendar year 2000, thermoelectric power generation accounted for 39 percent of all freshwater withdrawals in the U.S., or about the same as water withdrawals for irrigated agriculture (34 percent — withdrawals are water diverted or withdrawn from a surface-water or groundwater source).[4] Water withdrawals for thermo-electric power are dominated by power plants that return virtually all withdrawn water to the source and account for 3.3 percent of total freshwater consumption (3.3 billion gallons per day) and represented over 20 percent of non-agricultural water withdrawal.[5] Although this water is returned at a higher temperature and with other changes in quality, it remains available for future use. A number of power plants, including most of those built since 1980, withdraw much less water but consume much of what they withdraw through the process of evaporative cooling, which causes greater pressure on water supplies.

The latest U.S. Census Bureau projections estimate a population increase of 70 million in the next 25 years. Using this estimate, the Energy Information Administration (EIA) predicts electricity demand to grow by about 50 percent.[6] This projection assumes current laws, regulations, policies, technological progress, and consumer preferences will continue through the projection period. Much of this growth is expected to occur in the Southeast, Southwest, and Far West U.S., where water stress is already prevalent. Additionally, these determinations do not factor in potential destruction by transnational or domestic terrorist groups. Further, nearly all of these systems have no supply redundancy. Once they are destroyed, supply is permanently interrupted until infrastructure is completely rebuilt.

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[3] J. Tindall, and Campbell, A., “Water Security: Conflicts, Threats, Policies,” 2010, DTP Publishing, Denver, 452 p.

[4] Hutson, "Estimated Use of Water in the United States in 2000."

[5] Ibid

[6] EIA, "Annual Energy Outlook 2006: With Projections to 2030," (Washington, DC: Energy Information Administration, 2006.

Following current trends for U.S. withdrawal rates, the consumption of water in the electric industry could grow substantially. Although increased demand for water would provide an incentive for technologies that reduce water use, it is unlikely that these technologies would prevent water shortages that are likely to occur if only through general climate changes in which cyclic droughts are common. While technologies are available that can reduce water use in the electric industry, including alternative cooling for thermoelectric power plants, wind power, and solar photo-voltaics — economics, policy, and environmental factors have limited implementation. In contrast, water use in the extraction and processing of transportation fuels is relatively small. However, as the U.S. seeks to replace imported petroleum and natural gas with fuels from domestic sources, such as biofuels, synfuel from coal, hydrogen, and oil shale, the demand for water to produce energy fuels will likely grow significantly.

Case Study: Water for Energy Production — the Roan Plateau

Domestic growth of natural gas and oil shale development will probably continue to be increasingly concentrated in the western U.S. One of the more important areas is the Roan Plateau in northwestern Colorado, which has large amounts of both natural gas and oil shale (a rock that contains kerogen, a precursor to conventional crude oil generally associated with marine lakes). The Office of Technology Assessment estimated that the amount of water used for oil shale production would range from 2.1 to 5.2 barrels for each barrel of oil.[7] Current operations processes required three barrels of water for each barrel of oil. The Bureau of Land Management (BLM) used a daily production of 350,000 barrels/day (denoted as bbl/day); projections for the entire planning area are 2.5 million bbl/day. This level of production would require 740,000 acre-feet of water annually (241 billion gallons or enough to provide the annual water needs of 3,569,049 U.S. residents). In 2002, this figure was updated to 21 trillion cubic feet (tcf). Further, BLM estimates that the Roan Plateau alone (an area of approximately 77,000 acres) holds 15.4 tcf, which is enough energy to heat four million homes for 20 years, with leases worth as much as $1.3 billion for Colorado.[8]

Findings suggest such large sums of money are not conductive to good decision making for policy development and implementation. For example, will the revenue from energy production be thought more important than life-sustaining water, which will be used in exorbitant quantities? One may not need to look further than the BP oil leak in the Gulf of Mexico, in which it appeared that the rights of the oil company surpassed the desires of a presidential administration and trumped established environmental regulations. Is this the future?

The increasing domestic, agricultural, and environmental water demands and the strain these place on freshwater resources can limit growth in energy supply as a result of competition between these sources. Since 1980, few new dams or reservoirs have been built; freshwater surface withdrawals have leveled off at about 260 billion gallons per day. Many regions around the world, but particularly in the U.S., depend on groundwater to meet increasing water demands; however,

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[7] Oil Shale and Tar Sands Resource Management Plan Amendments to addrress land-use allocations in Colorado, Utah, and Wyoming and Programmatic Environmental Impact Statement BLM, 2008.

[8] BLM, "Blm Roan Plateau Eligibility Report for the National Wild and Scenic Rivers System," ed. Bureau of Land Management (Washington DC: Government Printing Office, 2002).

declining groundwater tables could severely limit future water availability. Some regions have experienced a severe drop in groundwater levels (as much as 300 to 900 feet) during the past 50 years due to water withdrawal from aquifers because of a greater rate of withdrawal than the rate of natural recharge. This is a widespread, global problem. As an example, a commonly used aquifer that provides water to metropolitan Denver, Colorado, is the Dawson aquifer. Annual withdrawal rates from this aquifer are about 85 cm per year while the natural recharge rate is only 1.5 cm per year, or 56 times less than the withdrawal rate.[9]

A 2003 General Accounting Office study showed that most state water managers expect either local or regional water shortages within the next 10 years under average climate conditions.[10] For drought conditions, more severe water shortages would be expected. This will likely become a recurring problem since many regions experience cyclical droughts. With each succeeding cycle, groundwater levels are generally reduced and surface water supplies during drought periods often decline dramatically; this will increase water stress and cause greater competition between users, energy production, and resources. Further, water shortages will greatly affect energy and food prices as cascading failures begin to occur throughout these systems. Because the average food supplies are trucked 1,500 miles from production areas, food prices could soar out of control and become the number one spending priority for the majority of the population.

Depending on the water quality needs such as cooling of nuclear power plants, freshwater supplies can be augmented with degraded/brackish water or waste water. For example, the Palo Verde Power Plant (nuclear), 45 miles west of Phoenix, uses treated sewage from several nearby municipalities (this plant produces 3.2 GW annually and serves four million customers).[11] Water quantities available for distribution are dependent on the water qualities needed for each use. Increased use of brackish or degraded water may be required in some areas if water users can accept the quality limitations or can afford the cost of energy and infrastructure for water treatment. Many areas around the coastal U.S. and other countries already face the recurring problem of salt-water intrusion. This is due to increased population in these areas that creates greater demand for groundwater supplies. The groundwater is withdrawn, creating less pressure than that provided by the adjacent salt-water table — this pressure difference (greater pressure on the salt-water side) promotes salt water intrusion into freshwater supplies. This is a common problem along coastal areas.

Energy-Water Link

Energy production requires an abundant, predictable, and reliable source of water. However, good quality water is already in short supply throughout much of the U.S. and the world — especially in water-stressed areas. Agriculture uses approximately 70 percent of total water in the U.S., which compares similarly to other countries and, if people wish to eat, there is little that can be done to trim

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[9] R.G. Rayolds, Moore, J.E., and Barkmann, P.E., "Groundwater Mining of Bedrock Aquifers in the Denver Basin - Past, Present, and Future," *Environmental Geology* 47, no. 1 (2004); J.E. Moore, Rayolds, R.G., and Barkmann, P.E., "Groundwater Mining of Bedrock Aquifers in the Denver Basin - Past, Present, and Future," *Environmental Geology* 47, no. 1 (2004).

[10] GAO, "Freshwater Supply: States' Views of How Federal Agencies Could Help Them Meet the Challenges of Expected Shortages," (Government Accounting Office, 2003).

[11] Kate Galbraith, "Treated Wastewater for Thirsty Power Plants," *New York Times*, November 4 2008.

agricultural consumption long-term — due to population increase, agricultural productions must dramatically increase. However, this will cause increased pressure on both water and energy supplies and resources.

