Integrating Energy and Water Resources Decision Making in the Great Lakes Basin

An Examination of Future Power Generation Scenarios and Water Resource Impacts

A Report of the Great Lakes Energy-Water Nexus Team

Prepared by:

The Great Lakes Commission

October 2011

Table of Contents

Integrating Energy and Water Resources Decision Making in the Great Lakes Basin

An Examination of Future Power Generation Scenarios and Water Resource Impacts

I. Overview of energy and water in the Great Lakes Basin

Large amounts of water are withdrawn every day within the Great Lakes and St. Lawrence River Basin for a multitude of purposes, predominantly for uses in regional power production.[1] In 2004, the latest year for which Great Lakes Basin water use data are available, total water withdrawals were slightly over 41 billion gallons a day (BGD). This figure includes public water supply, domestic and industrial uses, irrigation and livestock supply, and uses within thermoelectric power generation, but excludes hydro-electric power generation.[2]

Energy and water in the Great Lakes Basin are inextricably linked. Energy in the form of electric power and fossil fuel consumption is used to pump, convey, store, heat and treat water. On the other hand, the power sector withdraws more water than any other sector in the United States and is heavily dependent upon available water resources. Changes in available water resources or policies dictating water use may impact the efficiency of power generation.[3] Conversely, variations in the energy sources we use may impact the quality and quantity of basin water supply and affect consumers. Recent advances in water use management (*e.g.,* the Great Lakes and St. Lawrence River Basin Water Resources Compact; see section VI-A below) among the Great Lakes states and provinces reflect a growing desire for improved understanding of how water use affects the functional integrity of the Great Lakes Basin ecosystem.

---

[1] Much of this water is returned to the basin and thus is not "consumed" in ways that remove it from the basin or prevent its use by others.

[2] Great Lakes Commission. 2006. *Annual Report of the Great Lakes Regional Water Use Data Base Repository – Representing 2004 Water Use Data in Gallons*. GLC: Ann Arbor. Available online at http://glc.org/wateruse/database/pdf/2004-gallons.pdf. [Thereafter, *Great Lakes Regional Water Use*.]

[3] National Renewable Energy Laboratory. 2010. *A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies*. Available online at: http://www.windpoweringamerica.gov/pdfs/2011_water_consumption_electricity.pdf

This report focuses on how Great Lakes water is used for thermoelectric power generation and explores ecological impacts and tradeoffs associated with alternate future power generation scenarios in the Great Lakes Basin.

A. Energy Requires Water

Water is used to produce electricity or transport fuel that is used for much of the basin's energy supply. Generally, this energy is either in the form of electricity or fuels that run our cars, trucks, boats, and other vehicles. In the Great Lakes Basin, most of the water used directly for power production is used for hydroelectric power generation or in boilers for the production of steam, as well as a cooling medium for thermoelectric power plants. Although hydroelectric dams "use" flowing water to move a turbine, this is not considered a "water use" from a water policy or water management standpoint in this study because the water never leaves its source (*i.e.,* insignificant net volume change). To be sure, other energy production activities also use large quantities of water. Large amounts of water are used in petroleum refining processes to create gasoline[4], as well as to convert corn or other biomass into ethanol or other biofuels. Water use and related impacts associated with fuel processing and production are important issues, but are not addressed in this study.

B. Water Requires Energy

Satisfying our water needs requires energy to supply, purify, distribute, and treat water and wastewater. Each year, about 4 percent of all U.S. power generation is related to providing and treating water. Public water supplies, for instance, consume between 1,400 and 1,800 kilowatt-hours (kWh) for every million gallons of water distributed.

Energy use is estimated to represent between 10 to 30 percent of the total costs of providing water through public systems.[5] A majority of Americans (approximately 86 percent) receive water from publicly owned water and sewer utilities, while the remainder receive water from private (so-called "investor-owned") water utilities

---

[4] Refineries use about 1 to 2.5 gallons of water for every gallon of product, meaning that the United States, which refines nearly 800 million gallons of petroleum products per day, consumes about 1 to 2 billion gallons of water each day to produce fuel (U.S. Department Of Energy (USDOE). 2011: Available online at: http://www.epa.gov/region9/waterinfrastructure/oilrefineries.html

[5] Dr. Janice Beecher, *pers. comm*. Michigan State University Institute of Public Utilities Regulatory Research and Education.

> ***Thermoelectric power generation is a broad category of power plants consisting of coal, nuclear, oil, natural gas, and gas-fired combined cycle that generate heat, either by the combustion of fossil fuels or biofuels or by nuclear fission, to turn water into steam, which drives a turbine to generate electricity.***

or self-supplied (*e.g.,* well) sources.[6] Surface waters for drinking water supply generally require more treatment, thus more energy, than groundwater.[7]

Wastewater treatment facilities in the Great Lakes Basin serve approximately 17.5 million people.[8] Adding in the seven-county Water Reclamation District of Greater Chicago,[9] which treats wastewater for the more than eight million energy and water users in the Chicago metropolitan area alone (though it is technically outside of the basin), a total of over 25 million people are served in and directly around the Great Lakes Basin by wastewater treatment facilities. Regardless of the volumes of water that pass through a water treatment plant, the predominant use of electricity for delivering surface water for public supply nationally is to pump the water to the distribution system, which represents about 80 to 85 percent of the total electricity consumption for surface water treatment.[10]

Energy requirements for distribution, wastewater collection, and treatment vary depending on system size, topography, and age. Additionally, the energy required to pump water can be reduced as users are located closer to the source.

C. Report Context

This report focuses on how Great Lakes Basin water is used for thermoelectric power generation and explores ecological impacts and tradeoffs associated with alternate future power generation scenarios in the U.S. portion of the Great Lakes

---

[6] Kenny, J.F., N.L. Barber, S. S. Hutson, K.S. Linsey, J.K. Lovelace, and M.A. Maupin. 2009. *Estimated Use of Water in the United States in 2005.* USGS, Circular 1344. Available online at: http://pubs.usgs.gov/circ/1344/.

[7] U.S. Department of Energy. 2006. *Energy Demands on Water Resources - Report to Congress on the Interdependency of Energy and Water*, at p. 18. Available online at: http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf [Thereafter, *Energy Demands.*]

[8] U.S. Environmental Protection Agency (EPA) Great Lakes National Program Office, Chicago, IL, *State of the Great Lakes 2009.* Available online at: http://www.epa.gov/solec/sogl2009/7065wastewater.pdf

[9] Cook, DuPage, Kane, Kendall, Lake, McHenry and Will Counties.

[10] Electric Power Research Institute, 2000. *Water and Sustainability: U.S. Electricity Consumption for Water Supply & Treatment—The Next Half Century*. Palo Alto, CA: 1006787. [Thereafter, *Electricity Consumption.*]

Basin.[11] The findings and conclusions in this report are based on several background reports that were prepared between 2010 and 2011 as part of the Great Lakes Energy-Water Nexus Initiative[12]. These background reports aimed to: 1) describe new ecological metrics for measuring impacts on Great Lakes Basin water resources; 2) conduct scenario analyses to inform potential changes in environmental impacts from different energy futures; and 3) assess electric market and power plant siting policies and regulations to identify gaps and opportunities for improvements. These reports are referenced throughout.

D. Great Lakes Basin Power Profile

A brief overview of energy production in the Great Lakes Basin provides useful context. At the beginning of 2011, the Great Lakes Basin hosted 583 power generating facilities, including conventional fossil fuel power plants as well as renewable-sourced power generation systems (e.g., windmills, biofuel-fired steam electric). In total, these 583 power plants have the capacity to produce 68,936.2 megawatts of electricity – enough energy to power about 45 million homes.[13] These plants are located throughout the Great Lakes Basin and range in age from less than one year to 109 years old, with an average age of 41 years.

Power plants in the Great Lakes Basin use a variety of fuels to produce energy. In 2006, nearly 70 percent of the 8-state Great Lakes region's electric supply came from fossil fuel (coal, petroleum, and gas-fired) thermoelectric power plants, while more than 25 percent of the region's electricity came from nuclear plants.[14]

The most recent data available show the picture has not changed much in the last several years.[15] Coal, natural gas, and nuclear are predominant fuel sources for power generation in the Great Lakes Basin. Most power plants use the heat from these fuels to convert purified water to high pressure steam which turns a turbine to generate electricity. This process is called "thermoelectric power generation."[16] Some forms of thermoelectric power do not use steam (*e.g.,* simple-cycle combustion turbines) and, therefore, are less dependent on available water resources.

---

[11] Hereinafter, "Great Lakes Basin" refers to the U.S. portion of the Great Lakes Basin which corresponds with the United States Geological Survey (USGS) Hydrologic Region 04.

[12] GLEW Initiative webpage available at: http://www.glc.org/energy/glew/

[13] Scanlong, Bill. 2011. *NREL Adds Giant Wind Turbine to Research Site.* National Renewable Energy Laboratory. Available online at: http://www.renewableenergyworld.com/rea/news/article/2011/05/nrel-adds-giant-wind-turbine-to-research-site.

[14] Great Lakes Commission. 2009. *The Energy Water Nexus: Implications for the Great Lakes*. [Thereafter, *Energy Water Nexus*.]

[15] Great Lakes Power Plant Fleet data set, compiled by Sandia National Laboratories, 2010. [Thereafter, *Great Lakes Power data*].

[16] U.S. Department of Energy, *IEP Water-Energy Interface: Power Generation*, National Energy Technology Laboratory. Accessed July, 2011. Available online at: http://www.netl.doe.gov/technologies/coalpower/ewr/water/power-gen.html

Coal-fired power plants in the basin generate 39.4 percent of the electricity. Natural gas-fired plants generate 28.9 percent, while nuclear power provides 16 percent of the basin's power. Hydroelectric power provides 9.1 percent of all power produced in the region (Figure 1).

Currently, biomass-fueled thermoelectric plants account for less than 1 percent (0.065 percent) of the energy capacity in the Great Lakes Basin, as many of these plants have only been a recent addition to the region's energy portfolio. The average age of a biofuel plant in the basin is just 14.6 years. Wind- and solar-based generation have also only recently been introduced to the basin, particularly as a number of states have enacted renewable portfolio standards requiring an increase in renewable energy deployment. Figure 1 shows total power generating capacity in the Great Lakes Basin by fuel type (2010 data).

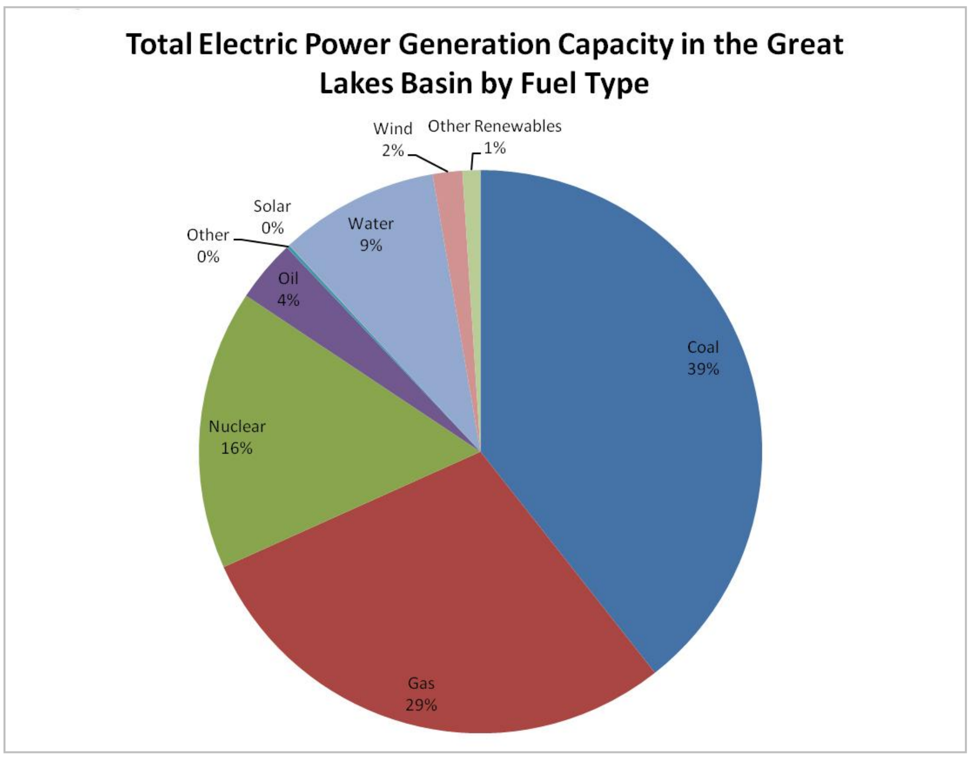


Figure 1: Distribution of electric power generation capacity in the Great Lakes Basin by fuel type.[17]

[17] *Great Lakes Power data,* supra note 15.

