WATER USE BENCHMARKS FOR THERMOELECTRIC POWER GENERATION

PROJECT COMPLETION REPORT

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Water Use Benchmarks for Thermoelectric Power Generation

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EXECUTIVE SUMMARY

Water Use Benchmarks for Thermoelectric Power Generation

by

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Study Purpose

The purpose of this study was to examine water use at electric power plants in the United States and determine both the average rates of water withdrawals and consumptive use as well as the levels of water-conserving usage in the most water-efficient plants and cooling systems. The generalized water-use parameters represent benchmark measures of the quantities of water used by the different types of cooling systems and power plants. This was accomplished by exploring publicly-accessible thermoelectric water use data from the U.S. Department of Energy, Energy Information Administration (EIA), as well as by conducting on-site visits at power plants and completing a questionnaire survey of plant water managers.

Significance of Thermoelectric Water Use

Generation of electricity requires large quantities of water either for turning water turbines to generate hydroelectric power or for cooling and condensing steam in thermoelectric generation. Nearly 90 percent of generation capacity in the U.S. is in thermoelectric plants.

Precise estimates of the actual volume of water that is used to generate electricity at the national level are difficult to obtain. The U.S. Geological Survey's National Water Use Information Program (NWUIP) prepares nationwide compilations of all reported water uses, which are published every five years (Hudson et al., 2004).

The most recent USGS compilation reported that the combined country-wide water withdrawals by all sectors had increased since 1995 and in the year 2000 had reached an average daily volume of 408 billion gallons per day or 1,432 gallons per capita per day. Nearly 48 percent of all withdrawals, or 195.5 billion gallons per day, were for thermoelectric power generation, primarily to satisfy cooling requirements of power plants. Total utility-based generation of electricity in the year 2000 (not counting hydroelectric power) reached 2,762,200 million kWh, and required approximately 26 gallons per each kWh of generation. In per capita terms, total withdrawals for thermoelectric generation in the year 2000 amounted to 686 gallons per capita per day – more than four and a half times the per capita amount of all publicly supplied water for domestic, commercial and industrial uses.

Nearly 85 percent of all water withdrawals and nearly 70 percent of all thermoelectric withdrawals are obtained from the country's limited supplies of fresh water. In 2000, thermoelectric use accounted for nearly 40 percent of all freshwater withdrawals in the country, with the total freshwater withdrawals for the thermoelectric sector approximately equal to those of the irrigation sector. Despite these high annual withdrawals for thermoelectric power generation, only a few studies of thermoelectric water demands have been conducted. The reason may be that unlike irrigated agriculture where most of the water is evaporated or lost, approximately 98 percent of water withdrawn by thermoelectric sector is returned back to the source.

However, even the “non-consumptive” withdrawals of water for thermoelectric power plants can have significant impacts on water resources. Power plants are the largest dischargers of thermal pollution that affects both aquatic ecosystems and evaporation rates. Also, the large quantities of water required for power generation must be continuously available for power utilities to provide reliable service to their customers. This quantity of water is therefore “reserved” for power generation and is not available to other user such as irrigators or public water suppliers

Average Rates of Water Use

The database used in the statistical analysis was developed primarily from the information in the Department of Energy’s Form EIA-767, and contained 7,365 observations of estimated thermoelectric water withdrawals and consumptive use, for cooling systems in fossil-fuel plants, during the nine-year period from 1996 to 2004. A smaller number of observations was available for nuclear-powered plants because the annual EIA data reporting for this type of plants was discontinued after 2000, and the data were only available from 1996 to 2000.

In addition to the data on water withdrawals and consumptive use, five categories of likely determinants of cooling water withdrawals were included in the analysis: (1) cooling systems type; (2) fuel type; (3) operational conditions; (4) water sources; and (5) other relevant variables. Additional information about thermoelectric water use was obtained from site visits and interviews at five power generation facilities and questionnaire survey responses from 40 power plants.

Water withdrawals per unit of net generation of electricity were estimated from the EIA-767 data, and the average unit-use was calculated for ten different types or combinations of cooling systems. A review of the distribution of unit-use estimates determined that these calculated averages were significantly influenced by outlier values. The outliers were removed from the analysis and the mean values of water withdrawals for each cooling system type were recalculated (see Figure ES-1).

Unit withdrawals for once-through systems were estimated to range from approximately 50 to 65 gal./kWh; for closed-loop systems with cooling towers from 1.0 to 2.0 gal/kWh; and for recirculating systems with cooling ponds or canals and other mixed recirculating systems from 14 to 24 gal/kWh. Net generation weighted averages were also calculated for three general aggregations of the ten cooling system types for both fossil-fuel and nuclear plants. The resultant weighted average water use rates represent water use benchmark measures for these categories of cooling systems (see Table ES-1). Because of the weighing by total (net) generation the resultant estimates tend to reflect water usage rates in larger plants.

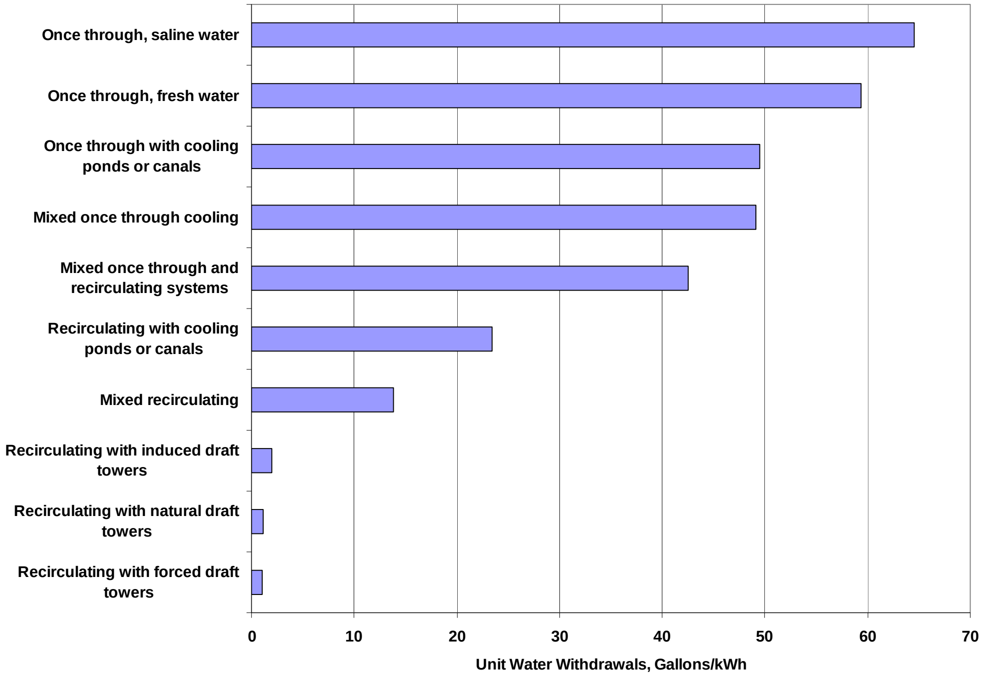

Figure ES-1. Average Rates of Unit Water Withdrawals in Different Types of Cooling Systems in Fossil-Fuel Plants

Table ES-1. Benchmarks of Weighted-average Use Rates of Cooling Water

Description	Withdrawals per unit (gallons/kWh)	Consumptive use (gallons/kWh)	Percent consumptive use (%)
Fossil fuel plants:			
Once-through systems	44.0	0.2	0.5
Recirculating systems with ponds	24.0	0.7	3.0
Closed-loop w/ cooling towers	1.0	0.7	70.0
Nuclear plants:			
Once-through systems	48.0	0.4	0.7
Recirculating systems with ponds	13.0	0.5	4.0
Closed-loop w/ cooling towers	2.6	0.8	30.0

Regressions of Water Use on Explanatory Variables

Ordinary least-squares regression procedures were used to identify the relationship between water withdrawals and various plant and cooling system characteristics. The resulting regression models demonstrated that unit water withdrawals are primarily a function of the operational efficiency (i.e., percent of capacity utilization), maximum temperature rise at the condenser, and, to a lesser extent, the age of the cooling system and thermal efficiency of the generators. The observed rates of water withdrawals were also found to depend on the type of water source and the type of fuel.

The estimated regression equations were used to calculate low, average, and high water rates for different types of cooling systems. The average water withdrawals and consumptive use were calculated by substituting the mean values of the continuous explanatory variables into the estimated regression equation (Table ES-2). The lowest value was calculated by combining the 90 percentile values for variables with negative coefficients and 10 percentile values for variables with positive coefficients. The reversed 10 and 90 percentile values were used to calculate the maximum value. Also, because some regression equations included binary indicator variables, the values in Table ES-2 apply to systems with only some water sources and fuel types as indicated in the footnotes under the table.

Table ES-2. Regression-based Benchmarks of Average Water Withdrawal Rates

Description	Minimum (gallons/kWh)	Average (gallons/kWh)	Maximum (gallons/kWh)
WATER WITHDRAWALS			
Fossil fuel plants:			
Once-through systems[a]	--	78	181
Recirculating systems with ponds[b]	19	53	91
Closed-loop w/ cooling towers[c]	0.4	1.2	2.4
Nuclear plants:			
Once-through systems	30	49	56
Recirculating systems with ponds[d]	--	0.8	2.2
Closed-loop w/ cooling towers[e]	0.9	1.5	2.3
CONSUMPTIVE USE			
Fossil fuel plants			
Once-through systems[f]	1.7	3.1	4.1
Closed-loop w/ cooling towers[g]	0.5	0.9	1.5

[a] Other than public water delivery or mixed water sources; [b] Other than recirculating systems w/ponds; [c] Other than mixed fuels with coal, petroleum as fuel, fresh groundwater source, or saline surface water source; [d] Other than surface freshwater source; [e] Other than saline surface water supply or induced air-flow tower; [f] Other than once-through freshwater systems or petroleum as fuel; [g] Other than mixed fuel w/ coal, or fresh groundwater source

The regression-based benchmarks for average water use in Table ES-2 differ from the weighted estimates in Table ES-1 (and are generally higher) because no weights were applied during the regression procedure, and because of the added regression effects of the fuel types and water supply source. However, the estimates are generally consistent across the different types of cooling systems.

Technical Efficiency Estimates

The stochastic production frontier analysis of the data demonstrated that the estimated technical efficiencies of cooling system water use vary significantly, and are lower (on average) in fossil fuel plants than in nuclear power plants (Table ES-3).

Table ES-3. Technical Efficiency Estimates for Cooling Systems Based on Stochastic Production Frontier

Description	Minimum (%)	Average (%)	Maximum (%)
Fossil fuel plants:			
Once-through systems	22.5	52.9	91.6
Closed-loop w/ cooling towers	40.0	67.2	93.0
Nuclear plants:			
Once-through systems	44.0	69.6	100.0
Closed-loop w/ cooling towers	55.8	80.8	100.0

The mean technical efficiency in once-through systems is 52.9 percent for fossil-fuel plants and 69.6 percent for nuclear plants. Closed-loop systems with cooling towers were estimated to have mean efficiencies of 67.2 and 80.8 percent, respectively. This result suggests that nuclear plants tend to use cooling water more efficiently than fossil-fuel plants. Nevertheless, there is still a 20 to 30 percent theoretical potential for reducing water withdrawals at nuclear plants, and a 30 to 50 percent potential for reductions at fossil-fuel plants.

Recommendations

The results of this study indicate that the reported average rates of water withdrawals and consumptive use in thermoelectric power plants exhibit very high variability within the same cooling system type at different power generation facilities. While a part of this variability can be explained in terms of the system design parameters and operational conditions, a significant portion of the variability cannot be explained and can be attributed to inefficiency of using cooling water. The results of the stochastic frontier analysis conducted in this study indicate that water intake by thermoelectric power plants could be reduced on average between 20 and 50 percent depending on the type of plant and cooling system.

Further development and refinement of water-use benchmarks should be undertaken to facilitate the improvement of water-use efficiency in thermoelectric generation. Further studies should include the collection of data from a sample of "best performing" plants, which could be identified using the analysis presented in this study. The benchmark practices at these facilities could serve as standards in the design and operation of wet cooling systems, and guide the process of gradual elimination of inefficient use of water in thermoelectric power generation.

CHAPTER I
INTRODUCTION

PURPOSE

The future economic, social, and environmental costs of meeting water supply needs of the United States (U.S.) depends largely on our ability to understand and manage both present and future water demands. Total water withdrawals in the country continue to increase and, in 2000, were estimated to exceed 408 billion gallons per day (bgd) or 1,430 gallons per capita per day. Nearly 48 percent of all withdrawals are for thermoelectric power generation, primarily to satisfy cooling requirements of power plants. Also, nearly 85 percent of all withdrawals and nearly 70 percent of thermoelectric withdrawals are obtained from limited supplies of fresh water. In 2000, the fresh water withdrawals of the thermoelectric sector (136 bgd) were approximately the same as those of the irrigation sector (137 bgd) (Hutson et al., 2005).

In spite of the large quantities of annual withdrawals of water by thermoelectric sector, few studies of thermoelectric water demands have been conducted. This lack of attention to thermoelectric water withdrawals may be due to the fact that, unlike irrigated agriculture where most of the water is evaporated or lost, approximately 90 percent of water withdrawn by thermoelectric sector is returned back to the source. However, the substantial withdrawals of water for thermoelectric cooling can have significant impacts on water resources, especially in areas where fresh water supplies are limited.

The principal objective of this research project was to use publicly-accessible thermoelectric water use data from the U.S. Department of Energy, Energy Information Administration (EIA), and standard analytical procedures to develop generalized water use parameters for thermoelectric water use in the United States. These parameters represent benchmark measures for several categories of thermoelectric facilities, as determined by cooling system type and other plant characteristics.

BACKGROUND

Energy Production in the U.S. in 2003

According to the statistics available from EIA for 2003, the total U.S electric generating capacity was 948,446 megawatts (MW), of which 57.7 percent (547,249 MW) was at electric utility plants, with the remainder (401,198 MW) at non-utility plants. Coal-fired plants account for the largest percentage of generation capacity followed by natural gas and dual-fired plants, which can burn both petroleum and natural gas. Nuclear and hydroelectric plants each accounted for 10.5 percent of total generating capacity (Table I-1).

Table I-1. U.S. Electric Generating Capacity by Energy Source in 2003

Energy Source	Total Capacity MW	Percent of Total Capacity	Percent in Electric Utilities
Coal[1]	313,019	33.0	75.5
Natural gas	208,447	22.0	23.1
Dual fired	171,295	18.1	52.1
Hydro-electric[4]	99,216	10.5	91.3
Nuclear	99,209	10.5	61.5
Petroleum[2]	36,429	3.8	57.0
Other renewables[5]	18,199	1.9	5.1
Other gases[3]	1,994	0.2	3.1
Other[6]	638	0.1	2.0
Totals	948,446	100.0	57.7

[1] Anthracite, bituminous coal, sub-bituminous coal, lignite, waste coal, and synthetic coal
[2] Distillate fuel oil, residual fuel oil, jet fuel, kerosene, petroleum coke (converted to liquid petroleum), and waste oil
[3] Blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels
[4] Conventional hydroelectric power and including hydroelectric pumped storage facility production; Pumped storage is the capacity to generate electricity from water previously pumped to an elevated reservoir and then released through a conduit to turbine generators located at a lower level.
[5] Wood, black liquor, other wood waste, municipal solid waste, landfill gas, sludge waste, tires, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind
[6] Batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies
Source: EIA Quick Facts (2005)

If all power plants operated at 100 percent capacity, year-round, then the total annual generation would be 8,308,386 thousand megawatt hour (MWh) (or million kilowatt hour [kWh]). The actual total net generation was 3,883,185 million kWh, approximately 47 percent of this potential maximum (Table I-2). At the estimated 2003 U.S. population of 290,809,777 persons, the total per capita generation was 13,353 kWh per person per year, or 36.6 kWh per person per day.

In 2003, generation in coal-fired plants accounted for 50.8 percent of total U.S. generation. Natural gas and nuclear plants together accounted for an additional 36.4 percent, and hydroelectric plants accounted for 7.1 percent. Approximately 63.4 percent, or 2,462,281 million kWh, was generated by electric utilities using all energy sources (Table I-2).

Table I-2. U.S. Net Energy Generation by Energy Source in 2003

Energy Source	Total Net Generation 1000s MWh	Percent of Total Generation	Percent in Electric Utilities
Coal[1]	1,973,737	50.8	76.0
Nuclear	763,733	19.7	60.1
Natural Gas	649,908	16.7	28.8
Hydroelectric Conventional[4]	275,806	7.1	90.5
Petroleum[2]	119,406	3.1	58.6
Other Renewables[5]	87,410	2.3	4.5
Other Gases[3]	15,600	0.4	1.6
Other[7]	6,121	0.2	--
Pumped Storage[6]	-8,535	-0.2	88.2
All Energy Sources	3,883,185	100.0	63.4

[1] Anthracite, bituminous coal, sub-bituminous coal, lignite, waste coal, and synthetic coal
[2] Distillate fuel oil, residual fuel oil, jet fuel, kerosene, petroleum coke (converted to liquid petroleum), and waste oil
[3] Blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels
[4] Conventional hydroelectric power and excluding hydroelectric pumped storage facility production
[5] Wood, black liquor, other wood waste, municipal solid waste, landfill gas, sludge waste, tires, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind
[6] The generation from a hydroelectric pumped storage facility is the net value of production minus the energy used for pumping.
[7] Batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies
Source: EIA Quick Facts (2005)

EIA conducts a mandatory survey of organic and nuclear-fueled steam-electric plants with a generator nameplate rating of 10 megawatts or more using Form EIA-767: *Steam-Electric Plant Operation and Design Report.* The data from this form serves as the basis of the analysis presented in this study.

The 2003 EIA-767 contains information on 1,382 existing, planned, and retired steam generation facilities, but does not include data from the nation's 104 nuclear power plants. The EIA-767 stopped reporting data from nuclear plants in 2000, and therefore analysis of these facilities uses data from that last year of public reporting.

Electric utilities are the dominant owners and operators of the power plants that employ the generating units and auxiliary equipment used to convert various types of energy into electric power. In 2000, there were 3,856 electric power plants in the country, of which 2,776 plants were operated by electric utilities (EIA, 2000).

Power generation facilities are not required to account for the water used in the production of electricity and precise estimates of the actual volume are difficult to obtain. The primary use of water at power plants is to satisfy the cooling needs of the thermoelectric generation.

The Cooling Process

The main use of water at power plants is for cooling. Nearly 90 percent of electricity in the United States is produced with thermally-driven, water-cooled generation systems, which require large amounts of water. Three major types of thermoelectric plants can be distinguished, based upon their fuel type and method of generation: conventional steam, nuclear steam, and internal combustion plants. In internal combustion plants, the prime mover is an internal combustion diesel or gas-fired engine. Since no steam or condensation cooling is involved, almost no water is used by internal combustion power generation.

In conventional steam and nuclear steam power plants, the prime mover is a steam turbine. Water is heated in a boiler until it turns into steam. The steam is then used to turn the turbine-generator, which produces electricity. The shaft power is produced when a nozzle directs jets of high-pressure steam against the blades of the turbine's rotor. The rotor is attached to a shaft that is coupled to an electrical generator. Large quantities of cooling water are required in steam-electric plants for condensing steam that leaves the turbine and then, in the form of condensate, is returned back to the boiler to be converted to steam again, thus beginning a new cycle (Figure I-1).

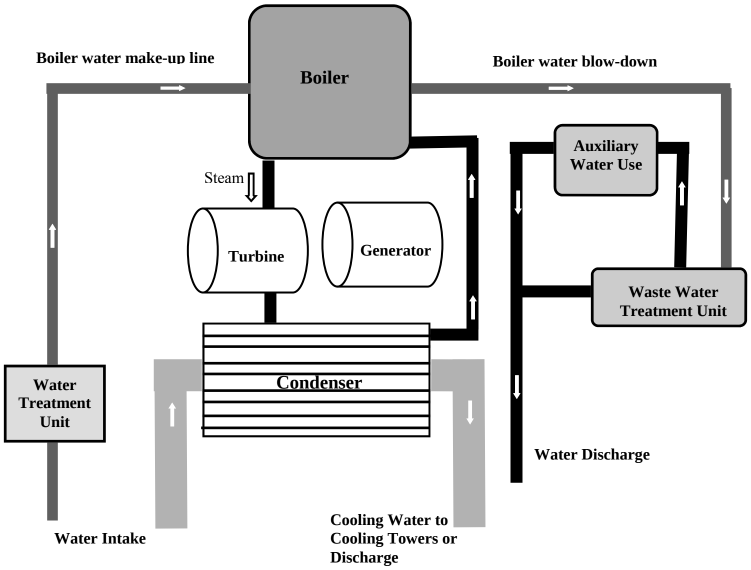

Figure I-1 Water Use in Thermoelectric Cooling Systems

The steam turbine does not consume steam; it only reduces its pressure. In a conventional power-only steam turbine installation, designers increase efficiency by maximizing the pressure drop across the turbines. In this type of generation, the use of cooling water is essential because the collapse of steam volume in the condenser creates a vacuum (or backpressure) which affects the rotation of the turbine. Modern Rankine-cycle power plants with 1,800 pounds per square inch gauge (psig) superheated steam boilers, and condensing turbines exhausting at near-vacuum pressures, can generate electricity with efficiencies of approximately 40 percent. The conventional low-pressure steam turbine generators can operate over a modest backpressure range from 1.0 to 4.0 inches of mercury absolute (Hga) and the optimal efficiency range from 2.0 to 3.5 inches Hga (Micheletti and Burns, 2002). Because the backpressure depends on the removal of "waste" heat by cooling water, the cooling system is an integral part of the power generation process.

Types of Cooling Systems

The "waste" heat removed by the cooling system is transferred to the surrounding environment. In "wet" systems this is done through a combination of evaporation and sensible heating of water or air. In "dry" systems the heat is transferred to the atmosphere through sensible heating. The dry cooling systems are outside the focus of this study and the subsequent discussion is limited only to 'wet" cooling systems that use water as the cooling medium. The wet systems fall into two broad categories: once-through cooling systems and closed-loop (or recirculating) systems.

In once-through cooling systems, water is withdrawn from a natural water body (such as river, reservoir, estuary, or ocean) and is pumped through a heat exchanger to cool down and condense the steam. After leaving the condenser, the water, with an elevated temperature, is discharged into the receiving water body. Thus, in once-through cooling systems the heat is transferred into a surface water body to which the heated cooling water is discharged.

The once-through method has several advantages. It is the least costly to construct; it requires less water treatment; and it evaporates less water than evaporative cooling towers. However, it also has some drawbacks. The two most important drawbacks are the large amount of water needed and its contribution to thermal pollution (Gloyna, 1975). A variation of a once-through system is a recirculating system with an evaporation pond or canal. In such a system the heated water is discharged into a pond or canal where its temperature is lowered by mixing with the receiving waters and further cooled by heat exchange and forced evaporation. In systems with cooling ponds, the total volume of water withdrawals is generally lower as compared to the water required for once-through cooling because of different operating conditions.

In wet closed-loop cooling systems, the total volume of water withdrawals can be reduced by nearly 95 percent compared to the water required for once-through cooling (Harte, 1978). The conventional type of wet cooling system uses towers that are designed to remove heat by pumping hot water to the top of the tower and then allowing it to fall down while contacting the air which comes in from the bottom and/or sides of the tower. As the air passes through the water, it exchanges some of the heat and evaporates some of the water. In cooling towers, as much as 50 percent or more of water is evaporated. The cooled water is collected at the bottom of the tower and is then pumped back to the condenser for reuse. Cooling towers have been increasingly used because they require much less water and land than once-through cooling systems.

QUANTIFYING THERMOELECTRIC WATER USE

Precise estimates of thermoelectric water use at the national level are not available. However, the United States Geological Survey (USGS) under the National Water Use Information Program (NWUIP) regularly prepares nationwide compilations of all reported water use, which are published at five year intervals (Hutson et al., 2005).

In 1995 the total thermoelectric withdrawals were estimated to be 190 bgd with a corresponding total thermoelectric electric generation of 2,690,000 million kWh (Solley et al., 1998). By combining the 1995 USGS estimates of withdrawals and generation, it is calculated that an average of 25.8 gallons of water were withdrawn to produce each 1.0 kWh of electricity.

The most recent compilation for 2000 estimates the total thermoelectric withdrawals to be 195.5 billion gallons per day (bgd) or 685 gallons per capita per day. The total annual generation that corresponded with these withdrawals was not reported by USGS but can be estimated using data collected by the EIA. Nationwide total utility generation (excluding 18,183 million kWh of hydropower) for 2000 was estimated to be 2,762,228 million kWh (EIA, 2005). When combined with the USGS estimate of withdrawals, this also results in an estimated average unit withdrawal of 25.8 gallons/kWh.

However, the EIA also reports a substantial quantity of non-utility electric generation (439,357 million kWh) in 2000 from independent producers. It is unclear from the USGS water-use compilation whether or not water use from these generators is included in the 195.5 bgd total. Also, the 2000 USGS compilation excludes public-supply water deliveries to thermoelectric-power plants, another substantial quantity of water use for this sector. The average unit withdrawals calculated using USGS are conditional on the methodologies used to assemble the data, which may not be consistent in consecutive inventories.

While the USGS water use inventories provide a valuable overview of water use in the thermoelectric sector, they lack the precision needed to examine water use at generation facilities using different types of cooling systems, different fuel mixes, and different water sources, and they lack the precision to develop water use benchmarks for each of these types of facilities.

The principal source of information on thermoelectric water use in this study is the average annual rate of cooling water withdrawal data that all generation facilities are required to report to the DOE using the Form EIA 767. As described in other sections of this report, there are technical difficulties that need to be overcome in order to correctly transpose this flow rate data into quantity data that can be used in the calculation of thermoelectric water use benchmarks. Nonetheless, Form EIA 767 serves as the principal source of data for the estimation of water use, as well as power generation, plant characteristics, and virtually all other data required for the analysis presented in this study.

CHAPTER SYNOPSES

This project completion report is organized into seven chapters. This first chapter has introduced the objectives of this research and provided a background on thermoelectric power generation and its associated water use. Chapter II provides further information on thermoelectric water use and summarizes the findings of previous water use studies in this sector. Chapter III describes the data sources and analytical methods used to examine the historical data on water use. Chapter IV describes the results of site visits and a survey of generating facilities that were conducted as part of this research. An extensive analysis of cooling system-level data in fossil fuel plants is presented in Chapter V. Chapter VI analyzes cooling-system level data in nuclear plants. Chapter VII identifies benchmark quantities for thermoelectric water withdrawals and consumptive use. The conclusions of the study are summarized in Chapter VIII, along with several recommendations for how the study results might influence future research and energy-related water policy.

CHAPTER II
THERMOELECTRIC WATER USE

DEFINITIONS AND SIGNIFICANCE OF WATER USE

The term “water use” is often applied using its broad meaning that denotes the interaction of humans with, and their influence on, the hydrologic cycle and may include both off-stream and in-stream uses such as water withdrawal, delivery, consumptive use, wastewater release, reclaimed wastewater, return flow, hydroelectric power use, and other uses. For the USGS 2000 water use inventory, the term “thermoelectric-power water use” refers only to self-supplied water that is removed from the ground or diverted from surface-water sources, both saline and freshwater, for use in the process of generating electricity with steam-driven turbine generators (Hutson et al., 2004).

The term “water withdrawal” is more precise than the term “water use” because it clearly designates the amount of water that is extracted from natural water sources. In many uses, most of the water withdrawn is returned back to the source. The USGS classifies the difference between withdrawals and return flows (or discharge) as “consumptive use.” This is the quantity of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. The quantity of water consumed is utilized in calculating regional annual and monthly water budgets, and provides a measure of the volume of water that is not available for repeated use.

“Non-consumptive” withdrawals of water for cooling of thermoelectric power plants can have significant impacts on water resources. For example, the large quantities of water required for power generation must be continuously available for power utilities to provide reliable service to their customers. This quantity of water is therefore “reserved” for power generation and is not available to other user such as irrigators or public water suppliers.

Power plants are also the largest dischargers of thermal pollution. Under §316(a) of the U.S. Clean Water Act (CWA, 2002), the current controls are likely to be made more stringent in places where receiving streams are being impacted by pollutants other than thermal pollutants. This could potentially lead to plant shut downs, seasonal restrictions on water pumping, or the addition of cooling towers to once-through systems (Veil, 2002).

There are also significant environmental impacts from cooling water intakes. Under §316(b) of the CWA, the location, design, construction, and capacity of water intakes must reflect the best technology available to minimize adverse environmental impacts. The regulatory schedule (Phase II) of the U.S. Environmental Protection Agency (EPA) requires that all intake facilities must reduce the impingement mortality of water organisms by 80 to 95 percent and in some cases must reduce the intake of small aquatic life (entrainment) by 60 to 90 percent. Some of these regulatory targets can be achieved simply by reducing the rates of water pumping thus reducing the velocity of water at the fish screens.

HISTORICAL THERMOELECTRIC WITHDRAWALS

Aggregate Data

Aggregate data on thermoelectric water withdrawals are collected by the USGS under the National Water Use Information Program (NWUIP) and nationwide compilations of all reported water use are published every five years (Hutson et al., 2005). The data on water withdrawals are collected by water use sector and by water source and are aggregated into county, state, and national totals. The reported estimates are obtained primarily from detailed inventories of point withdrawals within each accounting unit (i.e., county or state). The point withdrawals represent measured volumes of water at pumping or diversion points or estimates of the withdrawn volumes based on the time of pump operation, irrigated acreage, or some other indirect measure. The data reported by the USGS do not account for all withdrawals for the production of thermoelectric power. They capture primarily water withdrawals by power plants that operate within electric utilities and exclude withdrawals by independent generators. USGS estimates of water withdrawals for thermoelectric generation and other uses from 1950 to 2000 are shown in Table II-1 and Figure II-1.