The electricity industry ranks second as the largest user of water. Electricity production from fossil fuels and nuclear energy requires 190,000 million gallons of water per day (39 percent of all freshwater withdrawals in the U.S., with 71 percent attributed to fossil-fuel electricity generation).[12] Coal, the most abundant fossil fuel, accounts for 52 percent of U.S. electricity generation; each kWh (kilowatt hour) generated from coal requires the withdrawal of 25 gallons of water. However, this is far less than water use needed for extraction of oil from oil shale. For U.S. citizens, this implies that indirect use of water (home lighting and electric appliances) is approximately equal to direct use (drinking water, water lawns, and taking showers). According to the 2001 National Energy Policy, population and economic growth in the U.S. alone will require 393,000 MW of new generating capacity by the year 2020. This will further strain U.S. water resources. To supply this demand would require 1,000 new, 400 MW power plants or, about 70 trillion gallons and 88 trillion gallons for fossil/biomass/waste and nuclear power plants, respectively. How much water is that? To illustrate, Lake Mead requires about two years of annual flow from the Colorado River to fill the reservoirs to capacity, which is about nine trillion gallons. Thus, additional power plant water requirements, for fossil/biomass/waste plants, would be enough to fill Lake Mead about eight times.

This scope is difficult for most to comprehend. Additionally, given current economic problems across the nation and within all states, construction of these facilities is very unlikely, which means decreasing energy supplies per capita. It would therefore appear that the most probable solution will be strict limits on energy and water use and/or rolling blackouts to provide necessary supplies. This will help conserve both resources. Continued lack of a formal energy policy, which should be joined to a water policy, will only exacerbate this process. However, due to political self interests, party partisanship, and related issues, it appears unlikely the U.S. will develop an effective energy policy; after all, the efforts first began in 1930 and yet no policy exists.

There is a problem with this scenario, which underscores whether a stable, affordable supply of water will exist to support future U.S. electricity demands and continued economic development at a time when additional jobs are greatly needed:

- U.S. and global populations are expected to increase significantly; accessible freshwater supplies will not. These supplies are finite; two of the few options to increase or supplement these water supplies are desalination and drinking water treated from city sewage and wastewater as is done in Singapore. The latter is unappealing to most Americans.
- Energy necessary for treatment and distribution of water accounts for about 80 percent of its cost; an insufficient supply of affordable energy will have a negative impact on both the price and availability of water. Increasing gas prices will have a dramatic impact on water availability and pricing.
- Population migration and increase in relation to energy demand do not always coincide with water availability. For example, during the 1990s in the U.S., the largest regional

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[12] Hutson, "Estimated Use of Water in the United States in 2000."

population growth, 25 percent, occurred in one of the most water deficient regions, the mountain west.

- Water availability is a serious issue in water-stressed regions of the U.S., particularly in the southeast, where population has increased by nearly 14 percent since 1990. In comparison, the water-rich northeast has experienced only a two percent population growth.[13] In other countries such as Darfur, Jordan, and Israel, this problem is more aggravated. **Figure 2** illustrates population growth in water-stressed areas of the U.S. compared to those with more plentiful water supplies.
- An increasing population will require more electricity and more food. More food requires more energy from fossil fuels and more water for crop production. This will create serious competition between the nation's two largest water users for limited water supplies (energy and agriculture). For example, ethanol produced from corn requires nearly 2,500 liters of water to produce one kilogram (300 gal per lb) of ethanol. And, in the U.S., corn commonly is grown in areas experiencing a 20 to 50 percent growth in population. This combination changes irrigation and crop management practices and significantly stresses water resources. Similar trends occur globally.
- Proposed restrictions on the use of water for power generation to protect fish and other aquatic organisms could result in both increased costs of electricity and potential energy shortages. This may be especially true since 'green' advocates are calling for the dismantling of existing dams. A line will be drawn — either man is more important or fish and other aquatic life are. Who will make this choice and what will the consequences be?

The critical interdependence between water and energy is inseparable; one resource cannot exist in an industrial economy without the other. Also, the interdependence between these critical infrastructure and others, as well as economic industries and sectors is far deeper than most imagine. If the serious threat of population growth and competition between these resources is not frightening, it should at least be of grave concern.

Demands from Energy on Water Resources

Because of increasing population, trends in increased energy use, water stress, and reduced water availability, and increasing water demand indicate the U.S. and the world will continue to confront issues related to the development, management, and utilization of both resources. Increasing global populations will increase demand for direct use of water, as well as for energy and agricultural production. Historically, water withdrawals for domestic supplies have grown at about the same rate as the population. However, during the 20th century, while global population increased three fold, demand for water worldwide increased six fold.[14] New technologies, conservation efforts, public education, and other measures must be implemented to ensure adequate energy and water

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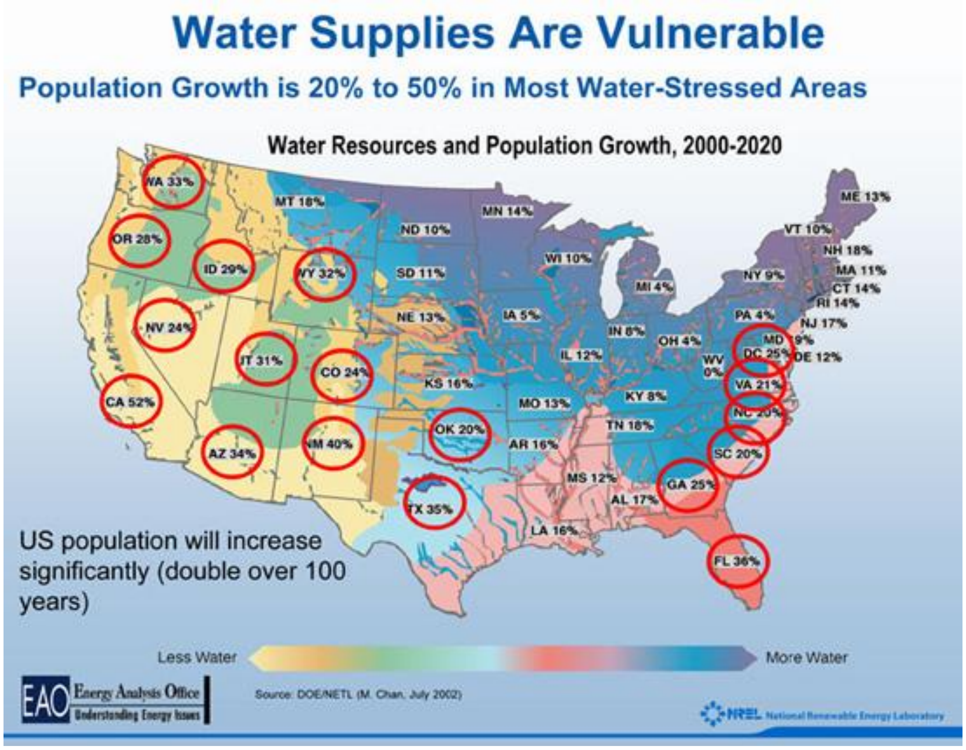
[13] U.S. Census Bureau. Population Estimates program, Population Division.

[14] WWC, "Water Crises," http://www.worldwatercouncil.org/index/php?id=25; World Water Council, "Water Crisis," World Water Council, http://www.worldwatercouncil.org/index/php?id=25.

supplies. Continuing to use the technology of evaporative cooling for power plants as an example, consumption of water for electrical energy production could more than double by 2030, i.e., to 7.3 billion gallons per day.[15] In the U.S., consumption by the electric industry alone could equal the entire country's 1995 domestic water consumption. This amount would be in addition to water use for extraction and production of transportation fuels from domestic sources, as well as cyclical drought problems, agricultural use, and other needs. In the future, we can expect less freshwater, not more, to be available.

Figure 2: U.S. population growth in water-stressed regions (Source: Energy Analysis Office).