II. Power Generation and Water Use in the Great Lakes Basin[18]

A. Thermoelectric power generation and water use

A significant quantity of water is required for thermoelectric power generation. Each kilowatt-hour generated from coal, for example, which accounts for nearly half (~45 percent) of U.S. electricity generation[19], requires an average of 25 gallons of water. The largest demand for water in thermoelectric plants is cooling water used to condense steam. However, thermoelectric plants also require water for operation of pollution control devices, wastewater treatment, and wash water,[20] among many other uses.

In 2005, thermoelectric power production accounted for 41 percent of total U.S. freshwater withdrawals, or 140 billion gallons per day (BGD), slightly ahead of irrigated agriculture.[21] Thermoelectric water consumption, by contrast, was estimated to account for only about 3 percent of total U.S. consumption, or 3.7 BGD.[22] Consumptive use refers to that portion of water withdrawn or withheld from the source waterbody and assumed to be lost or otherwise not returned to the source waterbody due to evaporation, incorporation into products, or other processes and thus not returned directly to a surface waterbody or groundwater for further use in the basin.[23] Thermoelectric water consumption is roughly equivalent to the total of all other industrial demands and the sector has been rapidly growing since about 1980 [24] (with a further projected increase of about 40-60 percent in the next 20 years).[25] The projected growth in thermoelectric water consumption is a function of many factors, such as the fuel mix and cooling technology employed by

[18] This report attempts to advance the broader Great Lakes energy-water nexus discussion by focusing on the relationship between electric power generation and Great Lakes aquatic resources, including how electric power generation impacts the quality or quantity of water available for those habitats and organisms that are dependent on that water.

[19] U.S. Department of Energy. 2010. *Power Plant Operations Report (EIA-923).* Energy Information Administration, preliminary generation data.

[20] U.S. Department of Energy, *IEP Water-Energy Interface: Power Generation*, National Energy Technology Laboratory. Accessed July, 2011. Available online at: http://www.netl.doe.gov/technologies/coalpower/ewr/water/power-gen.html.

[21] USGS, 1985, 1990, 1995, 2000, 2005. *Water Use in the United States*. Available online at: http://water.usgs.gov/watuse/

[22] National Energy Technology Laboratory. 2008 *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements*. DOE/NETL- 400/2008/1339,[Thereafter, *NETL 2008*].

[23] Great Lakes Regional Water Use Data Base. Accessed July, 2011. Available online at: http://www.glc.org/wateruse/database/definitions.html

[24] However, withdrawal per unit of electricity has decreased from 1950-2000 due to increased plant efficiencies (B. Hannegan. 2009. EPRI. Testimony to U.S. House of Representatives, Subcommittee on Energy and Environment).

[25] *NETL 2008* supra note 22.

the future power plants and possible environmental control requirements, including potential new policies regulating cooling water intake structures.[26]

In the Great Lakes Basin, similar trends for thermoelectric withdrawal and consumption were noted in 2007. While withdrawals amounted to 25.9 BGD (76 percent), consumption accounted for 0.4 BGD. Water withdrawals in the region by other sectors include municipal at 3.8 BGD (11 percent), industrial at 3.3 BGD (10 percent), irrigation at 0.4 BGD (1 percent), mining at 0.4 BGD (1 percent) and livestock at 0.2 BGD (1 percent).[27] [28] Unlike withdrawal, consumptive use of Great Lakes water is not dominated by the thermoelectric sector. The industrial sector [29] leads consumption at 1.6 BGD or 53 percent of all consumption whereas thermoelectric power sector represents only 0.4 BGD (13 percent) of all consumptive use in the basin. This is no doubt due to the prevalence of open-loop or "once-through"[30] cooling technology for thermoelectric power generation in this region,[31] a process that involves less evaporative consumption of water than closed-loop or "closed-cycle" cooling (see section II-B below).

In spite of the tight link between water and energy, the nexus between thermoelectric power production and water use is not uniform across the U.S. Rather, it differs according to region-specific characteristics such as physiography and demography, composition of the power plant fleet, and the power transmission network. Thus, in some regions water use for thermoelectric purposes is relatively small while in other regions it represents the dominate use. The latter is the case for the Great Lakes region, and this has important implications for the water resources and aquatic ecology of the Great Lakes Basin.[32]

---

[26] *Ibid.*

[27] It should be noted that much of the withdrawn water is returned to the original water source (except in the case of groundwater withdrawals, which are generally returned to a nearby surface water feature). The difference in volume is simply equal to consumption. The quality of the returned water is also often altered.

[28] Tidwell, Vince and B. Moreland. 2011. *Energy and Water in the Great Lakes*. Sandia National Laboratories, [Thereafter, *Energy and Water]*.

[29] As per USGS definitions of water use sectors, thermoelectric power production is considered separately from the industrial sector (although in other cases, it is considered part of the industrial sector). See: USGS. 2005. *Summary of Estimated Water Use in the United States in 2005*. Accessed September 2011. Available online at: http://pubs.usgs.gov/fs/2009/3098/pdf/2009-3098.pdf.

[30] For the purposes of this report, "open-loop," "once-through," and "open-cycle" cooling are used interchangeably.

[31] *Energy Water Nexus,* supra note 14.

[32] *Energy and Water,* supra note 28.

B. Power Plant Cooling Technologies

A variety of cooling technologies are used in thermoelectric power generation. A brief overview of these technologies is provided below (Box 1[33]). About two-thirds (59 percent) of the thermoelectric generation capacity in the region utilizes once-through cooling, where almost all of the water is returned directly to its source. About a third of the thermoelectric power generation uses closed-cycle cooling, which has higher consumptive use factors (due to evaporation), and other environmental effects, and which results in energy penalties in two forms—loss of energy from reduced efficiency and loss of output due to parasitic load to run the equipment. These are the only types of cooling technology used in the Great Lakes basin[34] [35], and a breakdown of water use by these technologies, as well as by fuel type, is shown in Tables 1 and 2.

Table 1: Total thermoelectric water withdrawal from Great Lakes power plants by fuel type and cooling technology in millions of gallons per day (MGD).[36]

Fuel Type	Open-Loop	Closed-Loop	TOTAL
Coal	15245	860	**16105**
Nuclear	7020	619	**7639**
Oil	267	0.4	**267.4**
Gas	539	341	**880**
Renewables	N/A	316	**316**
TOTAL	**23071**	**2136.4**	

Table 2: Total thermoelectric water consumption from Great Lakes power plants by fuel type and cooling technology in millions of gallons per day (MGD).[37]

Fuel Type	Open-Loop	Closed-Loop	TOTAL
Coal	151	9	**160**
Nuclear	191	37	**228**
Oil	3	0	**3**
Gas	2	5	**7**
Renewables	N/A	4	**4**
TOTAL	**347**	**55**	

[33] Excerpted from: Anderson, E, G. Nash, and M. Bain. 2011. *Background paper for Healthy Uses, Healthy Water Integrating Energy and Water Resources Decision Making*.

[34] V. Tidwell, pers. comm.

[35] *Great Lakes Power data*, supra note 15.

[36] *Ibid.*

[37] *Ibid.*

C. Water Use for Carbon Capture and Storage

Carbon Capture and Sequestration/Storage (CCS), whereby carbon dioxide (CO_2) is captured from sources such as electric power plants and injected deep underground for storage, has been proposed as a technique to capture power plant CO_2 emissions.[38] There may be chemical and physical processes involved with CCS that require additional water use (in addition to the water used for the original power production technology) to purify, separate, and export the CO_2. Recent studies sponsored by the U.S. DOE have highlighted the potential "capture penalty" associated with various fossil fuel technologies noting that, in three scenarios, CO_2 capture increased the average raw water consumption (Gallons/MWh) by approximately 37percent.[39] [40] In addition to increased water use, this process comes with its own set of water resource impact concerns, such as brine displacement into freshwater formations, reservoir pressure increases, and CO_2 leakage into groundwater sources.

Though suggested as a means to curb future greenhouse gas emissions and climate change impacts from existing low-cost fossil fuel-based generation, CCS is a relatively new technology and legalities and technical basis for such must still be established. Current work is being completed in the Midwest region to test its feasibility[41], but its potential water use footprint would likely be relatively low in the Great Lakes Basin. Nevertheless, the potential impacts of CCS on water quantity in the basin are worth noting, especially as we try to estimate shifts in future energy portfolio standards (discussed in section IV below).

---

[38] Newmark, R.L., S. J. Friedmann, and S. A. Carroll. 2010. *Water Challenges for Geological Carbon Capture and Sequestration*. Environmental Management 45: 651-661.

[39] In all cases, technologies were varying forms of Gas Combined Cycle; U.S. Department of Energy. 2007. *Cost and performance baseline for fossil energy plants. Vol. 1. Bituminous coal and natural gas to electricity, Revision 1.* National Energy Technology Laboratory. [Thereafter, *Cost and performance*].

[40] U.S. Department of Energy. 2007. *Estimating freshwater needs for thermoelectric generation.* National Energy Technology Laboratory.

[41] Midwest Regional Carbon Sequestration Partnership (MRCSP). 2005. *Phase I Final Report*. Available online at: http://216.109.210.162/userdata/Phase%20I%20Report/MRCSP_Phase_I_Final.pdf

Box 1: Power Plant Cooling Technologies

Once-Through (Open-Cycle)

Once-through cooling (also known as direct or open-cycle cooling) is considered the most energy efficient and economical method of cooling. Where once-through cooling is employed, water is withdrawn from a waterbody and heated in a boiler to create steam, which is used to turn a turbine. The heated water is then pumped back to the source waterbody. This method is most effective when large, cold-water sources are used. Often, the water being returned to the water body is substantially warmer than when it was withdrawn. This excess heat entering the ecosystem is referred to as thermal discharge (See Box 2 below). Impingement and entrainment are among the ecological impacts that may occur from use of this cooling technology. Impingement occurs if larger organisms are pinned against the intake screen due to the high velocity of water being pulled into the system. Entrainment occurs if organisms small enough to pass through the intake screens are pulled into the cooling system pipes. Entrainment mortality occurs when those organisms are killed in the process either by heat or mechanical trauma. Research has shown that the number of fish and aquatic organisms that are killed by impingement and entrainment is widely variable, depending on system designs and locations.