Table II-1. Sectoral Water Withdrawals in the United States 1950-2000
(in billions of gallons per day)

Year	Domestic	Industrial	Irrigation	Thermo-electric	Total Withdrawals*
1950	17.6	37.0	89.0	40.0	183.6
1955	20.6	39.0	110.0	72.0	241.6
1960	24.6	38.0	110.0	100.0	272.6
1965	28.0	46.0	120.0	130.0	324.0
1970	31.5	47.0	130.0	170.0	378.5
1975	33.9	45.0	140.0	200.0	418.9
1980	39.6	45.0	150.0	210.0	444.6
1985	44.3	30.5	137.0	187.0	398.8
1990	46.4	29.9	137.0	195.0	408.3
1995	49.1	29.1	134.0	190.0	402.2
2000	52.4	23.3	137.0	195.5	408.2

* Starting in 1975 the data are for 50 States and District of Columbia, Puerto Rico, and U.S. Virgin Islands.
Source: USGS (2004)

Since 1965, thermoelectric generation has been the largest sector of water withdrawals, accounting for nearly one-half of total national withdrawals. Thermoelectric withdrawals peaked in 1980 at 210 bgd, and have fluctuated between 187 and 195 bgd between 1990 and 2000. The total thermoelectric withdrawals of 195.5 bgd in 2000 were equivalent to per capita withdrawals of 685 gallons per capita per day, nearly four times the average per capita water withdrawals for domestic uses.

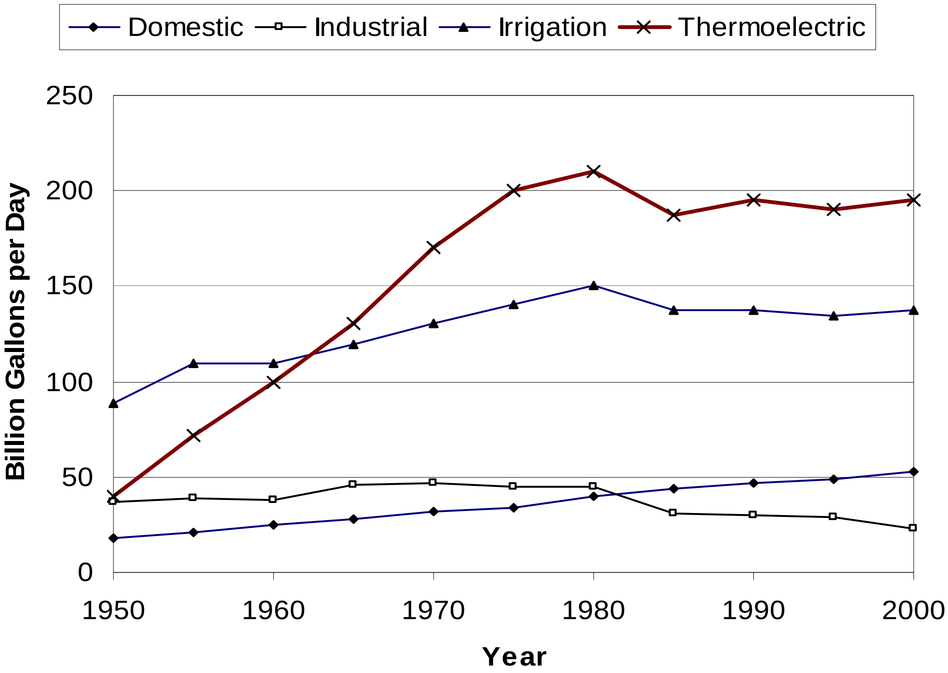

Figure II-1. Historical U.S. Water Withdrawals by Major Sectors: 1950-2000
Source: USGS (2004)

In the USGS 2000 compilation, water withdrawals are also disaggregated into two cooling system categories: once-through and closed loop-cooling. Table II-2 shows the national total withdrawals for these two types of cooling broken down by water source.

Table II-2. 2000 Thermoelectric Withdrawals by Cooling Type
(in million gallons per day)

Water Source	Once-through Cooling	Closed loop Cooling	All Cooling Withdrawals
Surface water	177,000	17,900	194,900
Fresh	119,000	16,300	135,300
Saline	58,000	1,530	59,530
Ground water	--	409	409
Totals	177,000	18,300	195,300

Note: The numbers do not add up due to independent rounding.
Source: Derived from USGS (2004)

The USGS withdrawal data can be combined with power generation data from the Energy Information Administration (EIA, 2005) to estimate the differences in the water requirements of different types of cooling systems. Using the EIA total generation estimate of 2,762,228*10^6 kWh per day, and a 40 percent contribution by once-through cooling systems, the unit water requirements for once-through cooling systems are approximately 54.4 gallons/kWh (177,000 mgd *365/2,762,228 * *0.4). The estimation of unit water use for the 60 percent of plants using closed-loop cooling systems is a much lower 4.0 gallons/kWh (18,300 mgd *365/2,762,228 *10^6 kWh *0.6).

Plant-Level Data

The aggregate withdrawals data that are compiled by the USGS are largely estimated from the cooling water flow data of individual power plants collected and published by EIA (Kenney, 2004). Annual data available from EIA include information on plant operation and equipment design (including boilers, generators, cooling systems, flue gas desulphurization, flue gas particulate collectors, and stacks). The EIA-767 databases consists of sixteen different data tables that present data on different aspects of the power plant operation, and can be used to estimate thermoelectric water withdrawals. The EIA-767 are available from the EIA website for the years 1996 to 2004 (http://www.eia.doe.gov/cneaf/electricity/page/eia767hist.html).

The annual time series of total withdrawals estimated from the Form EIA-767 data shows a gradual increase in withdrawals until 1999 and then a large, abrupt decrease in 2000 and 2001 and a continuation of a slight decreasing trend in 2002 and 2003 (Table II-2). The 2001 drop in water withdrawals was associated with a drop in the number of reporting systems. This is a result of EIA discontinuing collection of operational data from nuclear power plants.

Table II-3. Estimated Water Use in EIA-767 Annual Data Sets

Year	Number of Reporting Cooling Units	Units with Water Use Data	Sum of Water Withdrawals (mgd)
1996	1,544	1,243	216,032
1997	1,534	1,282	215,029
1998	1,521	1,261	235,393
1999	1,524	1,261	293,069
2000	1,525	1,262	212,356
2001	1,517	1,227	169,072
2002	1,625	1,234	164,154
2003	1,632	1,226	156,977

Source: EIA (2005)
Water withdrawal estimates were calculated from the reported flow rates.

The total water use for thermoelectric cooling estimated from the Form EIA-767 in 2000 differs significantly from the water use reported by the USGS (Hutson et al., 2004).

Estimated total water withdrawals from the EIA data are 212.4 bgd, while the USGS estimate is 195.5 bgd. This discrepancy is an example of the difficulty in obtaining reliable estimates of thermoelectric withdrawals. The difference is likely the result of additional data that USGS used to supplement information from the EIA database in their estimation of national thermoelectric water use.

Table II-4 shows number of power plants with cooling water intake structures (CWIS) and national pollutant discharge elimination system (NPDES) permits and is organized by water source and cooling system type. Table II-4 shows that rivers were the most common water source followed by lakes and that more than half of the power plants were once-through type.

Table II-4. Number of Plants with CWIS and NPDES permit by Water Source and Cooling System Type

	Number of Plants								Total
Cooling System Type	Closed Cycle		Once Through		Combination		Unknown		
Water Source/Facility Type	U	NU	U	NU	U	NU	U	NU	
Estuary	4	2	75	13	7	0	2	0	103
Lake	39	11	89	2	12	0	1	0	154
Ocean	1	0	16	8	1	0	0	0	26
River	102	27	214	16	52	1	1	0	413
Other	22	0	9	2	6	0	25	2	66
Total	168	41	403	41	78	1	29	2	
Total by Cooling Type		209		444		79		31	763
% by Cooling Type		27		58		10		4	100

*U = Utility; NU= Non-Utility

Sources: Form EIA-767, 1997; Form EIA-860A, 1998; Form EIA-860-B, 1998; EPA, 2000; UDI database, 1994

PREVIOUS STUDIES OF THERMOELECTRIC WATER USE

Determinants of Water Demand

The issues related to water demand and its determinants were considered in several earlier studies of the thermoelectric water use. In the first study, Cootner and Lof (1965) developed an economic model for estimating water demand in steam electric utility industry in which water was considered a joint factor input along with fuel, where fuel is usually the major cost in producing electrical power. They estimated withdrawal demand as a function of: (1) the quantity and cost of water available; (2) the economics of heat exchange and recycling; and (3) any costs to the plant that may be associated with the disposal of waste heat.

In the second study, Wallman and Bonem (1971) also analyzed thermoelectric water demands and determined that the amount of fresh water withdrawn for unit steam electric power generation depends on: (1) thermal efficiency (the higher the thermal efficiency, the less heat to be dissipated and, thus, the smaller the amount of cooling water needed); (2) the degree to which brackish or ocean water can substitute for fresh water; and (3) the rate of recirculation, which is a function of the price and availability of water as compared with the cost of recirculation equipment.

In the third study, Young and Thompson (1973) identified three categories of demand factors that can affect water use in thermoelectric generation. The first category includes the factors affecting water use directly, such as water pricing and change in generation technology. The second category includes factors that affect the demand for electricity, such as the price of electricity, the price of substitutes for electricity (such as gas), population, and the level of general economic activity. The third category includes those factors that affect waste and heat discharge to water, such as standards or taxes and the changes in cooling technologies that they would induce.

In their analysis of the USGS national water use inventory data from 1950 to 1995, Dziegielewski et al. (1999) examined eight different water use sectors, including cooling water for thermoelectric generation. The analysis focused on identifying robust explanatory models of water withdrawals or use and on building predictive models. Both linear and log-linear models were developed for total and per unit of thermoelectric withdrawals (in gallons per kWh). The study developed state and national level regression models, testing 24 continuous variables and more than 50 binary variables as predictors of thermoelectric withdrawals. The variables were grouped into several general categories:

- Energy generation by fuel type
- Generation by method
- Installed generation capacity
- Availability of cooling towers
- Weather conditions
- State water laws
- Number of generating units

The variables that achieved statistical significance were slightly different for each model. The final predictive log-linear model of unit thermoelectric withdrawals (g/kWh) included five continuous variables and 23 state binary variables. The findings of the analyses were summarized by presenting the elasticities of explanatory variables obtained from regression models of per-unit use. Table II-5 compares the estimated elasticities of key explanatory variables. Because the magnitude of estimates varied depending on model specification, both the range of values and the value of the best predictive model are presented.

Table II-5. Explanatory Variables and Elasticities of Thermoelectric Water Use

Use-category/ Explanatory Variable	Low value	High Value	Used in Prediction
Percent of installed capacity that is utilized for generation	-0.707	-0.752	-0.752
Percent installed capacity with cooling towers	-0.270	-0.270	-0.270
Percent fuel/gas steam generating units with cooling towers	-0.117	-0.128	-0.128
Percent of total steam cooling capacity from petroleum/gas	0.067	0.100	0.067
Logarithm of cooling degree days	-0.137	-0.286	-0.189

Source: Dziegielewski et al. (1999)

Estimates of Water Requirements

In his essay on "water and energy," Gleick (1993) gave a brief review of water requirement for energy including electricity generation. Based on his review of other studies, he estimated the consumptive water use of different energy technologies (Table II-6).

Table II-6. Consumptive Water Use for Electricity Generation

Generation Technology	System Efficiency[a] (%)	Consumptive Use ($m^3/10^3$ kWh)
Conventional coal combustion		
Once-through cooling	35	1.2
Cooling towers	35	2.6
Fluidized bed coal combustion		
Once-through cooling	36	0.8
Oil and natural gas combustion		
Once-through cooling	36	1.1
Cooling towers	36	2.6
Nuclear generation (LWR)		
Cooling towers	31	3.2
Nuclear generation (HTGR)		
Cooling towers	40	2.2

[a] Efficiency of conversion of thermal energy to electrical energy

Source*:* Gleick (1993)

The estimates in Table II-6 indicate the average consumptive use in once-through cooling systems ranges from 0.8 to 1.2 m^3/MWh (0.211 to 0.317 gallons/kWh). For cooling towers, the consumptive use ranges from 2.2 to 3.2 m^3/MWH (0.581 to 0.845 gallons per kWh).

Torcellini et al. (2003) developed a metric for relating water to energy use and examined evaporative water losses from both thermoelectric and hydroelectric production using estimates from the USGS 1995 water use inventory and power generation estimates from the Energy Information Administration. They adjusted the quantity of power production to account for power used in the generation process (i.e., power is used to crush and transport coal, excitation for generators, and power other machinery within the plant) and distribution losses. They estimated that thermoelectric power plants use approximately 5 percent of their gross generation to power equipment and transmission and distribution losses for the United States as 9 percent of the gross generation. Their metric was then calculated by taking the total adjusted consumptive water use divided by the total power output.

Torcellini et al.'s (2003) estimate of consumptive water use for typical thermoelectric power plants was 0.47 gal (1.8 L) of fresh water evaporated per kWh of end-use electricity. Estimates of consumptive use were also estimated for each state, which ranged from 0.0 gallons/kWh in Idaho and Tennessee to 1.61gallons/kWh in Delaware. The authors note that a thorough understanding of local conditions is necessary to properly interpret their results and that "there are river basins where evaporation is a substantial percentage of the total river flow, and this evaporation reduces the available supply both for downstream human consumption as well as having environmental consequences for coastal ecosystems that depend on fresh water supply" (Torcellini et al., 2003: 6).

SUMMARY

Thermoelectric water withdrawals represent the largest percentage of water withdrawals in the United States. While more than 90 percent of water withdrawn for cooling in thermoelectric generation is discharged back to water bodies, the quantities required to operate generation facilities must be consistently available and are thus cannot be withdrawn for other uses. In closed-loop cooling systems, a significant proportion of water withdrawals are evaporated, and completely removed from the local hydrological cycle. Alternative management of cooling water use at thermoelectric generating facilities can potentially free-up water for other uses, such as public water supply and irrigation, and/or reduce the impacts of these withdrawals on the aquatic environment. While data from the Energy Information Administration can be used to estimate thermoelectric water use, precise water use data from generating facilities is currently not universally available. Historical estimates of thermoelectric water use prepared by the USGS suggest that changes in water use management are already taking place within the power generation industry with a flattening of total national withdrawals over the past two decades.

CHAPTER III
STUDY DESIGN

STUDY COMPONENTS

The study has three main components: (1) a series of site visits and interviews with power plant personnel; (2) a survey of the U.S. power generation facilities; and (3) the statistical analysis of power generation facility data and other associated information.

SITE VISITS AND POWER PLANT SURVEY

Many of the published research estimates of thermoelectric water withdrawals and consumptive use, including the USGS inventories, are based upon the same source of data, Form EIA 767, even though there are potential ambiguities in the application of these data in the calculation of average and total thermoelectric water use. In order to clarify the way that generation facility managers respond to this survey in practice, and to solicit information from plant managers on factors that influence water use at power generation facilities, the first task in this study was to conduct a series of site visits and a national survey of power plants. The site visits and survey collected information on how water use and power generation are measured and recorded, the accuracy of data reporting in EIA forms, and the applicability of EIA data in the estimation of unit water use ratios (gallons/kWh) for thermoelectric generation facilities.

Survey Development and Implementation

Survey development consisted of three steps. The first step was a review of the plant characteristics, power generation, and water use estimates available in 2003 Form EIA-767 database. This review was performed in order to:

(1) Categorize the generation and cooling characteristics of thermoelectric facilities in the United States;
(2) Identify those facilities that would receive mail surveys; and
(3) Develop preliminary standardized measures of water use.

The second step of the survey development involved a series of site visits and personal interviews with plant managers at a sample of thermoelectric generation facilities in the Midwest. The interviews were used to identify the types of on-site water uses, the measurement of these uses, and the water use concerns of plant managers. The site visits provided information on the various types of cooling systems, measurement points, and water use estimation procedures employed by thermoelectric generation facilities. A complete description of the site visit procedures appears in Appendix B.

The final step was the preparation of the questionnaire tool and implementation of the survey. The information collected during the previous components guided both the content and distribution of the surveys to power plant representatives. Three slightly different versions of the questionnaire were prepared, based upon the primary cooling system type:

(1) once-through cooling systems;
(2) re-circulating cooling systems with ponds or canals; and
(3) closed-loop cooling systems with cooling towers.

The survey questionnaire consisted of three parts. In the first part of the survey respondents were presented with a table containing the estimated water use coefficients that had been calculated based on the 2003 EIA-767 data. Respondents were asked to compare these estimates to their own calculations of water use at their facilities and to identify potential sources of variance in water use of the cooling systems in the sample. The second part of the questionnaire consisted of questions pertaining to the measurement and reporting of water use and power generation. The third part provided an opportunity for respondents to provide contact information and general comments pertaining to water use at power generating facilities.

Feedback collected during the site visits had indicated that electronic surveys would be the most effective way to ensure that power generation personnel received the survey, and could easily share it with the administrative and/or water management staff members in their organization who might need to provide approvals or technical information. The Department of Energy was contacted in order to obtain a list of the email addresses of the contact persons for each generation facility. A personalized email form letter describing the study and the survey were sent to the Form EIA-767 administrator at each facility, along with a copy of the appropriate cooling system survey. Form EIA-767 administrators that were responsible for multiple facilities received individualized cover letters and the appropriate surveys for each of their facilities. If email messages were returned due to a bad address, the utility was contacted by phone to see if another contact email address could be obtained. A week after the initial emails were sent, a reminder email was sent to all of the contact persons on the revised mailing list.

It was anticipated that some generating facility email system might have security systems in place that would block the survey email attachments. Therefore, the email cover letter also directed respondents to a web page that contained an explanation of the project and copies of the surveys and associated tables. This web page was posted on the SIUC Geography Department research website, and remained available for several months following the end of the survey collection process.

The detailed review of 2003 Form EIA-767 data (mentioned above) was also used to identify the generating facilities that were included in the survey sample. The procedure used to identify these facilities is described in detail in Appendix A. Of the 1,382 organically-fueled power generation facilities submitting data in 2003, 669 met the necessary criteria to be included in the survey sample.

Reporting data from the nation's nuclear power generating facilities are not available in the Form EIA-767 after 2000. The U.S. Nuclear Regulatory Commission was contacted to obtain a list of those utilities that operate nuclear power generation facilities, and these facilities were contacted by email or telephone and invited to participate in the survey. Several nuclear power plants are operated by utilities that also operate organically-fueled plants. Surveys for these nuclear facilities were sent to the Form EIA-767 manager for that utility. A separate set of coefficient tables was also prepared for the nuclear powered generation facilities based on the most recently available data (2000).

Copies of the survey cover letter, the three versions of the questionnaire, and associated tables appear in Appendix C. The observations made during the site visits and results of the email survey of thermoelectric generation facilities are presented in Chapter IV.

STATISTICAL ANALYSIS OF GENERATION FACILITY DATA

The purpose of the statistical analysis was to estimate water use relationships (and water-use coefficients) for discreet types of thermoelectric generation facilities and operating conditions. The results were then used to develop "benchmark" measures that estimate both the average performance, as well as the best potential performance, of each category of cooling systems. Two types of statistical analysis were used: (1) multiple regression analysis, and (2) stochastic frontier analysis.

Multiple Regression Analysis

The principal source of data used in the statistical analyses is the Form EIA-767, Steam Electric Plant Operation and Design Report. EIA-767 provides a fairly comprehensive review of plant characteristics, power generation, and water withdrawal and consumptive use summaries. The EIA-767 survey is conducted annually. Reporting is mandatory under Section 13(b) of the Federal Energy Administration Act of 1974, so the information available from EIA-767 can be considered to be comprehensive. Data in electronic format were available for the years 1996 to 2004.

In addition to the generation and cooling system data, weather data at power generation locations was collected in order to examine the influence of the regional air temperature and rainfall characteristics. This weather data set was developed using the methodologies described in a previous study by the same research team (Dziegielewski et al., 1999).

Multiple regression analyses were performed using the generating facility and weather data from 1996 to 2004 in order to identify the major determinants of thermoelectric water withdrawals and consumptive use, and to estimate their respective effects on the quantities of cooling water in both once-through and recirculating cooling systems. Four categories of potential influencing factors were examined:

(1) Cooling system type;
(2) Fuel type and thermal efficiency;
(3) Operational conditions; and
(4) Type of water source.

Separate regression models were estimated for three types of cooling systems: once-through cooling, recirculating systems with cooling ponds or canals, and closed-loop systems with cooling towers. Linear and log-linear models were tested using an ordinary least-squares regression procedure. The log-linear model of total annual withdrawals was specified as:

$$\ln(TW_{it}) = a + \sum_{j} b_j \ln(X_{ijt}) + \sum_{k} c_k B_{ikt} + \ln(\varepsilon_{it}) \qquad 3.1$$

where: TW_{it} is the amount of thermoelectric withdrawals (or consumptive use) in million gallons per day, by cooling system i during year t; X_{ijt} is a set *j* of determinants represented as continuous variables; B_{ikt} is a set *k* of determinants represented as binary (indicator) variables; a, b_j, and c_k are the estimated regression coefficients; and ε_{it} is the disturbance term.

A similar linear model of withdrawals per unit of net generation was used to further explore the variability of unit withdrawal rates among different plant and cooling system types. Regression models for both total and unit withdrawals for once-through and recirculating cooling systems were estimated using the stepwise regression procedure of the JMP 6.0 software. The data set, specific explanatory variables, and regression results are discussed in Chapter V.

Predictions from the regression models described above were used to generate simple benchmarks of water withdrawals, by cooling system type. However, such benchmarks only represent average conditions among the existing power plants and not the conditions at plants that would be considered to have the best performance in their class. In order to measure the level of performance in terms of technical efficiency of water use, the econometric technique of “stochastic production frontier analysis” was applied to the data set.

Stochastic Frontier Analysis

Stochastic frontier regression analysis, is a refinement of the ordinary least-squares regression analysis for the purpose of deriving measures of best performance. It can identify the best performance at the plant level and provide a measure of inefficiency in the process of using water to produce electricity.

Theoretical Background

Frontier analysis is derived from the economic definition of a production technology as a set of feasible input and output combinations, which can be described by the following equation (Kumbhakar and Lovell, 2000):

$$Y = \{(y, x): x \text{ can produce } y\} \qquad 3.2$$

This equation states that the production technology set Y is a set of all combinations of input and output in which input x produces output y. In the case of cooling water, water can be considered as an input in the production of electricity. The boundary of the production technology represents the maximum output that can be obtained from any given input, or alternatively, the minimum input usage required to produce any given output. It therefore represents a standard against which the technical efficiency of production can be measured. Accordingly, a production frontier function can be described as follows:

$$f(x) = \max\{y: x \in L(y)\} \qquad 3.3$$

where $L(y) = \{x: (x,y) \in Y \}$ describes the sets of inputs that are feasible for each output. The production frontier provides the upper boundary of production possibilities, and the input-output combination of each producer is located on or beneath the production frontier. Measurement of technical efficiency involves the measurement of distance from the input-output combination to the production frontier graph.

A production frontier utilizes only input and output quantity data. Two measures of technical efficiency used for this study are input oriented and output oriented. These are often referred to as the Debreu-Farrrell measures of technical efficiency (Kumbhakar and Lovell, 2000) shown in Equations III-2 and III-3, respectively. These two measures assume that producers produce a single output from a single input; in this case, water is used to generate electricity.

According to Kumbhakar and Lovell (2000), if only a single output is produced, the input-oriented measure of technical efficiency is given by the function below:

$$TE_i\,(x,y) = \min\{\theta: y \le f(\theta x)\}. \qquad 3.4$$

Technical efficiency in this case is measured in terms of equi-proportionate contraction of all inputs. An input vector is technically efficient when no equi-proportionate contraction of all inputs is possible. For this study, input related technical efficiency is represented by the factor by which the amount of water use can be decreased from x_1 to θx_1 and still generate the same amount of electricity (Figure 3.1).

On the other hand, if only a single output is produced, the output-oriented measure of technical efficiency is given by the function:

$$TE_o\,(x,y) = [\max\{\Phi: \Phi y \le f(x)\}]^{-1}. \qquad 3.5$$

Technical efficiency is measured in terms of equi-proportionate expansion of all outputs. An output vector is called technically efficient when no equi-proportionate expansion of all outputs is possible. The output-related technical efficiency is represented by the factor by which the production of electricity can be increased from y_1 to the efficient level of $\Phi y_{1,}$ using the same amount of water x_1 (Figure III-1).

Both measures of technical efficiency are illustrated in Figure 3.1 below.

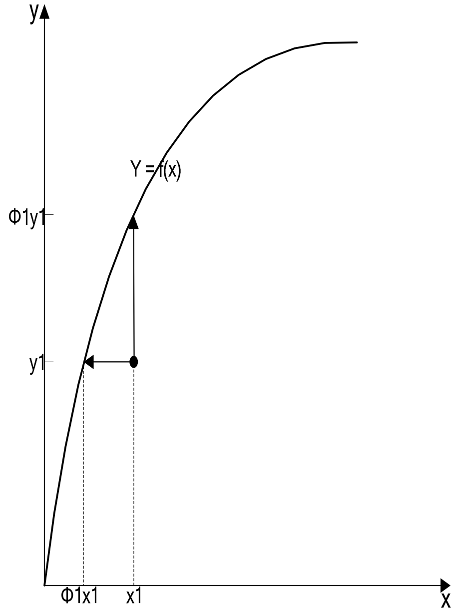

Figure III-1: Single Input and Single Output Case of Technical Efficiency
Source: adapted from Kumbhakar and Lovell (2000)

A producer using x_1 to produce y_1 is technically inefficient, since it operates beneath f(x). TE_i (x_1, y_1), the input-oriented measure of technical efficiency at (x_1, y_1), measures the maximum contraction of x_1 that enables continued production of y_1, and equals $\theta < 1$, since $y_1 = f(\theta x_1)$. $TE_o(x_1, y_1)$, the output-oriented measure of technical efficiency at (x_1, y_1), measures the reciprocal of the maximum expansion of y_1 that is feasible with x_1 and is equal to $(\Phi)^{-1} < 1$, since $\Phi y_1 = f(x_1)$.

Estimation Procedure

A statistical method for estimating a stochastic production frontier was developed in mid-1970s (Aigner, Lovell and Schmidt, 1977; Battese and Corra, 1977; Meeusen and Van den Broeck, 1977). In our case, the model separates electricity production into systematic effects, inefficiency and random error. Following Battese and Coelli (1992), the stochastic production function model for panel data can be expressed as:

$$Y_{it} = x_{it}\beta + (V_{it} - U_{it}) \qquad i=1,\ldots,n;\ t=1,\ldots,T \qquad 3.6$$

where Y_{it} is the logarithm of the production of the *i*-th plant in the *t*-th time period; x_{it} is the vector of input quantities, β is a vector of unknown parameters. V_{it} are random variables assumed to be independently and identically distributed (iid) as N(0,σ_v^2) and independent of U_{it}, where

$$U_{it} = (U_i \exp(-\eta(t-T))) \qquad 3.7$$

and where U_i are nonnegative random variables associated with technical inefficiency in production, which are assumed to be "iid" as truncations (at zero) of the normal distributions with mean μ and variance σ_U^2, and η is a parameter to be estimated.

In order to attempt to identify some of the reasons for differences in efficiencies of individual plants, the predicted technical inefficiency can be regressed upon plant-specific variables (such as type of fuel or source of water). While this is a useful exercise, the two-stage estimation procedure is inconsistent in its assumptions regarding the independence of the inefficiency effects in the two estimation stages. Battese and Coelli (1995) proposed a model in which the inefficiency effects (U_i) are independently distributed as N(m_{it},σ_U^2) with truncation at zero and are expressed as an explicit function of a vector of plant-specific variables and a random error term:

$$m_{it} = z_{it}\delta \qquad 3.8$$

where z_{it} is a vector of variables which may influence the efficiency of a firm, and δ is a vector of parameters to be estimated.

The FRONTIER Version 4.1 computer program developed by Coelli (1992; 1996) was used in a preliminary analysis of the plant-level data (actually cooling-system level observations) for the period 1996 to 2004 to obtain maximum likelihood estimates of the stochastic frontier production function for each of the two types of cooling systems. The program calculates predictions of individual firm technical efficiencies from estimated stochastic production frontiers. The measure of technical efficiency of the *i*th sample firm is given as:

$$TE_i = \exp(-U_i) = \frac{E(\exp(Y_i)|U_i, X_i)}{E(\exp(Y_i)|U_i = 0, X_i)} \qquad 3.9$$

TE_i takes a value between zero and one. This prediction of technical efficiencies is based on the conditional expectation of Equation III-5, given the model specifications.

The maximum likelihood estimates (MLE) for the pooled stochastic production frontier model and those for the technical inefficiency model for the two types of cooling systems based upon a sample of cooling system level data (1996-2004) from EIA 767 are presented in Chapters V and VI.

DEVELOPMENT OF BENCHMARKS

The results of the descriptive data analysis, and the regression and stochastic frontier analyses were used in deriving benchmark values of unit water withdrawals and unit consumptive use in gallons per kilowatt-hour of net energy production. Separate benchmarks of water use were derived for three general types of cooling systems: once-through systems, recirculating systems with ponds or canals, and closed-loop systems with cooling towers.

The data and results of the statistical analyses allowed for the derivation of two types of benchmarks: “average performance” benchmarks and “best performance” benchmarks. The values of the benchmarks are presented and discussed in Chapter VII. The average performance benchmarks are based on the results of the descriptive statistics and regression analyses. The best performance benchmarks are derived from the results of the stochastic frontier analyses.