Water Supplies Are Vulnerable

Population Growth is 20% to 50% in Most Water-Stressed Areas

Water Resources and Population Growth, 2000-2020

US population will increase significantly (double over 100 years)

Source: DOE/NETL (M. Chan, July 2002)

The availability of adequate water supplies has an impact on the availability of energy. Concurrently, energy production and generation activities affect the availability and quality of water. Energy and water, due to interdependence, must be managed together to maintain reliable energy and water supplies or severe shortages of both could occur. Examples include low water levels from drought and competing uses that can and limit the ability of power plants to generate power.[16] Additionally, water levels in aquifers in many regions of the U.S. have declined significantly, increasing energy requirements for pumping, and, in some cases, leading to ground subsidence issues, i.e., sinkholes. Further, lack of water for thermoelectric power plant cooling and for hydropower that can

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[15] S. Forbes, Hoffmann, J., and Feeley, T., "Estimating Freshwater Needs to Meet 2025 Electricity Generating Capacity Forecasts," ed. National Energy Technology Laboratory (Washington DC: Government Printing Office, 2004); Sarah Forbes Jeffrey Hoffmann, and Thomas Feeley, "Estimating Freshwater Needs to Meet 2025 Electricity Generating Capacity Forecasts," ed. National Energy Technology Laboratory (U.S. Department of Energy, 2004).

[16] Staff, ""Bpa Outlines Impacts of Summer Spill on Transmission System," *Columbia Basin Bulletin*, January 13, 2006 2006; Basin Bulletin, "Bpa Outlines Impacts of Summer Spill on Transmission System," *Columbia Basin Bulletin*, January 13 2006.

limit generation has the potential to increase demand for technologies that reduce the water intensity of the energy industry.

As population increases, the demand for energy will continue to grow. The EIA projects that demand for energy supplies from 2003 to 2030 will grow as follows: petroleum, 38 percent; natural gas, 20 percent; coal, 54 percent; nuclear power, 14 percent; and renewable energy, 58 percent. Demand for electricity from all sources is projected to increase by 53 percent. [17]

Freshwater withdrawals exceed precipitation[18] in many areas across the U.S. The shortfalls are most dramatic in the Southwest, the high plains, California, and Florida. Population growth in these regions between 2000 and 2025 is estimated to be 30 to 50 percent.[19] This growth will place an increased demand on both water and energy. EPRI estimates that most of the western shoreline of Lake Michigan has water demand above available precipitation.[20] For example, groundwater levels along the southwestern shores of Lake Michigan have declined hundreds of feet since predevelopment and by 1980 had reached maximum withdrawals of up to 900 feet near Chicago.[21] Levels are declining as much as 17 feet per year in some locations.[22]

Energy Requires Water — Impacts on Water Quality

Water is used throughout the energy industry for resource extraction, refining and processing, electric power generation, storage, and transport. The energy industry also can impact water quality via waste streams, runoff from mining operations (generally mine tailings), produced water from oil and gas extraction (such as from coal-bed methane), and air emissions that may affect downwind watersheds. Examples of these interactions of energy and water are shown in **Table 1**. Large energy facilities such as power plants, mines, and refineries can have a significant impact on local water supplies and water quality. For example, water withdrawals for thermoelectric power generation alone are comparable to water withdrawals for irrigation. While each represents about 40 percent of U.S. water withdrawals (water that is diverted or withdrawn from a surface-water or groundwater source), energy production returns the majority of withdrawn water. In 1995, all but about 3.3 billion gallons per day (three percent of the 132 billion gallons per day of freshwater withdrawn for thermoelectric power plants) was returned to the source. Although this water was returned at a higher temperature and with other changes in water quality, it remains available for future use. In contrast, of the 134 billion gallons per day withdrawn for irrigation in 1995, 81 billion gallons per day were consumed by evaporation

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[17] EIA, "Annual Energy Outlook 2006: With Projections to 2030."

[18] Note: portions of this report have been extracted, modified, and updated from J. Tindall, and Campbell, A., “Water Security: Conflicts, Threats, Policies,” 2010, DTP Publishing, Denver, 452 p.

[19] P. Campbell, "Population Projections: States, 1995-2025, Current Population Reports," ed. Economics and Statistics Administration (Washington DC: U.S. Department of Commerce, 1997).

[20] EPRI, "Water and Sustainability (Vol. 3)," in *U. S. Water Consumption for Power Production — the Next Half Century* (Electric Power Research Institute, 2002); — — — , "Water and Sustainability (Volume 3): U. S. Water Consumption for Power Production — the Next Half Century," (Electric Power Research Institute, 2002a).

[21] J.R. Bartolino, and Cunningham, W.L., "Groundwater Depletion across the Nation," ed. U.S. Geological Survey (Reston: Government Printing Office, 2003); J.R. Bartolino and W.L. Cunningham, "Groundwater Depletion across the Nation," ed. U.S. Geological Survey (Government Printing Office, 2003).

[22] Staff, "Lake Michigan's Wild West Coast: Looking for Water Laws and Order, Code Red in a Blue Water Basin," (Michigan Land Use Institute, 2003); Michigan Land Use Institute, "Lake Michigan's Wild West Coast: Looking for Water Laws and Order, Code Red in a Blue Water Basin," (2003).

and transpiration (60 percent); another 25 billion gallons per day (19 percent) were reported as lost in conveyance; this would be loss in infiltration to groundwater and some evaporation; it would not be immediately available for future use.[23] However, due to recharge rates, water used for irrigation (that which is not used by plants), i.e., leaked through the conveyance process or evaporated, will eventually become available for future use as governed by recharge rates and hydrologic cycle. In the case of recharge rates, since they are generally slow, withdrawal rates could always be in excess of recharge, causing a growing water deficit.

Another area that relates to energy use, logistics, etc., is the water needed for standing armies, i.e., the military during war and conflict occupation. Their water use is substantial, but will not be focused on in this report.

Water Use and Thermoelectric Power Generation

Thermoelectric power generating technologies using steam to drive turbine generators require cooling to condense the steam at the turbine exhaust. These plants receive heat from a variety of sources, including coal, nuclear, natural gas, oil, biomass (e.g., wood and crop waste), concentrated solar energy, and geothermal energy. The amount of freshwater required for cooling is significant (59 billion gallons of seawater and 136 billion gallons of freshwater per day).[24]

Table 1: Interaction of Water to Energy Processes

Energy Element	**Link to Water Quality**	**Link to Water Quality**
Electric Power Generation		
Thermoelectric (fossil, biomass, nuclear)	Water required for cooling[1] and scrubbing	Thermal and air emissions can impact surface-water quality and ecology
Hydroelectric	Reservoirs have huge evaporation losses	Can impact water quality, temperatures, and ecology
Solar Photovoltaic's and Wind	None during operation	
Energy Extraction and Production		
Oil and Gas Exploration	Water required for drilling, completion, and fracturing	Impact on shallow groundwater quality
Oil and Gas	Large volume of	Produced water can

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[23] Hutson, "Estimated Use of Water in the United States in 2000."
[24] Ibid.

Production	produced, impaired water[2]	impact surface and groundwater supplies
Coal and Uranium Mining	Mining operations usually generate large quantities of water	Tailings and drainage can impact surface and ground-water quality
Refining and Processing		
Traditional Oil and Gas Refining	Water needed for refinement processes	End use can impact water quality
Biofuels and Ethanol	Water needed for agricultural production and refining	Refinery requires waste-water treatment
Synfuels and Hydrogen	Water needed for synthesis or steam reforming[3]	Wastewater requires treatment
Energy Transportation and Storage		
Energy Pipelines	Water needed for hydrostatic testing	Wastewater requires treatment
Coal Slurry Pipelines	Water needed for slurry transport; water not recycled	Wastewater requires treatment
Barge Transport of Energy	River flows and stages impact fuel delivery; time and cost	Spills or accidents may impact water quality
Oil and Gas Storage Caverns	Slurry mining of caverns requires large quantities of water	Slurry disposal impacts water quality and ecology

[1] Includes geothermal (steam) and solar electric plants.

[2] Impaired water may include contaminants or be saline; production of Coal-bed methane is a good example.

[3] Steam reforming is the conversion of methane into hydrogen and carbon monoxide in reaction with steam over a nickel catalyst.

