Water Policy 17 (2015) 1163–1175

The electricity–water nexus: is a crisis imminent?

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Abstract

Several recent studies have warned that there will be widespread water shortages in many regions of the USA in the near future largely because of high demand for water in the production of electricity. This study reviews studies addressing electricity generation and water availability and concludes that electricity production is not likely to lead to water shortages in most regions for several reasons. First, the alarmist studies erroneously rely on water withdrawals rather than water consumption to measure gaps between water demand and supply. Second, these studies fail to account for market dynamics, which will lead to improvements in greater water recycling and reuse as well as new resources on the supply side, and conservation and improved efficiency via new technology on the demand side. Electricity is increasingly generated by low water use technologies such as solar and wind. In addition, fossil-fired power plant technologies exist that greatly reduce water withdrawals and consumption. As water prices rise in the face of tighter supplies these technologies will become more attractive. Third, policies designed to overcome market failures related to pricing regulation, water rights, and government boundaries can reduce, if not eliminate, widespread electricity and water shortages.

Keywords: Energy–water nexus; Water demand; Water economics; Water markets; Water policy; Water supply

1. Introduction

A number of studies published in the last few years anticipate a water crisis in many regions of the United States driven primarily by electricity generation water demand (Sovoacool & Sovacool, 2009; Avery *et al.*, 2011; Roy *et al.*, 2012). A careful review of these studies and other studies addressing the so-called energy–water nexus, however, indicate that a crisis is not at hand in most if not all of these regions even accounting for potential droughts attributed to climate change. These 'crisis' studies reflect similar metrics or assumptions that explain their somewhat alarmist conclusions. First, they all focus on water withdrawals rather than water consumption as the basis for measuring water demand. Second, they all assume no water demand or supply side response to rising water prices that are

doi: 10.2166/wp.2015.060

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likely to accompany growing water scarcity. Third, they do not account for changing technologies prompted by expected relative energy prices and public policies that affect both water supply and demand. As discussed below, focusing on water consumption rather than withdrawal and accounting for both demand and supply responses to rising water prices related to scarcity, greatly diminishes or eliminates the likelihood of water shortages and electricity blackouts.

2. The electricity–water nexus

A great deal of attention has been paid to the relationship between electricity generation and water supply especially in the face of recent drought conditions in various parts of the country and projections of reduced rainfall attributed to climate change. In a few instances power plant operations have been constrained by water shortages and proposed power plants have been delayed or rejected over water concerns. Electricity generation is often identified as a very large water consumer suggesting that future water shortages will result in substantial constraints on electricity production. At the same time, water supplies require electricity for treatment, pumping, and conveyance. Thus, the specter of simultaneous water and electricity shortages arises.

This fear, however, is misplaced. The nexus between water and electricity is relatively modest. Electricity generation does not demand a particularly large share of water supply. As shown in Figure 1, electricity accounts for only 4% of US water consumption. Only when water withdrawal is considered, does electricity generation appear to represent a large share of water use. As shown in Figure 2, electricity accounts for 49% of withdrawals. This is misleading because as much as 96% of water withdrawn by power plants is returned to the water supply.

Reliance on withdrawals to estimate water supply stresses is problematic. To the extent withdrawals are relevant, the crisis studies do not take into account how water networks operate within a given watershed to realistically determine whether a water shortage will occur. In brief, the order of withdrawals

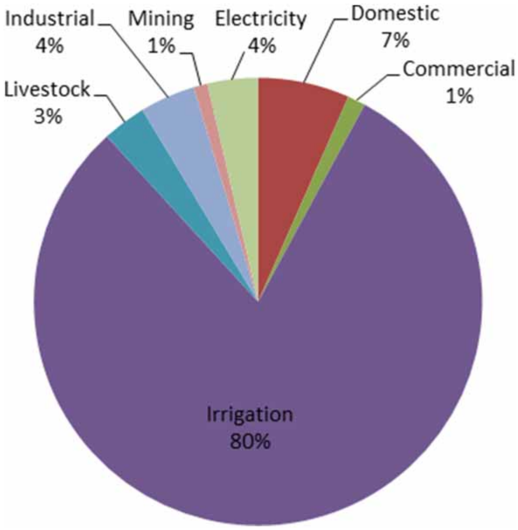

Fig. 1. US water consumptive use by source, 1995. *Source:* Solley *et al.* (1998).