Cooling Towers (Closed-Cycle)

With cooling towers, which utilize closed-cycle cooling, the hot water is recirculated inside the plant and is passed through a heat exchanger (also referred to as a condenser) to absorb energy from the exhaust steam that was used to turn the turbine. The warm water is conveyed into a cooling tower, where it is cooled by a forced draft of air and collected at the bottom of the tower. A large fraction of the cooled water is then returned to the plant for reuse in the steam cycle. Although some cooling towers rely on natural draft to move air into the tower, most others rely on fans to mechanically "pump" air through the tower, further increasing costs and decreasing overall efficiency of the power plant (this means more fuel must be used to produce the same net amount of electricity to serve customers). Plants utilizing cooling towers withdraw between 97 and 99 percent less water than plants with once-through systems. Although cooling towers withdraw less water than direct or once-through cooling, some 55 to 63 percent more water is consumed during the process through evaporation. This can create a large plume of steam. Cooling tower systems are also less energy efficient (e.g., have a lower capacity factor) than once-through cooling because some of the energy generated by the plant is consumed in pumping the water through the towers, whereas in once through systems gravity is sometimes used to carry water back to its source. Finally, since the water in a closed cycle cooling system comes from either surface or ground water sources, impingement and entrainment are still among the potential associated ecological impacts.

Cooling Ponds, Lakes, and Canals

Cooling ponds, lakes, and/or canals are another form of re-circulating cooling. These systems dilute hot water within a small water impoundment, where it is cooled at a slower rate by convection and evaporation. They require more land than a cooling tower, but consume similar amounts of water.

Dry (Air) Cooling

In a dry cooling system, the steam from a turbine is carried in large ducts to an air-cooled condenser (ACC) where the heat is transferred directly to the air passing over the surface. Dry cooling also takes place in a tower, but the water being cooled is isolated from the outside air. The hot water passes through finned arrays of metal tubes, and associated fans or natural circulation transfer the contained heat to the atmosphere. This method is considered by far to be the least efficient means of cooling because the hot water is separated from the air by metal resulting in a water-to-air transfer that is not nearly as effective as evaporation. Dry cooling is used where access to water is severely limited, or where ecological or aesthetic concerns take priority. Compared to wet cooling towers, dry cooling towers are larger and occupy more land because a dry cooling tower requires double the surface area of a wet cooling tower. The prevalence of water resources in the Great Lakes thus has led to enhanced use of open or closed water cooling cycles.

D. Thermoelectric power water use by source

Approximately one quarter (26 percent) of the Great Lakes watershed's thermoelectric generating capacity is represented by thermoelectric power plants that withdraw water from groundwater or a Great Lakes tributary. The balance, or about three-fourths, of all thermoelectric power generation withdraws water directly from the Great Lakes. Figure 2 and Tables 3 and 4 depict the breakdown of water withdrawal and consumption by thermoelectric power technology and source water.

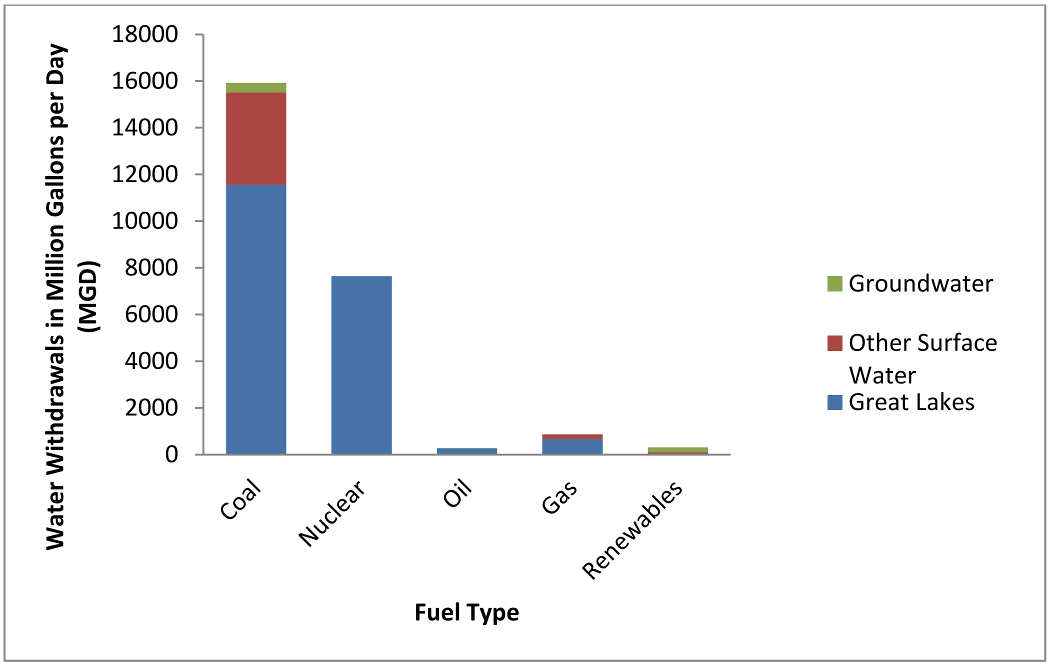


Figure 2: Thermoelectric water withdrawals by source and fuel type, in millions of gallons per day (MGD).[42]

[42] *Great Lakes Power data,* supra note 15.

Table 3: Total thermoelectric water withdrawal from Great Lakes power plants by water source and fuel type, in millions of gallons per day (MGD).[43]

Fuel Type	Great Lakes	Groundwater	Other Surface Water
Coal	11556	405	3963
Nuclear	7638	0	0
Oil	267	0.4	0
Gas	670	2	181
Renewables	5	215	95

Table 4: Total thermoelectric water consumption from Great Lakes power plants by water source and fuel type, in millions of gallons per day (MGD).[44]

Fuel Type	Great Lakes	Groundwater	Other Surface Water
Coal	83	1	76
Nuclear	227	0	0
Oil	3	0	0
Gas	3	0.03	3
Renewables	0.2	1	2

Understanding how power generated in the Great Lakes Basin impacts the basin – where water is generally abundant – is no small task. Part of the challenge, as described below, is having access to very detailed data about where water is used, for what purposes, how such use affects the "water balance," and cross-walking those data with the varying ecological conditions and vulnerabilities of different species and habitats in the Great Lakes Basin.

III. From Water Use to Ecosystem Impact: Ecosystem Metrics and Development of the Great Lakes Energy-Water Model

From mayflies to walleyes, Great Lakes aquatic organisms are impacted by energy production in a variety of ways. Fish and other organisms may be caught in or killed by cooling systems, and warmed discharge water may negatively affect habitat and could have adverse life cycle impacts, though no adverse population level impacts have been demonstrated. Furthermore, uncontrolled emissions from carbon based fuel sources contribute to climate change and air pollution. Even hydroelectric dams, which do not actually consume water, can cause problems in rivers by

---

[43] Calculations based on 2010 *Great Lakes Power* data, supra note 15.
[44] *Ibid.*

retaining toxic sediments and prohibiting fish and other aquatic organisms from moving up- and downstream. Substantial research has been done to examine the impacts of air emissions and local land and water resource impacts (such as impingement and entrainment) that result from siting and operating power plants. Much less research has been conducted to determine how water use and consumption impact aquatic resource health in the Great Lakes Basin. What effect does the water withdrawal or consumption associated with power production have on the health of a stream or river? What about impacts on riparian habitat, or nearshore environments? How is it affected by other water uses in that watershed? While water withdrawal and consumption are features of energy production, examining total withdrawal and consumption alone fails to describe how those uses impact the ecological health of the Great Lakes or areas within the Great Lakes Basin. This project begins to address some of the aforementioned questions, as will be described below. However, much more work needs to be done to fully address these issues.

A. Model Selection

Knowing how much water is being used or consumed in a water rich region like the Great Lakes does not alone reveal how that use or consumption is impacting the ecosystem and water-dependent natural resources in particular. Phase I of the Great Lakes Energy-Water Nexus (GLEW) Initiative, a 21-month effort led by the Great Lakes Commission[45], attempted to develop new metrics for aquatic resource impacts and apply those metrics in a scenario analysis modeling effort. The model selected for this purpose, the "Energy and Water-Power Simulation Model" (EWPS) was previously developed by Sandia National Laboratories. This model was selected because of its unique capabilities to analyze water use, water consumption, and greenhouse gas emissions (GHG) outputs under different future energy scenarios. Several other models also examine tradeoffs associated with future energy production scenarios, but the EWPS model stood apart due to its unique focus on water resources (water use and consumption) as a basis for analysis (not as an afterthought or an additional factor on top of numerous other factors).

Though the EWPS model was originally calibrated to work at the Hydrologic Unit Code (HUC) 6 watershed level, GLEW was able to enhance the model to perform analyses at the HUC-8 watershed level.[46] [47] Data on water use by individual power

---

[45] Funding for the Great Lakes Energy Water Nexus Initiative was provided by the Great Lakes Protection Fund.

[46] HUC-8 data were obtained from the Large Basin Runoff Model developed by NOAA's Great Lakes Environmental Research Laboratory

[47] Within the USGS Hydrological Unit classification system for the U.S., HUC-8 represents the smallest level of categorization (preceded by region, sub-region, and accounting units). This "cataloging unit" – often used interchangeably with "watershed"– is a geographic area representing all or part of a surface drainage basin, a combination of basins, or a distinct hydrologic feature. [See USGS *Water Resources.* Accessed September 2011. Available online at: http://water.usgs.gov/GIS/huc.html.]

plants were collected by the Great Lakes Commission and provided to Sandia as model inputs, complementing county-level water use data from the U.S. Geological Survey already in the model.

B. Aquatic Resource Impact Metrics

GLEW characterized the energy-water nexus in the Great Lakes region on a more detailed level than has been done previously. A significant piece of the effort was the development of a series of ecological metrics designed to assess aquatic resource impacts from power generation. Metrics [48] related to water supply, low-flow vulnerability, thermal vulnerability, and water quality sensitivity were developed to try to better understand and build capacity to measure potential impacts on aquatic systems from power sector water withdrawals and consumptive uses. [49] These metrics are described in the following section.

a. Low Flow Vulnerability

This metric specifies a portion of surface water flow necessary to meet environmental quality during low flow periods using August as an index, or proxy, month for calculations. This metric was developed as a ratio of streamflow to water withdrawal during the driest time of year, also the time of year of highest human demand– typically the month of August (Table 3). A formula was developed [50] using August streamflow and all water uses to calculate the amount of water available to meet aquatic resource needs, or the amount of water flows which are needed to sustain a desired ecosystem, to meet abstraction requirements, and to support basin water uses [51] (Eq. 1).

$$(1): X(\%) = \frac{Mean\ basin\ August\ streamflow\ (MGD)}{((Mean\ basin\ August\ streamflow, MGD) + (sum\ of\ August\ water\ uses\ , MGD))}$$

Watersheds were ranked from 0 to 1 at three levels of vulnerability. Basins that ranked high (1) had adequate water availability (> 80 percent) in August to meet aquatic resource needs. Conversely, basins that received the lowest rating (0) were most vulnerable; they often had more water use than streamflow in August indicating that further water use would reduce streamflow and may impact other users. For the most vulnerable basins, less than 50 percent of the water was

---

[48] Metrics were focused on impacts to hydrologic flows and resources dependent on flows. Direct impacts from impingement and entrainment were not part of metric development and, therefore, were not factored into the scenario analyses for this study.

[49] These metrics were developed by Dr. Mark Bain of Cornell University as part of the Great Lakes Energy Water Nexus Initiative. For more details, including methods for metric development, see *Great Lakes Energy-Water Nexus Initiative: Environmental Rules to Classify Basins for Sensitivity from Future Energy Development.* Prepared by Mark Bain, February 2011. [Thereafter, *Environmental Rules*].

[50] *Environmental Rules*, supra note 49.