About 31 percent of current U.S. generating capacity is composed of thermoelectric generating stations (older plants prior to 1970) using open-loop cooling; water is withdrawn for cooling then discharged back to the source. This discharged water is heated through the cooling process; being heated, it can lead to about 1 percent enhanced evaporative loss to the atmosphere.[25] Although not consumed, the availability of large volumes of water for cooling is critical to plant operations. Additionally, the intake and discharge of large volumes of water by these plants have potential environmental consequences. Aquatic life can be adversely affected by impingement (entrapment on intake screens), entrainment (sucked into the cooling water system), and by the discharge of warm water back to the source. Existing open-loop cooling systems may have several more decades of service life and therefore continue to represent a significant demand for water, though an increased value of water could provide an incentive for cooling improvements that need less water.

Most thermoelectric plants installed since the mid-1970s are cooled by evaporation of the cooling water.[26] Water is pumped in a closed loop through a cooling tower or a cooling pond. These systems withdraw less than five percent of the water withdrawn by open-loop systems, but most of the water withdrawn is lost to evaporation. Total freshwater consumption for the thermoelectric power industry was 3.3 billion gallons per day in 1995.[27] This represents only 3.3 percent of total U.S. water consumption, about 100 billion gallons/day, but is nearly 20 percent of nonagricultural consumption.

Water Power Generation Use for Hydroelectric

Hydroelectric power is also an important part of the electrical industry in the U.S. because it plays an important role in stabilizing the electrical transmission grid and in meeting peak loads, reserve requirements, and other ancillary electrical energy needs. It is unique because it can respond very quickly to changing demand. In addition to the U.S., hydroelectric power generation is an important part of electricity generation in Europe, parts of the Middle East, China (particularly the Three Gorges Dam), and other countries. Within the U.S. it supplied about 6 to 10 percent of generated power between 1990 and 2003.[28] A primary hazard associated with hydroelectric power is that its production varies significantly with water availability (the less water available, the less electricity generated), which can depend upon weather patterns and local hydrology, competing water uses, such as agriculture, flood control, water supply, recreation, and in-stream flow needs such as for navigation and aquatic environments. In this regard, system failures that begin to cascade can have a significant consequence, and a terrorist attack or catastrophic natural hazard such as an earthquake can cause ramifications that could affect the entire country.

Hydroelectric plant design and operation is highly diverse; projects vary from large, multipurpose storage reservoirs to run-of-river projects that have little or no active water storage. About 85 percent of critical infrastructure in the U.S. is owned by the private industry, but in the case of hydroelectric production, almost one half is federally owned; the other half consists of nonfederal projects that are regulated by the Federal Energy Regulatory Commission (FERC). However,

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[25] EPRI, "Water and Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply & Treatment-the Next Half Century," (Electric Power Research Institute, 2002b); "Water and Sustainability (Volume 3): U. S. Water Consumption for Power Production — the Next Half Century."

[26] EIA, "Steam Electric Plant Operation and Design Report," (Energy Information Administration, 2004).

[27] Hutson, "Estimated Use of Water in the United States in 2000."

[28] EIA, "Annual Energy Review 2004," (Energy Information Administration, 2005).

being of smaller scale, there are ten times more nonfederal hydropower projects in the U.S. than federal projects. The average water flow through hydroelectric turbines is 3,160 billion gallons/day — about ten times the withdrawals of water from rivers.[29] This water is not categorized as withdrawn water since it remains in the river and is, therefore, generally used multiple times by successive dams.[30] Because of this, reservoir operation can reallocate water releases relative to natural flows. Hydropower projects, such as Lake Mead associated with Hoover Dam near Las Vegas, involves large storage reservoirs; evaporation of water from these reservoirs can represent a significant consumptive use. An estimated, annual average loss for U.S. hydroelectric reservoirs is 4,500 gal/MWh; annual electricity generation is about 300 million MWh.[31] Total evaporation losses are estimated at 3.8 billion gallons per day, but due to multiple use, hydroelectric power is not the only cause of evaporative losses. This evaporation occurs from reservoir surfaces as well as from water use.

Water Use for Energy Extraction and Fuel Production

Water consumption for energy extraction and fuel production is categorized within the industrial/mining industry.[32] Although large amounts of water are used in the conventional extraction of resources, more water is used in conversion into useful forms of energy, whether for converting coal or uranium to electricity as described above or converting petroleum into fuels such as gasoline or diesel. This will likely become very problematic in the future as population increases and forces a natural competition between the energy and agricultural industries for available water resources. This also implies that the threat of a terrorist-attack scenario could be significantly more devastating with time. Refinery use of water for processing and cooling is about 1 to 2.5 gallons of water for every gallon of product. The United States refines nearly 800 million gallons of petroleum products per day, representing about 1 to 2 billion gallons of water per day for the refining process.[33] Natural gas processing and pipeline operations consume an additional 0.4 billion gallons per day. Water is used in the mining industry to cool or lubricate cutting and drilling equipment for dust suppression, fuel processing, and re-vegetation when mining operations and energy extraction are completed. The total water estimated for use in coal mining varies from 1 to 6 gallons per million British thermal units (MMBtu), depending on the source of the coal.[34] When combined with 2003 coal production data (EIA, 2006), total water use for coal mining is estimated at 70 to 260 million gallons per day. Oil shale (the case of the Roan Plateau was mentioned earlier) is another potential domestic source of oil. Based on increasing oil demands and prices, opportunities may exist for significant expansion in the future. But, because oil shale resources are predominantly located in water-stressed areas, development may be constrained by water availability and cost.

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[29] Hutson, "Estimated Use of Water in the United States in 2000."

[30] The USGS serves the U.S. by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biologicical, energy, and mineral resources; and enhance and protect quality of life (www.usgs.gov).

[31] EIA, "Annual Energy Review 2004."

[32] The USGS categorizes water sources for various purposes.

[33] — — — , "Annual Energy Outlook 2006: With Projections to 2030."

[34] M.S. Lancet, "Distribution and Material Balances of Trace Elements During Coal Cleaning" (paper presented at the International Coal Preparation Conference, 1993).

Biofuels currently provide about 3 percent of U.S. transportation fuel, with more than 130 ethanol and biodiesel plants in operation, producing over four billion gallons of biofuel each year.[35] The most water-intensive aspect of biofuel production is growing the feedstock, with water consumption for refining generally similar to that for oil refining. When the feedstock is corn or soy (used to make ethanol and biodiesel, respectively) and grown on irrigated land, water consumption per gallon of fuel produced can exceed the water consumption for refining by a factor of one thousand.[36] Considering that costs to produce $1 USD of Ethanol are actually $1.30, this is a poor use of water resources since the virtual water represented by the feedstock production represents a costlier resource use.

Initial extraction of conventional oil and gas requires minimal consumption of water. However, significant quantities of water (termed produced water) are extracted with the oil and gas. The quality of produced water can range from nearly fresh to hyper saline; the majority is as saline as seawater. As oil wells age, enhanced recovery techniques are used to extract additional oil, which involve injection of water or steam into the well; some are very water-intensive. Water consumption ranges from 2 to 350 gallons of water per gallon of oil extracted, depending upon the recovery enhancement process. Most of the water used for these purposes is not otherwise usable.[37] Most produced water associated with onshore production is injected back into the producing zones to enhance production or into other formations well below any usable groundwater resources.

Produced Water Volumes during Energy Extraction

In 1995, oil and gas operations generated about 18 billion barrels of produced water (49 million gallons per day), compared to total annual petroleum production of 6.7 billion barrels of oil equivalent (both onshore and offshore production, including crude oil, natural gas, and natural gas liquids production).[38] Produced water varies in quality; with treatment, some may be used for other purposes. Today, the amount of water produced per well varies greatly. For example, water produced by coal-bed methane extraction can vary from 7 barrels of water per barrel of oil equivalent in the San Juan Basin (Colorado and New Mexico) to approximately 900 barrels of water per barrel of oil equivalent in the Powder River Basin (Wyoming and Montana).[39] In the Powder River Basin in Wyoming, coal-bed methane produced waters substantially increased soil salinity, making it difficult for vegetation to extract nutrients for plant growth, which affects water resources, the environment, and farmers in the region with serious problems likely to manifest within the next decade.[40]

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[35] RFA, "Ethanol Industry Outlook 2006," (Renewable Fuels Association, 2006).