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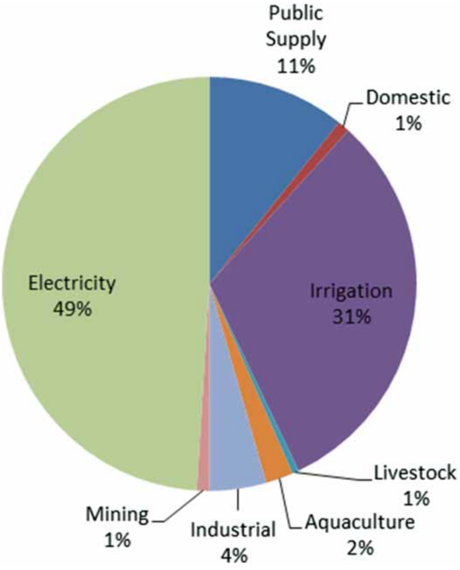

Fig. 2. US water withdrawals by source, 2005. *Source:* Kenny *et al.* (2009).

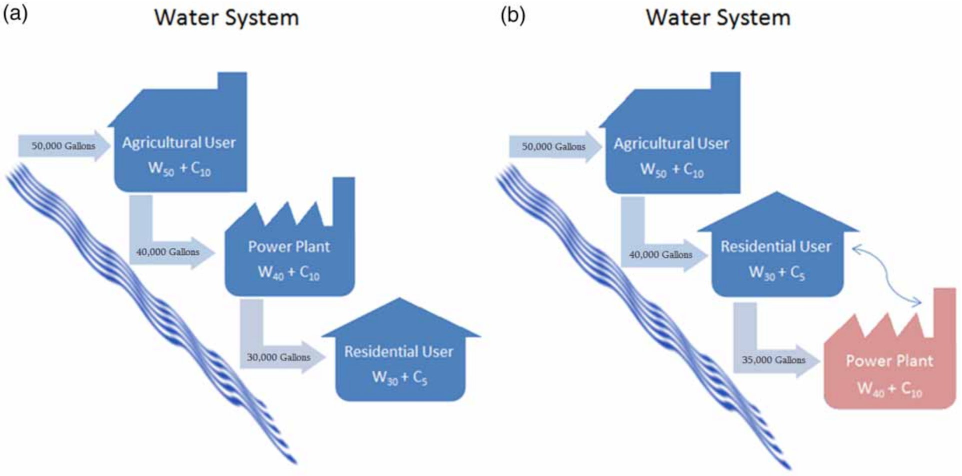

Fig. 3. Location matters in determining water withdrawal constraints.

matters. To see this, one can consider two very simple watersheds with exactly the same water supply of 50,000 gallons[1] from a single river, and three users with similar withdrawal and consumption characteristics in each watershed (here representing the agricultural, thermoelectric, and residential sectors), as illustrated in Figure 3. The only difference in the two watersheds is the order in which these users draw water from the river. Despite identical total withdrawals one watershed has sufficient water to

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[1] US gallon = 3.79 litres.

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meet demand, the other does not. In the first watershed, the agricultural user is located up river and withdraws 50,000 gallons and consumes 10,000 gallons, returning 40,000 gallons to the river. A power plant is located mid-river, withdrawing 40,000 gallons, consuming 10,000, and returning 30,000 gallons. Thus, downriver of the power plant, there are 30,000 gallons available, meeting the residential user's requirements so that no water user is constrained. In the second watershed, however, the power plant and residential user switch positions along the river. In this example, after the residential user's consumption mid-river, only 35,000 gallons remain for downstream use by the power plant, leaving it unable to meet its demand of 40,000 gallons. Although obviously oversimplified, this example reveals that stress on water supplies is partially dependent on the organization of users within a water network. Calculating total withdrawals alone is insufficient to accurately diagnose water supply stresses. Not surprisingly, state water planners consider water consumption rather than withdrawals when establishing water availability. This is not to say that for any given water system withdrawals will not pose constraints on access, but that any broad assessment of water shortages will be misleading if it relies on withdrawals as the key measure of water demand.