[51] Petts, G. E., M. A. Bickerton, C. Crawford, D. N. Lerner, and D. Evans. 1999. *Flow management to sustain groundwater-dominated stream ecosystems.* Hydrological Processes 13:497–513.

available during August to support environmental needs. Based on prior assessments, [52] [53] the metric recommended 50 percent (*i.e.,* a ratio equal to 0.5) instream flow as a threshold to maintain aquatic health. Basins having less than 50 percent water availability during low flow periods were identified as being vulnerable to significant environmental degradation in circumstances where additional water withdrawals were considered. In sum, increasing withdrawals will reduce this ratio. When this ratio drops below 0.5, there is the potential for environmental degradation.

Table 5 shows how each HUC-8 watershed ranks when this metric is applied. When used in the GLEW model (see section III-C below), these rankings provide a basis for judging the vulnerability to increased future water need during low flow seasons across the Great Lakes Basin. **Applying this metric shows that 24 of the 102**[54] **HUC-8 watersheds (~25 percent) in the Great Lakes Basin are classified as vulnerable** (Figure 3).

Table 5: Low Flow Vulnerability Metric [55]

Numerical Measure	Water Availability	Vulnerability Ranking	No. of HUC-8 Basins	Notes
0.0	< 50%	High	24	Additional withdrawals likely to result in significant environmental degradation
0.5	50-80%	Moderate	21	Likely to maintain good environmental conditions with additional water withdrawals
1.0	>80%	Low	57	Likely to maintain excellent environmental conditions with additional water withdrawals

[52] *Environmental Rules,* supra note 49.
[53] Hamilton and Seelbach. 2010. *Determining Environmental Limits to Streamflow Depletion Across Michigan*. The Book of the States, Council of State Governments, 534-537. Accessed August 2011. Available online at: http://www.miwwat.org/wateruse/documents/BOS%202010%20Hamilton%20and%20Seelbach.pdf.
[54] Five watersheds on the St. Lawrence River (Grass, Raquette, St. Regis, Salmon, and Chateaugay-English) that are sometimes considered part of the basin (depending on geographic bounds) were not included in this analysis.
[55] Based on data provided by M. Bain. See *Environmental Rules*, supra note 49.

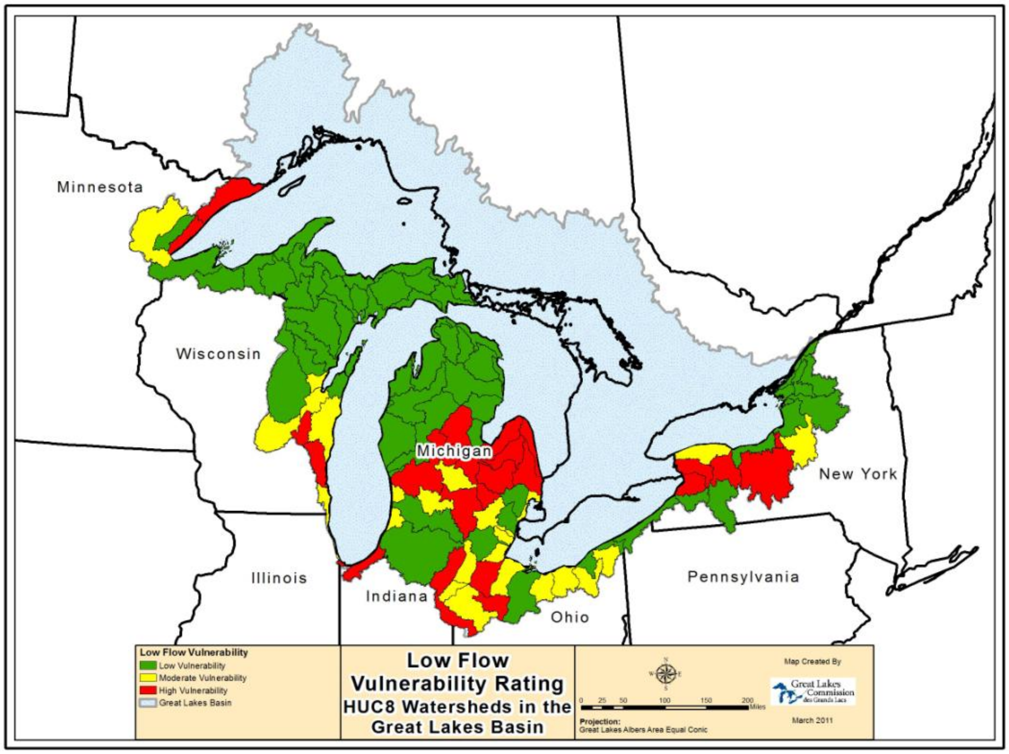


Figure 3: Low-flow vulnerability rankings of HUC-8 watersheds in the Great Lakes Basin.[56]

b. Thermal Vulnerability and Coldwater Resource Threat

Because temperature fluctuations can have a notable impact on aquatic ecosystems (Box 2), a measure of vulnerability of Great Lakes watersheds to thermal loading (*e.g.*, from power generation) was developed and was based on the most influential factors that shape thermal conditions: mean annual air temperature, groundwater discharge potential, surface water extent, and riparian forest cover. These variables were weighted and used to develop an environmental index of aquatic resource sensitivity or vulnerability to thermal loadings. Another dimension of the thermal alteration impact is the extent of coldwater (mean July temperature of <17.5˚C [57]) stream miles, or coldwater resource in the basin. The product of the thermal vulnerability and the miles of coldwater resource is a measure of threat to coldwater resources.

This metric has four levels of ranking (Table 6), which consider overall thermal vulnerability and threat to coldwater resources. Applying this metric shows that

[56] This map (and Figures 4, 5 below) was created by the Great Lakes Commission GIS staff, and is based on data provided by M. Bain. See *Environmental Rules,* supra note 49.

[57] Data for this metric were obtained from the Value of Great Lakes Water Initiative. 2011. *Watershed Selection Metric Profile*. [Thereafter, *VGLWI*].VGLWI utilized the stream classification system employed by the USGS based on size of drainage area and temperature class.

only 15 Great Lakes HUC-8 watersheds show an extremely low threat to coldwater resources, while the majority exhibits some degree of potential risk (Figure 4).

Table 6: Thermal Vulnerability & Coldwater Resource Threat Metric [58]

Numerical Measure	Ranking	No. of HUC-8	Notes
0.00	High	29	Either significant coldwater resources or high warming potential
0.33	Moderate Threat	29	Moderate warming potential and/or few coldwater resources
0.66	Low Threat	29	Low warming potential and marginal coldwater resources present
1.00	Extremely low threat	15	Either the warming potential was low or little or no coldwater resource exists in the basin

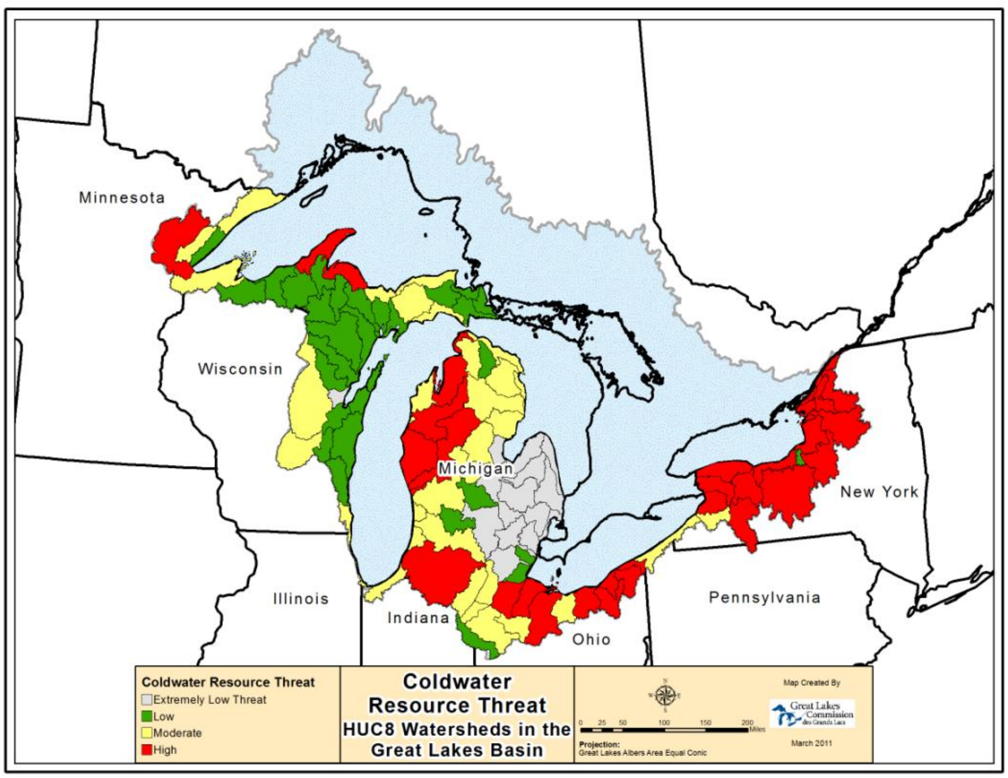


Figure 4: Thermal vulnerability and coldwater resource threat in HUC-8 watersheds in the Great Lakes Basin.

[58] Based on data provided by M. Bain. See *Environmental Rules*, supra note 49.

Box 2: Thermal Impacts on Aquatic Ecosystems†

Thermal discharges can directly affect the physiology of aquatic wildlife, which may ultimately affect food availability and ecosystem dynamics. Numerous studies have shown that thermal discharges may substantially alter the structure of aquatic communities by modifying photosynthetic, metabolic, and growth rates. Elevated temperatures can cause a decrease in the amount of dissolved oxygen in the water. If temperatures increase dramatically, reproductive function and nervous system function may degenerate. Warmer temperatures can also increase aquatic organism susceptibility to certain pathogens or environmental pollutants. The relative impact of thermal pollution is dependent in part on the water volumes and surface area involved.

Adverse temperature effects may also be more pronounced in aquatic ecosystems that are already subject to other environmental stressors such as high levels of biochemical oxygen demand, sediment contamination, or pathogens. Within mixing zones (the area where a discharge load integrates with receiving waters), which often extend several miles downstream from outfalls, thermal discharges may impair efforts to restore and protect the waterbody. For example, permit requirements to limit nutrient discharges in a watershed, and thereby reduce harmful algal blooms, may be counteracted by thermal discharges which can promote growth of harmful algae. Thermal discharges may have indirect effects on fish and other vertebrate populations through increasing pathogen growth and infection rates.

Thermal discharges may thus alter the ecological services, and reduce the benefits, of aquatic ecosystems that receive heated effluent. The magnitude of thermal effects on ecosystem services is related to facility-specific factors, including the volume of the waterbody from which cooling water is withdrawn and returned, other heat loads, the rate of water exchange, the presence of nearby refugia, and the assemblage of nearby fish species. Facilities must obtain and maintain National Pollutant Discharge Elimination System (NPDES) permits for thermal discharges. Under a permit, the designated use of the waterbody must be maintained. A demonstration must be made and agreed to by the state permitting authority. If a variance is granted, the permittee must demonstrate to the satisfaction of the permitting authority that a balanced indigenous population of fish is maintained in the waterbody.

† *National Pollutant Discharge Elimination System—Cooling Water Intake Structures at Existing Facilities and Phase I Facilities (*Proposed Rules). Federal Register 76: 76 (20 April 2011): p. 22173-22222.

c. Water Quality Sensitivity

A metric was developed to measure surface water vulnerability to further water quality stress using EPA data [59] on the extent of impaired waters. Watersheds were ranked into five numerical classes based on the percentage of impaired waters in that watershed (Table 7). These classes can be used directly to infer vulnerability to further water quality stresses: the greater the extent of impaired waters in the basin the greater the vulnerability.[60] When this metric is employed, results show that only 3 Great Lakes HUC-8 watersheds show no sign of water quality impairment (Figure 5).