[36] USDA, "Farm and Ranch Irrigation Survey," ed. National Agriculture Statistics Service (U.S. Dept of Agriculture, 2004).

[37] API, "Overview of Exploration and Production Water Volumes and Wast Management Practices in the United States," ed. ICF Consulting (American Petroleum Institute, 2000); P.H. Gleick, "Water and Energy," *Annual Reviews Environmental Resources* 19(1994).

[38] API, "Overview of Exploration and Production Water Volumes and Wast Management Practices in the United States."

[39] C.A. Rice, and Nuccio, V., "Water Produced with Coal-Bed Methane," ed. Water Resources Division (Reston: USGS, 2000); C.A. Rice and Vito Nuccio, "Water Produced with Coal-Bed Methane," ed. Water Resources Division (U.S. Geological Survey, 2000).

[40] M. Stearns, Tindall, J.A., Cronin, G., Friedel, M.J., and Bergquist, E., "Effects of Coal-Bed Methane Discharge Waters on the Vegetation and Soil Ecosystem in Powder River Basin, Wyoming," *Water, Air, and Soil Pollution* no. 168 (2005).

Energy Processes — Impacts on Water Quality

Oil and gas production that is not adequately managed and monitored can contaminate surface water and shallow aquifers through drilling and production operations or from spills of produced hydrocarbons or brackish water. Refining and processing of oil and gas can generate by-products and wastewater streams that, if not handled appropriately, can cause water contamination. Fuel additives, such as methyl tertiary-butyl ether (MTBE), that have been used to reduce air emissions have also emerged as potential groundwater contaminants.

Energy resource mining and processing, such as coal and uranium mining and oil shale development, can contaminate surface and groundwater. Runoff from both main mine operations and tailings piles can significantly reduce soil and water pH levels and increase heavy metals concentrations in mine drainage water, termed acid-mine drainage. Additionally, runoff from oil shale residue can wash into surface waters and byproducts from in-place extraction methods can impact groundwater quality. An increased interest in U.S. uranium supplies has led to the reopening of some older mines in New Mexico and Utah. By doing so, these mines could generate three to five million gallons of water a day that would need to be properly disposed. Water from some abandoned mines must be pumped and treated to prevent contamination of surface waters.[41] This requires more energy and more water. Additionally, water used for pipeline testing, coal slurry pipelines, and solution mining for oil and gas storage caverns creates a range of contaminants that can pollute fresh or coastal water sources if not adequately managed. Hydroelectric plants can impact water quality and river ecology in several ways by changing water temperatures and dissolved oxygen and nitrogen levels in downstream waters and by changing natural flow characteristics of rivers, thereby impacting aquatic ecology. All of these issues can become problems associated with water and public health.[42]

Supplying Water Requires Energy

Satisfying U.S. and global water needs requires energy for supply, purification, distribution, and treatment of water and wastewater. About four percent of U.S. power generation is used for water supply and treatment.[43] Electricity represents approximately 75 percent of the cost of municipal water processing and distribution.[44] The major difference between water uses among regions is in the amount of energy used to supply water for agriculture. In general, per capita non-agricultural use of energy for water is similar region to region. However, within regions, there can be substantial variation in energy requirements for water supply and treatment, depending upon the source, the distance water is conveyed, and local topography. California is an interesting case study in electrical consumption and illustrates the cost of long-distance water conveyance. California uses about five percent of its

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[41] C.B. Cecil, and Tewalt, S.J., "Coal Extraction-Environmental Prediction," ed. Water Resources Division (Reston: USGS, 2002); C. Blaine Cecil and Susan J. Tewalt, "Coal Extraction-Environmental Prediction," ed. Water Resources Division (U.S. Geological Survey, 2002).

[42] J. Tindall, and Campbell, A., “Water Security: Conflicts, Threats, Policies,” 2010, DTP Publishing, Denver, 452 p.

[43] EPRI, "Water and Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply & Treatment-the Next Half Century."

[44] C. Powicki, "The Water Imperative," *Electric Power Research Institute* (2002).

electricity consumption for water supply and treatment, which is substantially above the national average.[45]

Energy for Water Supply and Conveyance

Supply and conveyance can be the most energy-intensive portion of the water delivery chain. If the water source is groundwater, pumping requirements for supply of freshwater from aquifers varies with depth: 540 kWh per million gallons from a depth of 120 feet, 2000 kWh per million gallons from 400 feet.[46] These energy needs increase in areas where groundwater levels are declining, such as in large or mega-city areas.[47] Energy requirements to pump water from surface waters can be negligible for users located close to the source, with increased requirements with distance. In California, water is conveyed from Northern California up to 400 miles via the State Water Project to the cities of Southern California. Energy savings can be realized when wastewater streams are made available for reuse, rather than conveying freshwater over long distances, as demonstrated in the example of the Palo Verde nuclear power plant. Additionally, long-distance conveyance introduces enhanced security risks for both resources and for the people who rely upon them.

Energy for Treatment and Distribution

Generally, groundwater requires minimal energy for purification, while surface water requires more. Also, energy requirements for distribution and collection vary depending on system size, topography, and age. Older systems often require more energy because of older infrastructure and less efficient equipment. In both the U.S. and internationally, this infrastructure, at least for established cities such as New York, San Francisco, Beijing, New Delhi, and others is over 100 years old and in bad repair. Water leakage through distribution systems in such cities and in most cities is about 20 percent, substantially increasing energy conveyance and delivery costs and, of course, increasing water quantities.

Energy consumption associated with water use is greater than energy consumption for supply and treatment.[48] Activities such as water heating and washing and drying clothes require 14 percent of California's electricity consumption and 31 percent of its natural gas consumption. Most of that use is residential. Both water and energy can be conserved through the use of appliances such as low flush toilets, energy saving bulbs, and other technologies that reduce use. Even old technologies, still in use today, such as clothes lines in rural areas, could save enormous amounts of energy.

Future Energy Demands — Water Supply and Treatment

Population growth is creating an increased demand for water pumping from greater distances and greater depths. Therefore, as freshwater supplies become more limited, treating water from

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[45] CEC, "2005 Integrated Energy Policy Report: Committee Draft Report," (California Energy Commission, 2005).

[46] R. Cohen, "Energy Down the Drain: The Hidden Costs of California's Water Supply," (National Resources Defense Council, 2004).

[47] A mega-city has been defined as having a population of 10 million or more persons.

[48] J. Tindall, and Campbell, A., "Water Security: Conflicts, Threats, Policies," 2010, DTP Publishing, Denver, 452 p.

alternative sources will increase energy demand and costs. Additionally, emerging water treatment requirements, such as those for arsenic removal and emerging contaminants, are becoming more stringent. In 2050, per capita energy requirements are expected to be largely unchanged, except in the industrial and agricultural industries. Energy for public and commercial water supply and treatment are expected to grow with population, with an average increase for the U.S. of about 50 percent between 2000 and 2050. It remains to be seen how much it will cost to treat water containing emerging contaminants. However, due to their pernicious nature, the cost will likely be high. Emerging contaminants are generally the products not used but excreted from our bodies into wastewater systems and that are not currently treated for their removal. Examples of emerging contaminants include caffeine and a wide range of medications prescribed for patients as well as over the counter drugs such as cold medicines and so forth.

Water Shortages and Impacts on Energy Infrastructure

The U.S. energy infrastructure depends heavily on the availability of water and there are multiple problems concerning water availability and value due to growth from competing demands. Most state water managers expect shortages of water over the next decade, since water supply issues are already affecting many existing and proposed energy projects. In some regions, power plants have been required to limit electricity generation because of insufficient water supplies. Citizens and public officials concerned about the availability of water have opposed new high-water-use energy facilities, suggesting clear incentives for using lower water intensity designs in future energy-infrastructure developments. And yet, alternative energy such as wind, solar, and geothermal are limited in their availability to fill the gap in this area. The forms of energy are geographically specific and while large in areas of origin — wind in the northeast, solar energy in the southwest, etc. — conveyance over the distances needed for providing additional energy supplies is not economically viable with current technology. This is because Joule's Law states that the amount of energy lost is in proportion to the squared value of the current voltage. For example, for an electrical current voltage in a circuit of 110 volts, the electrical current lost is a factor of 10. To illustrate this concept, attach a standard 100 foot (30.5 meters) power cable and plug it into a lamp with a 100 watt bulb. If nine more 100 foot extension cables between the lamp and the power outlet are attached, the total distance the electricity would need to travel is 1,000 feet (304.8 meters). Due to the amount of electrical current lost while traveling this distance, there would not be enough power available to light the 100 watt bulb. In contrast, while power stations emit huge mega-watt amounts of power, these stations are also used by many, many consumers, which serves to illustrate the conveyance distance and use limitations.

