Quantifying the Water-Energy Nexus at the Building Project Scale

Understanding Water Consumption Associated with Electric Energy Generation and Use

Prepared by:

New Buildings Institute

Mark Frankel

Kevin Carbonnier, PhD

June 2017

Prepared for:

Edwards Mother Earth Foundation

TABLE OF CONTENTS

FIGURES AND TABLES

EXECUTIVE SUMMARY

The water-energy nexus is a nascent topic in the building industry. The impact on water systems linked to energy generation has important ecological, conservation, and sustainability implications, particularly in water-strained areas such as the southwestern desert of the United States. In the vast majority of power plants in the United States, water provides a cooling source to condense steam in traditional thermoelectric power generation. This process requires various amounts of water depending on several factors, including the age of the plant, the fuel consumed, and others. In this report, we focus on the consumed water used for power generation. Consumed water is primarily lost to the atmosphere due to evaporation, most commonly from a cooling tower or from a reservoir's surface evaporation.

We have laid the groundwork to connect the water-energy nexus at the power plant with the energy consumed at the building level in four broad steps:

- Quantify the water cost of energy consumption at the building level as Gallons/kWh
- Create a calculation tool to compare water savings at the power plant from energy efficiency to building level water conservation savings
- Generate a state-by-state impact study for two sample buildings, an office and a school
- Identify next steps to align water and energy conservation efforts

The water cost of energy consumption ranges from about 0.25 to 0.75 gallons per kWh, depending on the state. One large factor is hydropower, which loses large quantities of water to surface evaporation in the reservoir. For this reason, the Pacific Northwest is particularly water intensive.

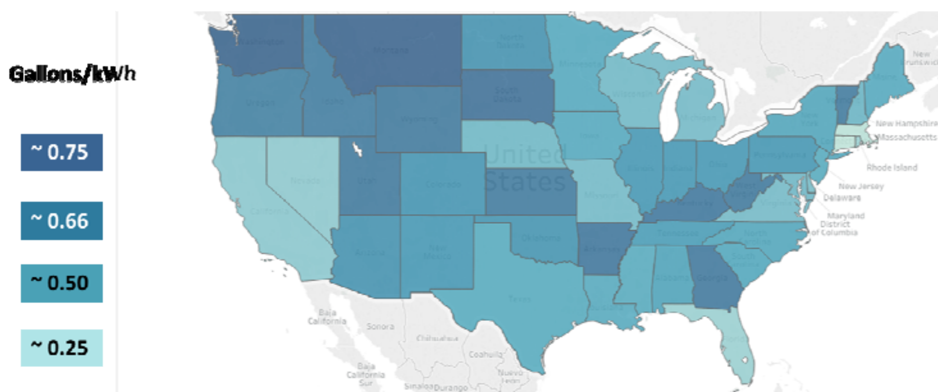

Figure 1: Water Intensity of Energy Generation in the US by State

For new office buildings saving 20% energy and 20% water over modern energy codes, the water-energy savings from efficiency are on the same order of magnitude as the building-level water savings. In some states, the water-energy savings even outweigh the building-level water savings. Energy savings in less efficient existing buildings with cost-effective energy retrofits can have a large impact on the overall water consumption for the region.

By quantifying the water cost of energy consumption and creating a tool to calculate those costs at a building level, we have created an opportunity to evaluate the impact of buildings at a large scale, which can connect energy and water conservation efforts, particularly in areas with historical or anticipated water constraints.

UNDERSTANDING THE RELATIONSHIP BETWEEN WATER AND ENERGY PRODUCTION

Using Water to Generate Electricity

Many people have heard the term *water-energy nexus*, but few realize the vast scale of water resources needed in this country to support the generation of electricity, or the deep interconnections of the water and energy sectors. The amount of water diverted each year for power generation is approximately equal to the amount of water used for agricultural irrigation. There are many aspects to the connection between water and energy, but the main linkage is the need for vast quantities of water to provide cooling for thermoelectric power generation. Nearly 90% of the electricity generated in the US is generated at thermoelectric power plants, which use various fuels to create steam to drive turbines. At these plants, the steam must be condensed and cooled before it can be used in the turbines again, and at nearly every plant this cooling is provided by vast quantities of water.

In the early years of the development of the electrical generation industry, plants were located adjacent to large water sources to simplify the withdrawal of large quantities of cooling water to serve the power plant. The majority of these older plants use 'once-through' cooling where water is withdrawn from a lake or river, pumped across hot steam pipes to condense the steam, and returned to the river or lake from which it was withdrawn. The returning water is significantly warmer than it was when it left the river, but only a small amount of water is evaporated in this process, so the return flow is nearly equal to the amount withdrawn. While this process may have adverse impacts on the ecology of the river due to temperature and water quality changes, once-through cooling does not significantly reduce the amount of water in the river or lake compared to other cooling strategies discussed below. The majority of power plants in the eastern US, especially older plants, use once through cooling. This type of water 'use' is referred to as **withdrawal**, meaning the water is withdrawn from its source, but then most of it is returned to the original water body. Figure 2 shows the extent of water withdrawals supporting thermoelectric power generation in the continental US.

It should also be noted that nearly a quarter of all once-through thermoelectric cooling systems utilize seawater, rather than freshwater sources.

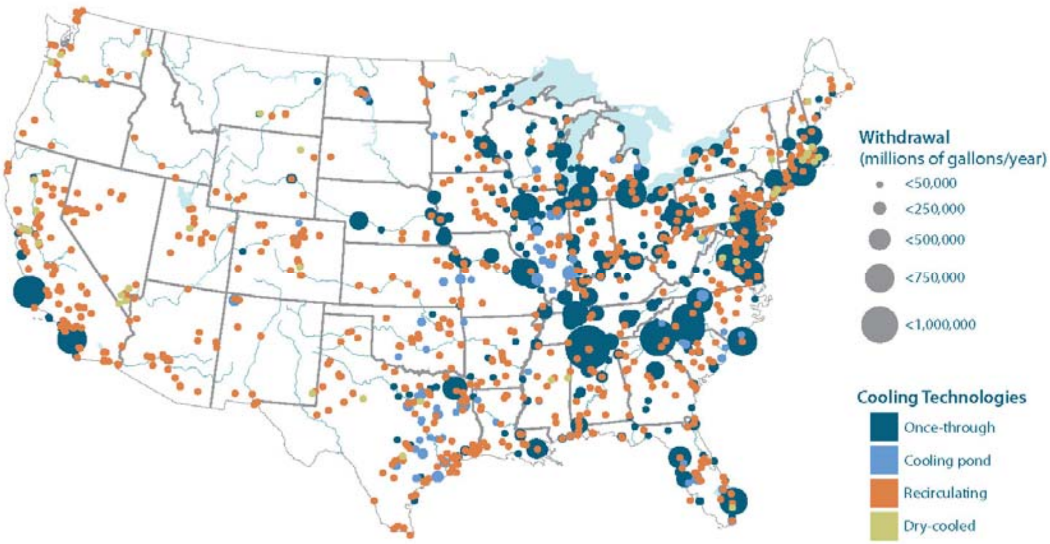

Figure 2 – Water Withdrawals for Power Generation. From: Freshwater Use by U.S. Power Plants; Union of Concerned Scientists, 2011