Table 7: Water Quality Sensitivity [61]

Numerical Measure	Percent Impaired Waters	Threat /Vulnerability Ranking	No. of HUC-8 Basins
0.00	>25	Very High	18
0.25	10-25	Moderately High	19
0.50	5-10	Moderate	19
0.75	<5	Low	43
1.0	0	None	3

[59] U.S. EPA 303(d) data consider the effects of sediments, excess nutrients, harmful pathogens, and toxics (including metals, mercury, and pesticides). It is important to note that, while all impairment assessments are based on these factors, each state uses different criteria for classifying impaired waters.

[60] This is based on site-specific loading trends (as per EPA 303(d) data, supra note 59) as well as the fact that areas with impaired water quality have been shown to exhibit degraded biological/ecological conditions. U.S. EPA National Aquatic Resource Surveys program. 2011. *National Aquatic Resource Surveys: An Update*. Accessed October, 2011. Available online at: http://water.epa.gov/type/watersheds/monitoring/upload/nars-progress.pdf

[61] Based on data provided by M. Bain. See *Environmental Rules*, supra note 49.

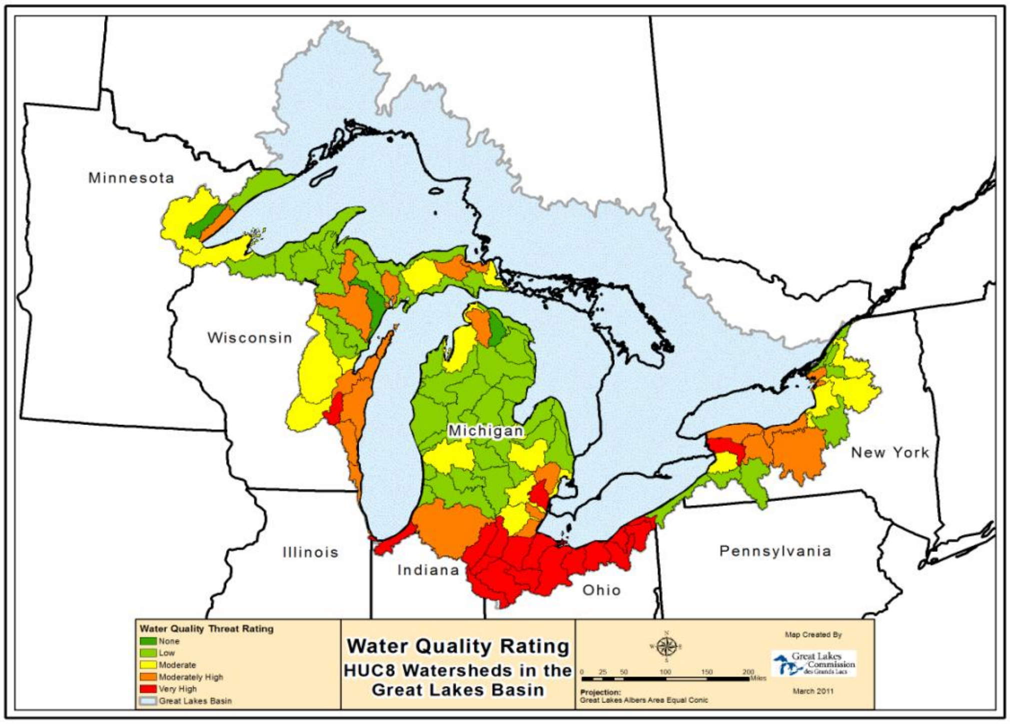


Figure 5: Water quality vulnerabilities of HUC-8 watersheds in the Great Lakes Basin.

d. Water Quantity Vulnerability

This metric measured water quantity resource impacts across all basins, but its application was abandoned for this project when the results showed that all watersheds received values greater than 1 on a 0-to-1 scale for vulnerability to further environmental stress. This exercise was informative to demonstrate that use of average annual flows in a water-rich region like the Great Lakes Basin is not helpful in discerning where hydrologic vulnerabilities exist.

C. The Great Lakes Energy-Water Model[62]

As noted above, the EPWS model, developed by Sandia National Laboratories, was designed to assess water use, consumption, and GHG emissions under various power generation scenarios. Originally, it was envisioned that additional metrics would be integrated into the model to enable the model to predict a more comprehensive range of ecological impacts from power sector water uses in the Great Lakes Basin. A lack of adequate data (and time and resources to acquire and process that data) to inform rates of change (*e.g*., future values) for the thermal vulnerability and the water quality metrics prevented their use in the modeling exercise. Consequently, only the low-flow vulnerability (see section III-B.a above) metric was usable for purposes of the modeling conducted under the project.

---

[62] The GLEW model was developed by Vince Tidwell and Barbie Moreland of Sandia National Laboratories as part of the Great Lakes Energy Water Nexus Initiative. See *Energy and Water,* supra note 28.

The low-flow vulnerability metric was integrated into the EPWS model, enhancing it such that it could also calculate where water withdrawals for power generation would exceed available supply under low flow conditions (*i.e.,* hydrologically vulnerable watersheds). Thus, we were able to analyze aquatic resource vulnerability to increased thermoelectric water withdrawals/uses during seasonal periods of low surface water flow. With the integration of several specific Great Lakes features and data sources (the low-flow vulnerability metric, the HUC-8 level data, and Great Lakes-specific water use data) , the enhanced model became the Great Lakes Energy-Water (GLEW) model.

The model is designed to operate on an annual time step over a 28-year period, 2007 to 2035. The spatial extent of the model is defined both by the Great Lakes watershed as well as the accompanying "energyshed" (the geographic area over which electric power used in the Great Lakes Watershed is produced).

Future electric generation projections were developed by looking at those regional energy markets that cover some portion of the Great Lakes Basin and, based on their role in serving the basin in 2010, making projections about how those markets might react or develop to serve the basin's electric energy needs in the future.

Electricity generated in the basin does not necessarily stay in the basin. Conversely, electricity used in the basin is not necessarily generated in the basin. The analyses described in this report provide only a snapshot of potential impacts and tradeoffs associated with electric power generation that is generated in the Great Lakes Basin. Electric power generated elsewhere, but consumed in the basin, is not considered here.

As noted above, considerable research has been undertaken to identify the water withdrawal and consumptive use required by different power generation technologies.[63] [64] [65] The model was seeded with data representing the highest level of detail that was publically available. These data include such factors as population at the county level, changes in per capita water use at the state level, and stream gauge data at the watershed level. The model was designed to translate these data from disparate scales into a compatible reference system for this analysis.

[63] U.S. Department of Energy. 2006. *Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water*. Available online at: http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf.

[64] Energy Information Administration, *Annual Energy Outlook 2011*.

[65] E. Nash, G. Anderson, and M. Bain. 2011. *Environmental Impacts of Energy Production in the Great Lakes*. Cornell University.

Electricity is distributed through a complex maze of energy markets that are defined as "energy market modules." In the larger energy market region that surrounds the Great Lakes, the power travels along a complex web of transmission infrastructure that is run by Independent System Operators (ISOs), each of which covers a variety of territories, but who also coordinate to buy and sell power to ensure that adequate energy supplies are available within the basin.

The GLEW model is organized according to six interacting modules: demography, electric power production, thermoelectric water demand, non-thermoelectric water demand, water supply, and environmental health.[66] Within the modules, changes in population and gross state product (GSP), power demand, and the construction of new power plants were modeled. Plant retirements, retrofits, emission control requirement, and/or intake structure restrictions were also considered.[67] The thermoelectric module calculated water withdrawal and consumption based on the mix of power plants, cooling type, and associated production, while the non-thermoelectric water demand module calculated both withdrawal and consumption by source (lake, other surface water, and groundwater) and by use sector (municipal, industrial, mining, livestock, and agriculture). Growing demands were compared to various water supply metrics to identify regions in danger of water stress and, finally, all of these factors were combined to provide an estimate of watershed environmental quality.

The purpose of the modeling is not to provide predictions of future water use and environmental quality...but to highlight relative change in impacts among different energy futures and the distribution of impacts across the Great Lakes Basin over time.

IV. Great Lakes Basin Impacts Under Future Power Generation Scenarios

The GLEW model was used to examine tributary (non-Great Lake) and groundwater withdrawals and consumptive uses at the subwatershed (HUC-8) scale. Analyses examined alternative future power generation scenarios and their different impacts on water use, water consumption, and vulnerable watersheds in the Great Lakes Basin. Five alternative future power

[66] For details on how each of these modules was developed, see *Energy and Water*, supra note 28, at p. 4.
[67] For details on how plant retirements and emission controls were considered, refer to *Energy and Water*, supra note 28, at p. 6.

scenarios were analyzed for the period of 2007 to 2035:[68]

1. Business as Usual Case
2. No New Open-Loop Cooling (NNOLC)—Clean Water Act (CWA) Section 316(b)
3. Open-Loop Cooling Prohibited (OLCP)-retrofit all plants
4. Renewable Portfolio Standard (RPS)
5. Carbon Capture and Sequestration (CCS)

Each scenario used population and electric energy demand projections from reputable national sources. U.S. Census Bureau (2004) projections indicate that the Great Lakes Basin population is expected to grow 32 percent (increase from 22.6 million in 2007 to 29.9 million by 2035). Energy Information Administration (EIA) projections indicate that electric power demand is projected to increase by 25 percent during the same period. Additionally, siting of new plants throughout the projections assume a ratio of local watershed (HUC-8) to overall basin electric power production equal to that of 2005.

Each scenario aimed to quantify tradeoffs in terms of water withdrawal, water consumption, and environmental vulnerability to low flows relative to the five scenarios. The scenarios also aimed to illustrate the extent to which new thermoelectric power production will compete with growing demands in other water use sectors.[69]

A. Business as Usual Case (BAU)

This scenario assumes that both population size and power demand will grow at rates consistent with the estimates noted above. Construction of new plants is assumed to maintain a comparable fuel mix and cooling mix (62 percent open-loop, 31 percent closed-loop cooling tower, and 7 percent closed-loop cooling pond), to that of the 2007 fleet. Likewise, source water for plants is maintained according to the current distribution; specifically, 79 percent Great Lakes, 18 percent other surface water and 3 percent groundwater. Finally, this scenario assumes no changes with regard to current policies regulating power plant intake structures or GHG emissions.

---

[68] The GLEW scenarios were developed by Vince Tidwell and Barbie Moreland of Sandia National Laboratories as part of the Great Lakes Energy Water Nexus Initiative. See *Energy and Water,* supra note 28.

[69] *Energy and Water,* supra note 28 at p. 16.

B. No New Open-Loop Cooling (NNOLC)[70]

In this case, we adopted the same assumptions as the BAU scenario with two exceptions. First, no new power plant construction will utilize open-loop cooling. Second, new construction will consist of a variation in source water distribution, one that is less dependent on Great Lakes resources; specifically, the new source water mix is taken as 15 percent Great Lakes, 70 percent other surface water and 15 percent groundwater. This shift in the source water ratio is hypothesized to occur due to the decreased reliance on cooling water (shift from open-loop to closed-loop cooling) coupled with the relatively high cost of lake-front property.

C. Open-Loop Cooling Prohibited (OLCP)[71]

In this scenario, open-loop cooling intake structures on both new and existing power plants are restricted. Any plant older than 35 years with a capacity factor of 20 percent or lower is assumed to be retired (thresholds based on the professional judgment of the GLEW project team). All other assumptions are similar to those in the BAU case except the water source mix. Here, the water source distribution is 15 percent Great Lakes, 70 percent other surface water and 15 percent groundwater.