Compounding the uncertainty regarding supply is the lack of current data on water consumption. Steady or declining rates of water withdrawal do not necessarily imply steady or declining consumption. For example, communities have responded to water shortages, in part, by increasing water re-use for such non-potable (not drinkable) uses as irrigation for parks and recreation, replacing lawns with native grass species, and so forth. Diverting wastewater effluent from return flows to consumptive uses reduces the need for water withdrawal but does not reduce the rate of water consumption. Following are some examples:

1. Browns Ferry Nuclear Power Plant, part of the TVA complex on the Tennessee River, often experiences warm river flows, such that the temperature of the water at the plant's cooling intakes often approaches or exceeds the Alabama water quality criterion of 86 °F, nearly the plant's discharge limit of 90 °F.[49]
2. Low water on the Missouri River leads to high pumping energy, blocked screens, lower efficiency, load reduction, or shutdown at power plants.[50]
3. Arizona rejected permitting for a proposed power plant because of potential impact on a local aquifer.[51]
4. University of Texas researchers said power plants would have to curtail production if 20th century drought conditions recurred.[52]

National water availability and use has not been comprehensively assessed in 25 years, but current trends indicate that demands on U.S. water supplies are growing. Water use in relation to energy demand and production processes is also a problem due to lack of policy linkage. The nation's capacity for storing surface-water is limited, resulting in significant groundwater depletion. Conjointly, population growth, urbanization, and pressures to keep water in streams for fisheries and the environment are placing new demands on freshwater supplies. The potential effects of oscillating drought cycles and weather patterns associated with cyclical climate change also create uncertainty about future water availability and use.

Water-Management Challenges

Managing water resources requires balancing the competing needs for water with availability of supplies and storage capacity. Reservoirs store water to mitigate the effects of seasonal and annual variations in supply. Water resources are managed to meet the needs of many uses, including irrigation, recreation, hydroelectric power, downstream communities, industry, thermoelectric plants, and in-stream uses, such as navigation, fisheries, and wildlife habitat. Effective policy measures will be required.[53] As a case study, the Colorado River system provides an example of the challenges of management to meet competing needs. The river system provides a wide range of public benefits: navigation, flood damage reduction, affordable electricity, water quality, water supply, recreation, and economic growth, as well as water to California, principally Los Angeles (50 percent of its needs) and Mexico.

Each of these benefited areas wait in line as a wide variety of stakeholders want the system managed to serve Colorado interests first since the water originates there. Many similar examples occur around the world, including the Indus, Nile, Jordan, and Danube Rivers. For these systems, one of the greatest impacts, especially on surface water, is drought, which affects all stakeholders. Even high precipitation provides no guarantee of adequate water if inflow from precipitation does not coincide with

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[49] T.R. Curlee and M.J. Sale, "Water and Energy Security" (paper presented at the Universities Council on Water Resources, Washington DC, 2003).

[50] J.R. Kruse and A. Womack, "Implications of Alternative Missouri River Flows for Power Plants," (Washington DC: Food and Agricultural Policy Research Institute, 2004).

[51] Water News, "Idaho Denies Water Rights Request for Power Plants," *U.S. Water News Online* 2002.

[52] Clean Air Task Force, "Wounded Waters: The Hidden Side of Power Plant Pollution," (Boston: Clean Air Task Force, 2004).

[53] J. Tindall, and Campbell, A., "Water Security: Conflicts, Threats, Policies," 2010, DTP Publishing, Denver, 452 p.

demand. For example, snow pack provides 75 percent of the water supply in the West and is a key part of water storage for cities such as Denver, Colorado. Reservoirs on the middle and lower Colorado River basin can store several times the annual river flow, while reservoirs on the Columbia River can store only about 30 percent of annual flow. When warm temperatures cause rain instead of snow or snow melts earlier, Columbia River reservoirs lack the capacity to store early inflow. Consequently, water must be released early and is not available for later use. The best management tool for such circumstances would be a hydrospheric model — a combined hydrology and climate model of the region that could accurately predict both processes at least seven years forward and link them to natural resources, critical infrastructure and the economy to develop stress/resiliency limits. The TinMore Institute (www.tinmore.com) has recently developed such a model.

Long-term cyclical changes in precipitation patterns and the effect on flows in rivers and the operation of reservoirs and hydroelectric plants are a major concern to the energy industry. For example, the 2001 drought in the Northwest significantly reduced hydroelectric power production, leading to the loss of thousands of jobs in the energy-intensive aluminum industry.[54] Such loss of hydroelectric power affects not only total power generation, but also power reliability. Because the level of output from hydropower can be quickly changed, it is used to provide peaking power when demand is highest. Peaking capability is especially valuable in the summer, when high temperatures and high humidity can reduce generation efficiency from thermoelectric plants. In the absence of hydroelectric power, peaking needs are being met in most cases by natural gas. Further, besides the water-energy interdependence there are greater economic concerns at many levels — job loss is only one. Lack of peaking power could result in short and possibly longer-term business cessation with coinciding economic effects.

There is a significant incentive to decrease water quantities used by the energy industry. When warm weather or low flow leads to high water temperatures at the plant inlet, power plants may need to reduce generation to avoid exceeding discharge temperature limits specified in plant operating permits, which reduces electricity output. This can be particularly problematic if it occurs during peak demand. In a few cases, low flows, other environmental concerns, and increasing water value are providing incentives for the replacement or upgrade of open-loop cooling systems with new cooling systems to achieve water-efficient and economical generation of power. If surface waters are severely constrained by drought, plant water supplies could be impacted, especially if priority rights or water sharing is imposed.

Groundwater Concerns

Almost 40 percent of water provided by private water suppliers in the U.S. is from groundwater sources, serving 90 million people in all 50 states; another 40 million are self-supplied with groundwater.[55] Some aquifers are adjacent to surface waters; when these aquifers are drained, levels of adjacent surface waters decline, and some riverbeds empty. Other aquifers are isolated from surface waters. Recharge of these aquifers can be very slow, and the water that is being pumped may have taken decades or centuries to accumulate. This is a global problem. The visible impact of over-

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[54] Washington State, "Washington State Hazard Mitigation Plan," ed. Emergency Management Division (Washington Military Department, 2004).

[55] Hutson, "Estimated Use of Water in the United States in 2000."

withdrawal occurs in some areas as the land surface sinks (subsidence) when the underlying water is withdrawn. The sinkholes that have remained in Florida, as reported in the news, are an example.

If the rate of withdrawal exceeds the rate of recharge, then through time, water must be pumped from ever greater depths, increasing energy costs and risking aquifer depletion and possible loss of water supplies. As aquifers are drawn down, water quality is degraded, often yielding brackish waters that require treatment before additional use. **Table 2** illustrates some typical examples of declining groundwater levels.

Table 2: Examples of Declining Groundwater Levels (Source: Bartolino and Cunningham, 2003).