In newer power plants, and those not able to locate nearby water surplus, cooling is provided by a variety of 'closed loop' cooling systems. Closed loop cooling is a much more common configuration in the western US and in newer power plants. There are a range of technologies deployed in power plants with closed loop cooling, with different water consumption characteristics, but the common characteristic is that in closed loop cooling, the same water is used repeatedly in an evaporative system to cool steam lines, significantly reducing the amount of water that needs to be diverted from surface water sources to the plant. Typically the cooling water is held in large towers or vessels, and evaporation is used to reduce the temperature of the cooling water so it can be recirculated to cool the steam system. Since this process relies on evaporation, a significant amount of water is lost from the system to the atmosphere. This process represents **consumption** of the cooling water, since it is not returned to the basin or water source from which it was extracted. Though closed loop systems utilize only a fraction of the water that open loop cooling requires, these systems end up removing much more water from the water basin through evaporation than open loop systems. It is perhaps ironic that closed loop cooling is deployed in response to general water scarcity, and yet it results in significantly more water consumption and a reduction in basin-level water resources.[1] This project is focused on evaluating the water consumption impact of power consumption, and relating this directly to water and power consumption patterns in buildings.

A very small percentage of thermoelectric generating plants use a third type of cooling system called dry cooling. As the name implies, these plants use air to cool the steam instead of water,

[1] Older power plants, with older cooling technologies needed large quantities of cooling water. Newer cooling technologies require smaller volumes of water diversion, relying instead on evaporation strategies to cool the plant. This has given more flexibility to locate plants in geographic areas with less water availability such as the Western US.

and have very little impact on water consumption. However, these plants tend to pay a penalty on the efficiency of plant operation, using more fuel to generate a comparable amount of electricity to water cooled plants. Most plants using dry cooling technology are natural gas-fired, since that generation technology is better able to incorporate dry cooling strategies than others. Dry cooling remains a very small percentage of the total generating capacity.

The vast majority of new power plants rely on water circulated in closed loop cooling systems. Upgrades and replacements of existing plants in the eastern US are also moving increasingly to closed-loop cooling and away from open loop cooling. This has the effect of generally increasing overall water consumption, even as the amount of water diverted to power plants through withdrawal may be decreasing.

Hydropower

Although hydropower is generally considered a benign and renewable source of electricity, hydropower dams also have an impact on water consumption. Hydropower represents a relatively small percentage of U.S. electrical generating capacity (6%), but this energy source has a surprisingly large impact on water consumption, especially in some regions. Eight states generate more than 25% of their electricity from hydropower, as seen in Table 1 below. In these states the impact of hydropower water consumption is substantially magnified compared to the rest of the country. There are many factors that affect the relationship between power generation and water use at hydropower facilities, and quantifying the impact of hydropower generation on water resources is significantly more complicated than with thermoelectric power generation.

Table 1: Hydropower Represents More Than 20% of the Generating Resource in Eight States

States With Significant Hydropower	
State	**Percent of Grid**
WA	67%
VT	57%
ID	56%
OR	54%
SD	50%
MT	34%
ME	29%
AK	25%

Water consumption at hydropower dams is related not to the dam or the water flowing through the turbines themselves, but to the size and configuration of the reservoir behind the dam and the climate in which it is located. As with all water bodies, reservoirs lose a significant quantity of water each year to evaporation, as well as to ‘bank seepage’ into the ground around the reservoir. In both of these cases, the water is not necessarily ‘lost’ but it is removed from the river system and therefore not available to meet surface water (and power generation) needs downstream. (Note that some portion of the water lost to bank seepage may re-enter the river basin through springs and seeps downstream of the dam. This is nearly impossible to quantify.)

In the Colorado River system, the impact of water loss at the hydropower dams at Lake Powell and Lake Mead have been extensively studied. Glen Canyon Dam (Lake Powell) and Hoover Dam (Lake Mead) were built to manage river flows and to generate electricity. Because both dams impound large reservoirs located in hot dry portions of the desert southwest, water loss to evaporation from these reservoirs is significant. Calculations and observations of evaporation rates suggest that Lake Powell loses over 5 vertical feet of water to evaporation each year, while Lake Mead loses up to 7 feet. At Lake Powell, this translates into roughly half a million acre feet of water per year evaporated out of the basin. (An acre-foot is the amount of water it would take to cover one acre of land with water to a depth of one foot. This is equivalent to 325,851 gallons of water.) An additional third of a million acre feet seeps into the bedrock below the lake each year. In total, Lake Powell is estimated to lose over 850,000 acre feet each year; an amount roughly equivalent to the annual water use of the City of Los Angeles.

Lakes Powell and Mead are well documented examples of the impact of reservoir evaporation, but this issue is common to all impoundment reservoirs. In dry areas of most western states evaporation rates range from 40 to 90+ inches per year from exposed surface areas, representing a significant source of water loss in western water basins. Estimates range widely on the quantity of water lost in association with hydropower generation, from a low of 0.25 gallons per kWh generated, to a high of over 30 gallons/kWh, with 4.5 gallons/kWh generally considered to be the national average by some sources. Even at the low end of this spectrum, water loss to evaporation at hydropower facilities creates a significant relationship between power generation and water consumption. Figure 3 below shows the average annual evaporation, in inches, from water bodies in the continental U.S.

Since reservoirs generally serve multiple purposes, including power generation, storage, recreation, flood control, and irrigation, there is also wide ranging disagreement on how much evaporative water loss should be attributed directly to the power generation functions of hydropower plants. It should also be pointed out that reservoir evaporation occurs whether power is being generated or not. In any case, it should be recognized that hydropower dams have a direct impact on water supply due to the evaporation and bank seepage impacts of the reservoirs that serve these facilities.