CHAPTER IV
FINDINGS OF SITE VISITS AND MAIL SURVEYS

SUMMARY OF SITE VISIT FINDINGS

Site visits were conducted at five power generation facilities. Cooling system types at these facilities included: once-through cooling, re-circulating systems with cooling towers, and re-circulating systems with cooling ponds. None of the plants visited had more than one type of cooling system. Visits began with an interview with the EIA 767 administrator or other staff member, followed by a tour of the facility. A detailed review of the site visit procedure and notes from each facility visit are presented in Appendix B. A summary of the key findings from the site visits is presented below.

EIA 767 Reporting / Application of EIA-767 Data to Unit Water Use Calculations

Facility personnel described several potential problems with using the data reported in EIA 767 to calculate the unit water use (gallons/kWh) of power generation facilities. Water quantities are often estimated based upon water pump ratings and hours of pump operation. The assumption of 24 hour/day, 100 percent flows may not apply to all cooling systems. Also, water used for non-cooling needs (i.e., cleaning, flushing, waste disposal, fly ash removal) may delivered by cooling water pumps. These flows may be significant at some facilities and would be reported as of cooling water.

Likewise, on-site use of electricity (i.e., electro-static precipitators) can be substantial at some facilities. This electric use represents a “service load” and would not be included in the total net generation reported in EIA 767. This can significantly affect the comparability of unit water use calculations among plants with different service loads. All of the interviewees were presented with copies of spreadsheets that were used to calculate the unit water withdrawals for their facility from the data presented in the EIA 767. Only one of the five thought that the calculated estimate did not accurately represent water use and generation at his facility.

Determinants of Water Flow

Site visit participants were asked to describe some of the factors that would influence the amount of water used at their facilities. Factors discussed included:

- The need to maintain backpressure when increasing generation requires increased water flows.
- Careful monitoring of the optimal mix between water flows and generation keeps the “cost of pumping” to a minimum, allowing more of the generated power to be sold on the grid.
- Increased water source temperatures require increased cooling water flows.
- The *quality* of groundwater affects the *quantity* of water used in cooling towers.
- Substantial amount of water may be necessary for “ash handling.”

- Flows may need to be decreased to accommodate recreational uses of water sources that are shared with other users.
- NPDES permits were mentioned as a potential influence on water flows; however, none of the facilities that were visited had ever needed to increase or decrease flows to meet permit requirements.

Water Use Management

Water management concerns appeared to be related to the cooling system type in use at each facility. Managers of plants using ponds needed to pay attention to high intake water temperatures in summer months, while the managers of cooling systems that used well water and cooling towers needed to be mindful of both water quantity and quality. Once-through cooling systems on large water bodies did not need to pay much attention to the quantity of water used. While there could potentially be some problems with exceeding the temperature limits of their discharge permits (NDPES), this had never been a problem for the facilities that were visited.

Most Knowledgeable Contact Person

The initial contact person at each facility was the EIA-767 manager. The duties of this person differed greatly at each facility. The larger utilities that participate in the site visits had a single staff person who responded to all Form-767 inquiries and who referred the research staff to other individuals at the generating facility. The site visits provided little insight into how to design a procedure to ensure that the person most knowledgeable about water use issues at each facility would receive and respond to the email survey.

Suggestions for Conducting a Questionnaire Survey of Power Generation Facilities

Survey participants were asked if they thought that power generation plant officials would respond to a voluntary questionnaire survey. They all agreed that few officials would respond to the survey and were unable to suggest any incentives or other actions that would help to improve response rates. It was noted that power plant officials are quite busy and are already required to fill out numerous state and federal forms. Also, all of the informants stated that if they received a survey questionnaire, they would need to forward it to other members of their organization, either for approval, consultation, or both. Several informants suggested that an email survey would have a better chance of success since it could be easily forwarded to other off-site personnel, if necessary.

SUMMARY OF SURVEY FINDINGS

This section describes the survey response rate and provides a summary of the answers to each of the fourteen questions on the survey questionnaire.

Survey Response Rate

The target population for the survey phase of this study was all of the U.S. thermoelectric power facilities for which generation and water flow data were available in the 2003 EIA-767 database. Appendix A describes the procedure used to select an initial sample of 669 facilities. Surveys were sent to the EIA 767 administrators who were asked to either complete and return the survey, or forward it to the appropriate person in their organization for completion. A list of email contacts of EIA 767 administrators was obtained from the Energy Information Administration, and all correspondence was conducted using email. The surveys themselves were sent as email attachments and were also made available on a web page that was established to support the study.

Both public and private power generation enterprises often operate more than one power generation facility, or even more than one electric utility, and often assign the responsibility for completing Form EIA 767 for all of their facilities to a single staff member. Therefore the number of persons who were sent the surveys was smaller than the number of facilities.

Email addresses were unavailable for the contact persons for 36 facilities in the initial sample and these were dropped from the study. Email messages and electronic copies of the survey were sent to 215 EIA 767 administrators, representing 636 power plants. Of these, 21 email messages were returned as undeliverable and attempts to find other email address, phone numbers, or other contact information were not successful. Eighteen of the contact persons, representing a total of 63 plants sent an email reply that they were not interested in participating in the study. One firm responded that three of the plants included in their list of surveyed facilities had been “mothballed.”

Completed surveys were returned for 38 facilities (21 with cooling towers, 3 with cooling ponds, 14 with once-through cooling). Several other survey participants responded directly to the project principal investigator by phone, and did not submit a survey. A few others responded via email, with descriptions of water use at their facilities, rather than completing the surveys.

The low response rate is consistent with the predictions made by EIA 767 administrators during the site visits. Indeed, only two of the five facilities that participated in the site visits, returned email surveys sent to their facilities. Several reasons for the lack of response to the survey can be inferred from comments solicited during the site visits or that were provided by survey respondents in email messages or in telephone conversations. These are:

- Surveys are a difficult tool to use to collect information from complex organizations, such as those of most power generation facilities. Hierarchical administrative structures make it difficult for staff to participate in surveys without prior approvals.
- The EIA 767 administrator may not have access to the information needed to complete the survey form, and may find it too time consuming to obtain the information from other staff members, especially at utilities that operate multiple power generation facilities.
- Privately-owned utilities may consider some of the information requested on the survey to be proprietary, and believe that it is against their best interest to participate.
- There may be a general reluctance by any large organization to provide any information that is not strictly mandated.
- There may be some concern that participating in studies about power generation water use "only results in efforts to further regulate power generation facilities."
- Several persons who received the survey form contacted the research team to complain that the survey designed was inadequate and could not be used to collect any meaningful information about power generation water use. These individuals declined to participate in the study or to suggest ways to prepare more meaningful survey questionnaires.

Review of Survey Questionnaire Results

Copies of the three different types of survey forms (one for each cooling system type) appear in Appendix C. Detailed responses to the survey appear in Appendix D. These responses have been edited slightly to preserve the anonymity of the respondents, as required under the survey protocol. The following section summarizes the responses to each survey question.

Question 1 - *How is the <u>average annual rate of cooling water withdrawals</u> estimated for the cooling systems at your facility?*

Form EIA 767 requires facilities to report their *average annual rate of cooling water withdrawals.* This estimated *flow rate* is used in the study as the key source of information to calculate the *quantity* of water used in the production of electricity by each cooling/generating system in the analysis. Survey questions 1 and 2 were used to collect information on how these estimates were prepared, and types of errors that could occur when using these flow rates to estimate quantities of water withdrawals.

All of the once-through facilities estimated water use based on pump operations, while almost all of the plants using cooling towers had measuring devices in place to record water use volumes. Two of the pond systems estimated water use based on pump operations, while the third measured the make-up water pumped into their cooling pond from another water source to calculate withdrawals, rather than water pumped through the cooling system. Several other methods of estimation and measurement were also mentioned.

Question 2 *- Do the water use ratios calculated from the data in Form EIA-767 for your cooling systems appear to be correct?*

More than half (25/38) of the respondents considered the estimated water use ratios calculated from the Form EIA-767 data to be reasonable estimates of water use at their facility. Those respondents answering “no” to the question cited various explanations for the inaccuracy of the estimated ratios.

- Assumptions about the number of pumps in operation and the number of hours of operation are incorrect (once-through systems).
- Misalignment of generation and reported cooling withdrawals. For some facilities cooling water withdrawals can only be reported for all cooling systems together. When the average annual rate of cooling water is known for the entire plant but not the individual cooling system, Form EIA-767 instructions require plant officials to assign the total flow rate to a single cooling system, and to report “EN” for all the remaining systems. For these facilities, the water use coefficient must be calculated by summing generation from all cooling systems, and then to calculate water use using the flow rate reported for the “non-EN” cooling system.
- Some facilities are running cooling water pumps full-time regardless of whether or not generation is operating at full capacity.
- The data in EIA-767 is inaccurate and cannot be used to calculate these ratios.

Question 3 *- Do water withdrawal ratios for the cooling systems at your facility differ significantly from the median for your cooling system type?*

Respondents were presented with a calculation of the median water use for all of the facilities with cooling systems that were similar to their own, and asked to compare water use at their facility to this median. The majority (25/38) stated that the median value was reasonably close to the estimated values for their own facilities.

All three facilities using cooling ponds thought that the median ratio was significantly different from the ratios that could be calculated for their facilities. However, no clear reasons were provided as possible sources or this difference. Ten other facilities (five once-through and five cooling-tower facilities) also responded that the median was not representative of the experience at their facilities. Only two of these suggested explanations for the differences. One respondent stated that their pumps operate continuously, regardless of the level of generation. The other respondent noted that each system that uses cooling towers can be considered to be unique because of the wide variation of cooling tower designs and operating practices.

Question 4 *– What might account for the wide range of unit water use values?*

Each survey included a histogram displaying the wide range of unit water use values calculated for the three different categories of cooling systems. Survey participants were asked to suggest reasons for the wide range of values that occur in all facilities, regardless of cooling type.

The reason most frequently cited by once-through cooling system respondents was the way that cooling water withdrawals are estimated or reported. Differences in the frequency and length of time of boiler/generator shutdown times and the designed temperature rise of the condenser(s) in use at each facility were the next most frequently suggested reasons. Other reported conditions included: differences in the interpretation of what constitutes cooling water, differences in inlet water temperature, and the use of condensate coolers in summer months.

All three of the respondents from facilities using re-circulating cooling systems with ponds cited differences in the way that cooling water withdrawals are estimated or reported as a reason for the wide range of unit water use values. Some of the other conditions suggested were: differences in the frequency and length of time of boiler/generator shutdowns, variable reservoir inflows due to weather conditions, and variable irrigation releases.

The most frequently cited reason for the wide range of unit water use values for closed-loop cooling systems with towers was differences in intake water quality that result in different blow-down rates. Differences in makeup water measurement, cooling tower and condenser designs, and shut-down times were also suggested. One respondents noted several plant and site characteristics that could influence the unit water use rate:

- recovery systems installed at the facility
- use of on-site wells
- water used in auxiliary systems at the plant (e.g., lime spray dryers)
- ambient conditions at the facility location (humid vs. dry climate, warm vs. cool climate)
- ways that plant design incorporate service water (auxiliary water) used to cool plant equipment

Question 5 - *Is it possible to measure or estimate cooling water consumption at your facility?*

Although large quantities of water may be used in the power generation cooling process, all but a small fraction of this water is returned to nearby surface water sources and is considered to be “consumed.”

Less than one-third of once-through cooling systems (4 out of 13 responses) reported that they were able to measure the consumptive use of water, with several responding that there was no “consumptive” use of water at once-through cooling facilities. The measurement methods used by those who were able to estimate consumptive use included: measurement at outfall weirs, rough evaporative estimates, cooling water pump flow curves, and the “water balance” method.

The majority (18/21) of the respondents with cooling towers reported that it was possible to measure or estimate cooling water consumption, due to the many measuring devices available at these facilities. Two of the three facilities using re-circulating systems with ponds answered that they could measure consumptive use with measuring devices, or prepare estimates based on a "water consumption factor."

Question 6 – *What are some of the possible sources of cooling water consumptive use?*

One-third of respondents from once-though cooling systems and cooling systems with ponds stated that there was no consumptive use at their facilities. The remaining respondents from these categories suggested several potential sources of consumptive use:

- water diverted to other uses
- vented to atmosphere during startups
- result of inaccurate measurement

Several sources of consumptive use were cited by facilities using cooling towers, including:

- tower evaporation
- drift
- vented steam
- water diverted to other uses
- blow-down to control cycles and prevent corrosion/scaling of the condenser
- water used for ash handling

Question 7 - *Are there any non-cooling water needs at your facility that use water from the cooling system?*

Ideally, water use coefficients would be calculated using only quantities of water that were used for cooling. However, water pumped for cooling is often used for other non-cooling needs. If these non-cooling uses are significant they can affect the unit water use values.

Approximately half of the respondents, from all cooling system types, indicated that there are non-cooling water needs at their facility that use water from the cooling system. The largest uses were processing/washing for once-through facilities, irrigation for facilities with ponds, and scrubber dilution water and ash handling for cooling towers facilities. A complete list of the non-cooling needs and estimated quantities is included in Appendix D.

Question 8 - *How is NET GENERATION calculated for the generators at your facility?*

As with non-cooling water uses, most facilities also use some of the electricity that they are generating to meet on-site energy needs. Substantial quantities of on-site electric use will influence the value of the unit water use ratio.

Almost all of the facilities responding to the survey indicated that metering is available to measure both the gross generation and the service load energy for each generator. However, Form EIA-767 does not require the reporting of gross generation.

Question 9 - *Approximately what percent of gross generation on annual basis does net generation represent at your facility?*

Almost all of the responding facilities maintain a record of gross generation for each generator at their power plant. The reported ranges of the percent of net to gross generation by cooling type were:

- 90 to 100 percent for once-through plants
- 94 to 94.7 percent for re-circulating cooling with ponds
- 87.5 to 98.6 percent for cooling towers

Question 10 - *Does your facility measure and record the ANNUAL TOTAL WATER WITHDRAWALS for your facility*

As discussed previously, the only publicly available water use data for all power generation facilities is the cooling water flow rate reported in Form EIA 767. This flow rate has been used in many studies that estimate water use at power plants. However, actual measures of total withdrawals would greatly simplify the analysis of the relationship of power generation and water use.

For all cooling types, the majority of the surveyed facilities indicated that they do measure and record the annual total water withdrawals. While they may provide this data for other state and federal agencies, it is not requested on Form EIA 767.

Question 11 - *Are there any constraints to cooling water withdrawals at your plant?*

The main constraints to cooling water withdrawals at once-through facilities were temperature and volume limitations mandated under NPDES, state permitting requirements, seasonal temperatures, and pumping capacity. Re-circulating facilities with ponds were mainly constrained by state permits, seasonal temperatures, and contractual and water right issues, while cooling towers were constrained by pumping capacity and contractual and water rights.

***Question 12** - Do you currently use any "alternative" sources of water at your plant?*

The majority of the respondents for once-through plants and re-circulating facilities with ponds do not use any "alternative" sources of water at their plants; however, ash ponds and wastewater were common for cooling tower plants. Alternative sources that were listed by survey respondents included:

- groundwater/deep wells
- city water (treated for boiler make-up)
- brackish water and city water
- direct rainfall (re-circulating with ponds)
- recycled water
- storm water sediment ponds

***Question 13** - If water intake from your current source had to be reduced, what actions could be taken at your plant to respond to this reduction?*

Understanding the actions that facilities would use to reduce water use is another method of determining those factors that influence cooling water use.

For all types of plants, generation reduction is the most likely response to reduce water use. The installation of cooling towers and supplemental water intake were other methods suggested for reducing water use. Several facilities suggested operating generators at sub-optimal pressures, but one respondent described several detrimental impacts from such actions. Other actions suggested by respondents included:

- alteration of cooling water structures to improve efficiency
- irrigation water exchanges or purchases
- use sea water
- reuse more pond discharge
- increase cycles of concentration in cooling towers
- increase chemical feed or modify pretreatment chemistry or cooling water chemistry and treatment

***Question 14** - What is your title and water management responsibilities?*

Information was requested on the title of the person who completed the survey in order to assess the range of personnel and skills that are dedicated to generating facility water management. The titles of the survey participants included:

- Air Program Coordinator
- Environmental Analyst/Supervisor/Specialist/Coordinator/Compliance Engineer
- Assistant Plant Superintendent
- Area Superintendent
- Chemical Supervisor/Chemist

- Operations Superintendent
- Performance Engineer/Plant Engineer/Results Engineer,
- Power Production Executive Manager
- Vice President
- Team Leader

More than half of the respondents had other recording and reporting responsibilities. Approximately one-third of all respondents for each type of cooling system also had some management and decision making responsibility relating to plant water use.

Summary of Findings

The site visits and the surveys helped to identify important concerns about water measurement and use at thermoelectric power plants, and factors that deserve attention in the development of models to describe thermoelectric water use. This information proved valuable in the design of the data analysis that was used to develop water use benchmarks and other comparative measures of water-use efficiency.

The first important finding is that the generation facilities (i.e., individual generators, also referred to as generating units) can be subdivided into three groups in terms of the continuity or frequency of their operations: base load generation, load following generation, and peak-load generation. Water use per kilowatt-hour of net generation will be affected depending on the type of generation. Because of the technical design characteristics, water pumps in the load-following and peak-load generation may continue to operate at the same flow rate regardless of the actual level of generation. This is likely to produce high ratios of cooling water volume per unit of electricity generation. This finding was taken into consideration by including a variable in the statistical analysis of the EIA 767 data that captured the utilization rate of the generating capacity.

The second critical finding is that the available net generation estimates by each generator (i.e., generating unit) in the EIA-767 database is not the appropriate measure of generation to be compared with the volume of cooling water being used. Cooling water requirements are driven by the amount of gross generation and therefore the amount of heat that needs to be removed. Net generation excludes a fraction of total generation that is used within the plant. While some remedial measures were employed in this research to capture the variance in “service loads” among different systems, future studies of water use in thermoelectric plants would benefit from obtaining gross generation for each generating unit, in order to be able to calculate gross generation for all generating units served by each cooling system.

Other, more specific, findings from the surveys were also taken into account in formulating statistical models of water withdrawals and the development of meaningful benchmarks of thermoelectric water use.

CHAPTER V
STATISTICAL ANALYSIS OF WATER USE IN FOSSIL FUEL PLANTS

DATABASE

EIA-767 Data Set

In a typical thermoelectric power plant, boilers, generators, and cooling systems are interconnected. One cooling system can be connected to several generators or boilers. Likewise, one boiler or generator can also be served by several cooling systems. The data contained in the EIA-767 databases are reported at different levels of observation: electricity generation data are recorded at the generator level, fuel source and quantity data are recorded at the boiler level, and water use data are recorded at the cooling system level.

The analyses in this study are conducted at the "cooling system" level. Form EIA-767's multi-level data reporting make it difficult to associate the reported thermoelectric water withdrawals with corresponding amounts of energy generation, fuel type, cooling system type, and other characteristics. Boilers, generators, and cooling systems all need to be correctly aligned before they could be used in the statistical analysis of water use.

The procedure for aligning the data consisted of two steps. First, the interconnected cooling systems, boilers, and generators were identified and grouped into generation-cooling units (referred to as simply "cooling systems" in the remainder of this report), represented by a unique system identification number (ID). Second, the values of the following seven factors were determined for each newly created unit: (1) total annual water use, (2) cooling system type and age, (3) average cooling water temperature rise in the condenser, (4) type of the fuels burned by the corresponding generators, (5) type of the water sources for cooling, (6) total annual net electricity generation and generation capacity by the corresponding generators, and (7) total annual supplied heat.

The resulting database used in the statistical analysis contained 7,365 observations of reported thermoelectric water withdrawals and consumptive use for cooling systems in fossil fuel plants during a nine-year period from 1996 to 2004(Table V-1). A preliminary analysis of the estimated unit withdrawals by cooling system type demonstrated that three general categories could be used to group all of the other cooling types (see Table C-1). The number of power plants with sufficient data to include in the analysis varied by year, and ranged from 377 plants in 1996 to 605 plants in 2003. The number of cooling units in the data set also varied by year, ranging from 585 in 1996 to 1,121 in 2001.

Variables

In addition to the data on water withdrawals and consumptive use, measurements on a large number of potential explanatory variables were included in the database. Five categories of likely determinants of cooling water withdrawals were examined (Table V-2). These included: (1) specific types of cooling systems; (2) fuel types; (3) operational conditions; (4) water sources, and (5) other variables. Most of the variables created for the regression procedure are binary indicator variables. Continuous variables included several measures of operational conditions.

Table V-1. Number of Plants and Cooling Systems Included in the Final Dataset by Year

Data Year	Number of Plants	Number of Cooling Units by Type			
		Once-through	Recirculating With Ponds	With Cooling Towers	All Cooling Types
1996	377	327	56	202	585
1997	397	366	61	208	635
1998	385	370	63	194	627
1999	403	361	64	193	618
2000	415	380	65	215	660
2001	595	639	119	363	1,121
2002	586	600	112	365	1,077
2003	605	542	119	398	1,059
2004	550	507	131	345	983
	Total	4,092	790	2,483	7,365

Three calculated variables were added to the data set: operational efficiency, thermal efficiency, and system age. The reported data on electricity generation and generation capacity were used to calculate operational efficiency (or capacity utilization) of the generation unit. Operational efficiency is defined as the ratio between the total electricity produced and the total potential electricity that could have been produced if the plant operated at 100 percent capacity:

$$\mu_{oe} = 100E/(C * 24hrs/day * 365days/year) \qquad 5.1$$

where μ_{oe} is operational efficiency (%); E is annual electricity generation (kWh); and C is generation capacity (kW).

To estimate thermal efficiency, total supplied heat was calculated by summing the heat content of all of the fuels burned in the boilers and combining the result with the data on electricity generation:

$$\mu_{te} = 360000E/H \qquad 5.2$$

where μ_{te} is thermal efficiency (%); E is annual electricity generation (kWh); and H is annual supplied heat (kJ). Finally, cooling system age was calculated by subtracting the reported “year in service” from the current data year.

Table V-2. Potential Determinants of Thermoelectric Withdrawals in the Database

Category of Variables	Explanatory Variables
Cooling system types	Once-through with cooling ponds or canals Fresh water once-through systems Saline once-through systems Mixed once-through cooling systems Recirculating cooling systems with cooling ponds or canals Forced draft cooling towers Induced draft cooling towers Natural draft cooling towers Mixed recirculating cooling systems Mixed once-through and recirculating cooling systems
Fuel types	Coal as fuel Natural gas as fuel Nuclear fuels Petroleum as fuel Mixed fuels Mixed fuels including coal Mixed fuels without coal
Operational conditions	Operational efficiency Thermal efficiency Age of cooling system Average cooling water temperature rise Average summer temperature (May to September) Average annual temperature Decade of system construction Mixed ages of systems Year cooling system put in service Year plant put in service Climatic division Winter air temperature (January-December) Intake water temperature –winter Intake water temperature –summer Discharge water temperature – winter Discharge water temperature – summer Temperature rise in condenser at 100 percent capacity
Water sources	Fresh groundwater Publicly delivered water Sewage (treated wastewater) Surface fresh water Surface saline water Mixed water sources
Other variables	Annual generation of electricity Capacity utilization Percent capacity utilization Plant type Number of generators Max rating capacity

AVERAGE RATES OF WATER USE

Unit Withdrawals by Different Types of Cooling Systems

The water withdrawals per unit of net generation of electricity as estimated using the data in the 1996-2004 data sets were analyzed for ten different categories of cooling systems. Descriptive statistics for each category are given in Table V-3.

Table V-3. Comparison of Unit Thermoelectric Withdrawals (gal/kWh)
by Cooling System Configurations

Type of Cooling Systems	N	Mean	Median	Standard Deviation	Coeff. of Variat. (%)	Min.	Max.
Once through with cooling ponds or canals							
All observations	324	135.4	41.7	489.0	361	1.11	5,003
38 values > 142.5 gal/kWh excluded	286	49.5	37.7	30.3	61	1.11	143
Once through, fresh water							
All observations	2,744	131.3	49.1	535.5	408	0.01	9,826
129 values > 277.5 gal/kWh excluded	2,615	59.4	47.7	43.2	73	0.01	277
Once through, saline water							
All observations	1,024	172.1	63.2	533.2	310	0.04	7,035
110 values > 230 gal/kWh excluded	914	64.5	58.6	40.2	62	0.04	227
Mixed once through cooling[							
All observations	119	85.2	45.4	233.6	274	0.34	2,183
4 values > 350 gal/kWh excluded	115	49.1	44.8	39.7	81	0.34	189.3
Mixed once through and recirculating systems							
All observations	146	52.3	35.3	96.1	184	0.75	1,076
2 values > 155 gal/kWh excluded	144	42.5	35.0	28.8	68	0.75	151
Mixed recirculating[a]							
All observations	77	38.6	0.7	189.3	491	0.10	1,640
Excluded 2 values > 100 gal/kWh excluded	75	13.8	0.7	25.4	184	0.10	96
Recirculating with cooling ponds or canals[							
All observations	448	40.2	21.6	85.4	213	0.04	931
Excluded 36 values > 101 gal/kWh excluded	412	23.4	11.6	26.2	112	0.04	101
Recirculating with forced draft towers							
All observations	1,172	10.2	0.8	105.7	1036	0.01	3,373
Excluded 163 values > 4.32 gal/kWh excluded	1,126	1.0	0.7	0.	78	0.01	4
Recirculating with induced draft towers							
All observations	886	18.3	0.8	173.4	948	0.04	4,574
Excluded 57 values > 32.2 gal/kWh	829	2.0	0.7	4.	201	0.04	32
Recirculating with natural draft towers							
All observations	425	8.3	0.8	53.3	645	0.03	715
Excluded 35 values > 6.5 gal/kWh excluded	390	1.1	0.8	1.	86	0.03	6

The influence of outliers on the distribution of unit thermoelectric withdrawals was clearly revealed in the analysis, and so a second set of descriptive statistics was prepared for a truncated set of data that had the highest outlier values removed. These appear in the second row for each cooling system type. The extreme values of unit water withdrawals may have been the result of faulty reporting or misinterpretation of the Form EIA-767 data. However, determining the causes of these extreme values was outside of the scope of the current study. The values from the truncated set of data are much more representative of withdrawals in each cooling category, and the averages from this data set can be used as water use benchmarks for each cooling systems configuration. The mean values from this reduced data set are compared in Figure V-1.

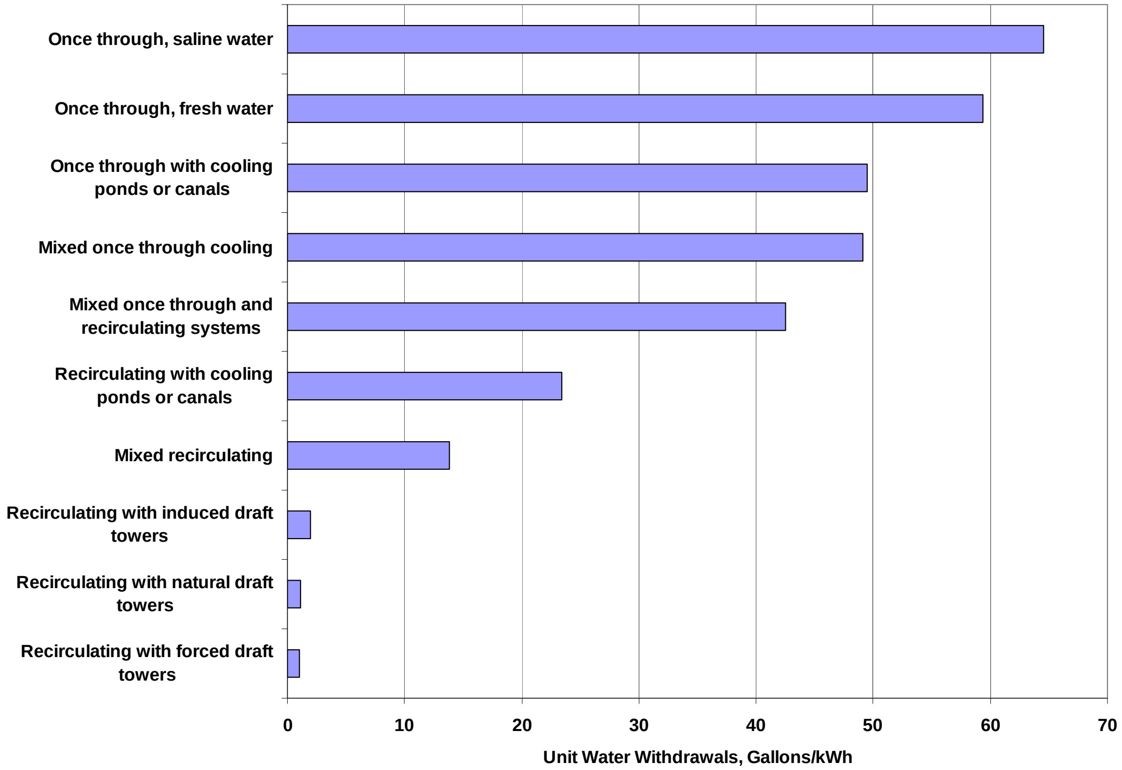

Figure V-1. Average Rates of Unit Water Withdrawals (gal/kWh)
by Cooling System Configuration, After Removing High Outlier Values

Once-through systems have the highest unit water use, ranging from approximately 50 to 65 gal/kWh. Average unit withdrawals in recirculating systems with cooling ponds or canals and other mixed recirculating systems fall between 14 and 24 gal/kWh. Closed-loop systems with cooling towers have unit withdrawals of water (primarily makeup water) that range from 1.0 to 2.0 gal/kWh

Average Water Use by Once-through, Recirculating and Closed-Loop Systems

The mean (weighted by net annual generation), median, and standard deviation were calculated for three aggregations of the ten types of cooling configurations developed from the 1996-2004 EIA-767 data (Table V-4). The “weighted means” were calculated by dividing the sum of total annual water use in all observations in the data (all plants and data years) by the sum of annual energy generation in all observations. The weighted mean values give greater weight to water usage rates in large plants (plants with high levels of electricity generation). The weighted means1 are rounded to the nearest one decimal place (or to an integer) to recognize the limited accuracy of these estimates.