Region	**Groundwater Decline**
Long Island, NY	Water table declined, stream flows reduced, salt water moving inland
West-central Florida	Groundwater and surface water declining, salt water intruding, sink holes forming
Baton Rouge, LA	Groundwater declining up to 200 feet
Houston, TX	Groundwater declining up to 400 feet, land subsidence up to 10 feet
Arkansas	Sparta aquifer declared “critical”
High Plains	Declines up to 100 feet, water supply (saturated thickness) reduced over half in some areas
Chicago-Milwaukee area	Groundwater serving 8.2 million people has declined as much as 900 feet, declining 17 feet/yr
Pacific Northwest	Declines up to 100 feet
Tucson/Phoenix, AZ	Declines of 300 to 500 feet, subsidence up to 12.5 feet
Las Vegas, NV	Declines up to 300 feet, subsidence up to 6 feet
Antelope Valley, CA	Declines over 300 feet, subsidence over 6 feet

Addressing Future Water Needs Related to Energy

A number of technologies in various stages of development have the potential to reduce water use per unit energy for power generation. These technologies will not likely be deployed until they are economically feasible — based on changes in water value and availability. Potential options for meeting future energy production and generation needs with reduced water use intensity are identified in **Table 3**. A range of electric-generating technologies, including water use for fuel extraction and processing are compared to pros and cons.

Table 3: Technology of power generation versus pros and cons of implementation

Technology	**Opportunity**[1]	**Gap**
Advanced Cooling (for thermoelectric power plants)	Reduced Water Use	Costs, complexity, hot weather performance, scalability to larger plant size
Combined-Cycle Gas Turbines	Water Use reduced 50percent	Fuel cost increase, increased dependence on gas imports, coal technology validation
Renewable Electric Power	Reduced water use, carbon-free, provides peak power needs	Costly, implementation and/or manufacturing capacity. For some technologies there is intermittent need for storage at high penetration
Oil Shale	Large domestic resource	Costly, competes with water use (especially in water-stressed areas), technology required to mitigate environmental impacts
Renewable/Alternative Fuels	Renewable, carbon-free/neutral domestic fuels	Costs, technology, high water use for bio-fuel

	and fuel from domestic coals and gas	production
Maximizing/Increasing Current Water Supplies	Understand supply, utilization, and sector use and dependency.	Educating the public, incomplete consumption data, water storage for future use, cyclic drought, policy, planning, management, coordination

[1] The amount of water required for manufacturing and construction of energy facilities, such as the water used in manufacturing the components of, or to construct, a power plant are not included.

The power generation technologies mentioned in Table 3 will only briefly be explained.

Advanced Cooling for Thermoelectric Power Plants

The amount of water used to condense steam from steam-driven turbine generators (per unit electricity output) depends on the type of cooling system and the efficiency of the turbine. Turbine efficiency increases as the difference between the steam temperature and the condensing temperature increases. Plants with higher efficiencies require less cooling per unit energy produced and, therefore, less water. Coal plants operate at higher temperatures than today’s nuclear plants, so coal plants require less water than current nuclear plants. One approach to reduce water use in thermoelectric plants is to replace the evaporative cooling towers in closed-loop systems with dry cooling towers cooled only by air, but this reduces plant efficiency. Plant efficiency is higher for plants using evaporative cooling than for plants using dry cooling, especially in a hot, arid climate.

Over the course of a year, the output of a plant with dry cooling will be about 2 percent less than that of a similar plant with evaporative closed-loop cooling, depending on the local climate. However, in the hottest weather, when power demands are highest, plant efficiency may decrease by up to 25 percent.[56] Decreased plant efficiency means increased fuel use and increased emissions, which could provide greater incentives for other efficiency and emission control technology improvements. As the value of water increases, there is increased need and value for technologies that reduce water and energy use, especially to meet peak demand on hot days, when dry-cooled systems lose efficiency.

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[56] DOE, "Energy Penalty Analysis of Possible Cooling Water Intake Strucgture Requirements on Existing Coal-Fired Power Plants," ed. National Energy Technology Laboratory (Argonne National Laboratory, 2002).

Dry-cooled systems impose a cost penalty ranging from two to five percent to 6 to 16 percent for the cost of energy compared to evaporative closed-loop cooling.[57] The fact that the cost penalty is highly dependent on the value placed on the energy that is not generated and must be replaced when the weather is hot and demand is high. Dry cooling is best suited to wet, cool climates (not the dry, arid climates of the West where water is most scarce). As of 2002, dry cooling had been installed on only a fraction of 1 percent of U.S. generating capacity, mostly on smaller plants.[58]

Combined-Cycle Gas Turbines

Natural-gas-fired combined-cycle gas turbines use (withdraw and consume) about half as much water as coal-fired plants and have been deployed in large numbers in recent years. The gas turbines in these plants provide two-thirds of their power generation. The hot exhaust from the gas turbine is used to generate steam, which drives a steam turbine to provide the remaining generation. Water use is reduced because only the steam turbine requires condensate cooling. In recent years, simple-cycle and combined-cycle natural gas turbine plants have provided much of the new generating capacity installed in the U.S. However, as natural gas prices increase, it is likely there will be fewer installations of these plants. As with the natural-gas combined-cycle plants, water use is lower than for conventional thermoelectric plants, although, some water is consumed in converting coal to syngas.[59]

Renewable Electric Power

A variety of renewable energy technologies consume no freshwater during operation; these technologies include:

- Geothermal hot water (binary) systems that are air cooled
- Ocean energy systems
- Run-of-river hydroelectric
- Solar dish-engine
- Solar photovoltaic's
- Wind

Additionally, existing reservoirs that do not currently have hydroelectric capacity are candidates for power generation. To reduce impacts on the aquatic environment, these plants could use fish-friendly turbines. Of these technologies, wind is currently being installed in the largest quantities, with more than 6300 MW of capacity installed in the United States.[60] Solar photovoltaic systems installation is also expanding rapidly, with approximately 400 MW installed through 2004. Generation of

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[57] CEC, "Comparison of Alternate Cooling Technologies for California Power Plants: Economic, Environmental and Other Tradeoffs," ed. Public Interest Energy Research (California Energy Commission, 2002).

[58] Ibid

[59] T.J. Feeley and M. Ramezan, "Electric Utilities and Water: Emerging Issues and R&D Needs" (paper presented at the 9th Annual Industrial Wastes Technical and Gegulatory Conference, San Antonio, Texas, April 13-16 2003).

[60] DOE, "Installed U.S. Wind Capacity, Wind Powering America," (U.S. Dept of Energy, 2005a).

electrical power by these low water use technologies can help offset power generation from more water-intensive technologies.

Although geothermal, hydropower, solar thermal power with integrated storage, and biomass power can provide dispatchable power (power that can be turned on/off or on demand at request of power grid operators); other technologies, such as wind and solar photovoltaic, are both regional and intermittent and must be backed up by other generating systems. Thus, as a sole source of energy they are inadequate at replacing these plants or coal powered energy sources. Connecting modest amounts of intermittent renewable sources to the grid has not been shown to undermine U.S. power grid stability. Both solar and wind have the potential to improve grid operation by providing power when it is most needed, during the hottest/windiest part of the day. Implementation of solar and wind technologies may also increase the need for energy storage.

Oil Shale

Many types of U.S. current transportation fuels are derived from imported petroleum. An approach being considered to reduce dependence on foreign sources of energy is to increase the development and use of domestic energy sources. Unfortunately, most energy extraction and processing operations require huge amounts of water. The U.S. is estimated to have two trillion barrels of oil in the form of oil shale deposits, which is more than triple the proven oil resources of Saudi Arabia. Due to high development costs, oil shale is not widely produced in the U.S., but is increasingly being considered as foreign oil imports prices rise and supplies become intermittent. However, the cost of water — over seven trillion barrels of water — to extract this oil may be too great a price to pay because it would be at the expense of all other water users, particularly agriculture, which is already suffering inadequate supplies resulting in decreased production for a growing population.

Initial recovery work is focused on mining and above-ground processing that consumes two to five gallons of water per gallon of refinery-ready oil.[61] To reduce foreign dependence, providing 25 percent of U.S. oil demand would require 400 million to one billion gallons of water per day. Because oil shale resources are predominantly located in water-stressed areas, development will likely be constrained.