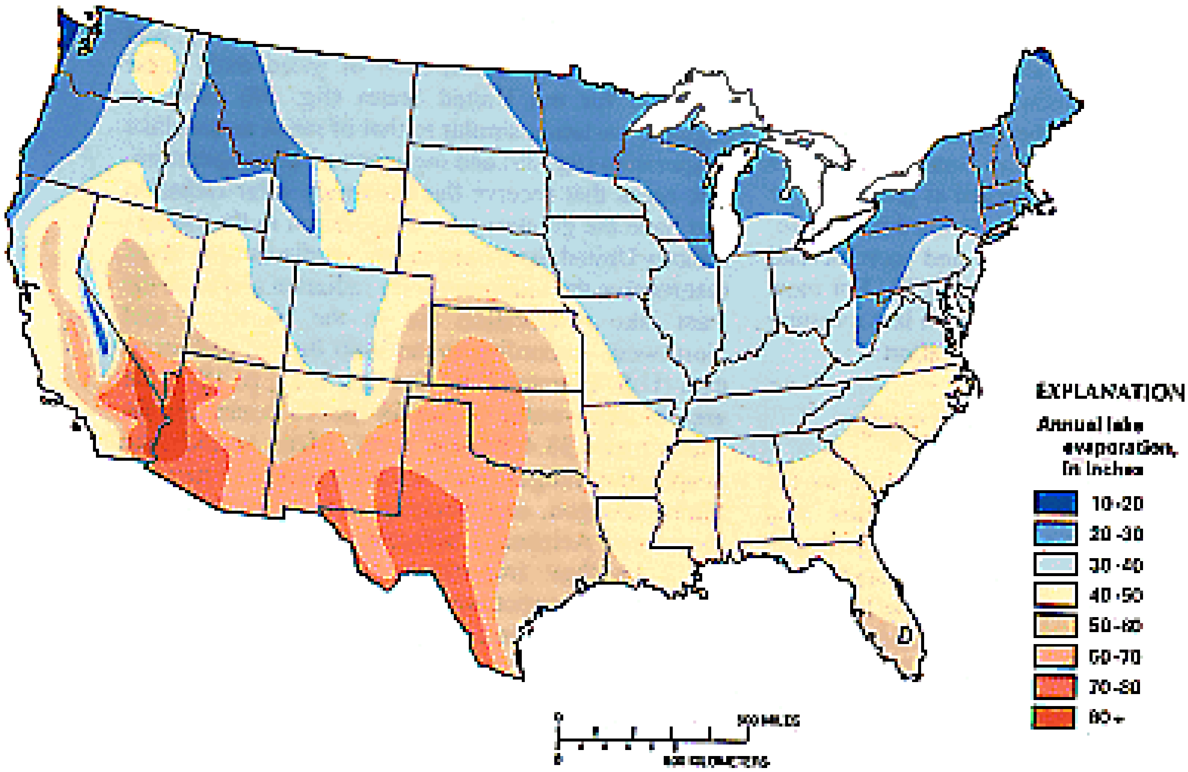

Figure 3 – Annual Evaporation from Lakes and Reservoirs
Source: U.S. Geological Survey

Water Consumption by Fuel in Thermoelectric Power Generation

Thermoelectric generation plants use a number of different fuels to generate steam to drive turbines. The major fuels used in the U.S. are coal, natural gas, and nuclear fuels. (See Figure 4 below.) Biomass and oil represent a small additional percentage of thermoelectric generating capacity. A very small fraction of thermoelectric generation is provided by concentrating solar collectors, which generally consume more water per megawatt hour of power generated than other fuel types, but these represent such a tiny fraction of overall generation that the use is not significant.

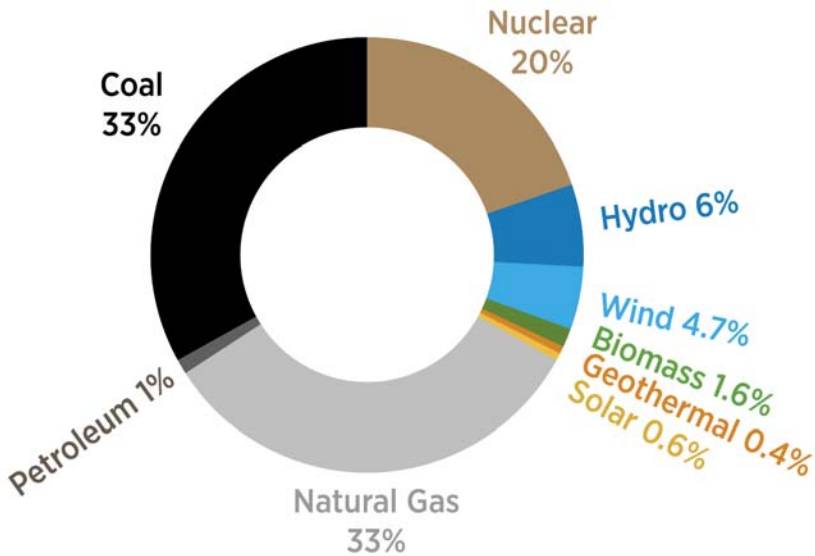

Figure 4: U.S. Electricity Generation Fuel Mix, 2015
Source: U.S. EIA

The fuel mix of the U.S. electricity grid has undergone relatively rapid transition in the past decade with significant implications for the water-energy nexus. The most striking change is the precipitous decline in the use of coal as a fuel source for electrical generation. In the past decade, the use of coal as a fuel source has dropped from 50% to 33% of US generation, while in the past 20 years the use of natural gas has nearly tripled to 33% of the grid mix. In the same period, the prevalence of wind power, photovoltaics, and other renewables (other than hydro) have increased rapidly, and now represent nearly 8% of generating capacity. Natural gas plants tend to be more water efficient than other fuel types, but these new plants almost always deploy closed loop cooling, in many cases replacing plants that were previously served by once-through cooling technologies. Since closed-loop cooling results in more actual water loss from the basin, this transition to newer gas-fired plants may therefore be more likely to increase pressure on water supply resources, rather than decrease it. For wind and photovoltaic technologies, the outcome is more positive from a water supply standpoint; these technologies require no water to generate power once deployed.

The general distinction between once-through and closed loop cooling represents about a fifty-fold difference in the volume of freshwater that is taken from the surface water source. Closed loop plants use the same volume of water repeatedly to cool the steam, withdrawing additional water only to replace that which is lost to evaporation. But within the closed loop plants, there is a great deal of variability in how much water is needed to serve the plants. This variability has mostly to do with different configurations of cooling towers, control technologies, air temperature and humidity, turbine configuration, age of plant and technology, and a host of other technical details that lead to a wide range of water consumption outcomes. With the exception of natural gas, the fuel type used to generate steam is not a strong predictor of water consumption, as can be seen in the range of outcomes and overlap among fuels in Figure 5 below. Natural gas-fired steam turbines tend to be more water efficient than other thermoelectric generating technologies. This may in part be due to the relatively recent construction of most natural gas generating plants, using newer cooling technologies than older plants using other fuels.