It is also important to consider the other side of the nexus – the demand for electricity by water suppliers. This demand is modest on a relative scale. Even in California, where long distance conveyance is much more extensive than most other states, water-related electricity demand accounts for 19% of total electricity consumption[2]. This figure, however, accounts for electricity for the entire water cycle, which includes pumping, treatment, conveyance, distribution, and waste water treatment, as well as residential, agricultural and industrial end use. Electricity for supply, treatment, and conveyance accounts for only about 4% of state electricity demand.

Finally, students of the nexus have also raised concerns regarding water use in fossil fuel extraction. Water use related to coal mining and water used in natural gas fracturing have been cited as important sources of water demand. The evidence, however, does not support this. Overall demand for water for energy resource extraction is very modest, under 10% of US water consumption. Mielke *et al.* (2010) report that coal mining water consumption averages 2.6 gallons/mmbtu[3], conventional natural gas well consumption is near zero, and shale gas consumption averages 1.3 gallons/mmbtu. Although Freyman (2014) concludes that over half of the oil and gas wells associated with fracking are in water stressed locations, there is reason to consider this an overstatement. First, as noted by Kimball (2013) the study relies on water withdrawals not consumption. Second, the study relies on county level comparisons even though water suppliers rarely conform to county borders. For example, a recent study of fracturing demand in Texas (Nicot & Scanlon, 2012), a major source of shale gas production, found that water consumption represented less than 1% of water demand at the state level. The study noted that the fraction of water demand in smaller regions was higher, but also noted that greater reliance on brackish water and less water intensive technologies would allow further shale gas production even in these regions. Thus, overall water demand for resource extraction will fall as the generation mix shifts from coal to natural gas and renewables.

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[2] California's water supplies are located primarily in the northern part of the state, while the largest share of water demand is accounted for in the south (California Energy Commission, 2005). Extensive pumping is required to move this water from north to south.

[3] mmbtu = million British thermal units = 1,055 joules.

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3. Demand side responses to water scarcity

The demand for water by its various users – electricity generators, households, agriculture, and environmental habitats – is dynamic by nature. Changing prices, input costs, technology, and climate all influence the magnitudes and patterns of water demand. Failing to account for demand responses from these users when determining whether a serious gap between water supply and demand will arise, will lead to poor investments and public policy. Potential responses are described below.

3.1. Electricity generation and the demand for water

In forecasting future developments in the electricity–water nexus, it is important to consider the economic behavior of power plants as water prices rise. As the US Department of Energy found in 2006, commercially available power plant technologies already exist that demand substantially less water than most existing plants[4]. Limits on deployment of these technologies are primarily economic. Consequently, as water prices increase and water supply uncertainty grows, these technologies will become more widely employed. This fact has been demonstrated in recent analyses and is not lost on electric utilities in their development of future resource plans. Lower natural gas prices will also reduce water demand as natural gas-fired plants replace existing coal-fired plants. Dry-cooled natural gas technology is available at costs similar to conventional wet systems, but uses very little water. Dry process natural gas plants withdraw only about 2 gallons of water per MWh compared to 11,389 gallons for combined cycle natural gas plants with once-through cooling and 36,350 gallons for generic coal plants with once-through cooling. Water consumption savings are notable as well. A dry-cooled combined cycle natural gas plant consumes only 2 gallons per MWh while a generic plant with once-through cooling consumes 100 gallons. Its higher capital costs and slightly reduced performance do not translate to a large difference in levelized costs. Stillwell & Webber (2013) found that at current capital and water prices less water intensive cooling was economically justified in 3 of 39 existing plants in Texas. They also found that more existing plants would find alternative cooling technology attractive as water prices and concern over availability increase.

The lower performance of the dry-cooled plant is offset by lower water demand and cost. There is a roughly $13 million difference in net present value (NPV) between the plants owing to the higher capital costs for dry cooling, which slightly reduces the return on investment, or necessitates a slightly higher energy price. The NPV difference will also decrease as water prices rise. Dry cooling is already making inroads, especially in the western USA where there are at least 11 power plants currently employing the technology (Cooley *et al.*, 2011).