Form EIA-767 also requires that plants report their “consumptive” water use, defined as the difference between average withdrawals and discharge rates. Estimates of consumptive use were calculated from this data and are also summarized in Table V-4. However, if generation facilities reported their the discharge flow rate as either zero (100% consumptive use) or as equal to their withdrawal flows (0% consumptive use), these observations were excluded from that calculations of average consumptive use. For the purposes of this analysis it was assumed that all systems (even once-through) experience some water losses, or release some withdrawals to the environment, even if facilities do not currently have a way to measure or estimate these flows. The percent of consumptive use for each cooling category was also calculated from the weighted means of withdrawals and consumptive use.

Table V-4. Unit Water Withdrawals (gal/kWh)
by Cooling System Category

Description	Once-through Systems	Recirculating With Ponds	Cooling Towers
Number of power plants	397	116	347
Withdrawals per unit (gallons/kWh):			
Number of observations	3,820	763	2,286
Weighted mean	44.0	23.6	1.
Median water intake	49.8	27.5	0.
Standard deviation	41.3	34.5	2.
Consumptive use (gallons/kWh)			
Number of observations	3,797	674	2,282
Weighted mean	0.22	0.71	0.
Median use	0.00	0.16	0.
Standard deviation	2.73	6.33	1.
Percent consumptive use (%)	0.51	3.02	70.

Most Likely Values

The descriptive analysis of the 1996-2004 data on water withdrawals and consumptive use represent a set of “most likely values” for three aggregations of cooling systems at thermoelectric power plants. The average water withdrawals for once-through cooling systems are approximately 44 gallons per kWh of net electric energy generation. The average consumptive use of approximately 0.2 gallons/kWh represents about 0.5 percent of water withdrawals.

In closed-loop systems with cooling towers, the average unit withdrawal is approximately 1.0 gallons per kWh of net electric energy generation with a consumptive use of 0.72 gal/kWh. Approximately 70 percent of water withdrawn is lost to evaporation, and only 30 percent is returned back to surface water bodies or groundwater.

The withdrawal rates and consumptive use in the recirculating systems with cooling ponds and canals and other recirculating and mixed systems fall between the values for once-through and closed-loop systems. However, the data for these systems are often unclear, and it appears that in a significant number of observations the reported quantities represented evaporation in cooling ponds and not quantities, which are pumped through the condensers.

Even after the removal of data outliers, unit water withdrawals and consumptive use still show significant variability (Table V-4). The standard deviation for the unit withdrawals of the three categories of cooling systems was approximately equal to or greater than their means. For consumptive use, standard deviations were much greater than the means. . For example, the standard deviation for consumptive use in once-through systems of 2.73 gal/kWh is more than 12 times greater than the weighted mean of 0.22 gal/kWh.

Although some of the high variability in water usage rates may be due to incorrect reporting of water quantities or incorrect assumptions about water losses, it is likely that a considerable proportion of variability can be explained by differences in the generating and cooling systems themselves and different operating conditions. The influence of such factors is investigated in the next section. In the first step, an ordinary least-squares regression procedure (stepwise) was applied to identify the relationship between water use and various plant and cooling system characteristics. In the second step, the significant determinants of water use identified in the first step were used as variables in stochastic frontier regression to estimate inefficiencies in water use at individual cooling systems.

REGRESSION ANALYSIS OF WATER USE

Once-through Cooling Systems

Tables V-5 to V-7 show the results of the regression models, which were estimated for both total and unit withdrawals as well as consumptive use for once-through cooling systems.

Water Withdrawals

The regression of total withdrawals (transformed into the natural logarithm) for once-through cooling systems includes 14 explanatory variables (Table V-5). Not surprisingly, annual (net) energy generation had by far the largest influence on total withdrawals, with increasing generation resulting in increased withdrawals. Both the design water temperature rise in the condenser, and the operational efficiency (the ratio of annual net generation/total design capacity were significant and inversely related to total withdrawals. The model also shows that water withdrawals depend on the type of water source and the type of fuel. Two less important, but statistically significant, variables are average summer air temperature and system age. Both variables show positive correlation with water withdrawals. Plants located in regions with warmer summers and older plants tend to withdraw more water. The latter reflects the effect of older technology on water use. Two observations from one power plant with unusually high withdrawals were introduced in the model as a binary "outlier" variable. Including this indicator variable in the model removed the effect of these observations on the intercept and regression coefficients.

Table V-5. Log-linear Regression of Total Water Withdrawals
in Once-through Cooling Systems

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	-1.7270	-2.0	0.0457	--
Annual generation (ln)	0.6930	42.6	0.0000	0.3613
Temperature rise (ln)	-0.7263	-14.0	<.0001	0.0299
Operational efficiency (%)	-0.0106	-11.7	<.0001	0.0196
Surface saline water source	-0.3533	-5.7	<.0001	0.0091
Fresh groundwater source	2.1999	7.0	<.0001	0.0073
Outlier binary #xxxx	4.0179	6.4	<.0001	0.0061
Thermal efficiency (%)	0.0153	6.3	<.0001	0.0048
Petroleum as fuel	-0.4001	-6.1	<.0001	0.0047
Average summer temperature(ln)	0.8152	4.3	<.0001	0.0036
Once-through w/ fresh water	-0.1949	-3.5	0.0005	0.0021
System age (ln)	0.2135	3.8	0.0002	0.0020
Mixed fuel w/o coal	-0.1761	-3.4	0.0007	0.0014
Reclaimed wastewater source	0.5740	2.9	0.0039	0.0012
Mixed water sources	0.8623	2.3	0.0194	0.0007
N= 3,916; R^2 = 0.452, Root MSE = 0.88, Mean Y = 4.89 (log)				

The statistics shown at the bottom row of Table V-5 indicate that the 14 independent variables explained 45.2 percent of variance in the dependent variable (i.e., logarithm of total water withdrawals).

The linear regression with unit water withdrawals per kWh as the dependent variable is shown in Table V-6. It confirms the influence of five determinants of the previous model and also shows the significant effect of public system water on water withdrawals. The regression coefficients indicate that unit withdrawals decrease with increasing operational efficiency (i.e., percent of capacity utilization) and with the cooling water temperature rise in the condenser. The unit withdrawals increase with increasing system age and increasing thermal efficiency.

Table V-6. Regressions of Water Withdrawals per Unit of Generation in Once-through Cooling Systems

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	95.7385	7.6	<.0001	--
Operational efficiency (%)	-1.8357	-29.8	<.0001	0.2244
Temperature rise at 100%	-2.1040	-8.0	<.0001	0.0192
System age	1.2240	8.6	<.0001	0.0134
Thermal efficiency (%)	1.9857	8.6	<.0001	0.0091
Public water delivery	38.4415	2.7	0.0076	0.0014
Mixed water sources	86.6474	2.4	0.0167	0.0010
N= 3,888*; R^2=0.261; Root MSE= 81.2 gal/kWh, Mean Y= 75.1 gal/kWh				

*Note: 76 observations greater than 1000 gal/kWh were excluded.

The data used in model estimation (Table V-6) excluded several systems with very high unit withdrawals (i.e., those greater than 1,000 gallons/kWh). Some of the unusually high withdrawals were caused by very low capacity utilization of the generators while others appeared to be the result of erroneously reported values for flow rates. This was a recurring problem in the data, and the effect of data outliers on the regression models had to be carefully considered. This was especially prevalent in the reported flow rates for consumptive use which are discussed in the next section.

Consumptive Use

The consumptive use of water in once-through cooling systems represents only a small percentage of total water withdrawals, on average approximately 1 percent or less of the total volume of water pumped. The consumptive use represents primarily leaks and water diverted from the cooling system that is not returned to the source and is usually lost to evaporation within the plant. Most of the power plants with once-through cooling systems report a value of zero for consumptive use on the Form EIA-767.

Only “non-zero” reported flow rates were used in the analysis of consumptive use. Values of the reported consumptive use of 100 percent of withdrawals were also excluded. The estimated log-linear regression of total consumptive use based on 779 observations is shown in Table V-7.

Table V-7. Log-linear Regression of Total Consumptive Use in Once-through Cooling Systems

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	-1.207	-2.1	0.0347	--
Annual generation (ln)	0.769	19.9	<.0001	0.2950
Surface saline water source	1.243	6.6	<.0001	0.0731
Temperature rise at 100 % (ln)	-1.079	-5.7	<.0001	0.0289
Natural gas as fuel	-0.506	-3.7	0.0002	0.0068
Once-through freshwater system	-0.337	-2.3	0.0211	0.0046
Thermal efficiency (%)	-0.018	-2.1	0.0364	0.0034
N= 779; R^2=0.407; Root MSE= 1.28; Mean Y= 0.32 (log)				

The results in Table V-7 indicate that total consumptive use depends primarily on annual generation of electricity. It also depends on the temperature rise at the condenser and on thermal efficiency of converting fuel into electric energy. Systems using surface saline water had higher consumptive use; for those with once-through freshwater systems it was lower. Systems using natural gas tended to have lower consumptive use.

The unit consumptive use (in gallons per kWh of generation) was also analyzed and the regression of non-zero values of consumptive use on four explanatory variables is shown in Table V-8. The regression indicates that once-through systems, which rely on freshwater for cooling tend to use less water per kilowatt-hour of electricity generation than other sub-categories of once-through cooling. The estimated equation also confirms the inverse relationship between unit consumptive use and the temperature rise of cooling water in the condenser.

Table V-8. Regression of Unit Consumptive Use
in Once-through Cooling Systems

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	10.503	4.2	<.0001	--
Once-through freshwater systems	-2.027	-5.0	<.0001	0.0300
Average summer temperature	-0.086	-2.7	0.0072	0.0093
Petroleum as fuel	3.615	2.8	0.0060	0.0087
Temperature rise at 100%	-0.076	-2.3	0.0232	0.0062
N= 788; R^2=0.054; Root MSE= 4.67 gal/kWh, Mean Y= 1.49 gal/kWh				

Closed-loop Systems with Cooling Towers

Tables V-9 to V-12 show regression models of water withdrawals in closed loop systems with cooling towers. Both water withdrawals and consumptive use were analyzed.

Water Withdrawals

The most important predictor of total annual water withdrawals in closed-loop systems is total (net) annual generation of electricity (Table V-9). Three variables show significant negative effect on withdrawals. These include: percent of capacity utilization (or operational efficiency), thermal efficiency, and the maximum rise of water temperature in the condenser. The sign of the coefficient for the utilization of saline surface water variable indicates that systems that use salt water tends to withdraw more water than systems using other water sources. Higher water withdrawals are shown to be associated with petroleum as fuel, surface freshwater sources, and higher average summer air temperature. Finally, the model includes the indicator (i.e., binary) variable which designates ten observations with unit withdrawals greater than 500 gallons per kWh. The inclusion of this variable in the model removes the effect of these high values on the intercept and the estimated coefficients of the remaining explanatory variables.

Table V-9. Log-linear Regressions of Total Water Withdrawals
in Closed-loop Systems with Cooling Towers

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	-6.8565	-5.1	<.0001	--
Annual net generation (ln)	1.0563	32.3	<.0001	0.3513
Operational efficiency %	-0.0240	-13.6	<.0001	0.0491
Indicator for outliers (>500 gal/kWh)	5.4832	9.2	<.0001	0.0212
Thermal efficiency (%)	-0.0272	-6.3	<.0001	0.0079
Surface saline water source	0.6350	5.1	<.0001	0.0061
Temperature rise at 100% (ln)	-0.4540	-4.3	<.0001	0.0037
Petroleum as fuel	0.8064	3.7	0.0002	0.0035
Surface freshwater source	0.2638	4.3	<.0001	0.0029
Average summer temperature (ln)	0.9839	3.3	0.0009	0.0027
N= 2,299; R^2 = 0.446, Root MSE =1.18 (log), Mean Y= 1.58 (log)				

The regression model for unit withdrawals by closed-loop systems with cooling towers (Table V-10) confirms the influence of four variables in the log-linear model of total withdrawals and four additional determinants including the negative effect of the design temperature rise in the condenser.

Table V-10. Regression of Water Withdrawals per Unit Generation
in Closed-loop Systems with Cooling Towers

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	44.1555	11.3	<.0001	--
Indicator for outliers (>500 gal/kWh)	851.1167	67.8	0.0000	0.6539
Operational efficiency (%)	-0.1908	-6.9	<.0001	0.0198
Thermal efficiency (%)	-0.6635	-7.5	<.0001	0.0068
Petroleum as fuel	22.5694	5.0	<.0001	0.0025
Natural gas as fuel	7.2263	4.2	<.0001	0.0014
Mixed fuel w/o coal	7.4314	3.2	0.0014	0.0009
Fresh groundwater source	-4.1076	-3.0	0.0031	0.0009
Temperature rise at 100%	-0.2810	-3.0	0.0024	0.0008
Public water delivery	-4.6319	-2.3	0.0211	0.0007
N= 2,306, R^2= 0.687, Root MSE= 25.0 gal/kWh, Mean Y= 7.5 gal/kWh				

The statistics in the last row of Table V-10 indicate that there is a large variability in unitary water use among the 2,306 observations which were used in estimating the model. The root mean square error (MSE) is 25 gallons per kWh, while the mean value of the dependent variable is 7.5 gallons per kWh. In order to deal with the effect of the small subset of observations with high unit water withdrawals, the distribution of the unit withdrawal values was analyzed by comparing the effect of the exclusion of the highest values on the mean unit withdrawal. This effect is illustrated on Figure V-2.

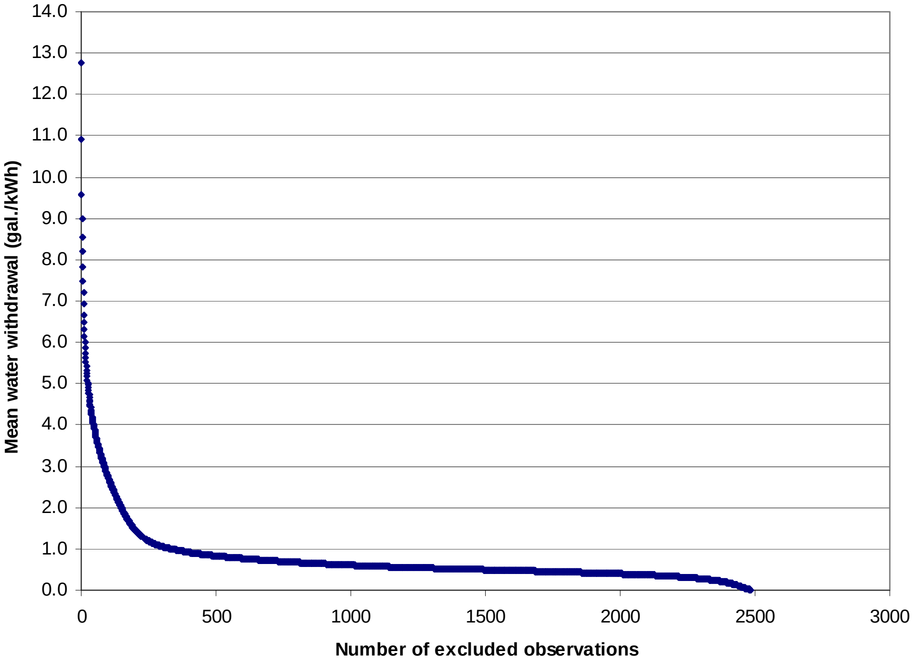

Figure V-2. The effect of excluding the highest values of unit water withdrawals on the mean in the data for closed-loop systems with cooling towers (Total n=2,483)

Figure V-2 indicates that the mean value of unit withdrawals is stabilized at a value of approximately 1.10 gallons/kWh when the highest values are removed. The data used for preparing the chart indicate that this takes place when 283 observations with unit use greater than 6 gallons/kWh are removed. Accordingly, the regression equation for unit withdrawals was re-estimated after removing 283 observations with the highest values. The results of the regression for the truncated data set are shown in Table V-11.

Table V-11. Regression of Water Withdrawals per Unit Generation in Recirculating Systems with Cooling Towers with Truncated Data

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	1.6604	6.0	<.0001	--
Operational efficiency (%)	-0.0212	-21.0	<.0001	0.1921
Surface saline water source	0.6476	7.3	<.0001	0.0239
Coal as fuel	0.4045	6.8	<.0001	0.0098
Fresh groundwater source	-0.1943	-4.2	<.0001	0.0089
Mixed fuel w/ coal	0.5503	6.8	<.0001	0.0060
System age	0.0085	4.3	<.0001	0.0052
Thermal efficiency (%)	-0.0114	-3.5	0.0005	0.0042
Petroleum as fuel	0.5543	2.9	0.0035	0.0026
Average summer air temperature	0.0078	2.6	0.0104	0.0024
N= 2,078*, R^2= 0.252, Root MSE= 0.80 gal/kWh, Mean Y= 1.06 gal/kWh				

*Unit withdrawals include only values less than 6 gallons/kWh.

The exclusion of 283 observations (about 11 percent of total observations) has a significant effect on the selection of the explanatory variables, which enter the model through stepwise regression and also on the magnitude of the regression coefficients. For example, the coefficient of operational efficiency changes from -0.1908 to -0.0212. The root MSE of the model in Table V-11 is reduced from the previous value of 25.0 gallons/kWh to 0.8 gallons/kWh. The model for the truncated data set is used to derive benchmark values of water use in Chapter VII.

Consumptive Water Use

The consumptive use of water in systems with cooling towers is considerably higher than in other types of systems. Significant amounts of the recirculating cooling water are lost due to evaporation and drift in the cooling towers. Also, measurements of consumptive use in closed-loop systems with cooling towers are generally available because plants tend to use meters on make-up water lines and to record the amount of bleed-off water. The reported consumptive water use was analyzed to determine the main causes of the observed variability in the required water quantities among different systems.

Table V-12 shows a log-linear regression of total consumptive water use in systems with cooling towers. The regression identified 12 variables that make significant contribution to the explanation of the variability of consumptive use. The most important variable is the total annual (net) production of electricity. Three other important variables include type of water source, operational efficiency, and type of fuel. Systems that rely on groundwater tend to use less water for cooling, while systems using petroleum or coal as fuel tend to use more water. Also higher operational efficiency is associated with lower water use.

Table V-12. Log-linear Regression of Total Consumptive Use
in Recirculating Systems with Cooling Towers

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	-7.6752	-6.8	<.0001	--
Annual generation (ln)	0.7160	24.5	<.0001	0.5228
Fresh groundwater source	-0.1476	-2.2	0.027	0.0149
Operational efficiency (%)	-0.0079	-5.3	<.0001	0.0074
Petroleum as fuel	1.1156	6.6	<.0001	0.0066
Coal as fuel	0.3928	5.9	<.0001	0.0060
System age (ln)	-0.1886	-3.8	0.0001	0.0031
Mixed fuels w/ coal	0.3302	3.7	0.0002	0.0030
Surface freshwater source	0.2331	3.8	0.0002	0.0027
Average summer temperature (ln)	0.9097	3.8	0.0001	0.0021
Natural draft cooling towers	0.1771	3.2	0.0016	0.0017
Thermal efficiency (%)	-0.0087	-2.5	0.0132	0.0013
Temperature rise at 100% (ln)	0.1759	2.0	0.0423	0.0008
N= 2,195; R^2= 0.570, Root MSE= 0.90, Mean Y= 1.10 (log)				

Two linear regressions of unit consumptive use are shown in Tables V-13 and V-14. The first model was estimated using a data set which excluded the observations that indicated the consumptive use as zero or as 100 percent of water withdrawals. Several observations in which unit consumptive use was greater than 50 gallons/kWh were also excluded. The estimated regression equation indicates that the two key explanatory variables are the indicator variables designating systems using petroleum as fuel and operational efficiency.

The statistics in the last row of Table V-13 indicate that the regression model explained only 6.6 percent of the variance in unit consumptive use. The root mean square error is 4.29 gallons/kWh, a relatively high value when compared to the mean value of the dependent variable (Mean Y) of 1.52 gallons/kWh. In order to examine the variability in the unit rates of consumptive water use in systems with cooling towers, the data were ranked from the highest to lowest value and a sequence of means was calculated after excluding the largest values of unit water use. The resultant distribution of means is plotted on Figure V-3.

Table V-13. Linear Regression of Unit Consumptive Use
in Closed-loop Systems with Cooling Towers

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	2.1130	1.5	0.1243	--
Petroleum as fuel	7.0403	8.5	<.0001	0.0371
Operational efficiency (%)	-0.0284	-5.8	<.0001	0.0172
Average summer temperature	0.0442	2.9	0.0035	0.0038
Induced air flow tower	-0.5738	-2.9	0.0040	0.0034
Thermal efficiency	-0.0446	-2.7	0.0063	0.0029
Temperature rise at 100%	-0.0425	-2.4	0.0165	0.0024
Coal as fuel	0.6320	2.5	0.0120	0.0020
N= 2190*; R^2= 0.066, Root MSE= 4.29 gal/kWh, Mean Y= 1.52 gal/kWh,				

* Systems reporting consumptive use less than 50 gallons/kWh were excluded.

Figure V-3 indicates that the mean value of unit consumptive use stabilizes at a value of approximately 0.8 gallons/kWh when the highest values are removed. The data used for preparing the chart indicate that this takes place when 125 observations with unit use greater than 4 gallons/kWh are removed

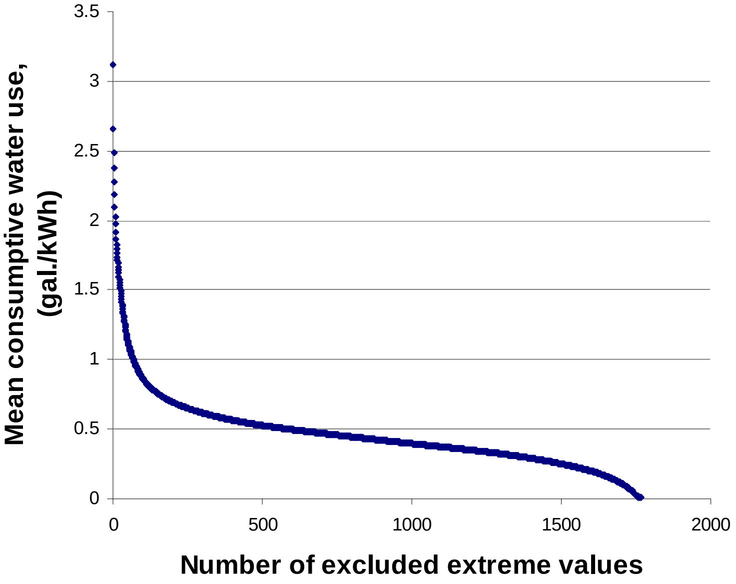

Figure V-3. The effect of excluding the highest values of unit consumptive water use on the mean in the data for closed-loop systems with cooling towers (Total n=1,768)

To examine the impact of removing the extreme values, the regression equation with the unit consumptive use as the dependent variable was re-estimated after removing additional 100 observations with the highest values from the data set used in model estimation of Table V-13. The resultant regression for the truncated dataset is shown in Table V-14 below.

Table V-14. Linear Regression of Unit Consumptive Use
in Closed-loop Systems with Cooling Towers
(Truncated Data Set)

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	1.5398	15.8	<.0001	--
Operational efficiency (%)	-0.0106	-15.1	<.0001	0.1095
Thermal efficiency (%)	-0.0112	-5.0	<.0001	0.0106
Fresh groundwater source	-0.1477	-4.7	<.0001	0.0107
Mixed fuel w/ coal	0.1915	3.5	0.0006	0.0049
Coal as fuel	0.1735	4.5	<.0001	0.0042
System age	0.0053	4.0	<.0001	0.0041
N= 2090*; R^2= 0.142, Root MSE= 0.56 gal/kWh, Mean Y= 0.76 gal/kWh,				

* Systems reporting consumptive use less than 4 gallons/kWh were excluded.

The results in Table V-14 show a different set of explanatory variables than the model in Table V-13. Two key predictors of unit water use are operational efficiency and thermal efficiency. Also, the use of fresh groundwater is shown to contribute to lower rates of consumptive water use. The model statistics indicate that the regression explained 14.2

percent of variance in the dependent variable. The root MSE has decreased from 4.29 gallons/kWh in the previous model (Table V-13) to 0.56 gallon/kWh in the re-estimated model. The model for the truncated data set is used to derive benchmark values of consumptive water use in Chapter VII.

Recirculating Systems with Cooling Ponds or Canals

Water Withdrawals

This category of cooling systems has some characteristics of both once-through and closed-loop systems. Water is withdrawn from the source, flows through the condensers, and is then returned to the source like in once-through systems. However, the sources are relatively small water bodies such as lakes or canals where the returned water cools off by mixing with the rest of the water and through forced evaporation and is then withdrawn again and pumped to the condensers. Often the evaporative loss of water in the cooling pond or canal has to be replenished from a nearby river or other source and this supplemental pumpage may be reported as withdrawals instead of the flow rate through the cooling system. Therefore, the reported values of water withdrawals and consumptive use may be less reliable in the case of these recirculating systems as compared to the other system types.

Table V-15 shows a log-linear regression equation of total water withdrawals for recirculating cooling systems. Ten explanatory variables were found to be significant predictors of total water withdrawals in these systems. However the variability of the dependent variable is large and only 25.9 percent of the variance is explained by the regression model.

Table V-15. Log-linear Regression of Total Water Withdrawals
in Recirculating Systems with Cooling Ponds or Canals and Mixed Systems

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	-0.1596	-0.4	0.7176	--
Annual (net) generation (ln)	0.6648	9.3	<.0001	0.0583
Mixed recirculating systems	-1.8828	-6.8	<.0001	0.0566
Recirculating system with cooling ponds	-0.5738	-2.9	0.0036	0.0492
Public water delivery	-2.3202	-5.7	<.0001	0.0306
Systems using more than 500 gal/kWh	3.1739	5.2	<.0001	0.0260
Mixed fuels w/o coal	0.6726	2.8	0.0057	0.0259
Surface saline water	1.1959	4.0	<.0001	0.0098
Operational efficiency	-0.0106	-2.7	0.0071	0.0047
Mixed once-through and recirculating systems	0.5311	2.3	0.0210	0.0042
Natural gas as fuel	-0.3458	-1.9	0.0625	0.0033
N=790, R^2 = 0.259, Root MSE =1.76, Mean Y= 3.69 (log)				

The regression of unit withdrawals by the recirculating systems is presented in Table V-16. The estimated model explained 26.1 percent of the variance but the root MSE of 30.9 gallons/kWh indicates a large variability in the dependent variable. In order to improve the fit of the regression model, the distribution of unit use values in the data was examined and the pattern in the data is shown in Figure V-3.

Table V-16. Regressions of Water Withdrawal per Unit of Generation in Recirculating Systems with Cooling Ponds or Canals and Mixed Systems

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	92.0155	9.2	<.0001	--
Operational efficiency (%)	-0.5760	-11.1	<.0001	0.1734
Temperature rise at 100 pct	-1.4544	-5.9	<.0001	0.0370
Surface saline water source	29.3816	5.1	<.0001	0.0189
Petroleum as fuel	35.0970	4.5	<.0001	0.0145
Surface freshwater source	12.5941	3.4	0.0006	0.0111
Mixed fuel	11.0367	3.4	0.0008	0.0091
Thermal efficiency (%)	-0.4948	-1.9	0.0598	0.0035
N=746, R^2= 0.261, Root MSE= 30.9 gal/kWh, Mean Y = 33.3 gal/kWh				

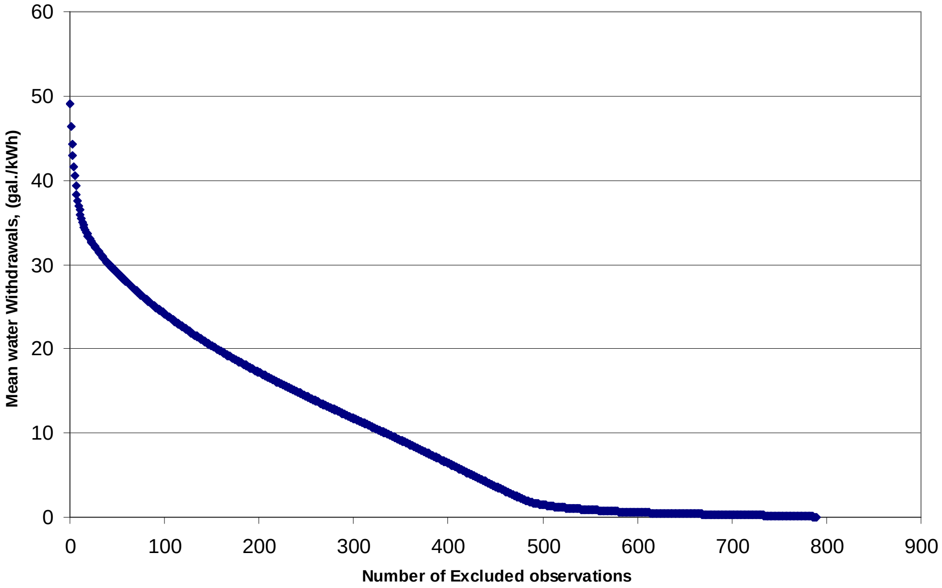

Figure V-4. The effect of excluding the highest values of unit water withdrawals use on the mean in the data for recirculating systems with cooling ponds or canals (Total n= 790)

Figure V-4 shows two inflection points on the line showing the relationship between the number of excluded high values of unit water withdrawals and the calculated mean water use obtained after the exclusion. These two points subdivide the curve into two sections. The lower section includes 302 observations with unit withdrawals below 10 gal/kWh (individual values are not shown on Figure V-4). These low withdrawal values indicate that the reported data most likely refer to the amount of water withdrawn to supplement the storage in cooling ponds. The second section includes 446 observations where the unit use ranges between 10 and 120 gallons/kWh, which most likely include systems that reported the values of water pumpage through the condensers. Systems with unit use in excess of 120 gallons/kWh were treated as outliers and were excluded in the subsequent model estimation. Table V-17 shows two regression equations, which were estimated from each of the two subsets of the data.