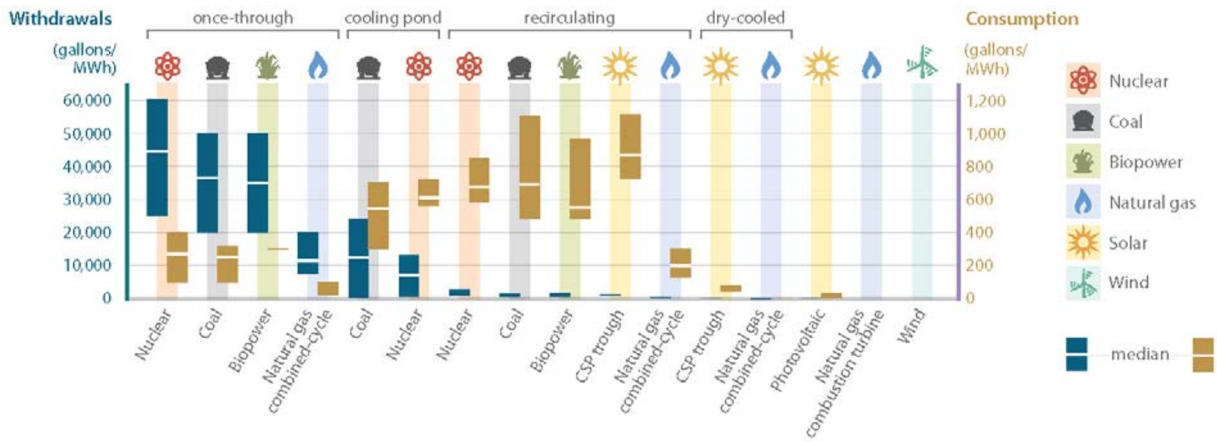

Figure 5: Comparison of US Water Consumption and Withdrawal for Thermoelectric Generation by Fuel Type. Source: Union of Concerned Scientists

Decreasing electricity use can have a direct impact on water consumption at conventional power plants, if use reductions can be used to idle some power generation resources. Water consumption may become a more important consideration in deciding which power resources to deploy if water supplies continue to be stressed in the US. Figure 6 below indicates the state by state water consumption associated with conventional power production excluding hydropower impacts.

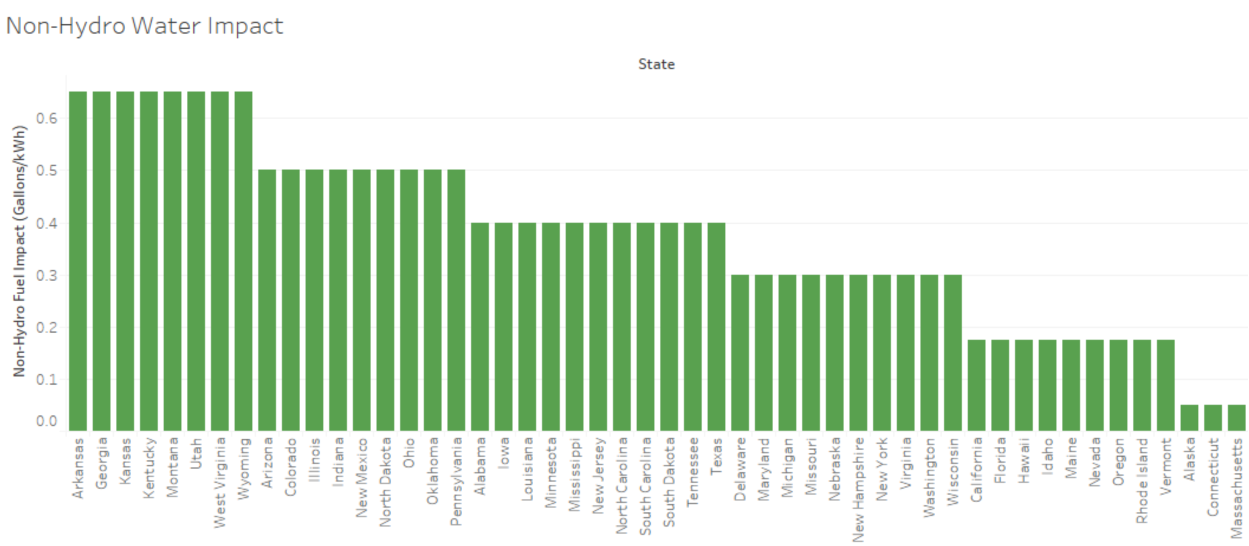

Figure 6: State by State Water Consumption from Non-Hydro Power Production

Other Linkages to Consider in the Water-Energy Nexus

Although use of cooling water for thermoelectric plants represents the most direct and significant relationship between energy supply and water use, there are a number of other linkages in the broader water energy nexus that should also be identified. The specific impact of these aspects of the Water-Energy Nexus will be explored more fully in subsequent work.

Water is used for production, extraction, and transportation of fuels:

- Hydraulic Fracturing, or fracking, has increased dramatically over the past two decades. This technology significantly increases well production and reduces cost by injecting water into the ground to drive natural gas out of the bedrock.
- Tar sands and shale oil deposits use similar technology in some cases, and often use steam to heat thick oil to a liquid that can be extracted from substrate.
- Coal may be transported by pipeline in a water-based slurry.
- Biofuels may require significant irrigation to generate plant matter that is used as fuel. Production of ethanol, the most common biofuel in the U.S., is particularly water intensive.
- The electric transmission system is not extremely efficient, and a percentage of power production at the plant is lost in transmission to the end user. This factor to account for delivery efficiency has not been included in the analysis of water consumption in this study.

The sheer magnitude of the energy industry can make these impacts significant, especially in areas already facing water supply issues. However, except in the case of irrigation to support the production of biofuels, these other production, extraction, and transportation impacts to water supply tend to represent only a fraction of the water consumption associated with thermoelectric power generation.

Water delivery systems of all types are heavily dependent on energy supply:

- Energy is needed to redistribute and deliver water into agricultural and urban supply systems. Nearly 20% of California's energy supply is used to pump water. Groundwater mining is particularly energy intensive, especially as groundwater levels drop from overuse.
- Energy is used to treat freshwater for human consumption, and to treat wastewater before discharge into the environment. Wastewater treatment is very energy intensive, and often represents one of the biggest municipal energy loads.
- In water-deficit coastal communities, desalination plants may be used to increase water supply. Desalination is incredibly energy intensive.

These issues represent the energy impacts of the water delivery system, as opposed to the water impacts of the energy system which are the focus of this analysis. And each use of energy to support water delivery includes an additional water impact for power generation.

CONSIDERING THE WATER-ENERGY NEXUS AT THE BUILDING PROJECT LEVEL

Quantifying the Water-Energy Nexus for the Building Community

The building sector uses nearly 75% of the electricity generated in the U.S., so buildings represent a major component of water use for energy production.[2] Efforts to conserve energy in buildings can directly contribute to significant water use reduction nationally. But information about the water-energy nexus is not widely available to the building sector, and even if there is some awareness of this issue, there is almost no actionable information available to help the building community understand how to specifically quantify the link between energy and water conservation efforts. A key goal of this project is to translate the many technical resources about the relationship between water use and energy supply into understandable, contextual, and actionable information for the building community.

On the energy side, there have been long-standing efforts to improve building energy performance, driven by energy code requirements for new construction, and by utility program incentives that offset the incremental cost of improved building energy performance. More recently there has been a wide recognition of the need to increase the sustainability of the building industry and reduce greenhouse gas impacts from energy use in the building sector. These efforts have led to a significant transition in the building sector leading to the incorporation of sustainable features in buildings and to the adoption of more aggressive energy performance goals for buildings. In the past decade, these efforts have coalesced in the USGBC's LEED program and other similar efforts to look more holistically at strategies to improve building environmental performance in many areas.