Renewable energy plants also do not typically require large amounts of water for withdrawal or use. Table 1 reveals that these technologies, as well as dry-cooled natural gas, operate with little or no water consumption by comparison to standard technologies. The role of renewables in meeting electricity demand is steadily increasing. The Energy Information Administration (EIA, 2012) long-term forecast expects that generation from renewables will grow 77% by 2035, accounting for 15% of total demand. This increased reliance will help reduce water demand from electricity production considerably. In

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[4] The US Department of Energy in its 2006 report to Congress, observed that, ‘Technologies are available that can reduce water use in the electric sector including alternative cooling for thermoelectric plants, wind power, and solar photovoltaics, but costs and economics, among other factors have limited deployment of these technologies’ (US Department of Energy, 2006, p. 10).

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Table 1. Water withdrawal and consumption rates for electricity generating technologies.

			Water withdrawals (gal/MWh)			Water consumption (gal/MWh)		
Fuel type	Cooling	Technology	*Median*	*Min*	*Max*	*Median*	*Min*	*Max*
Natural Gas	Once-through	Combined Cycle	11,380	7,500	20,000	100	20	100
	Dry	Combined Cycle	2	0	4	2	0	4
Coal	Once-through	Generic	36,350	20,000	50,000	250	100	317
Nuclear	Once-through	Generic	44,350	25,000	60,000	269	100	400
PhotoVoltaic	N/A	Utility Scale PV	–	–	–	26	0	33
Wind	N/A	Wind Turbine	–	–	–	0	0	1

Source: Macknick *et al.* (2011).

addition, as shown in Table 2, coal plant closures will also reduce water demand for electricity generation.

A recent study by the Pacific Institute demonstrates how demand responses by electricity producers can avoid any serious water shortages by 2035 through conversion to dry cooling, expansion of renewables, and increased electricity conservation and efficiency improvements (Cooley *et al.*, 2011). Its authors take EIA's electricity generation projections and determine the current water cooling system technology in use at thermoelectric power plants for the Intermountain West[5]. Current technologies are used to forecast base case water demand level, assuming all power plant additions will rely on cooling systems in the same proportions assumed today. Several scenarios are then developed to compare to the base case, assuming various levels of conversion to dry-cooling technologies and expanded use of renewable energy through 2035.

The study concludes that even under current trends, water withdrawals and consumption increase very little by 2035. Under the increased dry cooling and expanded renewables scenarios, water withdrawals and consumption fall substantially. Water withdrawals in 2010 of about 2,000 million gallons per day (MGD) fall to about 1,500 MGD in 2035 with 25% conversion to dry cooling, and to under 1,000 MGD under the expanded renewables scenario. Likewise, water consumption of roughly 375 MGD in 2010 falls to just over 300 MGD in 2035 with 25% conversion to dry cooling, and less than 250 MGD assuming expanded renewables use. Conversion to dry cooling combined with expanded renewables decreases water withdrawals and consumption even further. In addition, the authors note that these results do not factor in increased water supply potential from reliance on brackish water and recycling.

The assumptions behind these potential outcomes are reasonable. The economics of water-cooling technology make dry cooling an increasingly attractive option, especially if water prices are expected to rise. Natural gas capacity is already replacing coal-fired capacity to meet electricity demand growth, and many coal-fired plants are expected to retire over the next decade or so as more stringent air quality and greenhouse gas regulations are imposed and plants age out. Electricity price increases reflecting these investments will serve to encourage energy conservation as well.

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[5] The Intermountain West region covers Arizona, Nevada, Idaho, and parts of New Mexico, Colorado, Wyoming, Montana, Washington, and California.

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Table 2. Projected changes in electricity generation technologies will significantly decrease water consumption by 2035.

Technology	Projected additions (GW)	Projected retirement (GW)	Net capacity change (GW)	Water consumption (gal/GWh)	Capacity factor	Change in consumption (millions of gallons)
Coal	11	49	−38	250,000	0.85	−70,737
Oil and Natural Gas Steam	0	20.3	−20.3	240,000	0.87	−37,130
Combined Cycle	74.5	0.2	74.3	2,000	0.87	1,132
Combustion Turbine/Diesel	46.5	12.4	34.1	240,000	0.3	21,508
Nuclear	8.6	6.1	2.5	269,000	0.9	5,302
Renewable Sources	44.5	0.4	44.1	26,000	0.25	2,511
					TOTAL	−77,414

Source: EIA (2012).