The results in Table V-17 indicate that in the case of systems with unit withdrawals below 10 gallons/kWh, water use depends on the actual type of recirculating system (i.e., it is on average 2.44 gallons/kWh higher in mixed systems) and on system age (it increases with system age). It is also a function of the operational efficiency in electricity generation.

Table V-17. Linear Regression Models for Two Groups of Recirculating Cooling Systems with Ponds or Canals and Mixed Systems

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Sub-model 1 (<10 gal/kWh)				
Intercept	2.5425	5.3	<.0001	--
Mixed once-through & recirculating systems	2.4381	5.6	<.0001	0.1159
System age	0.0356	3.4	0.0007	0.0673
Operational efficiency (%)	-0.0254	-5.0	<.0001	0.0563
Mixed recirculating systems	-0.8322	-3.0	0.0032	0.0273
Natural gas as fuel	-1.3742	-4.9	<.0001	0.0188
Public water supply	-1.1589	-2.5	0.0128	0.0149
Statistics: N=302, R^2= 0.286, Root MSE= 1.76 gal/kWh, Mean Y = 1.77 gal/kWh				
Sub-model 2 (10 - 120 gal/kWh)				
Intercept	48.5313	3.8	0.0002	--
Operational efficiency (%)	-0.6923	-16.1	<.0001	0.4222
Temperature rise at 100 %	-1.1638	-5.7	<.0001	0.0443
Average summer air temperature	0.8379	5.3	<.0001	0.0214
Recirculating systems with cooling ponds	-5.8035	-3.1	0.002	0.0110
Statistics: N=446, R^2= 0.494, Root MSE= 17.8 gal/kWh, Mean Y = 49.0 gal/kWh				

In cooling systems with unit withdrawals between 10 and 120 gallons/kWh, operational efficiency is the most important predictor of water use. Other two predictors are the design water temperature rise in the condenser and average summer air temperature. The last variable indicates that system designated as RC type (recirculating with cooling ponds or canals) have lower unit water withdrawals than other recirculating systems. The second model in Table V-17 is used to derive the regression-based benchmarks in Chapter VII.

Consumptive Water Use

The consumptive water use in the recirculating systems was reported only for a subset of observations. Tables V-18 and V-19 show respectively the estimated regressions of the total and unit consumptive use for this type of cooling systems.

Table V-18. Log-linear Model of Total Consumptive Water Use for Recirculating Cooling Systems

Term	Estimate	t Ratio	Prob.>|t|	Partial R^2
Intercept	-0.7344	-1.5	0.1310	--
Annual generation (ln)	0.2158	3.3	0.0011	0.0322
Recirculating systems w/ponds	0.4207	2.7	0.0065	0.0134
Fresh groundwater source	0.8169	2.4	0.0156	0.0132
Public water delivery	-0.8812	-2.3	0.0237	0.0120
Natural gas as fuel	-0.4547	-2.3	0.0203	0.0119
N=402, R^2= 0.071, Rood MSE= 1.49, Mean Y = 0.98 (log)				

The estimated equation shown in Table V-18 explained only 7.1 percent of variance in the dependent variable. A slightly higher percent of variance explained was obtained for the regression of the unit consumptive use shown in Table V-19. However, the root MSE is relatively high indicating a significant variability of the reported consumptive use values.

Table V-19. Linear Regression of Unit Consumptive Use in Recirculating Cooling Systems

Term	Estimate	t Ratio	Prob.>|t|	Partial R^2
Intercept	3.3626	1.3	0.1806	--
Saline surface water source	33.7084	7.0	<.0001	0.0789
Operational efficiency (%)	-0.1181	-4.3	<.0001	0.0340
Coal as fuel	3.6668	2.8	0.0061	0.0203
System age	0.1241	2.4	0.0159	0.0127
N=402, R^2= 0.137, Root MSE= 11.4 gal/kWh, Mean Y = 4.19 gal/kWh				

Because of the likely reporting problem in the data for this type of systems, no derivation of benchmarks for consumptive water use in this type of cooling systems was performed.

Summary

The regression models presented in this section can be used to generate benchmarks of water withdrawals and consumptive use for individual cooling systems based on their system-specific characteristics. However, such benchmarks will represent only the average conditions among the existing power plants and cooling systems and not the conditions at plants that would be considered to have the best performance in their category. In order to measure the level of performance in terms of technical efficiency of water use, an econometric technique called stochastic production frontier analysis was used and the results are described in the following section.

STOCHASTIC FRONTIER EFFICIENCY ANALYSIS

The 1996-2004 data from the Form EIA 767 and explanatory variables for once-through, closed-loop, and recirculating systems were reformatted for the estimation of the stochastic production frontier models. The log of total annual energy generation (net) was used as the dependent variable and the log of total water withdrawals and other systems conditions and characteristics were used as independent variables.

The maximum likelihood estimates (MLE) for the pooled stochastic production frontier model and those for the technical inefficiency model for the three aggregated types of cooling systems are presented in Tables V-20 to V-22. The modeling output also included the estimates of technical efficiency (TE_i) for each cooling system during each year of the data. These outputs were used in developing distribution graphs of the estimated technical efficiency.

Efficiencies of Once-through Cooling Systems

In the case of once-through cooling systems, as expected, the estimated coefficients of the stochastic frontier are positive and indicate that the log of annual net generation of electric energy is proportional to log of annual water withdrawals and also, to a smaller degree, the percentage of capacity utilization (also known as operational efficiency).

The inefficiency model included five variables which were found to be associated with the estimated technical efficiency. According to the results, the inefficiency in using water by the once-through cooling systems decreases as the thermal efficiency of generation increases (negative sign) and as the maximum water temperature rise in the condenser at 100 percent generation capacity increases. The technical inefficiency increases with increasing system age and is higher for systems with fresh groundwater supply and systems with public water supply.

Table V-20 also includes statistics on the statistical noise in the estimation of the frontier. The sigma square σ^2 is the sum of variances of statistical noise σ_v^2 and inefficiency σ_u^2. The gamma γ is calculated as:

$$\gamma = \frac{\delta_u^2}{\delta_u^2 + \delta_v^2} \qquad 5.3$$

and measures the significance of the estimated stochastic frontier. Because the magnitude of gamma (0.1613) is not highly significant, this is an indication that the parameters of the model could be also consistently estimated using ordinary least squares.

The estimated technical efficiencies for individual systems (for each data year) ranged from 22.5 to 91.6 percent with a mean of 52.9 percent. This indicates that, on average, the once through cooling systems are only 52.9 percent efficient in using water to produce electric energy. This implies that there is a large potential for reducing the pumpage of water (i.e., water withdrawals) by improving the performance of existing systems. Figure V-5 shows the distribution of the estimated technical efficiencies during the 1996-2006 periods.

Table V-20. Estimates of Stochastic Production Frontier
for Once-through Cooling Systems

Parameter	Symbol	Coefficient	t-Ratio
Stochastic frontier model:			
Constant	β_0	2.8511	16.7
Annual water use (ln)	β_1	0.7817	63.4
Operational efficiency (%)	β_2	0.0172	28.8
Inefficiency model:			
Constant	δ_0	1.5401	5.8
Thermal efficiency (%)	δ_1	-0.0148	-6.3
System age (ln)	δ_2	0.2992	7.4
Temperature rise (ln)	δ_3	-0.5171	-12.7
Fresh groundwater source	δ_4	0.5739	2.5
Public water supply	δ_5	0.3194	2.9
Sigma-squared	σ^2	0.1624	28.2
Gamma	γ	0.1613	1.0
Log (likelihood)	--	-902.3	--

Model statistics: No. of observations = 1,773, No. of systems = 225, Max. no. of time periods = 9, Mean technical efficiency (TE) = 52.9 %

Dependent variable = log of net annual generation of electricity

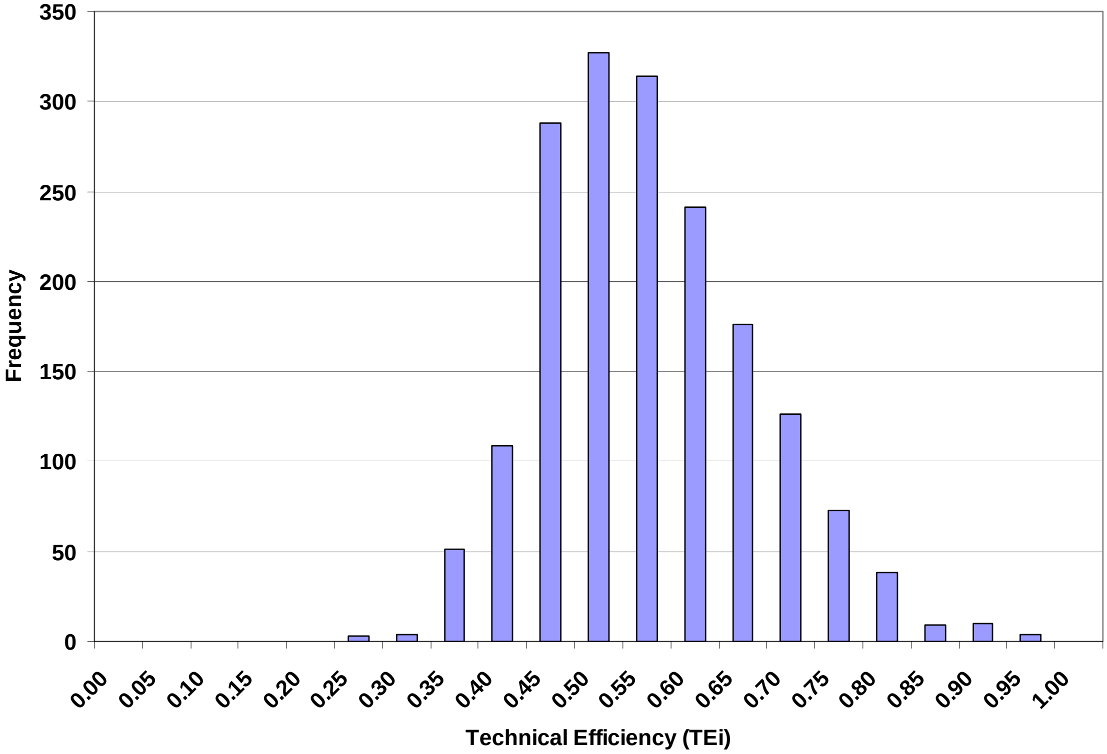

Figure V-5. Distribution of technical efficiency estimates for once-through cooling systems for the 1996-2004 period

Efficiency of Closed-loop Systems with Cooling Towers

The stochastic production frontier model for closed-loop cooling systems with cooling towers is shown in Table V-21. As in the model for once-through systems, the production frontier also shows a positive relationship between energy generation and total water withdrawals as well as the level of capacity utilization.

The inefficiency model indicates that plants with a higher thermal efficiency and higher design temperature rise in the condenser tend to have higher levels of technical efficiency in the use of cooling water. The efficiencies tend to be higher for natural draft cooling towers and in plants using surface freshwater sources.

The magnitude (0.3984) and significance (t= 4.8) of the variance parameter gamma indicate that the model variables are highly significant in explaining the variation in net generation of electricity relative to water use.

The estimated technical efficiencies for individual systems (for each data year) ranged from 40 to 93 percent with a mean of 67.2 percent. This indicates that on average the closed-loop cooling systems are 67.2 percent efficient in using water to produce electric energy. This implies that there is a significant potential for reducing the quantity of make-up water (i.e., water withdrawals) in cooling towers by improving the performance of existing systems.

Table V-21. Estimates of Stochastic Production Frontier for Closed-loop Cooling Systems with Cooling Towers

Parameter	Symbol	Coefficient	t-Ratio
Stochastic frontier model:			
Constant	β_0	6.4259	76.5
Annual water use (ln)	β_1	0.3494	21.9
Operational efficiency (%)	β_2	0.0181	20.0
Inefficiency model:			
Constant	δ_0	1.1438	2.5
Thermal efficiency (%)	δ_1	-0.0264	-4.5
System age (ln)	δ_2	0.7606	9.7
Temperature rise at 100% (ln)	δ_3	-0.6634	-8.7
Natural draft tower	δ_4	-0.6055	-6.0
Petroleum as fuel	δ_5	0.3322	2.5
Surface freshwater source	δ_6	-0.2211	-5.8
Sigma-squared	σ^2	0.1645	14.3
Gamma	γ	0.3984	4.8
Log (likelihood)	--	-540.9	--

Model statistics: No. of observations = 1,259, No. of systems = 156, Max. no. of time periods = 9, Mean technical efficiency = 67.2 %

Dependent variable = log of net annual generation of electricity

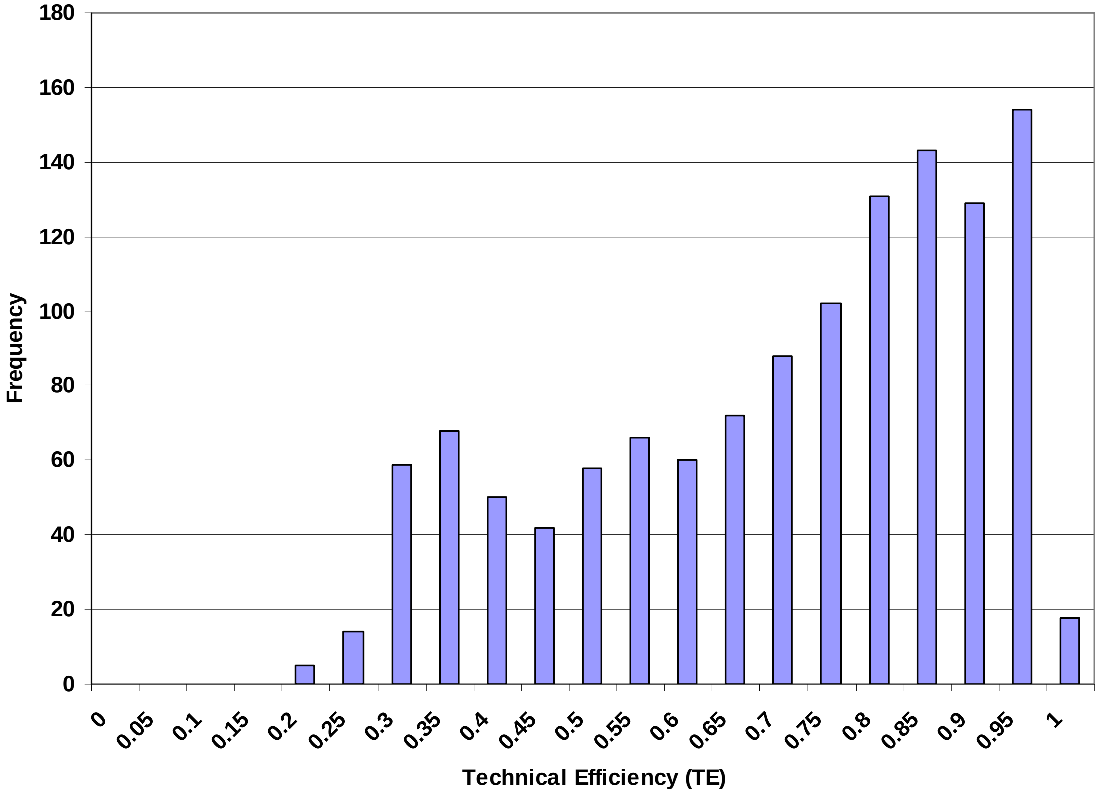

Figure V-6. Distribution of technical efficiency estimates for closed-loop systems with cooling towers for the 1996-2004 period

Figure V-6 shows the distribution of the technical efficiency scores among the 156 systems and nine data years. The distribution is negatively skewed and includes a large number of observations in the lower ranges of technical efficiency between 20 and 60 percent.

Recirculating Systems with Cooling Ponds or Canals

The estimate of the stochastic frontier model for recirculating systems with cooling ponds or canals and mixed recirculating systems is shown in Table V-22. The model is estimated based on 152 observations for 21 cooling systems for which unit water withdrawals ranged between 10 and 120 gallons/kWh.

The variables in the stochastic frontier model are significant, and the set of significant variables in the inefficiency model includes system age and maximum temperature rise in the condenser. However, the thermal efficiency variable was not significant. The three binary variables in the inefficiency model indicate that systems with mixed cooling types are more efficient than other systems and that those systems using mixed fuels and systems relying on surface freshwater sources tend to be less efficient than other systems.

Table V-22. Estimates of Stochastic Production Frontier
for Recirculating Cooling Systems

Parameter	Symbol	Coefficient	t-Ratio
Stochastic frontier model:			
Constant	β_0	4.3285	15.4
Annual water use (ln)	β_1	0.8525	26.2
Operational efficiency (%)	β_2	0.0136	14.0
Inefficiency model:			
Constant	δ_0	4.0364	10.7
System age (ln)	δ_1	0.2488	3.6
Temperature rise at 100% (ln)	δ_2	-0.9923	-13.0
Mixed once-through and recirculating	δ_3	-0.4047	-5.9
Mixed fuel	δ_4	0.1244	2.5
Surface freshwater sources	δ_5	0.2110	4.8
Sigma-squared	σ^2	0.0503	8.7
Gamma	γ	0.9998	19.5
Ln (likelihood)	--	11.5	--

Model statistics: No. of observations = 152, No. of systems = 21,
Max. no. of time periods = 9, Mean technical efficiency (TE) = 12.3 %

Dependent variable = log of net annual generation of electricity

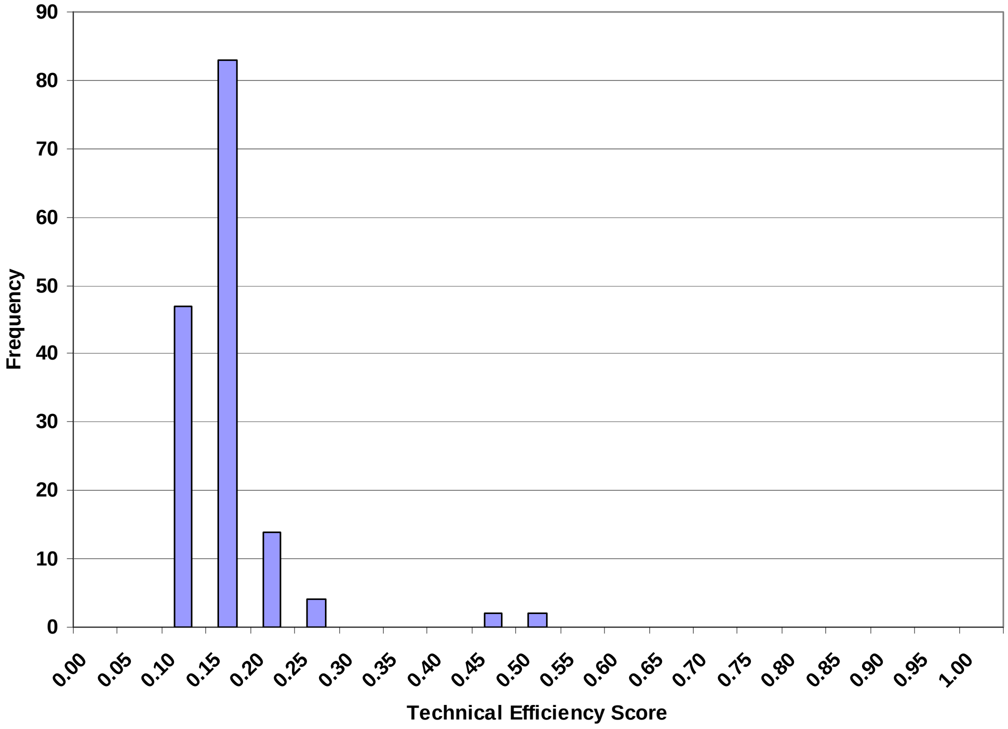

Figure V-7. Distribution of technical efficiency estimates for a subset of recirculating systems with cooling ponds or canals and mixed systems for the 1996-2004 period

The mean technical efficiency in the 152 observations is 12.3 percent. This is much lower value than in the once-through and closed-loop systems. Figure V-7 shows the distribution of the efficiency scores for individual systems and data years. The low technical efficiency in this group of systems may be related to the wide range of unit water use.

SUMMARY

Regressions of water withdrawals and consumptive use on plant and cooling system characteristics and operating conditions showed that unit withdrawal rates in gallons per kilowatt-hour of generation depend primarily on the percentage of capacity utilization and the design temperature rise in the condenser. Other important factors are system age, type of water source, and type of fuel.

The stochastic frontier analysis of the plant-level annual panel data for the period 1996-2004 showed the estimated average technical efficiency of individual cooling systems to be 52.9 percent in once-through systems and 67.2 percent in closed-loop systems with cooling towers. These results indicate that there may be a significant potential for improving technical efficiency of cooling water use in both once-through and closed-loop cooling systems at existing power plants.

CHAPTER VI
STATISTICAL ANALYSIS OF WATER USE IN NUCLEAR PLANTS

DATABASE

Nuclear power plants were analyzed separately because the annual EIA data reporting for this type of plants was discontinued after 2000. Therefore, the results for nuclear plants refer only to the 1996-2000 data. These data were available for 72 power plants. The following sections present average rates of water withdrawals and consumptive use and results of regressions of water use for three types of cooling in the nuclear plants.

The set of the dependent and explanatory variables for the nuclear plants is the same as the set for fossil fuel plants described previously, with the exception of the variable for thermal efficiency which was not applicable to nuclear power generation.

DESCRIPTIVE STATISTICS

Average Rates of Water Use

Table VI-1 shows average rates of unit water withdrawals and consumptive use for three aggregated types of cooling systems in power plants: once-through, recirculating with ponds, and closed-loop systems with cooling towers.

Table VI-1. Nuclear Unit Water Withdrawals by Type of Cooling System
(in Gallons per Kilowatt-hour)

Description	Once-through Systems	Recirculating With Ponds	Cooling Towers
Number of power plants	39	14	19
Number of cooling systems	123*	36*	82
Withdrawals per unit (gallons/kWh):			
Weighted mean	48.1	13.4	2.61
Median water intake	46.0	1.7	1.26
Standard deviation	18.6	18.9	9.05
Consumptive use (gallons/kWh)			
Weighted mean	0.39	0.49	0.77
Median use	0.45	0.46	0.73
Standard deviation	0.12	0.16	0.27
Percent consumptive use (%)	0.7	4.7	29.5

* Average consumptive use values exclude systems which reported 0 and 100 percent values of consumptive use.

The results in Table VI-1 are similar to those obtained for cooling systems in fossil-fuel generating facilities. One notable exception is the average rate of water withdrawal for closed-loop systems with cooling towers which show the weighted average value of 2.61 gallons/kWh as compared to 1.0 gallons/kWh for non-nuclear systems. This may be the result of lower concentration ratios used in nuclear plants to avoid the accumulation of dissolved radionuclides and suspended solids in the recirculating water. The share of consumptive use of 29.5 percent, as compared to 70.2 percent in non-nuclear plants, also indicates a relatively high ratio of blow-down in the closed-loop systems in nuclear plants.

MULTIPLE REGRESSION OF WATER USE

Once-through Cooling Systems

The total and unit withdrawals of water use in nuclear power plants were examined using multiple regressions with a number of potential explanatory variables. Separate regressions were estimated for once-through and closed-loop cooling systems with cooling towers.

Table VI-2 shows the estimated regression of total water withdrawals in once-through cooling systems. The estimated model includes four explanatory variables with total annual generation of electricity and the design temperature rise at the condenser accounting for most of the explanation of the variance in total water withdrawals. Two additional variables with statistically significant coefficients are average summer air temperature in the region where the plant is located and the percent of capacity utilization (i.e., operational efficiency). However, the sign on air temperature is negative, which is not consistent with the expectation that higher withdrawals are associated with warmer intake water.

Table VI-2. Log-linear Regressions of Total Water Withdrawals
In Nuclear Plants with Once-through Cooling Systems

Variables	Estimate	t Ratio	Prob.>|t|	Partial R^2
Intercept	9.7748	8.1	<.0001	--
Annual generation (ln)	1.0902	18.2	<.0001	0.4696
Temperature rise at 100% (ln)	-1.1729	-17.5	<.0001	0.3080
Average summer temperature (ln)	-2.0703	-7.9	<.0001	0.0762
Operational efficiency (%)	-0.0051	-2.2	0.0316	0.0059
N = 119, R^2 = 0.860, Root MSE = 0.19, Mean Y = 6.69 (log)				

Table VI-3 shows a regression model of unit water withdrawals by once-through cooling systems in nuclear plants. Only two statistically significant effects were found: the design temperature rise at the condenser and average summer air temperature. Again, the sign of the air temperature coefficients is opposite to the expected one: the negative sign indicates that the lower unit withdrawals are associated with higher summer season air temperature in the region where the plant is located. The expectation is that plants can pump less water if the intake water is cooler.

Table VI-3. Linear Regression of Water Withdrawals per Unit of Generation in Once-through Cooling Systems

Term	Estimate	t Ratio	Prob.>|t|	Partial R^2
Intercept	159.5149	10.7	<.0001	--
Temperature rise at 100%	-2.1389	-13.0	<.0001	0.4990
Average summer temperature	-1.0053	-5.3	<.0001	0.0974
N= 119, R^2 = 0.596, Root MSE= 10.2 gal./kWh, Mean Y= 45.4 gal./kWh				

For the purpose of deriving the regression-based benchmarks of water withdrawals for once through cooling systems in nuclear plants, the summer air temperature variable was removed from the model. The re-estimated regression with average water use in once-through cooling systems in nuclear power plants as a function of the design (maximum) temperature rise in the condenser when the generators are operated at 100 percent capacity appears in Table VI-4

Table VI-4. Benchmarking Regression of Water Withdrawals per Unit of Generation in Once-through Cooling Systems (Linear Model)

Term	Estimate	t Ratio	Prob.>|t|
Intercept	82.3514	23.1	<.0001
Temperature rise at 100 pct	-1.8610	-10.8	<.0001
N=119, R^2= 0.499, Root MSE= 11.3 gal./kWh, Mean Y= 45.4 gal/kWh			

The regression model in Table VI-4 will be used to derive regression based benchmarks in Chapter VII.

Closed-loop Systems with Cooling Towers

Table VI-5 shows a double log model of total withdrawals with four explanatory variables. The two continuous variables, the temperature rise at the condenser at 100 percent capacity and annual generation (both variables are converted into logarithms), account for 55 percent of the variance. Two binary variables are also included in the model: surface saline water source and induced flow cooling towers.

Table VI-5. Log-linear Regression of Total Water Withdrawals in Nuclear Plants with Closed-loop Systems with Cooling Towers

Term	Estimate	t Ratio	Prob.>|t|	Partial R^2
Intercept	-4.1915	-3.1	0.0032	--
Temperature rise at 100% (ln)	-1.9831	-8.4	<.0001	0.3268
Annual generation (ln)	1.5751	9.4	<.0001	0.2220
Saline surface water supply	0.6050	2.7	0.0094	0.0412
Induced air-flow tower	-0.2829	-2.6	0.0127	0.0336
N= 78, R^2= 0.624, Root MSE= 0.32, Mean Y= 3.36 (log)				

The regression of unit withdrawals per kilowatt-hour is shown in Table VI-6. It has the three of the same explanatory variables as the regression of total withdrawals. The equation in Table VI-6 is used to derive average use benchmarks for closed-loop cooling systems with cooling towers in the nuclear plants in Chapter VII.

Table VI-6. Regressions of Water Withdrawals per Unit of Generation in Nuclear Plants with Closed-loop Systems with Cooling Towers

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	4.2456	10.1	<.0001	--
Temperature rise at 100%	-0.0993	-6.7	<.0001	0.3212
Saline surface water supply	0.9641	2.3	0.0225	0.0488
Induced air-flow tower	-0.4134	-2.1	0.0422	0.3440
N= 78, R^2 = 0.404, Root MSE= 0.58 gal./kWh, Mean Y= 1.50 gal/kWh				

Recirculating Systems with Cooling Ponds or Canals

The third category of cooling systems in nuclear plants is recirculating systems with cooling ponds or canals. A regression of total water withdrawals is shown in Table VI-7. The estimated double-log regression shows seven significant variables. However, the signs of the estimated coefficients for system age and operational efficiency variables are contrary to expectations. A likely cause of the sign reversals is the bimodal nature of the data which contain 14 observations with withdrawals around 40 gallons/kWh and 22 observations with withdrawals of less than 2 gallons/kWh.

The regression of unit withdrawals was estimated using a binary variable which distinguished between these two values (Table VI-8).