D. Renewable Portfolio Standard (RPS)

This case uses the same assumptions as in the NNOLC case except for the future fuel mix employed in new plant construction. The new mix favors renewables in efforts to achieve the production targets set by the Great Lakes states in the RPS policies. As several Great Lakes states have aggressive RPS targets, we considered a case that favors high renewable expansion and low water demand. Specifically, new plant construction is assumed to be limited to 50 percent wind, 25 percent biofuel and 25 percent NGCC (Natural Gas Combined-Cycle).[72]

E. Carbon Capture and Sequestration (CCS)

This scenario assumes that future greenhouse gas levels must be reduced to 20 percent of the levels present in 2007. Selection of plants for retirement was based

---

[70] Although it is unlikely that such a large portion of all water use for power across the Great Lakes basin would occur from tributaries and groundwater (not the Great Lakes proper), a growth in tributary and groundwater sources for power generation is not inconceivable for individual watersheds of the Great Lakes basin. To that end, these scenarios are illustrative in that they enabled the analysis to identify where significant increases in tributary and groundwater use by the power sector would likely result in greater environmental or hydrologic vulnerabilities.

[71] *Ibid*.

[72] Many of the new natural gas fired power plants are known as 'combined-cycle' units. In these types of generating facilities, there is both a gas turbine and a steam unit. The gas turbine operates in much the same way as a normal gas turbine, using the hot gases released from burning natural gas to turn a turbine and generate electricity. In combined-cycle plants, the waste heat from the gas-turbine process is directed toward generating steam, which is then used to generate electricity much like a steam unit. (From NaturalGas.org, 2011. *Electric Generation Using Natural Gas*. Available online at: http://www.naturalgas.org/overview/uses_eletrical.asp)

on the work of the National Energy Technology Laboratory (NETL).[73] [74] New plant construction was assumed to follow the mix in the RPS scenario, while new cooling type mix and source water follow that in the NNOLC case.

V. Scenario Analyses Results: Impacts on Water Withdrawal and Consumption

The five scenarios largely resulted in differences in both the magnitude and directionality of projected water uses. Accordingly, this resulted in different recommended siting and configuration for construction of new electric power generation capacity within the Great Lakes Basin (Figure 6). Unique assumptions were associated with each scenario, as noted in their respective descriptions (above).

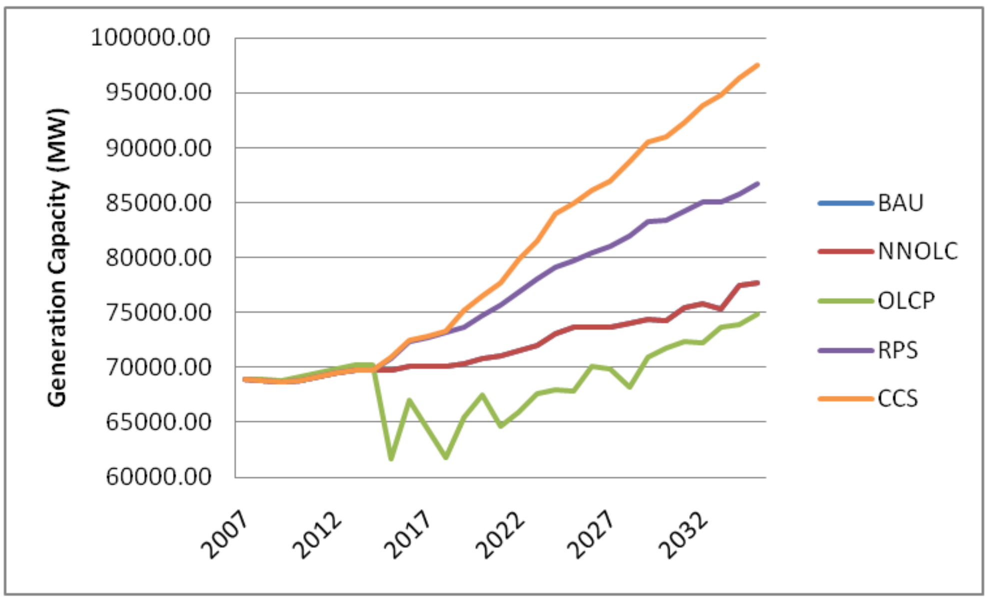


Figure 6: Projected change in electric power generation capacity in the Great Lakes watershed for the five alternative future scenarios. Because BAU and NNOLC result in similar growth in capacity, only one trend (NNOLC) is discernible.[75] The variability observed in the OLCP trend is likely caused by a balance between removing old plants and installing new plants with higher capacity factors.

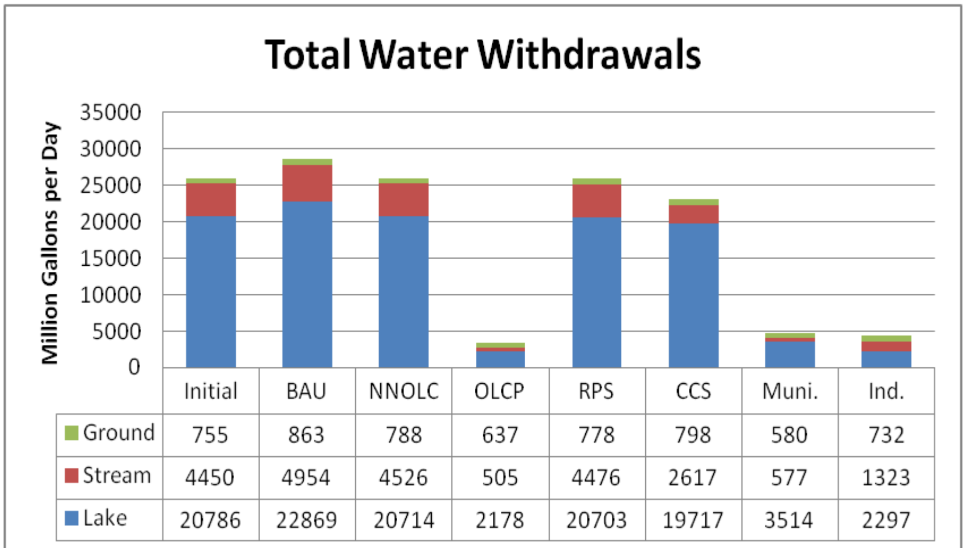
[73] *Cost and performance*, supra note 39.

[74] U.S. Department of Energy. 2007. *Power plant water usage and loss study*. National Energy Technology Laboratory.

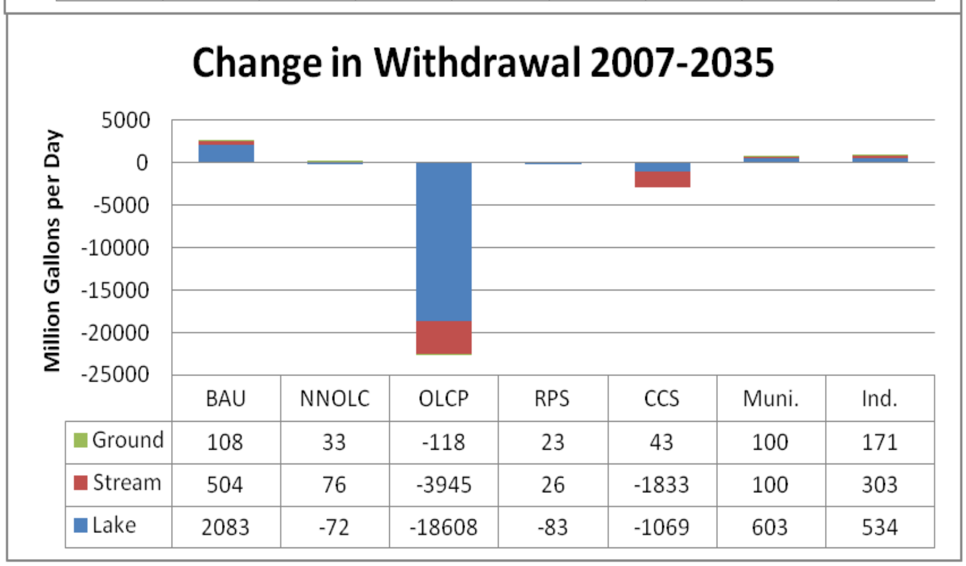
[75] *Energy and Water*, supra note 28 at p. 43

A. Regional Water Withdrawal

Due to differences in thermoelectric water demand as noted above, there was a large disparity in withdrawal across the five scenarios. When withdrawal in 2007 and projected withdrawals in 2035 were further compared against withdrawals by the municipal and industrial sectors, the results showed that growth in these non-thermoelectric sectors is predicted to be relatively small compared with changes in the thermoelectric sector (Figure 7).



	Initial	BAU	NNOLC	OLCP	RPS	CCS	Muni.	Ind.
Ground	755	863	788	637	778	798	580	732
Stream	4450	4954	4526	505	4476	2617	577	1323
Lake	20786	22869	20714	2178	20703	19717	3514	2297



	BAU	NNOLC	OLCP	RPS	CCS	Muni.	Ind.
Ground	108	33	-118	23	43	100	171
Stream	504	76	-3945	26	-1833	100	303
Lake	2083	-72	-18608	-83	-1069	603	534

Figure 7: Total water withdrawals by thermoelectric power generation for the four alternative scenarios (top) and the change in water withdrawal between 2007 and 2035 (bottom). Also included are withdrawals by the municipal and industrial sectors. Withdrawals are disaggregated by source (Great Lakes, stream, or groundwater).[76]

[76] *Energy and Water*, supra note 28, at p. 44.

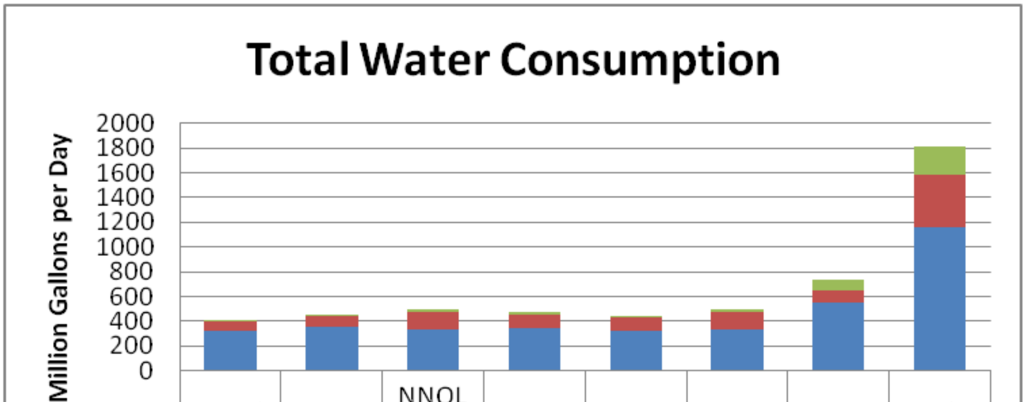
The BAU case showed the highest growth in withdrawal (2,695 MGD or a 10 percent increase), while the second largest rise in withdrawal occurred under the NNOLC scenario at 37 MGD. These differ, however, in their source water (Great Lakes and non-Great Lakes, respectively). When both plant retirement and source water distributions (15 percent directly from the Great Lakes in all cases other than BAU) are considered, total withdrawals from the Great Lakes are projected to decrease by 72 MGD, while stream and groundwater withdrawals increase to 109 MGD.

The remaining scenarios resulted in overall decreases in withdrawals, with the largest reductions associated with the OLCP case (22,671 MGD; 87 percent) followed by the CCS scenario (2,859 MGD). Finally, the RPS scenario resulted in a decrease in withdrawals of 36 MGD. While the CCS reductions can be attributed to the significant likelihood of plant retirement, reductions in the RPS case may be due to a combination of age-based plant retirement, very low water use by natural gas combined-cycle (NGCC) plants and biofuels, and no water use by wind power.