The USGBC LEED program represents one of the most significant and rapid market transformations in the building industry in the past 50 years. From the first ten projects delivered in 2000, there are now over one hundred thousand LEED projects of all types worldwide. The design and real estate community has transformed to widely adopt the LEED program, and a significant percentage of the design community has become accredited with the program. This means that the design community is well versed in the kinds of calculation protocols and integrated design considerations that are the basis of the program. This presents an opportunity to introduce a new metric to this community that uses similar calculation protocols to incorporate consideration of the inter-related impacts of water and energy. This approach led NBI to develop a project-specific calculator to quantify the inter-relationship of water and energy metrics.

The LEED program specifically targets both energy and water efficiency, but to date has made no effort to link these strategies in any way. The widespread adoption of the LEED program, combined with the broad familiarity with program mechanisms represents a unique opportunity to introduce a new water-energy metric to the building community.

[2] From analysis by Architecture 2030

Description of the Calculation Tool

The calculation protocol for this project is designed to do two things:

1) To allow the project team to evaluate regional impacts of the water-energy nexus using national data about fuel mix and electricity production

2) To allow individual project teams to evaluate the water consumption associated with energy use in a building and compare this to site-based efforts to reduce water consumption (e.g. low-flow faucets).

Both of these analyses are completed in the context of energy use and associated water use at the building project level. The project team developed a building-specific calculation tool to compare these water and energy impacts by state and region, as well as to inform building designers about the relative impact of energy use decisions on regional water supply. Figure 7 below shows the configuration of the calculation tool.

User Inputs

State	Oregon	Drop-down list
Non-Hydro Impact (Gallons/kWh)	Medium	Low, Medium, High
Hydro Impact (Gallons/kWh)	Low	w, Medium, High

	Baseline Building	*Proposed Building*	*Savings*
Site Energy Use (kBtu/ft^2-yr)	34	27.2	20%
Size (ft^2)	54,000	54,000	-
Number of Occupants	100	100	-
Gallons/Day-Occupant	10.95	8.76	20%
Building Type	Office		
Comment			

State Fuel Mix in 2015

Coal	4.1%
Geothermal	0.3%
Hydroelectric Conventional	54.0%
Natural Gas	28.1%
Nuclear	0.0%
Other	0.1%
Other Biomass	0.6%
Other Gases	0.0%
Petroleum	0.0%
Pumped Storage	0.0%
Solar Thermal and Photovoltaic	0.0%
Wind	11.5%
Wood and Wood Derived Fuels	1.3%

Water Consumption (Gallons/kWh)

Hydro	1.00
Other Fuels	0.175

Annual State Energy Generation (kWh)

Hydro	31,253,851,000
Other Fuels	26,612,684,000

Outputs

Total water impact of electricity generation (Gallons/kWh):	0.62

Water Consumption	*Baseline Building*	*Proposed Building*
Gallons/year due to Occupants	399,675	319,740
Gallons/year due to **Hydro Energy**	290,630	232,504
Gallons/year due to **Other Fuels**	43,307	34,646
Gallons/year due to Total Energy Use	333,937	267,150
Energy/Occupant Use Factor	0.8	0.8

Occupant or Building Level Water Savings

Gallons/year	79,935
Gallons/day	219
Flushes/day	137

Energy Driven Water Savings

	Hydro Power	Other Fuels	Total
Gallons/year	58,126	8,661	66,787
Gallons/day	159	24	183
Flushes/day	100	15	114

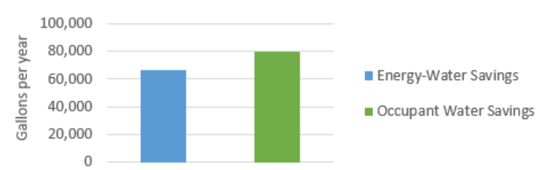

Figure 7: Water-Energy Nexus Calculation Tool

Calculation Methodology

The calculation protocol builds on published work by the Union of Concerned Scientists, the National Renewable Energy Lab, and others, that identify approximate water intensity of thermoelectric power generation by fuel type. For each state, the project team has combined these factors with state-by-state electric grid fuel mix to determine the water intensity of the statewide electric grid. In the case of hydropower, national average numbers are used for water intensity of hydropower generation. Within the analysis tool, the water consumption rates for hydropower and non-hydropower, as well as the state's fuel mix are combined to calculate the state's overall water impact of electricity generation. The non-hydropower impacts are based on estimates from the Union of Concerned Scientists[3]. Due to the wide range of predicted values for hydropower, the analysis incorporates three options for water consumption intensity; high, medium, and low. The medium intensity value represents the value developed from evaporation data published by the United States Geological Survey (USGS) for the U.S. average across hydropower plants[4], while the low value is generally considered to be the water intensity of CA-based hydropower[5]. Table 2 below shows the wide range of published values for hydropower water intensity, while Table 3 shows the values used in this analysis.

Table 2: Range of Values for Water Intensity of Hydropower Production from Published Research

m^3/MWh	Gal/kWh	Region/Citation
17	4.5	US Average - Gleik 1994
113.9	30.1	Arizona, Pasqualetti 2008
68	18	US Average, Torcellini 2003
5.4	1.4	California median, Gleick 1992

Table 3: Range of Values for Water Intensity of Hydropower Production Used in this Analysis

Galllons/kWh	
Low	1.0
Medium	4.5
High	9.0

Although hydropower represents only 6% of U.S. electricity production, the amount of water evaporated out of reservoirs in some analyses makes this an extremely water-intensive power source relative to other electrical generation strategies. Even at the lowest assumed value for the water intensity of hydropower, the heavy reliance on hydropower by some states like Washington makes it one of the most water-intensive electrical grids in the country.

---

[3] *Freshwater Use by U.S. Power Plants: Electricity's Thirst for a Precious Resource. A Report of the Energy and Water in a Warming World initiative*: Union of Concerned Scientists, 2011.

[4] Gleick, P. H.: Water and energy, Annual Rev. Energy Environ., 19, 1994

[5] ibid

In general, the nation's electric grid consumes between 0.25 gallons and 0.75 gallons of water for every kWh of electricity produced (at low-impact hydropower assumptions). This is represented for the continental U.S. in Figure 8. If higher assumptions about the impact of hydropower are tested, the water intensity of the electric grid goes up significantly in some areas of the country, to about 3 gallons of water consumption per kilowatt of electricity generated.