Other studies have also determined that electricity generation is not likely to be constrained by water availability. Webster *et al.* (2012), modeling the ERCOT electric reliability region defined by Texas, concluded that electricity demands by 2050 can be met even in the face of water and carbon emissions constraints with modest price increases except under very stringent constrains. Ackerman & Fisher (2013), modeling the western USA under carbon emissions and water limits, found that 'electricity planning is central to climate policy, but much less so to water planning'. Their modeling exercise indicated that water is only a constraint in meeting electricity demand if nuclear power is necessary to meet very stringent CO_2 limits.

Finally, electric power producers will respond to higher water prices in plant location decisions. New plants will be located where water is cheaper and more plentiful and less water intensive existing plants will be dispatched first. Power generators already consider water price and availability in regions with tight water resources. Pacsi *et al.* (2013) demonstrated that changing the location of electricity generation to meet drought conditions would have been feasible in Texas during the 2006 drought. The authors found that 'drought-based' electricity dispatch would have been expensive, but would have provided a rapid response.

3.2. Demand response from the residential sector

Over time, significant water conservation gains have been realized by the residential sector as the result of price increases and regulation. A survey of hundreds of local utilities spread across the USA found that over a 30-year period from 1978–2008, residential demand in single-family homes fell by 13.2%, the equivalent of 11,673 gallons per household (Coomes, 2010).

Much of this decline can be attributed to changes in the efficiency of water fixtures and appliances in the home. A study at the local level found that the introduction of efficient appliances accounted for a 16% decline in average residential water use over a 20-year period. The change in consumption due to technological advances in efficiency is highlighted by changes to the reported end uses of domestic water over the last decade. According to 1999 data from households in 12 Western communities, toilets and clothes washers account for roughly 50% of residential usage (Mayer & DeOreo, 1999). By 2010, a study of the average new single-family home in California found that the proportion of water dedicated to those end uses had fallen to under 10% (Consol, 2010). A substantial amount of this conservation has been encouraged by political and regulatory changes, notably by updates to federal water efficiency requirements enshrined in legislation such as the 1992 Energy Policy Act and the Energy Independence and Security Act of 2007.

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Economic incentives have also been shown to impact residential water use. During California's drought from 1987–1992, many urban areas used pricing changes to encourage cutbacks of 15–30% in total water usage (Pint, 1999). Dramatic increases in prices in Santa Barbara over that period resulted in water use reductions as high as 62%. A meta-analysis of close to 300 different price elasticity estimates found that a doubling of water prices would be expected to reduce use by roughly 41% (Dalhuisen *et al.*, 2003).

3.3. Demand response from the agricultural sector

Agriculture comprises the single largest demand for water in the USA, accounting for over 80% of all consumptive use (see Figure 1). While thermoelectric power accounts for larger water withdrawals than agriculture, almost 98% of thermoelectric withdrawals are returned to their source and are not consumed. Given the agricultural sector's dominance in US total water consumption, even relatively small agricultural conservation measures offer the opportunity for outsized impacts on regional water scarcity. Through innovation and adoption of improved irrigation technologies, many significant opportunities for conservation have already been identified, and historical trends reflect increasing efficiency gains in the application of irrigation water.

With an average application rate of 1.4 acre-feet (AF)[6] annually, sprinkler and drip irrigation systems are considerably more efficient than gravity systems, which average 2.4 AF (Schaible & Aillery, 2012). Over time, there has been a pronounced shift from less efficient gravity systems to pressurized sprinkler systems. In 1984, 71% of all applied irrigation water in the western USA was applied with gravity systems. By 2008, use of gravity systems had fallen to just 48%. Over that 1984–2008 time period, total irrigated acreage in the West grew by 2.1 million acres[7], but total water use fell by 100,000 AF annually.

In addition to technological advances in water delivery systems, significant conservation opportunities exist in the use of improved 'production systems' that help land managers make better water management decisions. At the current time, fewer than 10% of all farms take advantage of advanced irrigation management tools which allow for monitoring of water application needs and irrigation timing at the field level. Future adoption of technologies such as soil and plant moisture sensing devices, irrigation scheduling services, and crop simulation models will allow for further gains in conservation.