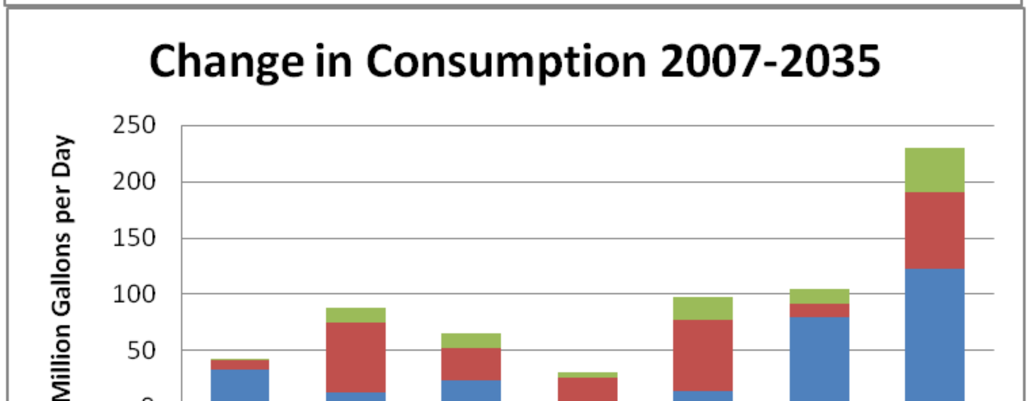
B. Regional Water Consumption

In contrast to withdrawals, consumptive water use increases under all five scenarios (Figure 8), though all are smaller than anticipated increases for municipal and industrial uses. The highest growth is shown in the CCS scenario with an increase of 24 percent (97 MGD). This case does not benefit from the retirement of the same set of plants as the OLCP scenario (see below) and additional water is consumed in the CCS process (See section II-C). The second highest increase in consumption is shown in the NNOLC scenario with a 22 percent increase (88 MGD), reflecting a higher consumptive use associated with closed-loop systems. The OLCP scenario increased consumption by 16 percent (65 MGD) and its relatively lower value is likely due to the retirement of older plants with less efficient cooling equipment followed by their replacement with new plants with lower consumptive use factors. While the BAU scenario increased consumption by 10 percent (42 MGD), the case with the lowest increase in consumption was the RPS scenario at 7.6 percent (31 MGD). This reflects the considerably lower water use associated with NGCC as well as wind power generation, which uses no water.

Similar to withdrawals, consumptive uses across the scenarios were further compared with consumption in 2007 as well as projected consumption in 2035 in both the municipal and industrial sectors. Whereas the growth in withdrawal in these sectors is comparatively lower than growth in thermoelectric withdrawals, growth in non-thermoelectric consumptive use is of a similar magnitude (or exceeds) that of every future thermoelectric scenario (as expected), though these sectors rely more heavily on direct Great Lakes water resources (Figure 8).



	Initial	BAU	NNOLC	OLCP	RPS	CCS	Muni.	Ind.
Ground	3	4	16	16	8	23	91	236
Stream	82	90	144	110	104	145	91	420
Lake	320	353	333	344	324	334	556	1159



	BAU	NNOLC	OLCP	RPS	CCS	Muni.	Ind.
Ground	1	13	13	5	20	13	39
Stream	8	62	28	22	63	13	69
Lake	33	13	24	4	14	79	122

Figure 8: Total water consumption by thermoelectric power generation for the four alternative scenarios (top) and the change in water withdrawal between 2007 and 2035 (bottom). Also included is consumption by the municipal and industrial sectors. Consumption is disaggregated by source (Great Lakes, stream, or groundwater).[77]

[77] *Energy and Water*, supra note 28, at p. 45.

C. Impacts on Vulnerable Watersheds

Using the low flow vulnerability metric described in section III-B, the GLEW model assessed those watersheds under the different future power generation scenarios. As noted earlier in Section III-B, in 2007, 24 of the 102 HUC-8 watersheds in the Great Lakes Basin are vulnerable, while 75 percent of the HUC-8 watersheds are classified as good or excellent (Figures 3, 9). The Business As Usual Scenario— the scenario subject to the greatest new withdrawals—projected six new basins becoming vulnerable to environmental degradation under low-flow conditions. The NNOLC and RPS scenarios each projected three additional watersheds becoming vulnerable, while the CCS resulted in no new vulnerable watersheds. The increase in vulnerable watersheds in both the NNOLC and the RPS cases may be due to several of the watersheds in the initial assessment straddling a vulnerability threshold or "tipping point", whereby *any* new future water use results in a change in vulnerability status. In the case of CCS, it is unclear as to why the number of vulnerable watersheds remains the same as in the initial (2007) condition. While this finding warrants further consideration, it may simply be that CCS plants are projected for siting within watersheds that do not straddle this vulnerability threshold.

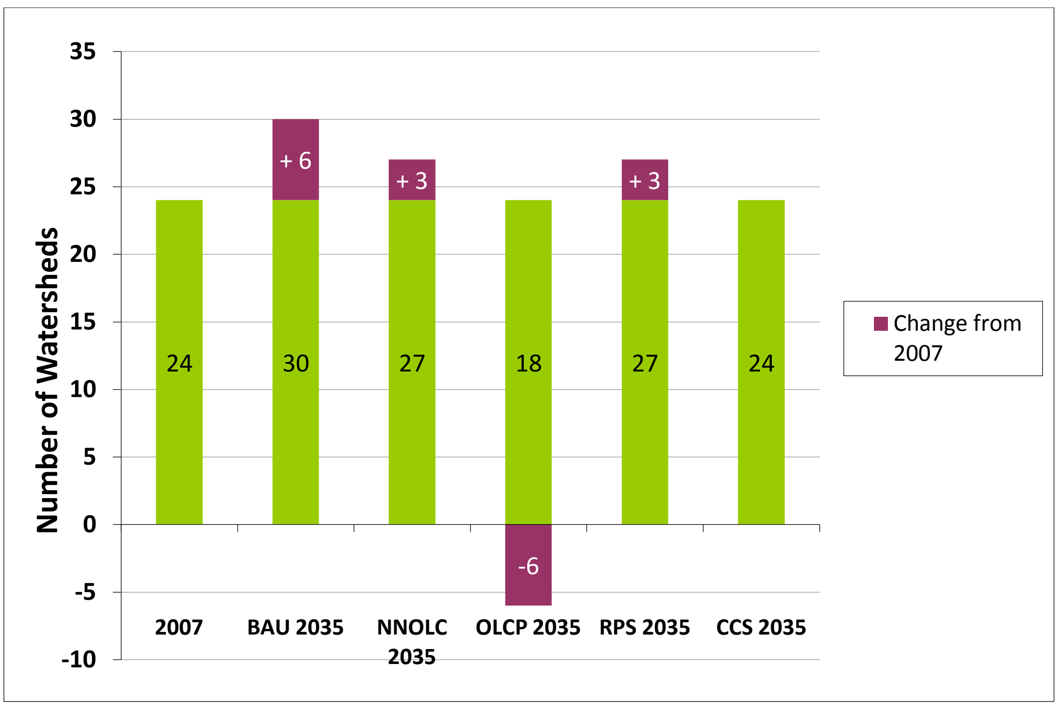


Figure 9: Number of watersheds classified as having vulnerable environmental quality based on the low-flow metric. The "2007" bar represents initial conditions, while the others show the total number of vulnerable watersheds (the total size of each bar) and also reflect any changes from initial conditions (the red portion of each bar) among the five future scenarios.[78]

[78] Figure 9 was created by GLC staff based on findings from *Energy and Water*, supra note 28.

In contrast, the OLCP scenario reduced the number of vulnerable watersheds from 24 to 18 (an improvement of six watersheds). The retirement and/or retrofitting of older plants with open-loop cooling are no doubt the cause of this improvement. While this may seem counterintuitive given the greater levels of water consumption associated with closed-cycle cooling (see Box 1 above), it is possible that the benefit of the retirement of a vast number of older plants using open-loop cooling systems exceeds the expected increase in impacts associated with higher consumptive use values incurred by closed-loop systems.

Results of the analysis suggest that changes in thermoelectric water use are more significant to a watershed than changes to municipal and industrial water uses. At the start of the modeling period (2007), 24 watersheds were classified as vulnerable, 14 of which were vulnerable considering only non-thermoelectric water uses. Looking only at non-thermoelectric water use, the number of vulnerable watersheds increases only by one (to 15) at the end of the modeling period in 2035, In contrast, changes in thermoelectric water use lead to greater changes (gains and losses) in watershed vulnerabilities, as illustrated above.

VI. Policy Analysis

A. EPA Clean Water Act Draft Regulations

EPA has proposed Clean Water Act (CWA) Section 316(b) regulations that, if adopted, would set standards applicable to cooling water intake structures at existing power generation and industrial facilities nationwide. The proposed regulations separately address impingement and entrainment at these facilities. Depending on a variety of factors, the standards could affect withdrawal and consumption rates in the basin.

For impingement, the EPA proposed rule would set national numeric standards that would require mortality or flow velocity reductions below certain levels. For entrainment, the proposed regulations give state permit writers the discretion to select the Best Technology Available (BTA), taking a variety of factors into account. Such discretion would apply to existing units as well as replacement units, repowered units, and rebuilt units, even if the replaced, repowered, or rebuilt units are larger than the original units involved. However, the proposed rule would require "new units" to add technology that reduces intake flow to a level that is equivalent to closed-cycle cooling.[79] [80] This is important because expanding

[79] U.S. EPA. 2011. *Proposed Regulations to Establish Requirements for Cooling Water Intake Structures at Existing Facilities*. Accessed October, 2011. Available online at: http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/upload/factsheet_proposed.pdf.

[80] U.S. EPA. 2011. *Clean Water Act Section 316(b) Existing Facilities Proposed Rule Qs and As.* Accessed October, 2011. Available online at: http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/upload/qa_proposed.pdf

capacity at an existing plant is easier than building an entirely new power plant and therefore new power capacity from conventional fuel sources is most likely to be added in locations where power plants already exist, whether or not they are subject to the new rule.

Given our results, these types of regulations will affect not only changes in water uses (withdrawal, consumption), but also the ways in which these changes may impact ecological health at the local watershed scale. As a majority of the thermoelectric power generated in the Great Lakes Basin relies on open-loop cooling processes (see section II-B), implementation of section 316(b) may result in considerable changes in water use and related ecological impacts in the basin. The NNOLC scenario (above) is the scenario that best reflects expected outcomes of these proposed regulatory changes, and infers some ecological impacts with respect to vulnerable watersheds. Below, we describe some implications for water use and consumption as they relate to the Great Lakes and St. Lawrence River Basin Water Resources Compact.

B. Water Use: Implications for the Great Lakes & St. Lawrence River Basin Water Resources Compact

The Great Lakes and St. Lawrence River Basin Water Resources Compact (hereafter "the Compact") was enacted in 2008 by the Great Lakes states to establish guidelines for water use and conservation.[81] Thresholds for reporting and registration of water withdrawals are currently set by the Compact at 100,000 GPD, with any withdrawal over this threshold being subject to possible legal action by an aggrieved citizen.[82] Additionally, proposals for consumptive uses greater than five MGD (over a 90-day period) are subject to a regional review process under the Compact. However, the majority of the states have passed legislation setting consumptive use thresholds at two MGD (over a 30-day average)[83], with varying consequences if those thresholds are exceeded. The scenarios examined above project varying water uses due to changing thermoelectric power demands. This reveals the potential for varying regulatory implications for power production facilities pursuant to the Compact's guidelines.

Across the five scenarios, the number of facilities that would exceed Compact withdrawal thresholds ranged from 22 to 113.[84] While the highest number of potentially regulated new withdrawals occurs under the CCS scenario, the lowest is associated with the NNOLC case, which also has relatively low overall withdrawals.