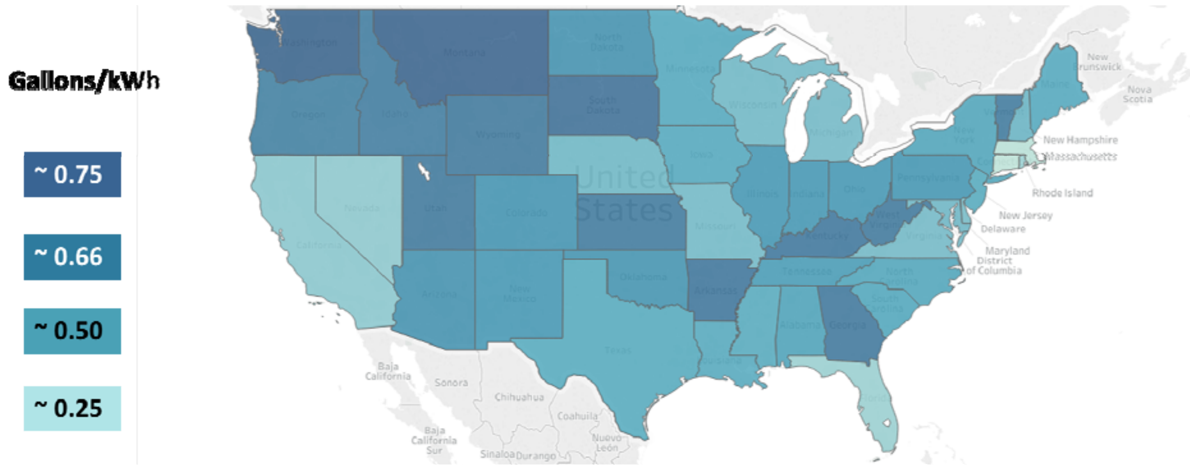

Figure 8: Water Intensity of Electricity Production in the US by State (low hydro impact)

In the context of individual project types, this analysis of the water intensity of electricity can be compared to the water impacts of specific water conservation strategies. This is where the LEED program provides useful context for these efforts.

The LEED program for new construction awards points toward certification based on specific steps taken by the project to reduce environmental impact. The categories of water and energy are two major categories in LEED, and nearly all projects using the LEED program seek points in both categories. In the water category, a point can be achieved by a project for demonstrating a 20% reduction in site water use through the adoption of water conserving fixtures and controls to reduce water use compared to a baseline. In the energy category, 20% savings is a relatively moderate performance target which can achieve 3 points in the program. For this analysis, a 20% savings target for both energy and water use was adopted as the basis for comparison. The calculation tool is built to analyze any savings target for energy and water defined by the user.

The goal of the analysis was to compare the amount of water savings (from power production) associated with a reduction in energy use at the building to the amount of site-water savings achieved through the adoption of water efficiency strategies in the building. The calculation in this analysis included two project types, a medium-sized office building and a secondary school. Prototypes defined by US Department of Energy were used as the basis of the calculation[6].

[6] DOE defines building prototypes to represent the U.S. building stock. These standardized prototypes are used to evaluate energy code stringency and building performance issues in a consistent analysis protocol. The prototypes include information about physical characteristics and typical occupancy patterns. For this project, the medium office and secondary school prototypes were used.

These prototypes specify building size and shape. The Pacific Northwest National Laboratory (PNNL) has modeled these prototypes at various code baseline levels. In this analysis, the baseline energy use in the calculation was set to national average model results for the ASHRAE 90.1-2013 energy code, while the baseline water consumption was set to the LEED program assumptions of consumption per occupant and fixture type in these project types.

By specifying project type, state, baseline energy and site water consumption and savings targets, the user of the calculation tool can generate a comparison of the site-water savings and energy-related water savings. The project team conducted this analysis for all states to identify the range of relative water savings across different grid fuel mixes. The analysis was also conducted for different assumptions about hydropower and non-hydropower water use intensities to evaluate the significance of assumptions about power sector water use.

Analysis Results

The results of the analysis suggest that even using the low value for the water consumption impact of hydropower, the water savings associated with a 20% reduction in energy use in an office building meets or exceeds the water savings achieved from a 20% site water use reduction in ten states, based on state electrical grid characteristics. Figure 9 shows this ratio for each state. If the water consumption from hydropower generation is evaluated at the medium value considered as the national average by USGS, 18 states show more water savings from energy use reduction than from site water reduction, with five states showing savings of more than three times as much water (See Figure 10). If we consider only the Western U.S. as in Figure 11, it is clear that hydropower is playing a very significant role in certain states to drive up these water impacts in the energy sector.

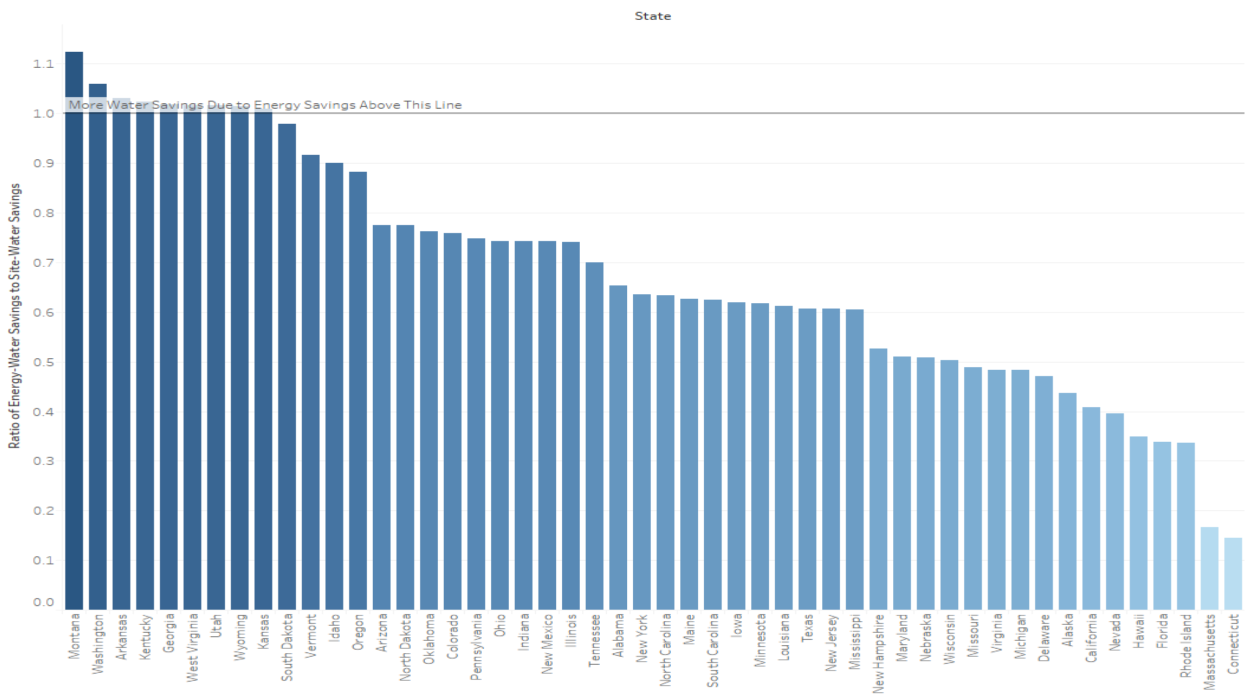

Figure 9: US Project Level Water Consumption from Energy Production by State (low hydro impact)