Table VI-7. Regression of Total Water Withdrawals in
Nuclear Recirculating Systems with Cooling Ponds or Canals

Term	Estimate	t Ratio	Prob>|t|	Partial R^2
Intercept	-30.9021	-4.5	0.0001	--
Mixed recycling system	-2.3673	-9.3	<.0001	0.5348
Annual generation (ln)	-1.7603	-6.7	<.0001	0.2318
Average summer temperature (ln)	11.2283	10.1	<.0001	0.1097
Public water supply source	-2.3464	-7.9	<.0001	0.0956
Temperature rise at 100% (ln)	1.1394	3.0	0.0053	0.0052
System age (ln)	-0.4496	-2.7	0.0115	0.0040
Operational efficiency (%)	0.0265	3.5	0.0015	0.0032
N= 36, R^2 = 0.984, Root MSE= 0.24, Mean Y= 4.71 (log)				

Table VI-8. Regression of Water Withdrawals per Unit of Generation
in Nuclear Recirculating Systems with Cooling Ponds or Canals
(Linear Model)

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-4.0987	-0.3	0.7762	
Large use system (> 2)	31.8441	13.1	<.0001	0.9731
Operational efficiency	-0.1014	-2.7	0.0123	0.0050
Recirculating with ponds	-6.1259	-3.3	0.0027	0.0041
Public water delivery	-8.2668	-2.7	0.0119	0.0030
Temperature rise at 100 %	-0.6751	-4.8	<.0001	0.0022
Average summer temperature	0.4915	2.8	0.0094	0.0003
N= 36, R^2 = 0.988, Root MSE= 2.30 gal./kWh, Mean Y= 15.76 gal/kWh				

The results in Table VI-8 indicate that unit withdrawals depend on the type of cooling system (binary variable for systems with large withdrawals) and also on five other explanatory variables. In a re-estimated model using stepwise regressions, two variables, average summer temperature and public water supply source, were the last to enter and were not statistically significant unless entered together. A reduced model with three explanatory variables is presented in Table VI-9.

Table VI-9. Regression of Water Withdrawals per Unit of Generation
in Nuclear Recirculating Systems with Cooling Ponds or Canals
(Linear Model)

Term	Estimate	t Ratio	Prob.>|t|	Partial R^2
Intercept	31.9145	4.8	<.0001	--
Large use system (> 2)	37.9099	32.2	<.0001	0.9731
Operational efficiency	-0.1249	-3.2	0.0035	0.0050
Recirculating with ponds	-6.8282	-3.7	0.001	0.0041
Temperature rise at 100 %	-0.6878	-4.5	<.0001	0.0022
N= 36, R^2= 0.982, Root MSE= 2.51 gal./kWh, Mean Y = 15.76 gal./kWh				

One additional model was estimated and used in deriving benchmarks in Chapter VII. This model included only 22 observations with unit water use less than 2 gallons/kWh (Table VI-10).

Table VI-10. Benchmarking Regression of Water Withdrawals per Unit of Generation in Nuclear Recirculating Systems with Cooling Ponds or Canals

Term	Estimate	t Ratio	Prob.>|t|	Partial R^2
Intercept	0.5990	1.0	0.3416	--
Temperature rise at 100 %	0.0323	3.2	0.0054	0.3557
Surface freshwater source	0.4210	3.5	0.0027	0.3231
System age	0.0567	5.8	<.0001	0.1580
Operational efficiency (%)	-0.0179	-3.4	0.0035	0.0658
N= 22*, R^2= 0.88, Root MSE= 0.17 gal./kWh, Mean Y= 1.08 gal./kWh				

* Only for systems using less than 2 gallons/kWh.

STOCHASTIC FRONTIER EFFICIENCY ANALYSIS

The EIA-767 data set for nuclear plants for 1996-2000 was reformatted for the estimation of the stochastic production frontier models. As in the case of fossil-fuel plants in the previous chapter, the total annual energy generation (net) was used as the dependent variable and total water withdrawals and other system conditions and characteristics were used as independent variables.

The maximum likelihood estimates (MLE) for the pooled stochastic production frontier model and those for the technical inefficiency model for the three aggregated types of cooling systems are presented below.

Once-through Cooling Systems

In the case of once-through cooling system, as expected, the estimated coefficients of the stochastic frontier are positive and indicate that the annual net generation of electric energy is proportional to annual water withdrawals and the percentage of capacity utilization (also known as operational efficiency).

The inefficiency model includes five variables which are found to influence technical efficiency. According to the results, the inefficiency in using water by the once-through cooling systems increases with system age and is generally higher for once-through systems with ponds, once through freshwater systems and systems with saline surface water supply. Average summer air temperature has a negative sign thus indicating that as temperature increases the inefficiency decreases.

The estimated technical efficiencies for individual systems and data years ranged from 44.0 to 100 percent with a mean of 69.6 percent. This indicates that, on average, the once-through cooling systems in nuclear plants are only 69.3 percent efficient in using water to produce electric energy.

Table VI-11. Estimates of Stochastic Production Frontier
for Once-through Cooling Systems in Nuclear Plants

Parameter	Symbol	Coefficient	t-Ratio
Stochastic frontier model:			
Constant	β_0	6.5395	31
Annual water use (ln)	β_1	0.2172	9
Operational efficiency (%)	β_2	0.0135	6
Inefficiency model:			
Constant	δ_0	4.6358	5
Once-through systems with ponds	δ_1	1.5067	2
Once through freshwater systems	δ_2	1.5885	2
Saline surface water supply	δ_3	1.5406	2
Average summer air temperature (ln)	δ_4	-1.6719	-8
System age (ln)	δ_5	0.4304	7
Sigma-squared	σ^2	0.0082	6
Gamma	γ	1.0000	56,995.0
Log (likelihood)	--	69.28	--

Model statistics: No. of observations = 69, No. of systems = 18,
Max. no. of time periods = 5, Mean technical efficiency (TE) = 69.6 %

Dependent variable = log of net annual electricity generation

Figure VI-1 shows the distribution of the estimated technical efficiencies during the 1996-2000 period.

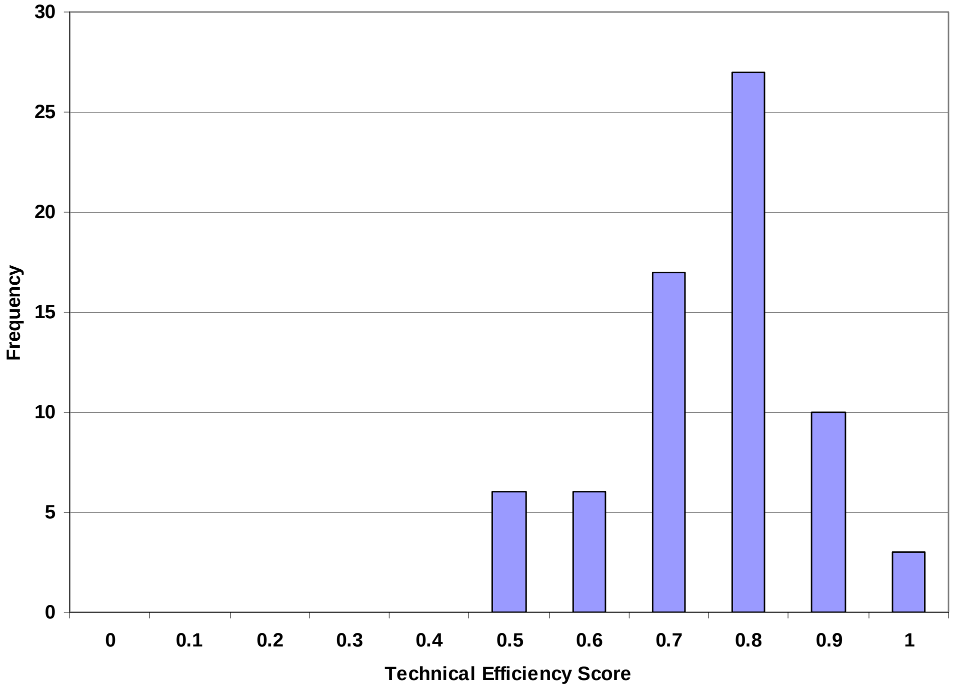

Figure VI-1. Distribution of technical efficiency scores in once-through cooling systems

Closed-loop Systems with Cooling Towers

The stochastic production frontier model for closed-loop cooling systems with cooling towers is shown in Table VI-12. As in the model for once-through systems, the production frontier also shows positive relationship between energy generation and total water withdrawals as well as the level of capacity utilization (i.e., operational efficiency).

The inefficiency model indicates that plants with a higher design temperature rise in the condenser tend to have higher levels of technical efficiency in the use of cooling water. The efficiencies also tend to be higher in regions with higher summer season air temperature although the reason for this effect is unclear. However, the coefficient of the temperature rise has low statistical significance (t-statistic of -0.3) and should be interpreted with caution.

Table VI-12. Estimates of Stochastic Production Frontier for Closed-loop Systems with Cooling Towers in Nuclear Plants

Parameter	Symbol	Coefficient	t-Ratio
Stochastic frontier model:			
Constant	β_0	7.3427	11.3
Annual water use (ln)	β_1	0.2496	1.3
Operational efficiency (%)	β_2	0.0121	4.4
Inefficiency model:			
Constant	δ_0	6.6275	0.6
Temperature rise at 100% (ln)	δ_1	-0.6600	-0.3
Average summer air temperature (ln)	δ_2	-1.0786	-1.9
Sigma-squared	σ^2	0.0209	1.0
Gamma	γ	1.0000	134.0
Log (likelihood)	--	35.78	--

Model statistics: No. of observations = 38, No. of systems = 9, Max. no. of time periods = 5, Mean technical efficiency (TE) = 80.8 %

Dependent variable = log of net annual electricity generation

The estimated technical efficiencies for individual systems and data years ranged from 55.8 to 100 percent with a mean of 80.8 percent. This indicates that on average, the closed-loop cooling systems are 80.8 percent efficient in using water to produce electric energy. This level of efficiency also implies that there is only a small potential for reducing the quantity of make-up water (i.e., water withdrawals) in cooling towers by improving the performance of existing systems in nuclear power plants.

The distribution of the technical efficiency scores in the data is shown on Figure VI-2. It indicates that 23 out of 38 observations have technical efficiency of cooling water use higher than 90 percent.

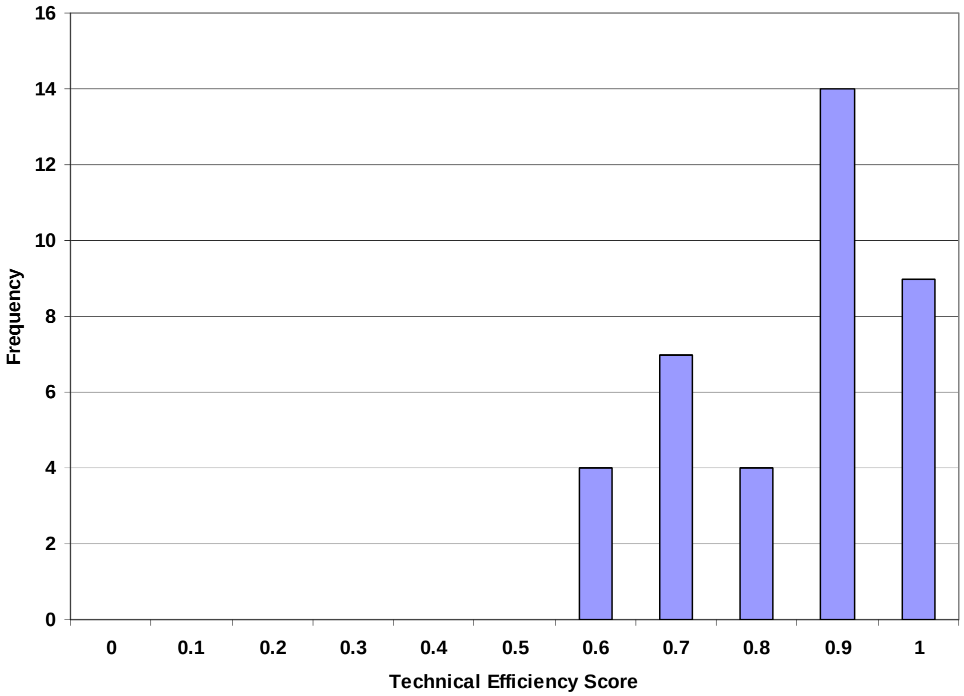

Figure VI-2. Distribution of technical efficiency scores in closed-loop systems with cooling towers

SUMMARY

Regressions of water withdrawals and consumptive use by cooling systems in nuclear power plants showed that the unit withdrawal rates in gallons per kilowatt-hour of generation primarily depend on the percentage of capacity utilization (operational efficiency) and the design temperature rise in the condenser.

The results of stochastic frontier analysis of the plant-level annual panel data for the period 1996-2000 showed the estimated average technical efficiency of individual cooling systems to be 69.6 percent in once-through systems and 80.8 percent in closed-loop systems with cooling towers. These results indicate that there is only a small potential for improving technical efficiency of cooling water use in the existing nuclear power plants: both those with once-through and closed-loop cooling systems.

CHAPTER VII

WATER-USE BENCHMARKS

PURPOSE

A necessary step in achieving water conservation and water demand management in the thermoelectric sector of water use is the development of methods to determine appropriate indicator measures and benchmark values for the quantities of water used in the process of electricity generation. Therefore, the main goal of this study was to derive numeric benchmarks that would allow water managers at power plants and water resources management agencies to determine the optimal quantities of water for cooling purposes in thermoelectric generation. Such benchmarks are commonly used in business enterprises, public sector organizations and water utilities (Cromwell and Rubin, 1995; Kingdom et al., 1996; Ammons, 2001).

This chapter defines the efficiency-in-use benchmarks for different types of cooling systems in thermoelectric generation plants. Benchmarks are developed for each type of cooling system using the results of the multiple regression and stochastic production frontier models presented in the previous chapters. The simplest benchmarks derived in this study are measures of average usage (both water withdrawals and consumptive use) expressed as the number of gallons per kilowatt-hour of net electricity generation. More detailed benchmark indicators are expressed as a function of more than one of the principal determinants of thermoelectric water withdrawals and consumptive use.

TECHNICAL WATER-USE EFFICIENCY

The development of water-use benchmarks relies on the concept of *efficiency-in-use*. This concept derives from engineering practice where it refers to the ratio of output to input, or *technical efficiency*. The criterion of technical efficiency is useful in comparing the performance of various products and processes. For example, in steam-electric generation, one cooling system would be considered more efficient than another if it could accomplish the same purpose (of condensing steam by cooling it) while using less water or other inputs (e.g., lower water pressure). In the water use sector, technical efficiency is often considered in the design of water dependent processes and facilities.

When the inputs and outputs are measured in *value* terms, an alternative expression of efficiency is obtained and is referred to as *economic efficiency*. The concept of economic efficiency is based upon the assumptions of neoclassical economics, which presumes that producers will make rational decisions on the quantities of water to use in producing goods and services. However, the exceptionally small impact of the cost of water on production costs and the difficulty in translating water costs into observable unit prices make it unlikely that strictly economic behaviors will be able to completely explain quantities of water use in thermoelectric generation. The concept of *efficiency-in-use*, as applied in this study, considers only the technical efficiency by examining the quantities of water used for cooling purposes in thermoelectric generation.

AVERAGE RATES OF WATER USE

The average quantities of water used in cooling operations at power plants represents useful points of reference in determining how much water is used in "typical" situations for each category of cooling system. These rates represent the existing average levels of technical efficiency that existed during the period for which the data were collected. The average rates of water withdrawal and consumptive use presented in Chapters V and VI are summarized in Table VII-1 below.

Table VII-1. Benchmarks of Average Use Rates of Cooling Water

Description	Withdrawals per unit (gallons/kWh)	Consumptive use (gallons/kWh)	Consumptive use (%)
Fossil fuel plants (1996 – 2004)			
Once-through systems	44.0	0.2	0.5
Recirculating with ponds	24.0	0.7	3.0
Closed-loop w/ cooling towers	1.0	0.7	70.0
Nuclear plants (1996 – 2000):			
Once-through systems	48.0	0.4	0.7
Recirculating with ponds	13.0	0.5	4.0
Closed-loop w/ cooling towers	2.6	0.8	30.0

As noted in Chapter V, the average values of withdrawals and consumptive use in Table VII-1 represent "weighted averages." These averages were calculated by dividing the sum of total annual water use in all observations in the data (all plants and data years) by the sum of annual energy generation in all observations. The weighted mean values give greater weight to water usage rates in large plants (plants with high levels of electricity generation). The numbers in Table VII-1 are also rounded to the nearest one decimal place (or to an integer) to acknowledge the limited accuracy of these estimates.

The average usage benchmarks in Table VII-1 were estimated using annual data for the period 1996-2004 for fossil fuel plants, and 1996-2000 data for nuclear-powered plants. These averages are slightly shifted toward lower values because the high outlier values were removed from data, and the averages were weighted by net generation. Nonetheless, these weighted averages can still serve as useful estimates of water withdrawals and consumptive use of water for the three types of cooling systems in both fossil-fuel and nuclear-powered plants.

However, the simple estimation of average water use rates fails to provide important information about the variability of water use among different systems. Water usage rates may be lower or higher than the average because of various system-specific conditions and characteristics. The average values of water use necessarily ignore the specific circumstances of many systems that determine the actual level of water use and that are not necessarily related to the efficiency of water use. For example, the temperature rise of cooling water in the steam condenser is a design parameter which at high temperature rise results in lower flow requirement for cooling water. Similarly, a once-through cooling system, which serves generating units that are operated as "load-following" or "peak load" generators, may show a high ratio of water volume to net generation (i.e., in gallons per kWh) because the flow of cooling water is often kept constant regardless of the level of generation. In order to adjust for the plant-specific and cooling system-specific circumstances, we used the multiple regression models from Chapters V and VI to quantify the effects of the operating conditions, design parameters and other characteristics on the amount of water use.

REGRESSION-BASED BENCHMARKS FOR FOSSIL FUEL PLANTS

Regression Benchmarks for Once-through Cooling Systems

Water Withdrawals

For once-through cooling systems, the regression results in Tables V-5 and V-6 in Chapter V indicate that average rates of unit water withdrawals (gallons per kWh) depend primarily on the level of capacity utilization (i.e., operational efficiency) of the generators connected to the cooling system and on the design temperature rise in the condenser. Generally, systems with higher capacity utilization and higher temperature rise would be expected to have lower unit water withdrawals. Cooling system age also affects water use: older systems, on average, use more water that those built more recently.

The regression coefficients of model binary variables represent the difference in average water use between systems in which the condition is present versus systems in which it is absent, after the effects of all other variables has been accounted for. For example, systems that withdraw cooling water from fresh surface water sources utilize, on average, less water per kWh of generation than systems that do not utilize this type of source, and instead rely on sea water, groundwater, reclaimed wastewater, or other sources.

The estimated regression equation from 3,888 observations for once-through cooling systems can be used to calculate the expected values of unit water use for any once-through cooling system once the values of the independent variables are known.

$$W = 95.74 - 1.836U - 2.104\Delta + 1.224G + 1.986F + 38.44PB + 88.65MS \qquad 7.1$$

where W is unit water withdrawals in gallons/kWh; U is capacity utilization (or operational efficiency in %; Δ is maximum temperature rise in the condenser (at 100 percent generation capacity) in degrees Fahrenheit; *G* is age of cooling system; *F* is thermal efficiency of generators in %; *PB* is public water supply source; and *MS* is mixed water supply sources.

The predicted rate of unit withdrawals will depend on the values of the independent variables. For example for systems utilizing other sources of water than public supply or mixed sources and which also operate at average values for the remaining four variables (i.e., at 49.6 percent operational efficiency, 17.7 °F temperature rise, 37.8 years of age, and 32 percent thermal efficiency) the predicted unit withdrawals would be 78.3 gallons/kWh. This is a higher number than the weighted mean of 44.0 gallons/kWh in Table VII-1 because it approximates the simple mean of 75.1 gallons/kWh in the data which were used in model estimation. Table VII-2 shows the predictions of expected water use that are obtained by substituting different combination of values into Equation 7.1. In order to obtain low and high predictions, the 10 and 90 percentile values for the four continuous independent variables were obtained from the data. These were used in combinations to generate one lowest and one highest predicted value of unit water withdrawal. For the lowest value, the 90 percentile values for the variables with the negative sign of the regression coefficient were combined with the 10 percentile values for the variables with the positive sign of the regression coefficient.

Table VII-2. Regression Benchmarks for Water Withdrawals
by Once-through Cooling Systems in Fossil Fuel Plants
(From Equation 7.1)

Description	Values of Continuous Variables: U/ Δ/ G/ F*	Predicted Benchmark gal/kWh
Low value**	77.6/25.0/25.0/26.5	(-16)
Average value	49.6/17.7/38.7/32.0	78
High value**	12.9/12.0/50.0/36.7	181
Average value with:		
Public water delivery	49.6/17.7/38.7/32.0	117
Mixed water sources	49.6/17.7/38.7/32.0	165

*U = operational efficiency, Δ = temperature rise in the condenser, G = system age, F = thermal efficiency; ** Low and high values based on a combination of 10 and 90 percentile values of independent variables

The results in Table VII-2 indicate that at average values of the dependent variables, the expected average rate of water withdrawal per kilowatt-hour of net generation of electricity in all once-through cooling systems, with the exception of those using water from public water supply systems and those using mixed water sources, is 78 gallons/kWh. Under the combination of conditions representing 10 percentile values for operational efficiency (12.9 percent) and temperature rise (12.0 °F) and 90 percentile values for system age (50 years) and thermal efficiency (36.7 percent), the high value of unit withdrawals would be 181 gallons/kWh. For plants with public supply source and at average values for other variables the expected unit withdrawal would be 117 gallons/kWh. It would be 165 gallons/kWh for systems with mixed water supply sources.

A negative value was obtained for the combination of variables used to produce the lowest estimate. This is partly a result of the unlikely combination of the values of predictor variables and partly due to the limitations of the linear regression model which explained only 26.1 percent of variance and that had root mean squared error of 81.2 gallons/kWh.

Consumptive Use

The estimated regression equation for consumptive use of water by once-through cooling systems in fossil-fuel plants is:

$$C = 10.503 - 0.086T - 0.076\Delta - 2.027OF + 3.615PET \qquad 7.2$$

where C is unit consumptive use of water in gallons/kWh; T is average summer air temperature in °F; Δ is maximum temperature rise in the condenser (at 100 percent generation capacity) in °F; OF is once-through freshwater cooling systems; and PET is petroleum as fuel. The predictions obtained from Equation 7.2 are shown in Table VII-3.

Table VII-3. Regression Benchmarks for Consumptive Water Use
by Once-through Cooling Systems in Fossil Fuel Plants
(From Equation 7.2)

Description	Values of Continuous Variables: T/ Δ/*	Predicted Benchmark gal/kWh
Low value**	79.9/ 25.0	1.7
Average value	70.6/ 17.7	3.1
High value**	64.2/ 12.0	4.1
Average value with:		
Once-through freshwater systems	70.6/ 17.7	1.1
Petroleum as fuel	70.6/ 17.7	6.7

*T = average summer air temperature, Δ = temperature rise in the condenser; ** Low and high values are based on a combination of 10 and 90 percentile values of independent variables

The results in Table VII-3 show the range of consumptive use, which extends from 1.7 to 4.1 gallons/kWh with an estimated average use of 3.1 gallons/kWh. Average use for once-through freshwater systems is 1.1 gallons/kWh and for systems in plants using petroleum as fuel it is 6.7 gallons/kWh.

Regression Benchmarks for Closed-loop Systems with Cooling Towers

Water Withdrawals

For closed-loop cooling systems, the regression results in Table V-11 in Chapter V were used to calculate the minimum, average, and maximum estimates of unit water withdrawals. The estimated equation for unit withdrawals is:

$$\begin{aligned} W &= 1.66 - 0.021U + 0.008G - 0.011F + 0.008T + 0.648SS + 0.405COAL \\ &- 0.194GF + 0.550MFC + 0.554PET \end{aligned} \qquad 7.3$$

where *W* is unit water withdrawals in gallons/kWh; *U* is capacity utilization (or operational efficiency in %; *G* is age of cooling system; *F* is thermal efficiency of generators in %; *T* is average summer air temperature in °F; *SS* is saline surface water source; *COAL* is coal as fuel; *GF* is fresh groundwater source; *MFC* is mixed fuels with coal; and *PET* is petroleum as fuel.

Table VII-4. Regression Benchmarks for Water Withdrawals
by Closed-loop Systems with Cooling Towers in Fossil Fuel Plants
(From Equation 7.3)

Description	Values of Continuous Variables: U/ F/ G/ T*	Predicted Benchmark gal/kWh
Low value**	84/36/9/64	0.4
Average value	58/31/24/72	1.2
High value**	15/27/42/80	2.4
Average value with:		
Mixed fuels with coal	58/31/24/72	1.4
Petroleum as fuel	58/31/24/72	1.4
Fresh groundwater source	58/31/24/72	0.6
Saline surface water source	58/31/24/72	1.5

*U = operational efficiency, F = thermal efficiency, G = system age, T= average summer air temperature in °F; ** Low and high values based on a combination of 10 and 90 percentile values of independent variables; these values are calculated for coal-fired power plants.

According to the results in Table VII-4, at the average values of the dependent variables and with the binary variable designating coal-fired plants, the expected average rate of water withdrawal per kilowatt-hour of net generation of electricity in the closed-loop cooling systems is 1.2 gallons/kWh. Using the 10 and 90 percentile values for the four continuous variables, the range of unit withdrawals extends from 0.4 to 2.4 gallons/kWh. Other average values in Table VII-4 refer to different combinations of fuels and water supply sources.

Consumptive Water Use

The estimated regression equation for consumptive use of water by closed-loop cooling systems (see Table V-14) is:

$$C = 1.540 - 0.011U - 0.011F + 0.005G + 0.174COAL + 0.192MFC - 0.148GF \qquad 7.4$$

where *C* is unit consumptive use of water in gallons/kWh; *U* is capacity utilization (or operational efficiency in %; *F* is thermal efficiency of generators in %; *G* is age of cooling system; *COAL* is coal as fuel, *MFC* is mixed fuels with coal, *GF* is fresh groundwater source. The predictions obtained from Equation 7.4 are shown in Table VII-5.

Table VII-5. Regression Benchmarks for Consumptive Water Use by Closed-loop Systems with Cooling Towers in Fossil Fuel Plants (From Equation 7.4)

Description	Values of Continuous Variables: U/ F/ G*	Predicted Benchmark gal/kWh
Low value**	84/36/ 9	0.5
Average value	58/31/24	0.9
High value**	15/27/42	1.5
Average value with:		
Mixed fuel w/ coal	58/31/24	1.1
Fresh groundwater source	58/31/24	0.7

*U = operational efficiency, G = system age, F = thermal efficiency;

** Low and high values based on a combination of 10 and 90 percentile values of independent variables; these values are calculated for coal-fired power plants.

The calculated benchmarks of consumptive use in cooling towers, shown in Table VII-5, range from 0.5 to 1.5 gallons/kWh for average operating conditions in coal-fired power plants. These estimates are consistent with the estimated unit withdrawals from Table VII-4 in terms of the percentage of consumptive use (i.e., 70 percent).

Regression Benchmarks for Recirculating Systems with Cooling Ponds

Water Withdrawals

As reported in Chapter V, the data on unit water use in recirculating systems spanned a wide range, and so regression equations were estimated for two distinct subsets of the data. The results for the data subset with unit withdrawals less than 10 gallons/kWh were not used to calculate benchmarks for unit water withdrawals. The benchmarks presented below are derived only for the data with unit withdrawal values ranging from 10 to 120 gallons/kWh. The estimated linear regression equation for this data subset (Table V-17, Sub-model 2) is:

$$W = 48.53 - 0.692U - 1.164\Delta + 0.838T - 5.804RC \qquad 7.5$$

where W is unit water withdrawals in gallons/kWh; U is capacity utilization (or operational efficiency in %; Δ is maximum temperature rise in the condenser (at 100 percent generation capacity) in °F; T is average summer air temperature; and RC is binary variable designating systems with cooling ponds.

Table VII-6. Regression Benchmarks for Water Withdrawals by Recirculating Systems with Cooling Ponds in Fossil Fuel Plants (From Equation 7.5)

Description	Values of Continuous Variables: U/ Δ / T*	Predicted Benchmark (gal/kWh)
Low value**	80/25/65	19
Average value	53/18/74	53
High value**	15/13/81	91
Average value in:		
Recirculating systems w/ponds	53/18/74	47

*U = operational efficiency, Δ = maximum temperature rise in the condenser, T = average summer air temperature in °F; ** Low and high values based on a combination of 10 and 90 percentile values of independent variables.

The calculated benchmarks in Table VII-6 apply to the rates of water pumpage through the cooling system and not the withdrawals to make up the evaporative losses in cooling ponds or canals. These unit withdrawals are comparable to the estimates for once-trough cooling systems, which are included in Table VII-2.

Consumptive Water Use

Because consumptive use data for recirculating systems were unclear, no derivation of benchmarks for consumptive water use was performed. The consumptive water use in recirculating systems should be similar to consumptive use in once-through systems (see Table VII-3). However, some consumptive use also takes place in the cooling ponds or canals, which receive the discharge of the heated water from the system.

REGRESSION BENCHMARKS FOR NUCLEAR PLANTS

Chapter VI contains several regression models that have been estimated for nuclear power plants based using the 1996-2000 EIA-767 data set. The linear regressions of unit water withdrawals were used to derive water-use benchmarks for nuclear plants. No benchmarks of consumptive use were calculated, but the equations in Chapter VI can be used to calculate consumptive use for individual plants.

Benchmarks for Once-through Cooling Systems

The regression model in Table VI-4 was used in deriving benchmarks for unit water withdrawals in once-through cooling systems. The estimated regression equation is:

$$W = 82.35 - 1.861\Delta \qquad 7.6$$

where W is unit water withdrawals in gallons/kWh, and Δ is maximum temperature rise in the condenser (at 100 percent generation capacity) in °F.