Renewable and Alternative Fuels

Biofuels provide about three percent of U.S. transportation fuels and are considered a potential domestic source for producing significantly larger volumes of transportation fuel.[62] The most water-intensive aspect of biofuel production is growing the feedstock. For the common feedstock (corn and soybeans) used to make ethanol and biodiesel respectively, water consumption is quite high. The production of ethanol is particularly detrimental to water capacity; it can shift the effects and economy of agricultural production since it may be grown in favor of other foodstuffs that reduce

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[61] J.T. Bartis, "Oil Shale Development in the United States: Prospects and Policy Issues," (Washington DC: Rand Corporation, 2005).

[62] DOE, "Multiyear Program Plan, 2007-2012," ed. Energy Efficiency and Renewable Energy Office of the Biomass Program (U.S. Dept of Energy, 2005b).

useable consumption of food, but also increases agricultural water use. Production of alternative fuels, such as synfuel from coal or hydrogen from methane, also requires water (up to triple the requirements for water consumption in petroleum refining). Virtually every alternative will require as much water as refineries consume now, if not substantially more.

Increasing and Extending Water Supplies

The U.S. has national programs to develop its vast water resources. Programs by the Bureau of Reclamation, the Army Corps of Engineers, and other federal and state agencies have enabled the U.S. to harness surface water resources of the country's river systems; control floods; store water for agricultural, industrial, and domestic uses; and generate hydroelectric power. In parallel, programs through agencies like the U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, and so forth have allowed states to exploit tremendous groundwater resources and monitor and manage surface water flows to achieve more efficient use of water. The ability to easily expand freshwater availability is limited.

The rate of water withdrawal has increased with the affluence increase of society through most of the last century but has leveled off and even declined in recent years. However, many signs indicate that consumption may be outpacing available supplies: aquifers are declining, stored water levels are low, and communities are seeking to improve access to water supplies, in part through desalination and re-use of water. The best courses of action cannot be accurately determined without detailed water use and consumption data, which are lacking. Although residential water use is currently less than the past decade due to better technologies, the increasing use of water supplies resultant to increasing population will override this effort long term as we continue to use water in vast quantities.

Several factors have affected the availability and use of freshwater supplies: decreased water storage capacity because of reservoir sedimentation, requirements to limit water level fluctuations within the reservoir (for recreation or aesthetic reasons), or requirements to meet downstream flow targets for fish and wildlife needs. Another type of storage is the natural storage of moisture in snow pack. Past climate trends suggest that snow packs are decreasing over time and annually are melting earlier.[63] The decreased storage of water in snow packs will limit the reliable yield of river systems that derive much of their flow from the melting of snow pack. However, new data suggest we may be going into a cooling phase climatologically and this may increase snow-pack storage.[64]

Artificial recharge and aquifer storage and recovery are approaches that can increase reliable supplies by purposefully augmenting recharge with excess surface water (or treated effluent) in times when it is readily available, and then withdrawing water when needed. However, significant energy is required to treat and inject water and then to pump it out when that water is needed. There also are efficiency questions; not all of the water injected can be withdrawn. There are a variety of geochemical

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[63] U.S. Senate Committee on Commerce, Science, and Transportation, *The West's Snow Resources in a Changing Climate*, 2004.

[64] E.H. Moran, and Tindall, J.A., "Part 1: Magnetic Intensity and Global Temperatures: A Strong Correlation," *Global Security Affairs and Analysis (GSAAJ)* 1, no. 2 (2007).

problems that can arise from the mixing of surface water and groundwater in an aquifer. These problems can result in the long-term decline in the effectiveness of these storage systems.

Desalination

Options to expand freshwater supply include use of impaired water such as brackish groundwater or seawater. These waters can be converted to drinkable water through desalination, which requires more energy than typical public water supplies, but may be offset as energy prices continue to rise. Energy requirements for desalination are similar to the requirements for pumping water long distances via projects like the California State Water Project. Additionally, produced water from conventional oil and gas production is usually saline. Depending on quality, produced waters can be used with minimal cleanup for non-potable applications such as irrigation, power plant cooling, and industrial and domestic uses. If the water is more heavily contaminated, treatment and disposal following applicable laws and regulations may be the only alternative. Re-use/recycle reduces withdrawal rates and pumping costs but may increase energy needed for treatment. Long-term water and energy conservation measures represent an opportunity to stretch both resources. Reducing water consumption can save energy for water supply and treatment as well as for heating water and can reduce water requirements to the energy industry.

Conclusions

To sustain a reliable and secure energy future that is cost effective, environmentally sound, and supports economic growth and development, energy and water challenges must be immediately and effectively addressed. Rather than only an energy policy, lawmakers should immediately consider a dual water-energy policy. This includes consideration of the impact that water policies and regulations have on energy supplies and demands, and the impact energy policies and regulations have on water demands and availability. Properly quantifying and valuing energy and water resources will enable the public and private sectors to better balance energy and water needs for all users and to develop strategies and approaches to enhance future energy security and sustainability.

Collaboration on energy and water resource planning is needed among federal, regional, and state agencies as well as with industry and other stakeholders. The lack of integrated energy and water planning and management has impacted energy production in many basins and regions across the U.S. For example, in three of the fastest growing regions in the country, the Southeast, Southwest, and the Northwest, new power plants have been opposed because of potential negative impacts on water supplies.[65] Recent droughts and emerging limitations of water resources has many states, including California, Georgia, Florida, Arizona, Nevada, Texas, South Dakota, Wisconsin, and Tennessee, scrambling to develop water-use priorities for different water-use industries.[66, 67] Collaboration between stakeholders and regional and state water and energy planning, management, and regulatory

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[65] News, "Idaho Denies Water Rights Request for Power Plants."

[66] Force, "Wounded Waters: The Hidden Side of Power Plant Pollution."

[67] Tindall, J.A., and Campbell, A.A., 2010, Water security—National and global issues: U.S. Geological Survey Fact Sheet 2010–3106, 6 p.

groups and agencies are critical. These efforts will ensure proper evaluation and valuation of water resources for all needs, including energy development and generation.

Often, polices or regulations developed to support or enhance one area, such as increasing domestic energy supplies can have unintended negative impacts on water resources. System-level evaluations by stakeholders and government agencies can be used to assess the impact of current or proposed natural resource policies and regulations and improve future energy development and water availability.

When the energy infrastructure is evaluated in a system context compared to water, agriculture and food, and other critical infrastructures, significant improvements in energy and water conservation can often be realized through implementation of innovative processes or technologies, co-location of energy and water facilities, or improvements to energy, water, and other infrastructures. For example, past investments in the water infrastructure by creating dams and surface-water reservoirs in the U.S. have significantly improved water availability. Increased competition for water resources among different users will grow; ways to reduce these conflicts through coordinated infrastructure and policy development would be beneficial.

Due to emerging trends in energy and water resource availability and use, the U.S. will continue to face issues related to natural resource planning and management. Available surface water supplies have not increased in 20 years, and groundwater supplies are decreasing. Ensuring ecosystem health will further constrain freshwater supplies. At the same time, continued population growth and migration to areas with already limited water supplies will likely create both water and energy shortages, at least on a sporadic basis, particularly in the arid Southwest and in the Southeast. Based on current water markets and values, the growth in energy demand, along with stricter environmental regulations on cooling water withdrawals, could double water consumption for electric power generation over the next 25 years, consuming as much additional water per day as would be used by 50 million people or more. Additionally, changes in energy strategies in the electricity and transportation industries could further increase water consumption and the value of freshwater supplies.

A continual assessment of regional and national energy and water issues and concerns and the identification of appropriate interactions and coordination approaches with federal and state energy and water agencies will become more necessary. Further, we must address energy and water-related issues surrounding adequate energy and water supplies as well as the optimal management and efficient use of both energy and water.

Finally, most of these systems are not redundant; that is, they have no back up. The failure of any one of these systems could be potentially devastating from a resource, human health, and economic perspective. Therefore, a broad, all-hazards approach to protect these systems from terrorist attacks such as cyber hacking, bio-attack, and other, as well as additional natural and technological hazards, is a necessary and substantial part of the policies implemented to ensure the sustainability and security of energy and water systems. Broad participation will be necessary from user communities, policy and regulatory groups, economic development organizations, industry associations, government agencies (federal, state, tribal), and many others to help address problems and develop and implement good-use policies.