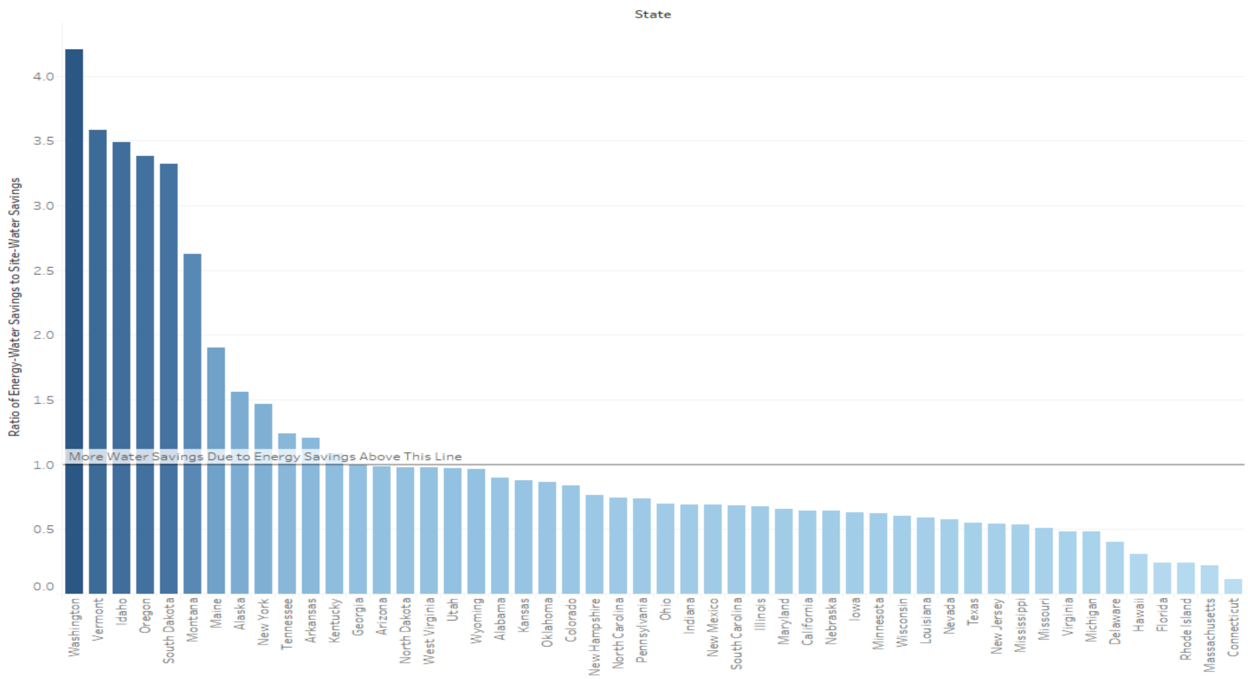

Figure 10: US Project Level Water Consumption from Energy Production by State (medium hydro impact)

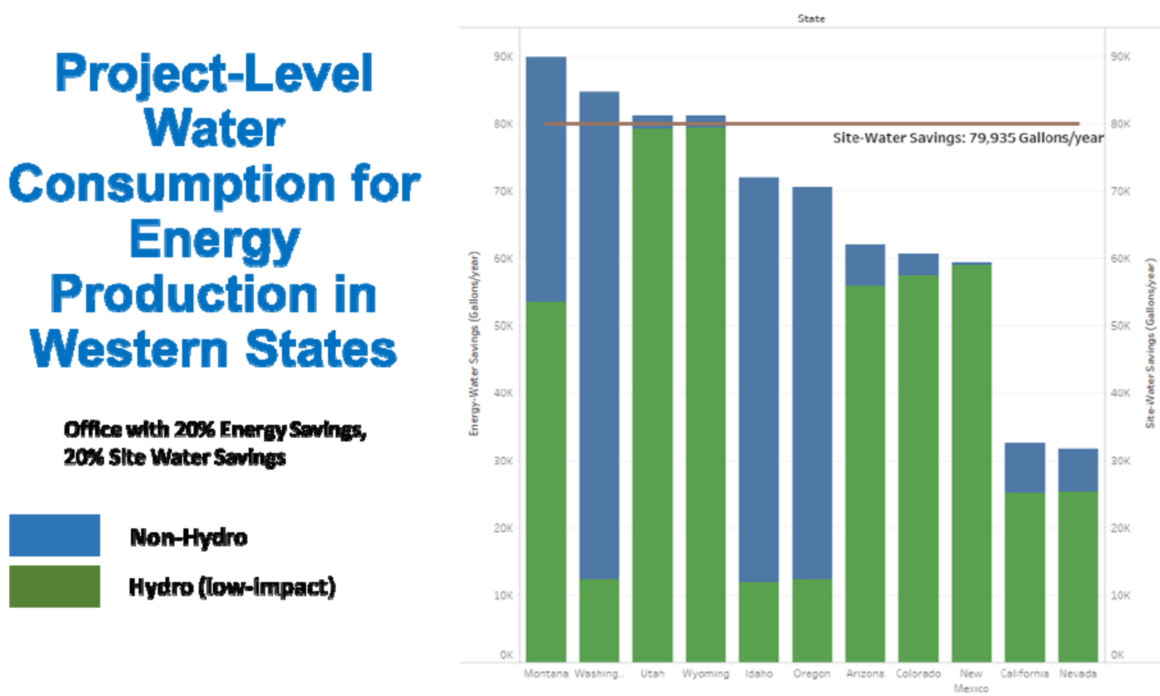

Figure 11: Western State Project-Level Water Consumption from Energy Production

Note that in the case of the secondary school prototype, increased occupancy results in higher daily occupant water use, while energy use intensity is lower than in the office prototype. In the evaluation of this prototype the site water savings typically exceeds the water savings from energy use reduction.

Leveraging Industry Efforts to Support Alignment of Water and Energy Conservation

By more closely linking the relationship between water and energy, there is an opportunity to strengthen efforts to encourage energy and water conservation. Currently, these two aspects of resource efficiency are relatively insulated or even completely separated from each other. The energy efficiency (EE) industry is comprised of a wide range of interest groups, manufacturers, utilities and energy suppliers, and others that have been driving the EE conversation for many years. There is a wide body of knowledge, outreach strategies, financial mechanisms, and other elements that support the adoption of EE strategies in buildings. Likewise, on the water side there are a host of interest groups, suppliers, environmental groups, and manufacturers with interest and experience in encouraging and deploying water conservation strategies in buildings. Yet despite the broad support network for each industry, there is almost no overlap between these groups. If a strong connection can be demonstrated between these resources, there is a huge opportunity to leverage the efforts of each group to support the broader goals both industries together.