Table VII-7. Regression Benchmarks for Water Withdrawals
by Once-through Systems in Fossil Fuel Plants
(From Equation 7.6)

Description	Values of Continuous Variables: Δ*	Predicted Benchmark (gal/kWh)
Low value**	14	30
Average value	18	49
High value**	28	56

* Δ = maximum temperature rise in the condenser, ** Low and high values based on a 90 and 10 percentile values of the independent variable, respectively.

The calculated rates of unit withdrawals in Table VII-7 are lower and span a smaller range than the benchmark withdrawals for fossil-fuel plants. However, the average withdrawal of 49 gallons/kWh is nearly the same as the average-use benchmark value of 48 gallons/kWh derived in Table VII-1.

Benchmarks for Closed-loop Cooling Systems

The regression equation for calculating benchmark withdrawals in closed-loop cooling systems with cooling towers is:

$$W = 4.25 - 0.099\Delta + 0.964SS - 0.413RI \qquad 7.7$$

where W is unit water withdrawals in gallons/kWh; Δ is maximum temperature rise in the condenser (at 100 percent generation capacity) in °F; SS is saline surface water source; and RI is cooling towers with induced air flow. The calculated benchmarks are presented in Table VII-8.

Table VII-8. Regression Benchmarks for Water Withdrawals
by Closed-loop in Nuclear Plants
(From Equation 7.7)

Description	Values of Continuous Variables: Δ*	Predicted Benchmark (Gallons/kWh)
Low value**	20	0.9
Average value	27	1.5
High value**	33	2.3
Average value in:		
Saline surface water supply	27	2.5
Induced air-flow tower	27	1.1

*Δ = maximum temperature rise in the condenser, ** Low and high values based on a combination of 10 and 90 percentile values of independent variables.

The calculated benchmarks range from 0.9 to 2.3 gal/kWh. The average value of 1.5 gal/kWh is lower than the average-use benchmark value reported in Table VII-1.

Benchmarks for Recirculating Systems

The regression equation for calculating benchmark water withdrawals in recirculating systems with cooling ponds or canals and mixed circulating and once-through systems (from Table VI-1 in Chapter VI) is:

$$W = 0.60 - 0.032\Delta + 0.018F + 0.057G + 0.421SF \qquad 7.8$$

where W is unit water withdrawals in gallons/kWh; Δ is maximum temperature rise in the condenser (at 100 percent generation capacity) in °F; F is thermal efficiency; G is system age; and SF is fresh surface water source. Equation VII-8 was estimated using the data on 22 observations with water withdrawals less than 2 gal/kWh. The calculated benchmarks derived from these truncated data are presented in Table VII-9.

The average value of water withdrawals is 0.8 gallons/kWh. The lowest value is negative, probably due to the unlikely combination of input variables produced by the benchmarking methodology. The highest predicted value is 2.2 gal/kWh and the average value for systems which use surface freshwater source is 1.2 gal/kWh.

Table VII-9. Regression Benchmarks for Water Withdrawals
by Recirculating Systems in Nuclear Plants
(From Equation 7.8)

Description	Values of Continuous Variables: U, Δ,G*	Predicted Benchmark (Gallons/kWh)
Low value**	93/17/4	-0.3
Average value	79/27/13	0.8
High value**	52/36/25	2.2
Average value in:		
Surface freshwater source	79/27/13	1.2

U = operational efficiency, Δ = maximum temperature rise in the condenser, G = system age.
** Low and high values based on a combination of 10 and 90 percentile values of independent variables.

STOCHASTIC FRONTIER BENCHMARKS IN FOSSIL PLANTS

Three stochastic frontier regression models were estimated from the data and the results were used to produce technical efficiency scores for individual cooling systems during the years for which data were available. The sample of systems used in the estimation was smaller than the sample used in the regression analysis because the estimation procedure of the Frontier Version 4.1 requires that the panel data include the first and the last year of the time series. This means that cooling systems with missing observations for 1996 or 2004 had to be excluded.

The technical efficiency estimates describe the change in the unit water withdrawals (the reduction) that would imply the movement of each observation to a position on the stochastic production frontier. For example if the estimated technical efficiency, TE_i was 70 percent then we assumed that at a 30 percent reduction in water withdrawal, the system (i.e., observation) would be 100 percent efficient. It is important to keep in mind that because of the assumptions used in the frontier analysis the resultant level of water use is only an approximation. The benchmark unit water withdrawal for each observation was calculated by dividing the observed unit withdrawal in gallons/kWh by the estimated technical efficiency score:

$$BW_{it} = W_{it} \cdot TE_{it} \qquad 7.9$$

where BW_{it} is benchmark unit withdrawals in gallons/kWh; W_{it} is observed unit withdrawal in system *i* during data year t; and TE_{it} is estimated technical efficiency score for system *i* during data year *t*.

Stochastic Frontier for Once-through Cooling Systems

The stochastic frontier model for once-through systems in fossil fuel plants was based on 1,773 observations of total annual (net) electricity production, water withdrawals and other variables. The estimated equation is:

$$\begin{aligned} \ln E &= 2.851 + 0.782 \ln W + 0.017U \\ &+ 1.540 - 0.015F + 0.299 \ln G - 0.517 \ln \Delta + 0.574GF + 0.319PB \end{aligned} \qquad 7.10$$

where *E* is annual (net) electricity generation in million kWh; *W* is annual water withdrawals in million gallons per day; and *U* is operational efficiency in %. The second part of the Equation 7.10 is called the "inefficiency model", where *F* is thermal efficiency of generators in %; *G* is system age in years; Δ is maximum temperature rise in the condenser (at 100 percent generation capacity) in degrees Fahrenheit; *GF* is fresh groundwater source; and *PB* is public water supply source.

By substituting variable values for any individual system into the inefficiency model (i.e., the second part of equation 7.10) and completing the calculations we can obtain the value of U_{it}, which can be converted to technical efficiency score using the equation:

$$TE_{it} = e^{-U_{it}} \qquad 7.11$$

For example, at the average values of thermal efficiency (31.8 percent), the natural logarithms of age (36 years) and temperature rise (17.4 °F), and assuming zero values for *GF* and *PB*, the predicted value of U_{it} is 0.66 and the corresponding value of thermal efficiency score TE_{it} is 0.51 (or 51 percent). The technical efficiency would be 74 percent if the 90 and 10 percentile values were used in the inefficiency model of Equation 7.10 (i.e., 35.6 percent thermal efficiency, 24 years for age and 25 °F for temperature rise).

The estimated technical efficiencies for individual systems and data years ranged from 22.5 percent to 91.6 percent. The TE_i scores (i.e., decimal fractions) were used with Equation 7.9 to calculate the benchmark rates of unit water withdrawals. Table VII-10 compares the parameters of the statistical distribution of the actual and predicted unit water use in once-through cooling systems. It indicates that at 100 percent technical efficiency, the mean and median values would be approximately one-half of the present values. Also, most of the large values in the right tail of the distribution would be reduced.

Table VII-10. Distribution of Benchmark Values for Unit Withdrawals at 100 Percent Technical Efficiency for Once-through Cooling Systems at Fossil Power Plants

Distribution Parameter	Actual Withdrawal Rates, gal/kWh	Predicted Withdrawal Rates, gal/kWh
Mean	57.3	27.9
Median	47.0	23.6
Standard Deviation	43.9	16.6
Minimum	2.1	1.7
Maximum	544.2	190.0

The distribution of the actual and predicted unit withdrawals is shown on Figure VII-1. It shows the shift of the reduced rates of water withdrawals to the left and the elimination of values greater then 190 gallons/kWh.

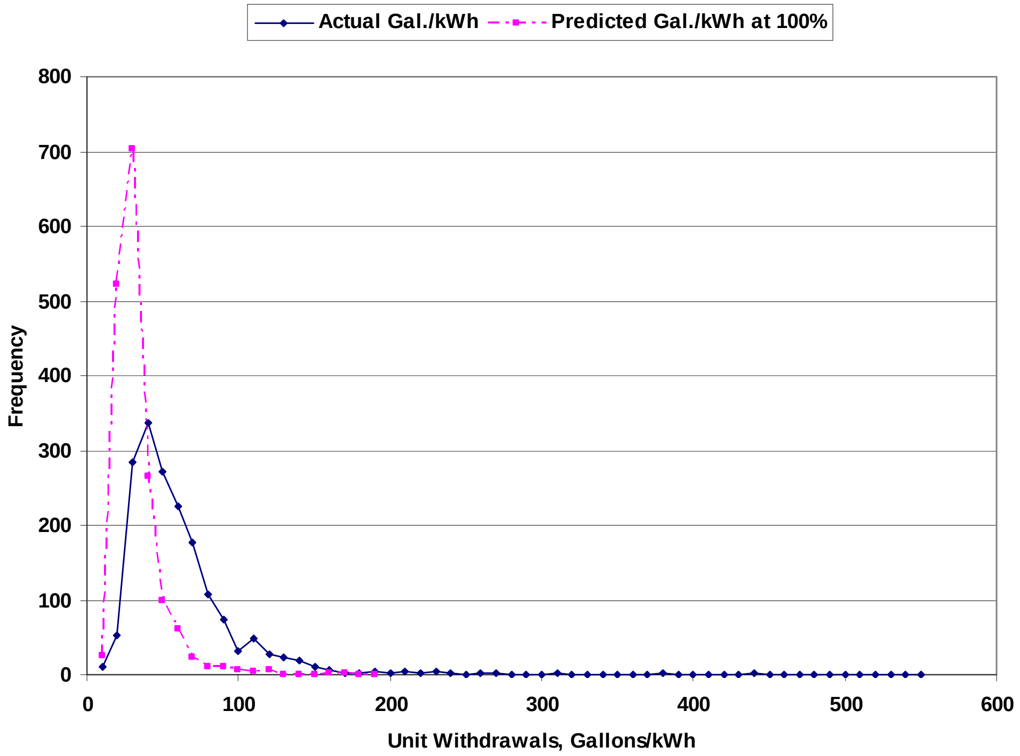

Figure VII-1. Change in the Distribution of Unit Water Withdrawals in Once-Through Systems at 100 Percent Technical Efficiency

Stochastic Frontier Benchmarks for Closed-loop Systems

The stochastic frontier model for closed-loop systems with cooling towers in fossil fuel plants was estimated based on 1,259 observations on total annual (net) electricity production, water withdrawals and several other variables. The estimated equation is:

$$\begin{aligned} &\ln E = 6.426 + 0.349 \ln W + 0.018U \\ &+ 1.144 - 0.026F + 0.761 \ln G - 0.663 \ln \Delta - 0.606RN + 0.332PET - 0.221SF \end{aligned} \tag{7.12}$$

where E is annual (net) electricity generation in million kWh; W is annual water withdrawals in million gallons per day; and U is operational efficiency in %. The inefficiency model of Equation 7.12 includes six variables: F is thermal efficiency of generators in %; G is system age in years; Δ is maximum temperature rise in the condenser (at 100 percent generation capacity) in °F; RN is binary variable indicating natural draft towers; PET is petroleum as fuel; and SF is fresh surface water source.

At the average values of thermal efficiency (31.7 percent), the natural logarithms of system age (22.4 years) and temperature rise (23 °F), and assuming zero value for PET and one for RN and SF, the predicted value of U_{it} is -0.24 and the corresponding value of thermal efficiency score TE_{it} is 0.79 (or 79 percent). The estimated actual technical efficiencies for individual systems (for each data year) ranged from 18.4 percent to 95.9 percent.

The TE_i scores (i.e., decimal fractions) generated by the model were used with Equation 7.9 to calculate the benchmark rates of unit water withdrawals. Table VII-11 compares the parameters of statistical distribution of the actual and predicted unit water use in closed-loop cooling systems. It indicates that at 100 percent technical efficiency, the mean value of unit water withdrawals would be approximately two-thirds of the present values.

Table VII-11. Distribution of Benchmark Values for Unit Withdrawals at 100 Percent Technical Efficiency for Closed-loop Cooling Systems at Fossil Power Plants

Distribution Parameter	Actual Withdrawal Rates, gal/kWh	Predicted Withdrawal Rates, gal/kWh
Mean	1.03	0.67
Median	0.68	0.46
Standard Deviation	1.40	1.08
Minimum	0.01	0.01
Maximum	25.54	22.61

The distribution of the actual and predicted unit withdrawals is shown on Figure VII-2. It shows the shift of the reduced rates of water withdrawals to the left, and the shifting of some large values in the right tail of the distribution would be reduced.

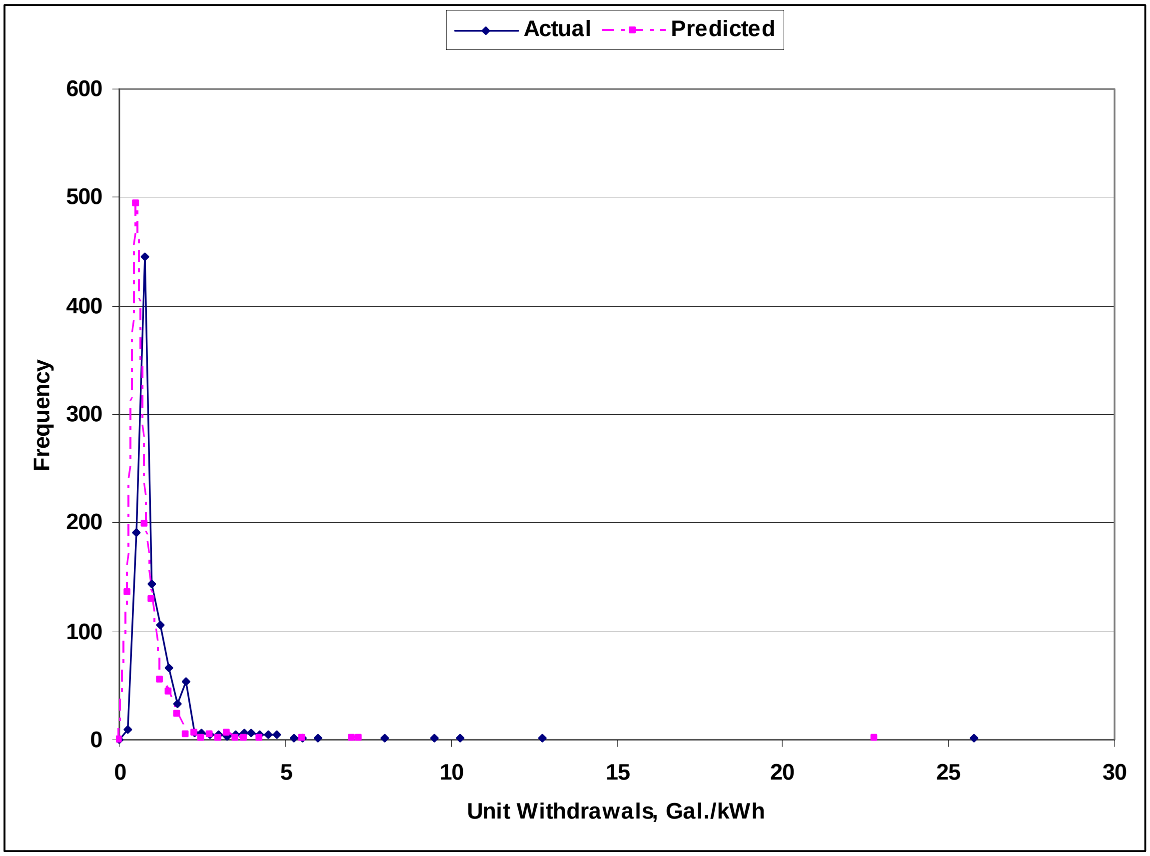

Figure VII-2. Change in the distribution of unit water withdrawals in closed-loop systems at 100 percent technical efficiency

Stochastic Frontier Benchmarks for Recirculating Systems

The stochastic frontier model for recirculating systems using between 10 and 120 gal/kWh in fossil fuel plants was estimated based on 152 observations on total annual (net) electricity production, water withdrawals, operational efficiency and five other variables. The estimated equation is:

$$\begin{aligned} \ln E &= 4.329 + 0.853 \ln W + 0.014U \\ &+ 4.036 + 0.249 \ln G - 0.992 \ln \Delta - 0.405 MOR + 0.124 MXF + 0.211 SF \end{aligned} \qquad 7.13$$

where *E* is annual (net) electricity generation in million kWh; *W* is annual water withdrawals in million gallons per day; and *U* is operational efficiency in %. The inefficiency model of Equation 7.13 includes five variables: *G* is system age in years, Δ is maximum temperature rise in the condenser (at 100 percent generation capacity) in °F; *MOR* is binary variable indicating mixed recirculating and once-through systems; *MXF* is mixed fuels; and *SF* is fresh surface water source.

The results indicate that the estimated actual technical efficiencies for individual systems (for each data year) ranged from 3.5 percent to 24.5 percent. Again, the TE_i scores (i.e., decimal fractions) generated by the model were used with Equation 7.9 to calculate the benchmark rates of unit water withdrawals. Table VII-12 compares the parameters of statistical distribution of the actual and predicted unit water use in closed-loop cooling systems. It indicates that at 100 percent technical efficiency, the mean value of unit water withdrawals would be greatly reduced. This is the result of the low technical efficiencies which were estimated for the truncated data set for recirculating systems.

Table VII-12. Distribution of Benchmark Values for Unit Withdrawals at 100 Percent Technical Efficiency for Recirculating Systems at Fossil Power Plants

Distribution Parameter	Actual Withdrawal Rates, gal/kWh	Predicted Withdrawal Rates, gal/kWh
Mean	49.7	5.2
Median	43.4	4.6
Standard Deviation	21.1	1.6
Minimum	15.9	3.3
Maximum	115.7	9.7

STOCHASTIC FRONTIER BENCHMARKS FOR NUCLEAR PLANTS

Two stochastic frontier models were estimated based on the available 1996-2000 data for nuclear power plants. Because of the restrictions of the estimation procedure the number of observations was relatively small. For once-through cooling systems, the model was estimated with data for 18 cooling systems with 69 total observations. The estimated equation is:

$$\begin{aligned} \ln E &= 6.540 + 0.217 \ln W + 0.014 U \\ &+ 4.036 + 0.430 \ln G - 1.672 \ln T + 1.507 RC + 1.589 OF + 1.541 SS \end{aligned} \qquad 7.14$$

where W is unit water withdrawals in gallons/kWh; G is age of cooling system; T is average summer air temperature; RC is binary variable indicating systems with cooling ponds or canals; OF is binary variable indicating once-through systems using freshwater; and SS is saline surface water source.

The results indicate that the estimated actual technical efficiencies for individual systems and data years ranged from 44.0 to 100 percent with a mean of 69.6 percent. Again, the TE_i scores (i.e., decimal fractions) generated by the model were used with Equation 7.9 to calculate the benchmark rates of unit water withdrawals. Table VII-13 compares the parameters of statistical distribution of the actual and predicted unit water use in once-through cooling systems.

Table VII-13. Distribution of Benchmark Values for Unit Withdrawals at 100 Percent Technical Efficiency for Once-through Cooling Systems at Nuclear Power Plants

Distribution Parameter	Actual Withdrawal Rates, gal/kWh	Predicted Withdrawal Rates, gal/kWh
Mean	44.9	26.5
Median	48.9	34.3
Standard Deviation	19.8	14.0
Minimum	19.7	16.1
Maximum	108.0	79.2

The estimated stochastic frontier model for the closed-loop systems with cooling towers (based on 38 observations on 9 systems) is:

$$\begin{aligned} \ln E &= 7.343 + 0.250 \ln W + 0.012U \\ &+ 6.628 - 0.660 \ln \Delta - 1.079 \ln T \end{aligned} \tag{7.15}$$

where *W* is unit water withdrawals in gallons/kWh; *U* is operational efficiency in %; Δ is temperature rise in the condenser, and *T* is average summer air temperature. The estimated technical efficiencies for individual systems (for each data year) ranged from 55.8 to 100 percent with a mean of 80.8 percent.

Because of the low number of observations in both stochastic frontier models, their application in deriving benchmarks of water use is limited. However, generally, the results for the nuclear power plants are similar to those obtained for fossil fuel plants.

SUMMARY

The results of the data analyses presented in Chapters V and VI were used in this chapter to derive numerical benchmarks of unit water use for three general types of cooling systems: once-through systems, closed-loop systems with cooling towers, and recirculating systems with cooling ponds or canals (including mixed systems). The benchmark values derived in this study can be used by system engineers to enhance the efficiency of water use in existing systems and to improve the design of new systems.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to examine water use at electric power plants and determine both the average rates of water withdrawals and consumptive use as well as to estimate the levels of water usage of the most water-efficient cooling systems. This was accomplished by examining data maintained by the Energy Information Agency of the U.S. Department of Energy and information obtained directly from a sample of power plants.

An important insight achieved through this study is that water conservation is not a priority at the thermal power plants with water-cooled steam turbine generators. Plants with once-through cooling systems are considered to have negligible consumptive use, and their primary water use concerns are limited to the protection of fish at intake screens and the impacts of thermal pollution on the receiving water bodies. In closed-loop systems with cooling towers, large amounts of water are being recirculated through the cooling system but the main concerns are water quality, to prevent the fouling of the cooling system, and vapor drift from cooling towers. Finally, in recirculating systems with cooling ponds or canals, plant managers are concerned mostly with achieving sufficient mixing of water to prevent excessive increases of the water temperature at facility cooling water intakes. The quantity of water pumped through the condensers or the volume lost to evaporation in cooling towers or cooling ponds, while understood and taken into consideration in controlling production costs, are not a primary focus of system managers. Their main concern is power generation and the reliable functioning of the cooling system.

Nevertheless, several participants of this study indicated that better knowledge of water usage rates would be helpful in optimizing the operations of their power plants and that the efficient water-use benchmarks can be most helpful in designing new cooling systems or in retrofitting existing systems. Therefore, the key findings and recommendations of this study focused on their potential applicability to the design and operation of the existing and future power plants and cooling systems.

STUDY FINDINGS

The review of pertinent literature, site visits, questionnaire surveys, and analysis of annual data on water withdrawals and consumptive use in thermoelectric power generation revealed several important findings:

1. The estimated water withdrawals and consumptive use per kilowatt-hour of net generation of electricity show very high variability among different power plants using the same type of cooling systems. The main reason for this variability is the mode of operation of electric generators. Unit water use per kilowatt-hour tends to be lower for cooling systems at “base-load” plants running nearly constantly at high levels of capacity utilization and it tends to be higher in “load following” and “peak load” plants operating at low levels of capacity utilization.

2. Once-through cooling systems withdraw the largest quantities of water per kilowatt-hour of generation (on average between 40 and 50 gallons/kWh) but have the lowest consumptive use within the plant (i.e., less than 1 percent of withdrawals). No data on increased evaporation in the receiving water bodies was obtained as a part of this study. The variability of unit water withdrawals among different once-through cooling systems was found to be primarily a function of the operational efficiency (i.e., percent of capacity utilization), designed maximum temperature rise of the condenser, and, to a lesser extent, the age of the cooling system and thermal efficiency of the generators. Lower usage rates were found in recently built systems with high operational efficiency and high temperature rise in the condenser and high thermal efficiency.

3. In closed-loop cooling systems with cooling towers, the average unit withdrawal is approximately 1.0 gallon/kWh of net electric energy generation with a consumptive use of approximately 70 percent of water withdrawn. The amount of withdrawals for make-up water intake in cooling towers was also found to depend on operational efficiency, thermal efficiency, and system age. The design temperature rise in the condenser was found to be less important than in once-through cooling systems.

4. The withdrawal rates and consumptive use in the recirculating systems with cooling ponds and canals (and other recirculating and mixed systems) fall between the values for once-through and closed-loop systems. However, the data for these systems are often inconsistent in whether the consumptive use estimate includes both losses to evaporation in cooling ponds as well as the quantities that are pumped through the condensers. In systems reporting withdrawals between 10 and 120 gallons/kWh, the variability of unit withdrawals are found to be a function of operational efficiency, temperature rise, and average summer air temperature at the plant location.

5. In all three types of cooling systems, the observed rates of water withdrawals were also found to depend on the type of water source and the type of fuel. On average, systems relying on fresh groundwater or public water supply used less water than systems relying on fresh surface water or saline water. With respect to fuel type, plants burning coal, coal mixtures, or petroleum tended to have higher water usage than plants burning natural gas.

6. Nuclear power plants usually operate as base-load generators and tend to have lower variability of water withdrawal and consumptive use rates; although, the average rates of water usage per kilowatt-hour of net generation are close to those for fossil-fuel plants that have the same cooling system characteristics.

7. In every category of cooling systems analyzed in this study there were observations with inexplicably high rates of unit water use. When these were excluded from calculations of average values or regression models estimations, the benchmark values of unit water withdrawals derived in this study showed a significant amount of consistency among estimates of average and “best performance” use of water derived through various methods of data analysis.

8. The stochastic production frontier analysis of the data showed that the estimated technical efficiencies of water use in various plants and cooling systems vary significantly and are

lower on average in fossil fuel plants and somewhat higher in nuclear power plants. In once-through systems the mean technical efficiency was 52.9 percent for fossil plants and 69.6 percent for nuclear plants. For closed-loop systems with cooling towers the respective mean efficiencies were 67.2 and 80.8 percent. This finding suggests that while nuclear plants tend to use cooling water more efficiently than plants using fossil fuels there is still 20 to 30 percent potential for reducing water withdrawals in many of those plants and a 30 to 50 percent potential reduction in many fossil-fuel plants.

RECOMMENDATIONS

The complex structure and reliability of the data and difficulty in obtaining feedback from power plant personnel were significant obstacles in achieving the goals set forth for this study. The following recommendations suggest improvements that may facilitate the development of improved methodologies and outcomes for future research in this important sector of water use.

1. The main shortcoming of the currently available data from the EIA-767 form is the lack of “gross” generation by the generating units. In this study, we used the operational efficiency to capture the effect of gross generation but this approach has its limitations. More useful benchmarks of water usage rates could be developed with gross generation data for each generator in a plant, as it is total generation that really determines the amount of cooling water flow (and/or consumptive use). The current Form EIA-767 only collects monthly and annual total "net generation" by generator (generating unit). We recommend that total annual gross generation for each generator unit be collected by adding an appropriate question to Schedule 5 of EIA-767 form.

2. Further development and refinement of water-use benchmarks should be undertaken as a collaborative effort between the electric power industry and a private or public research institution, and it should involve data collection from a sample of “best performing” plants, which could be identified using the results of this study. The main objective of the study would be to define appropriate standards for the design and operation of wet-cooling systems to eliminate inefficient use of water in thermoelectric power generation.

3. Improved water use efficiencies at power generation facilities are likely to require significant managerial and financial investments. The findings from this study suggest that reductions in power plant water use are always beneficial to the extent that reductions in the power generated to provide water pumping then become available to sell to customers. However, while this benefit is often considered to be marginal, there clearly appear to be other situations where reduced water usage can provide significant benefits. For example, generating facilities located on shared reservoirs or aquifers may be able to “free-up” water resources for economically important domestic or irrigation uses, or facilities using surface water sources may be able to significantly reduce the impacts of thermal pollution on aquatic resources. Research that can identify those situations that result in the most beneficial reductions of power plant water uses can focus water use efficiency studies on the categories of generating facilities that are most like to welcome improvements in water use efficiency.

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APPENDIX A

REVIEW OF EIA-767 AND SELECTION OF SAMPLE OF SURVEYED GENERATING FACILITIES

PURPOSE

The purpose of this appendix is:

- To describe the Form EIA-767 dataset;
- To describe the process that was use to select the sample of systems that were included in the national survey of power generation facilities; and
- To summarize some of the characteristics of the facilities included in the sample.

FORM EIA-767

The U.S. Department of Energy collects and publishes a substantial quantity of information from energy producers. EIA currently uses seven different data collection forms to produce the Electric Power Annual Report, including the *Form EIA-767: Steam Electric Plant Operation and Design Report*. (U.S. Department of Energy, 2003).

Form EIA-767 is used to collect information from all U.S. power plants with existing or planned organic-fueled or combustible renewable steam-electric plants with generator nameplate ratings of 10 megawatts or larger on an annual basis. Submission of the form is "mandatory" under Section 13(b) of the Federal Energy Administration Act of 1974. This data is used to "monitor the current status and trends of the electric power industry and to evaluate the future of the industry." (DOE, 2005: i).

Form EIA-767 also collects information on plant cooling systems that can be used to estimate the quantity of water used by each cooling system operated by each facility. The USGS has used the EIA-767 as one of its primary data sources in the estimation of thermoelectric water use that it prepares every five years (USGS, online). The data from this form was analyzed in this study to evaluate plant water use. The 2003 edition of EIA-767 was also used to select a sample of plants that were contacted and asked to respond to a survey of thermoelectric water use.

After 2000, the DOE/EIA no longer included data for plants using nuclear fuel in the Form EIA-767. Therefore the following review of the power generation facilities information does note include any of these facilities. The comparative tables used in the email survey to nuclear power facilities were based upon a summary of data in the 2000 survey.

SELECTION OF GENERATION FACILITIES INCLUDED IN THE SURVEY

The 2003 EIA-767 contains information for 1,382 existing, planned, and retired organic-fueled power generation facilities. A set of criteria was developed based upon the characteristics of the EIA-767 data set and based on the requirements of the study to ensure that only those facilities that were most likely to be able to provide the desired information would be selected.

The selection criteria and their progressive reduction in sample size are listed below:

1. Existing, as opposed to "planned" or "retired" (n=1,335);
2. Generation capacity of 100 MW or more (n=727);
3. Reported annual generation (2003) greater than zero (n=695); and
4. One or more "operational" cooling systems (n=669).