Moreover, future agricultural conservation measures need not be constrained by technological innovation. The use of marginal-cost based pricing or other economic incentives to encourage decreased agricultural water application rates can be viable tools in situations of increasing water scarcity, as agriculture typically has the lowest marginal value of water relative to that of competing energy and other out-of-stream demands (Huffaker & Whittlesey, 2003).

4. Supply side responses to water scarcity

4.1. New water supplies: prospects for desalination, recycling, and waste water

The studies warning of insufficient water to meet energy demands also fail to consider alternative water supply sources. These sources include desalination, reliance on brackish water, and recycling.

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[6] 1 acre-foot = 1,233.5 m^3.

[7] 1 acre = 4,047 m^2.

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All three of these sources are already in use and have the potential to provide substantial increases in water supply for residential, thermoelectric, agricultural, and industrial uses.

4.2. Desalination

Desalination plants have been growing as a source of water in the United States and elsewhere in the world. Capacity in the USA has grown from less than 2 million m^3 per day in 1980 to 5.7 million m^3 in 2005 (NRC, 2008). Worldwide desalination capacity has grown even more rapidly, reaching about 42 million m^3 per day in 2008. To date, much of the US capacity relies on inland saline or brackish water sources. Coastal plants using ocean water accounted for only 8% of domestic capacity in 2005, but this capacity is expected to grow. As of 2012, 17 ocean projects were currently under consideration in California alone (Cooley *et al*., 2012). If constructed, they would account for between 5 and 7% of average state water demand over the period from 2000 to 2005.

Desalination plants are already competitive with other water supplies in some regions and will become more attractive as water prices increase. The National Research Council (NRC) concluded in its 2008 review of desalination that:

> *'Recent advances in technology, especially improvements in membrane, have made desalination a realistic water supply option. The cost of desalinating seawater in the United States is now competitive with other alternatives in some locations and for some high value uses'* (NRC, 2008).

As water costs rise with increased scarcity from conventional sources, desalination will become more attractive in more locations.

Two constraints on more rapid deployment of these plants involve energy and environmental concerns. Energy costs represent a substantial share of operating costs. Thus, rising electricity prices – partly because of higher water prices – could limit plant economics. However, solutions to this problem are available in the form of increased reliance on power sources such as co-generation, solar, and even landfill methane (Karagiannis & Soldatos, 2008).

The chief environmental concerns with desalination depend on whether the water supply is coastal water or an inland aquifer. The primary concern for coastal desalination plants is impingement and entrainment of marine organisms. Impingement refers to trapping of fish and other large organisms during the water intake process. Entrainment refers to the killing of small marine organisms (plankton, fish eggs, etc.) from high temperature and pressure as they are pulled through the desalination plant. These problems can be reduced by proper intake location and intake pipe design, the use of filters, and shutdown during periods of potentially greater risk of damage. The chief environmental concern for inland desalination plants is resource sustainability and land subsidence. Subsidence occurs when withdrawals exceed recharge rates, but this problem is site-specific and can be avoided using available modeling tools.

Environmental water quality changes associated with the discharge of concentrate and chemicals used in the desalination process is a source of concern regardless of whether the water supply is coastal or inland. Studies of existing facilities present mixed findings on the magnitude of this problem. Again, proper management can help alleviate this concern. The NRC concluded in its 2008 review that although there are some environmental uncertainties regarding desalination, they are not sufficient to block desalination development (NRC, 2008). The National Academy of Sciences (NRC, 2008) also concluded that desalination of both brackish and seawater sources are likely to have a role in meeting future water needs in the United States.

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While water supply availability is not a problem for coastal desalination facilities, it may limit increased reliance on desalination inland. Several inland water supply sources, however, may become economically feasible as water prices rise. Return flow from irrigation is one possible source. Co-location with power plants to take advantage of cooling water discharge is another potential source, as is co-location with natural gas fracking operations. Brackish groundwater supplies can also be employed. Given the options, desalination represents a very large potential water source.

4.3. Recycling as a water source

Recycling is already providing the means to expand water supply through treatment and secondary use. Non-potable water is currently used for irrigation and other non-drinking uses including power plant cooling, and is a highly developed water source in Israel and Spain. The western states have also recognized the potential for re-use and it is common in several states (Bracken, 2012). The Palo Verde Nuclear Generating Station in Arizona successfully uses municipal waste water from Phoenix for cooling purposes. To use non-potable water, a separate distribution system is required. The necessary piping is distinguished by different coloring and is often referred to as ‘purple pipe’ to distinguish its contents from potable water. A proposed new residential community near Barstow, California, included a dual piping system that would recycle water to not only provide irrigation for landscaping, but also to create a small lake for recreational use[8].