---

[81] Council of Great Lakes Governors. *The Great Lakes and St. Lawrence River Basin Water Resources Compact*. Accessed August 2011. Available online at: http://www.cglg.org/projects/water/docs/12-13-05/Great_Lakes-St_Lawrence_River_Basin_Water_Resources_Compact.pdf. [Thereafter, *The Compact*].

[82] Schroeck, N. S. 2011. *Energy Facility Siting*. Great Lakes Environmental Law Center [Thereafter, *Facility Siting*]

[83] *Ibid.*

[84] *Energy and Water,* supra note 28 at Figure 19.

The number of facilities that would exceed Compact consumption thresholds ranged from 1 (BAU) to 12 (OLCP). In the BAU case, no new plants would be created which exceed thresholds due to the continued use of open-loop cooling processes. In the case of both RPS and CCS, the low number of plants exceeding the Compact thresholds likely stems from the relatively small, low water-use plants planned for construction. The relatively higher number of plants exceeding threshold standards under both the OLCP and NNOLC scenarios is largely due to the higher consumptive uses associated with closed-loop technology.

Our policy analysis and scenario modeling work highlight opportunities for improving policies and regulations to better address water quantity impacts by the power sector in the Great Lakes basin.

It is important to note that results are highly dependent upon where future power plants are sited. We have assumed siting patterns and density levels similar to those of the recent past (2005). Our results show that a number of Great Lakes watersheds may be on the verge of ecological vulnerability. In other words, new or increased water withdrawals even below the current Compact thresholds may result in significant adverse water resource impacts in these areas. Moreover, Compact guidelines dictate that, at the currently proposed 100,000 GPD withdrawal threshold, only registration and reporting are required.[85] Individual states, as the implementers of the Compact, should, therefore, consider requiring prior approval of withdrawals, subject to an environmental review, to ensure sustainable water use. Several states are moving in this direction. Furthermore, because only a regional review is required for consumptive uses of proposed facilities (many of which will submit proposals that fall below the five MGD threshold, thus avoiding regulation), individual states also need to consider setting consumptive use thresholds that ensure adequate resource protection.

Beyond individual state guidelines, the Compact calls for a cumulative impact assessment every five years or when the basin experiences an increase[86] in water losses equal to or greater than 50 MGD (over 90 days). This cumulative impact review is to be conducted by the Regional Body, which has drafted interim procedures for conducting such assessments. To help prevent excessive water use throughout the basin (*i.e.,* to trigger timely assessments), the GLEW model can be used as a tool to determine when such losses are occurring and, further, could be used to gain more sensitive measures of losses in individual watersheds within the basin.

---

[85] *Facility Siting,* supra note 82.
[86] Based on the quantity at the most recent past assessment.

C. Energy Facility Siting: Implications for Electric Power Grid Regulation

In other regions, the nexus between energy and water confronts issues unfamiliar to a water-rich region like the Great Lakes Basin. Recent seasonal droughts in the Tennessee Valley, for example, have led to the curtailment and/or suspension of operations of certain nuclear power plants due to high discharge water temperatures and reduced flows available for cooling.[87] The Great Lakes region may face similar issues given the likelihood of continued changes in climate patterns[88] [89], and due to communication barriers among water users in the basin. As light is shed on the ecological impacts of thermoelectric power production in the Great Lakes, the need to address existing communication gaps among the various water use sectors may arise. This could result in changes in electric power grid regulations at both state and regional levels.

Traditionally, state public utility commissions (PUCs) are a key decision-maker about when and where to site new power production facilities. However, PUCs and environmental organizations such as state Departments of Natural Resources (DNRs) have distinct charters that do not compel them to collaborate on energy facility planning and siting decisions. For example, while power plant water use and consumption disclosure is typically included in DNR reporting procedures, DNRs are not required to communicate this information to PUC agencies.[90] Strengthening the communication between PUCs and natural resource agencies can help individual states achieve progress in minimizing adverse impacts to the Great Lakes basin ecosystem.

In addition to these coordination efforts at the state level, communication opportunities also exist at a regional level. By virtue of their influence in planning and operations of the power grid, federally-authorized agencies such as the Federal Energy Regulatory Commission (FERC) and various Regional Transmission Organizations (RTOs), have the potential to influence the ways in which water resources are used. RTOs such as the Midwest Independent System Operator (MISO) are already aiming to increase attempts to inform future planning efforts, as evidenced by recent modeling exercises that show varying energy generation mixes

---

[87] D. Munson, *pers. comm*. Recycled Energy Development, Westmont, IL.

[88] Bernstein *et al.* 2007. *Climate Change 2007: An Assessment of the Intergovernmental Panel on Climate Change.* Synthesis Report. Accessed October 2011. Available online at: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[89] Dempsey, D., J. Elder, and D. Scavia. 2008. *Great Lakes Restoration and the Threat of Global Warming*. A report by the Healing Our Waters – Great Lakes Coalition. Accessed October, 2011. Available online at: http://www.miseagrant.umich.edu/climate/workshop/images/Scavia-Excerpt-from-Global-Warming-Report.pdf

[90] Moore, J. N. 2011. *The Confluence of Power and Water: How Regulation of the Electric Power Grid Affects Water and other Natural Resources.* Environmental Law and Policy Center. [Thereafter, *Regulation of the Electric Power Grid*].

for future power production scenarios.[91] These and other energy modeling and power projection analyses have emphasized variations in areas such as cost, reliability, and GHG emissions associated with different energy mixes; water quantity and uses have not traditionally been part of those analyses. The GLEW project was unique in that, for the first time, water resource factors were considered in future power generation scenarios for the Great Lakes basin. RTOs are in a position to use this type of information to educate commissioners and other stakeholders on the ecological implications of different energy futures. Our results may be a useful aid for RTOs and other agencies as they integrate water resource impacts into planning for the region's energy prospects.

The GLEW project was unique in that, for the first time, water resource factors were considered in future power generation scenarios for the Great Lakes basin.

There are also options for state commissions and regional agencies to work together on water-use issues. Commissioners in Midwestern states are likely already members of regional and/or national associations such as the Mid-America Regulatory Conference (MARC) and the National Association of Regulatory Utility Commissioners (NARUC).[92] These types of conferences and related events are well suited for communication related to inter-state water resource concerns. Here too, results from the GLEW modeling analysis would serve as a useful aid in raising awareness on the ecological impacts of water resource use for power production across state boundaries within the Great Lakes Basin.

VII. Summary and Conclusions

According to the analyses above, several key findings resulted. First, thermoelectric power production exerts a strong presence in the Great Lakes region. Accounting for 76 percent of the basin's withdrawals and 13 percent of the consumption, thermoelectric power generation is a significant source of water resource use. However, due to differences in policies and regulations, changing infrastructure requirements, increased sustainability efforts, etc., thermoelectric water use characteristics could radically change over the next 25 years. According to the five scenarios analyzed, different power production standards may result in vastly different water resource use by 2035. For example, withdrawals could either grow by 2,695 MGD (10 percent) for the BAU scenario or decrease by 22,671 MGD (87 percent) for the OLCP scenario, whereas growth in consumptive use occurs in all cases. At present, most of the thermoelectric water use comes directly from the

[91] *Ibid,* at p. 12.
[92] *Ibid,*at p. 21

Great Lakes, accounting for 81 percent of all withdrawals. The other 19 percent of total withdrawals from the lake tributaries is still important, though, particularly since this is where impacts on hydrologically vulnerable watersheds were postulated.

In 2007, 24 watersheds of the 102 in the basin were classified as hydrologically vulnerable, 19 of which had some thermoelectric withdrawal. The thermoelectric sector is expected to expand in the next several decades, potentially increasing the number of watersheds classified as vulnerable by three, three, and six for the NNOLC, RPS, and BAU cases respectively. The development of aquatic resource impact metrics allowed for new ways to measure and locate vulnerable watersheds at the HUC-8 level within the vast Great Lakes Basin. This helps to direct the focus to areas where future work on vulnerabilities should occur, though that work needs to be done at a finer scale still.

Changes in water uses also are expected in the non-thermoelectric sectors across the basin. As projected, withdrawals will increase by 1,811 MGD while consumption will grow by 335 MGD. Fortunately, some of the new growth in the thermoelectric sector is projected to occur in watersheds experiencing negligible non-thermoelectric growth. Interestingly, when only non-thermoelectric uses are considered (*e.g.,* if thermoelectric water withdrawals are ignored) in the year 2035, an overall decrease in the number of hydrologically vulnerable HUC-8 watersheds is projected. This highlights the role of the power sector as a dominant water user in the region, as well as the need for further investigation into the ecological effects of local water quantity fluctuations and human impacts in these areas.

Impending policy implications are expected as well. Changing thermoelectric water uses will likely necessitate the need for new permitting of power production facilities (and other changes in compliance) under the Great Lakes and St. Lawrence River Basin Water Resources Compact. Results show that the number of facilities subject to new withdrawal permitting could range from 22 (NOLC) to 113 (CCS) and tend to be clustered in New York, Wisconsin, and Michigan. There will be relatively fewer facilities subject to new permitting for consumptive water use, and siting of these plants is expected to “match” locations for those exceeding withdrawal thresholds. Despite the clear link between power generation and water, this nexus is highly complicated in the Great Lakes Basin, particularly because power generated in the basin does not necessarily stay in the basin. Moreover, not all power used in the basin is generated in the basin. Thus, a basin-wide analysis only tells part of the story of how energy production impacts Great Lakes water resources.

The regulatory framework for permitting water withdrawal, consumption, and thermal “use” from the power sector focuses largely on individual plant impacts on local water quality, and not on the cumulative quality and quantity impacts of multiple users on the total basin water available to meet ecological and human use needs. Indeed, a regulatory framework that focuses on water quality may not be adequate to meet the ecological needs of the aquatic organisms that depend on these waters; particularly at certain times of the year as our low-flow analysis showed. The "no significant adverse impact on the waters and water-dependent natural resources of the Great Lakes Basin" test provided by the Compact is an important first step in ensuring ecological requirements are met and sustained. As suggested above, the states and provinces can achieve these standards by requiring prior approval of withdrawals conditioned on an environmental review. More detailed assessments of water quantity impacts on ecological conditions at the local watershed level will help not only to identify ecologically-based water withdrawal thresholds, but also to identify the steps necessary for adopting more appropriate water management decisions across the Great Lakes Basin.

VIII. Acknowledgements

The Great Lakes Energy-Water (GLEW) Nexus Initiative Phase I Report was prepared by the staff at the Great Lakes Commission: Victoria Pebbles, Program Director and Cassie Bradley, Sea Grant Fellow. Input and support were also provided by a suite of GLEW Core Team members and Project Advisors† (listed below).

GLEW Core Team*:* Great Lakes Commission, Cornell University, Argonne National Laboratories, Sandia National Laboratories, the Great Lakes Environmental Law Center, and the Environmental Law and Policy Center.

GLEW Project Advisors*:* Alliance for Water Efficiency, DTE Energy Company, Edison Electric Institute, Electric Power Research Institute, Illinois Dept. of Natural Resources, Michigan Dept. of Energy, Labor and Economic Growth, New York Power Authority, Ontario Power Generation, Pennsylvania Dept. of Environmental Protection, Recycled Energy Development, U.S. Dept. of Energy (National Energy Technology Laboratory), University of Texas, Austin, We Energies, Wisconsin Dept. of Natural Resources, Wisconsin Public Service Commission.

Funding support for the Great Lakes Energy-Water Nexus Initiative was provided by the Great Lakes Protection Fund

† Representation on the GLEW Project Core Team or Advisory Team does not imply that the agency, company or organization agrees with or endorses all of the findings herein. This report does not necessarily express the view(s) of individuals of the GLEW project team members, advisors, or their organizations.