Summary

The findings of this project demonstrate and quantify the significant impact that efforts to save energy at the building level can have on regional water use. Generating electricity is very water intensive, and NBI was able to identify specific regional factors that can be used to quantify the amount of water consumption associated with building-level energy use and translate this into specific water savings calculations associated with building energy efficiency. NBI has built a calculation tool that is available for design teams to account for the water impact of energy efficiency decisions, and compare the magnitude of these impacts to direct water savings strategies at the building level. Through the evaluation of different project and location scenarios, it has become clear that in some regions and building types, more significant water savings are achievable by focusing on building energy performance than by conventional strategies to address water efficiency directly at the building level. In all cases across the western US, the upstream water savings associated with reduced energy use is significant.

Next Steps

Through the course of this work it has become clear that there is significant potential to leverage existing efforts to reduce water and energy use to support each other in more effective conservation strategies, and to provide building designers, operators, and tenants with more effective information and tools to quantify and encourage the impacts of conservation efforts. This work forms the basis of critical next steps to continue our work in this area in the following ways:

1) **Direct Outreach to the Building Community:**
   We propose to work directly with building designers and portfolio owners to apply the tools we have developed to real building projects and portfolios. The larger goal of this outreach would be to significantly increase the understanding of the building community of the intricate and critical relationship of water and energy resources. We anticipate three levels of engagement for this effort:

   a) *LEED Building Program Pilot Credit:*
      The USGBC's LEED program has had a major impact on the building sector, bringing widespread adoption of energy efficiency and sustainability strategies to the mainstream building market. This program specifically focuses on both energy efficiency and reduced water use, but it has not linked these two sectors in any way. We propose to bring this linkage directly into LEED projects by introducing the calculation tool to design teams targeting LEED certification, and using the tool to propose the achievement of additional LEED credits for innovation. This mechanism and the introduction of specific water-energy relationship calculations can have significant influence on the broader community of LEED buildings and designers, and could eventually lead the USGBC to incorporate these metrics into the LEED program. NBI is well-connected with both the USGBC organization and with a broad community of LEED consultants who would be in a position to directly apply this methodology to ongoing projects.

   b) *Deploy a portfolio-level focus for the calculator in a water-stressed region:*
      A second outreach strategy would be to engage with community organizations that operate or occupy building portfolios in dry regions of the western US, where water resources are under pressure. We anticipate engagement with schools, community organizations, or small municipalities in the desert southwest to bring additional strategies and impetus to their existing water savings efforts by aligning energy efficiency and water conservation outreach and education efforts more directly into a single message.

   c) *Alignment of effective efforts/constituencies between water and energy conservation advocates:*
      One huge area of opportunity for both energy and water conservation efforts is to more effectively link existing conservation efforts in each category to each other. There are many commonalities to these efforts in buildings: they both rely on daily behavior modification by building occupants for increased effectiveness, both require educational support to motivate occupants to actively participate in conservation behaviors ("turn off the faucet while you brush your teeth," "turn out the lights when you leave the room," etc.), and both efforts have constituency groups and public policies encouraging these behaviors. Imagine the potential leverage and resource efficiencies if the organizations engaged in these efforts could link resources from one cause to support the other. We propose to develop the kind of information and educational linkages that would allow for more direct collaboration among the many

organizations trying to independently create behavioral change among building occupants for water and energy efficiency.

2) **Incorporation of energy impacts of water conservation strategies into the calculation methodology:**
To date, our work has focused on quantifying the amount of water consumption inherent in energy use. There is another side of this equation that we propose to incorporate into the next phase of this work - the energy use implications of water delivery and consumption. Delivering and treating water for use in buildings requires vast quantities of energy to pump water out of the ground or other locations, treat the water, and maintain adequate delivery pressure in the system. We propose to build similar calculation methodologies into our analysis tool to characterize the energy use implications of water delivery at the building level. We will also consider whether the energy use of wastewater treatment can be incorporated into this protocol.

3) **Extension of the tool to address withdrawal issues:**
In the eastern United States, most of the water use associated with power plants is characterized as withdrawal rather than as consumption. Older energy plants in the east withdraw large quantities of water from lakes and rivers to provide cooling to power plants, but then return the water, somewhat warmer, to the source. Unlike western power plants, this water is not evaporated out of the basin, so it is not considered a consumptive use. These large-scale withdrawals can have local impacts on water temperature and quality that can have impacts on wildlife, droughts, or other water issues that can cause significant disruptions to the environment and power plant operation. Though withdrawal issues are different from water consumption issues, we propose to add the ability to account for water withdrawal to the tool as a separate impact category.

4) **Additional analysis of water impacts of hydropower generation:**

Estimates of the water consumption impact of hydropower generation vary widely among published research, making it difficult to accurately account for this issue in the context of the larger power grid. Nevertheless, even with very conservative assumptions about the impact of hydropower, the level of water consumption from this generation technology is staggering. As water resources become more constrained, it will be important to continue to zero in on the true impacts of hydropower generation on water resources.

REFERENCES

Averyt, K., J. Fisher, A. Huber-Lee, A. Lewis, J. Macknick, N. Madden, J. Rogers, and S. Tellinghuisen, *Freshwater Use by U.S. Power Plants: Electricity's Thirst for a Precious Resource. A Report of the Energy and Water in a Warming World initiative*. Cambridge, MA: Union of Concerned Scientists, 2011.

Electric Power Research Institute, *A Survey of Water Use and Sustainability in the United States With a Focus on Power Generation*, 2003

Jordan Macknick, Robin Newmark, Garvin Heath, and KC Hallett, *A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies*, National Renewable Energy Lab, 2011

LEED v4, Indoor Water Use Reduction Calculator, 2014 (http://www.usgbc.org/resources/indoor-water-use-calculator)

NOAA Technical Report NWS 34, *Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States*, 1982

Pacific Northwest National Lab (PNNL), *ANSI/ASHRAE/IES Standard 90.1-2013 Preliminary Determination: Quantitative Analysis*, 2014 (http://www.pnnl.gov/main/publications/external/technical_reports/pnnl-23236.pdf)

T. H. Bakken1,2, Å. Killingtveit1, K. Engeland2, K. Alfredsen1, and A. Harby2, *Water Consumption From Hydropower Plants – Review of Published Estimates and an Assessment of the Concept*, Norwegian University of Science and Technology, Department of Hydraulic and Environmental Engineering, Trondheim, Norway, 2013

US Department of the Interior, Bureau of Reclamation, *Report on Lake Powell Evaporation*, 1986

U.S. Energy Information Administration, *Net Generation by State by Type of Producer by Energy Source* (https://www.eia.gov/electricity/data/state/annual_generation_state.xls)

US EPA, *eGRID Summary Tables for State Resource Mix*, 2012