Recycling can also provide potable water. Indirect potable use typically involves a two-step process. First, water is treated to remove impurities before secondary discharge into an environmental buffer. The buffer is typically an aquifer that provides natural cleaning. Studies reviewed by the National Research Council (NRC, 2012) indicated that the resulting water is as safe, if not safer, than some current drinking water supplies. The Academy also determined that water reuse could contribute significantly to US water supply. In addition, there is already unplanned indirect potable use in the United States. On some river systems including the Mississippi, downstream municipalities treat river water for drinking after upstream municipalities have discharged treated sewage water into the river system. The Academy recommends a systematic study of this indirect potable use and its consequences, but the lack of reports of serious or persistent drinking water quality problems suggests that current treatment systems are sufficient. In fact, the Academy determined that direct treatment without the use of environmental buffers was capable of producing safe drinking water. As noted by the Academy, reusing the 12 billion (12×10^9) gallons of waste water discharged to oceans and estuaries in the United States alone would greatly enhance available domestic water supply.

The prospects for power plant cooling using municipal wastewater as well as irrigation return flows, brackish water, and seawater are good. An Argonne National Laboratory study completed in 2007 identified 50 power plants already using municipal waste water (Veil, 2007). A California Energy Commission study of salt water cooling likewise found it an attractive approach (Maulbetsch & DiFilippo, 2010). The study did find that salt water cooling was generally more costly than freshwater cooling because of decreased plant performance and the requirement for slightly larger cooling towers, but did not find any serious environmental concerns. The cost differential did not reflect the potential for rising freshwater costs as supplies become constrained.

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[8] The project proposed by SunCal was mothballed because of the collapse of the housing market in 2007.

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5. Policy implications

A review of water planning efforts in states facing water supply challenges reveals that electricity generation demand is not a primary source of concern, but that infrastructure (reservoirs and conveyance), conservation (especially agriculture) and regional cooperation are of primary concern[9]. Policies and regulations can help address these challenges by eliminating what are primarily market imperfections. Setting water prices to reflect scarcity will go a long way to promote more efficient use by all sectors. Pricing has long been advocated by economists studying water supply and allocation issues to better balance supply and demand (Turvey, 1976; Olmstead & Stavins, 2008; Mansur & Olmstead, 2011). This will require changes in traditional rate making by public utility commissions and pricing by private water companies. Water prices will rise in many parts of the country. As a consequence, power plant technologies investments, crop selection and irrigation investments, and household water conservation investments will be influenced. Equity considerations regarding the latter can be accommodated. Tiered or block pricing, for example, can ensure that households can meet basic water needs at low prices (Chan, 2012). Additional regulations to limit water demand growth may also be required. California has already imposed restriction on new housing developments. Developers must secure sufficient water supply to obtain building permits. Similar restrictions may make sense elsewhere. Water market expansion and improvements will improve the transfer of water from low value to high value uses (Hansen, 2010). Again California has promoted market development and these markets are likely to help manage supply limits imposed by the 2014 drought (Brewer *et al.*, 2008). The development and use of these markets face obstacles including transaction costs associated with complex water rights. Legislative or regulatory changes may be necessary to bring clarity to water rights. In addition, development of water and planning agencies that better reflect water basins than political jurisdictions will help avoid conflicts with respect to water rights that currently interfere with the most efficient use and management of water resources. Saliba (1987) noted that an alternative to new agencies is increased reliance on inter-jurisdictional agreements such as interstate compacts and tribal settlements.

6. Disclaimer

The opinions expressed here are the author's and not necessarily those of other Brattle Group principals. The research reflected here received no external funding.

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[9] The State planning documents reviewed include those of Arizona (Arizona Department of Water Resources, Commercial, Industrial, and Institutional Home Page, undated), California (CPUC, 2005, 2010), Georgia (Water Council, 2008), and Texas (TWDB, 2012).

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Received 2 April 2014; accepted in revised form 31 March 2015. Available online 8 May 2015

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