This procedure resulted in a sample size of 669 organically-fueled plants. Complete details of the sample selection process and some of the characteristics of these plants appear in the next section.

Reporting data from the nation's 104 nuclear power generating facilities is not available in the Form EIA-767 beyond 2000. The U.S. Nuclear Regulatory Commission was contacted to obtain a list of the 66 utilities that operate these power generation facilities, and they were invited to participate in the survey. However, the characteristics of those plants are not included in this appendix.

CHARACTERISTICS OF STEAM-GENERATION FOR 2003

Plant Characteristics

The 2003 EIA-767 contains information for 1,382 existing, planned, and retired organic-fueled power generation facilities (Table A.1).

Table A.1 Plant Status in EIA-767 2003

Plant Status	Number of Plants	Status Code
Existing	1,335	A
Planned	31	P
Retired	16	R
Total	1,382	---

These plants are classified by their generation capacity into those above and under 100 megawatts of total generation capacity. Slightly more than half (55 percent) of the plants included have generation capacity in excess of 100 megawatts.

Table A.2 Number of Plants by Type and Status

Plant Type		**Number of Plants by Type & Status**	**Type & Status Code**
Organic 100 MW or more		766	O
	Existing	727	A
	Planned	31	P
	Retired	8	R
Organic 10 MW or Greater to Under 100 MW		616	U
	Existing	608	A
	Retired	8	R
	All Plants	1,382	

Generation Characteristics

The 1,382 plants that submitted Form EIA-767 in 2003 identified 2,898 generators at their facilities and included the monthly and annual number of megawatt hours produced by each generator.

Table A.3 Number of Generators Reporting Production in 2003

Annual Net Electrical Generation (megawatt hours)	**Number of Generators**
>10 megawatt hours	1,802
No generation listed (blank)	848
Zero (0) generation	195
Negative generation	53
Total	2,898

All but four of the 848 generators that did not report annual generation were at facilities identified with a plant status code of “U,” indicating that their total generating capacity is less than 100 megawatts (suggesting that these facilities are not required to report generation). Three of the four other generators for the “O” facilities that did not report generation were from a facility that had no net electrical generation (a fourth generator at this facility reported only negative generation) suggesting that the plant was not yet fully operational. The fourth generator was listed for a plant identified as “planned.”

Three facilities identified with a plant status code of “U” did report a small amount of annual generation. A total of 195 generators reported no output, and 53 reported negative output, indicating that the annual service load from plant operations exceeded monthly gross electrical generation.

Generating plant size can be evaluated by the plant generating capacity (in megawatts, as listed on the maximum generator nameplate rating) and by the total annual net generation, as expressed in megawatt hours. These two measures were calculated for the 695 plants reporting positive annual generation by summing the nameplate ratings and annual generation for all of the generators at each plant (Table A4).

Table A.4 Generation Capacity and Annual Generation - 2003

Total Nameplate Rating (megawatts)	Number of Plants	Total Net Annual Generation (megawatt hours)	Number of Plants
67 to 100	6	0 to 100,000	47
101 to 250	189	100,001 to 500,000	103
251 to 500	168	500,001 to 1 million	118
501 to 1,000	160	1 to 5 million	280
1,001 to 2,000	132	5 to 10 million	96
2,001 to 3,000	35	10 to 15 million	29
3,001 to 3,954	5	15 to 21 million	22
Total	695		695

Approximately half (52 percent) of the plants in the analysis have generating capacity of 500 megawatts or less, and only 40 plants have generating capacity in excess 2,000 megawatts. However, more than 60 percent of the plants generate more than 1 million megawatt hours per year.

Boiler and Cooling System Characteristics

The 1,382 plants that submitted Form EIA-767 in 2003 also identified 3,964 boilers and 1,632 cooling systems. Not all of the boilers and cooling systems are currently in service at every facility. Table A.5 lists the number of boilers and cooling systems along with their reported status.

Table A.5 Status of Boilers and Cooling Systems Reported in EIA-767

System Status	System Status Code	Boilers	Cooling Systems
Operating	OP	3,425	1,436
Standby (not normally used but available for service)	SB	143	29
Out of service	OS	104	37
Cold Standby reserve (require 3 to 6 months to reactivate)	SC	102	39
Retired (and not expected to be put back into service)	RE	81	35
New unit under construction	CO	50	32
Planned (expected to go into service w/in five years)	PL	42	19
Operating under test conditions (not in commercial service)	TS	11	3
Cancelled	CN	6	2
Total		3,964	1,632

Perhaps the most important element in the understanding water use at thermoelectric plants is the type of cooling systems that are in use at each facility. Of the 695 planned or operating facilities that that reported positive generation, 669 facilities also reported operating (OP) cooling systems.

Table A.6 Operating Status of Operating Cooling Systems

System Status	**System Status Code**	**Cooling Systems**
Operating	OP	1,430
Standby (not normally used but available for service)	SB	20
Out of service	OS	20
Cold Standby reserve (require 3 to 6 months to reactivate	SC	20
Retired (and not expected to be put back into service)	RE	18
New unit under construction	CO	7
Operating under test conditions (not in commercial service)	TS	3
Planned (expected to go into service w/in five years)	PL	1
Total		1,520

Fifteen (of the 695) facilities that did not report having cooling systems reported 40 generators with nameplate ratings ranging from 6 to 476 megawatts and annual generation ranging from 0 to 1,280,613 megawatt hours. They also report operating 50 boilers (with six more on standby). It is unclear why cooling systems for these facilities are not reported in EIA-767, but they were dropped from further analysis in this report.

Another 11 facilities reported having cooling systems but did not report a single “operating” cooling system. Of these facilities, six had standby, planned, or new cooling systems under construction; four reported only retired or out of service cooling systems; and one facility reported operating three cooling systems under test conditions. These facilities were also dropped from further analysis.

Of the remaining 669 facilities that reported cooling systems that were operational for commercial service (OP), nearly 40 percent (265) had only a single cooling system.

Table A.7 Number of Cooling Systems per Plant

Number of Cooling Systems	**Number of Plants**
1	265
2	199
3	102
4	72
5	17
6	11
7	2
8	1
Total Plants	669

Each cooling system can have one or more cooling system types. Space is provided for four types of cooling for each cooling system on the Form EIA-767. However, no system reported having more than three types. Of the 669 plants operating with 1,430 cooling systems (see Table A.6), nearly 94 percent had a single cooling type (Table A.8).

Table A.8 Number of Cooling System Types per Cooling System

Number of Types of Cooling Per Cooling System	Number of Cooling Systems with One or more Types
Only 1 Type	1,341
2 Types	83
3 Types	6
Total Cooling Systems	1,430

Eight cooling system types (including "Other") are identified in the EIA-767. Table A.9 displays the distribution of cooling system types for the 669 facilities that reported positive annual generation of cooling system in the 2003 EIA-767. Cooling systems were almost evenly divided between the "once through" (54 percent) and "recirculating" (46 percent) types. Slightly more than one-third (36 percent) of all cooling systems were of the "once through, fresh water" type. Secondary (TYPE2) cooling systems were also nearly evenly divided between once through and recirculating and only a small number of facilities had tertiary (TYPE3) cooling systems.

Table A.9 Number of Cooling Systems by Type

Cooling System Type Description	Cooling System Type Code	Number of Cooling Systems		
		TYPE1	TYPE2	TYPE2
Once through, fresh water	OF	517	11	0
Recirculating with forced draft cooling tower(s)	RF	270	26	1
Recirculating with induced draft cooling tower(s)	RI	225	10	1
Once through, saline water	OS	194	7	0
Recirculating with cooling pond(s) or canal(s)	RC	90	5	1
Recirculating with natural draft cooling tower(s)	RN	67	3	0
Once through with cooling pond(s) or canal(s)	OC	61	12	1
Other types	OT	6	9	2
Total		1,430	83	6

Three types of recirculating cooling systems use cooling towers. There were 562 cooling systems that used one of these three types of recirculating systems. Table A.10 displays the type of tower used by cooling systems whose primary (TYPE1) cooling systems were one of these three types.

Of the 39 cooling systems using recirculating cooling as a secondary type (TYPE2), 33 were mechanical draft, wet process; one was mechanical draft, dry process and five were unknown (blank). There were two tertiary (TYPE3) cooling systems using recirculating with forced draft cooling towers (RF), and both of these towers were of the mechanical draft, wet process type.

Table A.10 Cooling Tower by Type for Primary (TYPE1) Cooling Systems

		Cooling System Type Code		
Tower Types	**Tower Type Code**	**RF**	**RI**	**RN**
Mechanical draft, dry process	MD	0	3	0
Mechanical draft, wet process	MW	269	218	2
Natural draft, dry process	ND	0	0	0
Natural draft, wet process	NW	0	3	65
Combination wet and dry processes	WD	1	0	0
Unknown	blank	0	1	0
Total		270	225	67

Sufficient information is provided in the EIA-767 to establish the linkages between boilers, generators, and cooling systems. The combinations of these three components are necessary to assess thermoelectric water use and are described in greater detail in the next section.

Cooling System Type and Generation

The 669 plants had a total of 1,897 generating units. Nearly 80 percent of all plants operated more than one generating unit, with 31 percent of plants operating two units.

Table A.11 Number of Generating Units per Plant

Number of Generating Units	Number of Plants
1	143
2	210
3	138
4	110
5	35
6	20
7	6
8	2
9	2
10	2
19	1
Total Plants	669

In order to assess whether there was a relationship between generation quantity and choice of cooling system type, annual plant generation from all generators was compared to the primary cooling types used for all cooling systems in each of the 669 plants.

Table A.12 Generation and Cooling Characteristics

Cooling System Type/ Combination	**Number of Plants**	**Annual Generation in 2003 (MWh)**			
		Mean	**Median**	**Minimum**	**Maximum**
Once through					
OF	200	1,900,385	741,374	122	18,835,625
OS	72	992,442	406,567	93	4,686,514
OC	38	2,769,721	754,864	15,632	16,484,395
OT	3	1,529,485	1,561,121	281,565	2,745,769
Recirculating					
RF	114	1,661,987	477,719	1,223	16,323,672
RI	114	1,354,378	475,658	1,253	14,493,167
RC	45	1,793,330	993,187	6,749	8,241,846
RN	27	4,771,009	1,362,237	179,599	19,259,534
Multiple Cooling Types					
OF, RF	21	3,072,803	529,451	799	13,112,146
OF, RI	6	2,670,817	936,136	24,952	12,161,552
OS, RF	5	1,659,349	527,865	8,895	5,184,293
OF, RN	5	923,050	791,677	298,325	1,586,319
OS, RN	3	2,560,281	1,624,658	144,448	5,911,738
OS, RI	2	17,311	17,311	9,162	25,459
RC, RF	5	5,364,125	768,165	682,142	15,199,422
RC, RI	4	1,634,291	72,435	13,158	6,379,135
RF, RI	2	4,928,636	4,928,636	74,917	9,782,354
OT, RI, OF	1	87,575	-----	-----	-----
OF, OT	1	1,955,583	-----	-----	-----
OF, RC	1	8,585,699	-----	-----	-----
Total	669	1,898,025	588,568	93	19,259,534

The dominant type of cooling used is once-through, fresh water cooling (OF), which is the sole cooling type in 30 percent of the 669 of the plants. Forced (RF) and induced (RI) draft types of recirculating cooling systems were each used at 114 types of plants, and smaller numbers of single type cooling systems were used in 185 other plants. Fifty-six plants used combinations of cooling types.

The mean, median, maximum, and minimum generation for each plant/cooling type choice was calculated and is presented in Table A.12. The largest mean annual generation for a single cooling type was found for the 27 plants operating recirculating systems using natural draft cooling towers; the smallest mean was for once through saline water facilities. However, the mean comparisons must be interpreted with caution at the plant level, because the generations of those plants using combinations of cooling systems are not calculated by individual cooling system type.

OTHER CHARACTERISTICS OF STEAM-GENERATION FACILITIES INCLUDED IN THE SURVEY

Utility Concentration

The 669 plants included in the survey sample are operated by 321 different utilities. Table A.13 identifies the number of utilities that operate one or more plants. Approximately 60 percent of the utilities included in this analysis operate only a single plant. There were four utilities operating ten or more plants.

Table A.13 Number of Utilities Operating One or More Plants

Number of Plants Operated	Number of Utilities Operating This Number of Plants
1	196
2	47
3	26
4	18
5	17
6	3
7	3
8	7
18	4
Number of Utilities	321

Note: The designation of "utility" is based upon the assignment of unique utility identification numbers. Some conglomerates may operate multiple "utilities."

Plant and Utility Location

Utility and plant addresses that appeared in EIA-767 were examined to determine the location of plants and utility home offices by state. The 669 plants reporting positive annual generation are located in 48 states and the District of Columbia. The utilities that operate these facilities are located in 44 states and the District of Columbia. Table A.14 displays the number of plants and utilities in each state.

Table A.14 Locations of Plants and Utility Home Offices

State/District Abbreviation	**Number of *Plants* in Each State**	**State/District Abbreviation**	**Number of *Utilities* in Each State**
TX	85	TX	116
FL	30	OH	34
PA	28	FL	30
CA	26	PA	28
IL	25	CA	27
IN, NY	24	NC	27
OH	23	MO	25
LA	22	NY, WI	23
MI	20	IN	21
KY	19	IL, LA	19
MO	18	MI	18
AZ, NC, OK	17	CO, GA	17
GA, VA, WI	16	AZ, OK	16
AL	14	KY, MN	15
CO, SC, WV	14	MD, SC, TN, VA	12
IA, KS, MS	13	AL, KS, OR	11
AR, MN	12	NJ	10
MD	11	CT	9
MA, NJ	9	MS	8
TN	8	MA, NE	7
CT, ND, NE, NM	7	IA	6
NV, UT	6	DE, ND, NV	5
WY	5	AR, HI	4
DE, HI	4	ME	3
MN, NH, OR	3	MT, NM, WA	2
ID, MT, WA	2	DC, ID, UT	1
DC, SD	1		

The five states with more than 25 plant locations are also the five states that reported the largest populations in the 2000 census. The location of utility home offices, however, is overwhelmingly concentrated in a just one state: Texas.

Cooling Water Source

Approximately 20 percent of the plants included in the survey used wells as their principal source of water, and 13 percent purchased water from municipal supplies. About 40 percent of the plants obtained their water from ocean or other major water sources. Table A.15 displays the water sources listed by 15 or more plants in the 2003 EIA-767.

Table A.15 Water Sources Listed by 15 or more of the 669

Source	Number
Wells	140
Ohio River	103
"Municipal"	84
Mississippi River	56
Missouri River	31
Lake Michigan	22
Illinois River	19
Ocean Water	15
Hudson River	15

APPENDIX B

SITE VISIT PROCEDURE

PURPOSE

The purpose of this appendix is:

- To describe the protocol that was used to conduct the Personal Interviews and Site Visit component of the research project; and
- To document the field note summaries from the site visits.

In order to preserve the anonymity of respondents, information that could potentially be used to identify the personnel or facility has been removed.

Interview - Site Visit Purpose

Prior to the development of the survey instrument, a series of on-site personal interviews were conducted with plant water use managers at five Midwestern power generation facilities. The purpose of these interviews was to:

1. Observe power generation water use and water flows from intake to discharge in different types of facilities;
2. Determine the way that water use is measured (or estimated) and reported in the EIA-767;
3. Observe a sample of the range of configurations of boiler-generation-cooling systems, and the influence of these systems on water use;
4. Inquire about significant on-site uses of water and significant determinants of water use;
5. Obtain feedback on the cooling system level water use coefficients calculated using 767 data;
6. Establish the level of interest and need for water use benchmarks by plant managers; and
7. Obtain suggestions for method to conduct the effective dissemination of a mail survey to power plant representatives.

PROTOCOL

The goal of the site visit component was to meet with the EIA-767 contact persons at between five and ten power generation facilities in the Midwest. The cooling system characteristics of all of the power facilities in these states were identified and a representative sample of 20 systems was selected.

A set of interview questions was developed (see Appendix B, page 3) and features of plant operations that would be valuable to observe were identified. Water-use coefficients were calculated for cooling systems at each facility and a comparative table of water use coefficients was prepared. This table was used during the interview to inquire about the accuracy of using EIA-767 to estimate plant water use and to discuss potential determinants of water use at each facility. A generic contact letter was drafted and submitted to the SIUC Human Subjects Committee for approval (see Appendix B, page 4).

A list of contact persons for all of the respondents to the 2003 Form EIA-767 was obtained from the DOE/EIA-767 Survey Manager. The initial contact to plants was made via fax and followed up by personal phone calls.

In some cases, it was found that the utility operated multiple plants, with the responsibility for completion of the Form EIA-767 centralized in central office of the utility. In these cases, multiple follow-up phone calls, faxes, and email messages were needed to determine the proper contact person at the actual power generation facility.

Six utilities eventually agreed to host an interview-site visit. However, in one case where a visit was approved at utility-level, the follow-up at plant-level was not successful and an interview was never scheduled.

Visits were made to five facilities. These consisted of a 60- to 90-minute interview with plant representatives, followed by tours of each facility lasting approximately one hour. Brief field notes were prepared detailing the information obtained during each visit (Appendix B, pages 5 to 10).

DEVELOPMENT OF WATER UTILIZATION BENCHMARKS FOR THERMOELECTRIC POWER GENERATION

SITE VISIT INTERVIEW DISCUSSION GUIDE

February 21, 2005

1. What is the route of the flow of cooling water from source to discharge? Can the flow of water be traced throughout the plant?

2. At what points in the flow of water through the facility is water flow measured (or estimated)? If water use is estimated, what is the procedure that is used? How often are measures or estimates prepared? Are monthly records available?

3. What are the non-cooling uses of water at your facility? Is water for these uses measured and/or monitored?

4. How is the flow of cooling water regulated? What factors or parameters determine flow requirements? Do environmental conditions (e.g., air temperature, intake water temperature) affect the rate of water flow?

5. Is cooling water discharged under NPDES permits? If yes, what are the permit conditions regarding quantity and quality? Do these conditions affect the quantity of cooling water being used?

6. Are there any restrictions on the amount of water available for use at your facility? If so, are these restrictions based upon the availability of the water, water quality (temperature/salinity), or some other factor?

7. Are there any State or Federal requirements to monitor or control the quantity of water used?

8. Have there been any recent changes in the configuration of the cooling system or in ways that cooling water is used in this plant?

9. Do you use any indicators of water pumping rates such as water quantity per 1.0 kWh of electricity generation an indicator of the relative rate of water usage? Are there any other measures that would be useful?

Contact Name Contact Date
Facility/Utility Name
Address

Dear Contact Person:

I am writing to request your assistance in a study of thermoelectric water use that is being conducted by Dr. Ben Dziegielewski and myself and sponsored by National Institute of Water Resources (NIWR) and Southern Illinois University Carbondale (SIUC). A complete description of the project is available on the NIWR web site: http://water.usgs.gov/wrri/04grants/national/nationalindex.html. The purpose of this project is to develop *benchmarks* that plant managers can use to evaluate the relative water-use performance of their facilities.

We are sending this letter to a sample of the generation facilities in the Midwest, addressed to the person identified in the year 2000, EIA 767 database as the "survey contact." One of those facilities is PLANT NAME. We are requesting the assistance of generating facility water-use managers to help us to identify the most important technical and managerial components of water use at various types of thermoelectric facilities.

Your participation would involve hosting a visit to your facility from the project's principal investigator, Dr. Ben Dziegielewski. Ben is a civil engineer and geography professor who has conducted numerous studies of water use at residential, commercial, institutional, and industrial facilities. We anticipate that the proposed visit will require approximately one hour of your time and, if possible, would include a brief tour of locations at your facility with water use measuring devices and cooling systems. Also, if possible, Ben will be accompanied by me, or one of his graduate students, who will assist with note-taking and observations. Participation in this study is, of course, completely voluntary, and any information collected during the site visit will not be attributed to your facility by name in any published reports without your expressed permission.

I will contact you again by phone next week to find out if it would be possible for you to participate in this study, and to answer any questions that you may have about the project. I will use the phone number listed in the EIA767 database to contact you: **(xxx) xxx-xxx, Ext. xxx**. I would greatly appreciate it if you would let me know as soon as possible if a different phone number would be more appropriate. You can contact me at 618-453-6023, or <*tombik@siu.edu*>. Finally, if it would be more appropriate to send this request to a different person at your facility, could you please pass this letter along to that person, and then let me know who I should contact.

Thank you again for taking the time to consider participating in this project. We anticipate that the final results of this study will be of considerable value to the managers of the more than 1,000 thermoelectric generating facilities across the country.

Sincerely,

Tom Bik, Researcher
Geography Department Southern Illinois University Carbondale
Phone: 618-453-6023; Fax: 618-453-6465; tombik@siu.edu

This project has been reviewed and approved by the SIUC Human Subjects Committee. Questions concerning your rights as a participant in this research may be addressed to the Committee Chairperson, Office of Research Development and Administration, Southern Illinois University Carbondale, IL 62901-4709. Phone: (618) 453-4533; E-mail: ***siuhsc@siu.edu*** .

ON-SITE INTERVIEW MEMORANDUM

Site Visit #1

Re-circulating Cooling System with Ponds or Canals

1. **Layout:** Four large pumps withdraw cooling water from a man-made reservoir. After leaving the condensers (heat exchangers) water is returned to the lake at a point 100 yards from the intake pumps. However the water must travel around a little peninsula to come back to intake pump (at least several hundred yards). From the pipes of the once-through cooling system water is taken to serve other purposes such as boiler feed, wet scrubbers, deluge system (fire control), and ash handling.

2. **Determinants of water flow:** The cooling load is the primary determinant of the cooling water flow. A manometer on the exhaust of each turbine shows the actual "back pressure" which should be between 2 and 3 inches of mercury for optimal turbine operation. A low back pressure is better but when it is too low the valves on discharge pipes from the condenser are "pinched" (i.e., throttled) to reduce flow. When the back pressure is increasing, the valves are being open and more water is pumped through the system). At the maximum flow and when the lake water is warm, the back pressure can reach 7 inches Hg, at which point the turbine trips off.

3. **Flow measurement:** The volume of flow is measured by correlating the current flow (in amperes) to flow based on pump characteristics. The amperage is recorded continuously for each pump on the computer in the control room. All other uses of water are estimated. The flow of water from ash handling is metered once a week (gallons per minute) and is reported as part of the NPDES permit. It represents a couple of millions of gallons per day (mgd) of water discharged to the creek below the dam. It is unclear if the auxiliary uses of water are subtracted from the intake volume. No estimation of the forced lake evaporation is conducted.

4. **Terminology:** One concern of the interviewee was the application of the term water use. He suggested using "water pumpage." In his view, water use pertains more to consumptive use, i.e., the amount of water that is being lost due to evaporation.

5. **Other issues:** The interviewee has agreed to review the draft mail survey questionnaire.

ON-SITE INTERVIEW MEMORANDUM
Site Visit #2
Closed-Loop Cooling System with Cooling Towers

1. **Layout:** Three pumps on three wells deliver makeup cooling water do the recirculating system with forced draft (fans on top). The wells are located on property and are 120-140 ft deep in the alluvium. The rated pumping capacity is 2,500 gtpm on each well. Approximately 75,000 gpm (gallons per minute) of water is circulated within the cooling system (using three large 50% pumps at the base of the cooling tower (with 14 independent sections each with a fan). From the pipes of the cooling system water is taken to serve other purposes such as cooling of bearings and cooling of gas hydrogen to cool the turbine shaft bearings. Some blow-down water is reused is the hydraulic transportation of bottom ash.

2. **Determinants of water flow:** The cooling load is the primary determinant of the cooling water flow. When generation is lower than less water is evaporated and less make-up water is needed. Another factor affecting the volume of make-up water is the quality of groundwater. The high contents of iron (14 mg/L) and manganese affects the maximum conductivity of the recirculating cooling water before it has to be bled off. The makeup water is generally flowing at 2,000 to 3,000 gpm (right at the return water tank at cooling towers). The maximum conductivity of the circulating water is maintained between 1,200 and 1,300 μS (micro simmens).

3. **Flow measurement:** The volume of flow is measured at the well pumps with integrating meters (Magflow make). Monthly records of flows are available. All other flows of water are estimated. Some blow-down and ash handling water is discharged to the environment is reported as part of two NPDES permits. It represents a couple of millions of gallons per day (mgd) of water discharged to the ditch. All the auxiliary uses of water are subtracted from the intake volume (make-up water). There are also elbow flow meters on the condensers but these are used only to optimize the cooling performance of the condensers.

4. **Terminology:** The interviewee has never used a ratio of water use to generation (i.e., gal/kWh) but he thinks it is a useful measure of efficiency.

5. **Other issues:** The speed of the shaft is kept constant at 3600 rpm. When reducing electric load per hour, some valves on steam/water could be adjusted. The generation is adjusted by electro-magnetic control on the generator coils. The interviewee has agreed to review the draft mail survey questionnaire.

ON-SITE INTERVIEW MEMORANDUM
Site Visit #3
Once Through Cooling System

1. **Layout:** There are 20 pumps (54,000 gpm each) on the condenser deck that pump approximately 1.1 to 1.2 million gpm of water from a large river (during winter) through the once-through cooling system. The 20 pumps are connected to 10 condensers – two pumps per condenser. When river levels are lower in the summer pumping declines to 800,000 to 900,000 gpm because the water level in the "wet box" affects the pumping head and the raw water pumps cannot keep the usual discharge rate. A dam and lock that are under construction will eventually raise the water level of the river and resolve this problem.

2. **Determinants of water flow:** As in other steam plants, the need to maintain low "backpressure" determines the amount of pumping of the cooling water. Although the system is design to operate with one pump per condenser, usually two pumps are turned on to keep the backpressure lower and the cost of energy for additional pumping is more than offset by the increase in electric generation. There are no limitations on the temperature of the return flow. The only condition is on the amount of waste head to be discharged to the river which is 8,000 MBtu/hour. This amount of heat is never generated by the plant. The plant has been recently operated as a "swing plant" with an automatic "governor" control to adjust the amount of generation over time. This is done by changing the flow of hot steam to the turbines.

3. **Flow measurement:** Some flow measurement is done by the DP method (differential pressure) on the outlet water box. Recently a dye tests were done to determine flows and to calibrate a Pitot tube with a copper coil. Generally the flows are estimated based on the number of hours of pumping.

4. **Other issues:** The interviewee agreed to review the draft mail survey questionnaire.

ON-SITE INTERVIEW MEMORANDUM
Site Visit #4
Re-circulating Cooling System with Ponds or Canals

1. **Layout:** Three pumps located on a nearby river (14,000 gpm each) deliver river water into a man-made reservoir. The cooling system draws water from this reservoir (a perched 2,000-acre, 12-foot deep cooling pond). The rated pumping capacity of each of the nine pumps (in three cribs) is 132,000 gpm. On the date of the site visit, the inlet water temperature (lake water) was 54 ºF and the return flow temperature was 76 ºF. The lake never freezes. Some water is also taken for cooling of bearings and pumps and for fire protection. Also, water is taken from the lake for the boiler make-up and this water is de-mineralized (down to 0.1 µS on boiler #2 and down to 0.08 µS on boiler #3, theoretical limit is 0.0055 µS). Water used for sluicing ash is discharged to the river under NPDES.

2. **Determinants of water flow:** The cooling load is the primary determinant of the cooling water flow. When generation is lower, less water is needed. The pumps do not have any regulating valves, so to regulate flow individual pumps are turned on and off. Usually all pumps are run during the summer. The speed of the shaft is kept constant at 3,600 rpm. When reducing electric load per hour, the generation is adjusted by electro-magnetic control on the generator coils. There are no limitations on withdrawals from the nearby river; however, pumps were turned off last July 4 to preserve river flow for boaters. The sufficient river flow for intake pumps is guaranteed by state department that regulates an upstream reservoir.

3. **Flow measurement:** The volume of flow is measured based on the hours of pump operation. Monthly records of flows are available. The average annual flow rate of 50 cfs on the EIA is incorrect. The interviewee provided calculation sheets (with data from 1992 to 2004) that indicate that for 2003, the total cooling water withdrawal was 439,084,800,000 gallons and the total generation was 13,090,406,030. This implies the unit uses 33.5 gal/kWh.

4. **Other issues:** The interviewee has agreed to review the draft mail survey questionnaire. Efficient water use is not a primary concern in the operations. One important concern is how to keep the net generation tighter (i.e., closer) to gross generation. For example the gross on one of the units is 605 MWh and net is 605 MWh. On Unit #2 these are 635 MWh and 605 MWh, respectively. The difference between these two is energy used within the plant especially for electrostatic precipitator and running water pumps. The total cost of power generation at the plant is $14/MWh. Of this, $11/MWh is the cost of fuel (coal). There is no data on the cost of pumping the cooling water. The cost of water treatment for boiler feed is $132,000 per year.

ON-SITE INTERVIEW MEMORANDUM
Site Visit #5
Once Through Cooling System

1. **Layout:** The plant uses 5 million tons of coal per year, approximately one unit train of coal per day. It is one of the "cheapest" plant in the country to operate ($/generation). The plant is a "base load" facility and operates at capacity as much as possible (at 83 to 86 percent). The plant was designed to be efficient and highly reliable. Cooling water flows from 12 pumps in 2 inlet bays (8/4) and feed 6 condensers. There are also 6 "service water" pumps (or feeds) off of river water intake lines for non-cooling plant uses (washing, bearing cooling); this water is returned to river (untreated??). The plant has two water storage tanks (towers): one for "service water" and the other for water from a nearby PWD for drinking/sanitation. Water for boiler feed is from a separate source: 4 deep wells. This water is treated (de-mineralized) before use. Boiler make-up water consumption is greater than 1mgd (more than 100 mg/year per well).

2. **Determinants of water flow:** The quantity of cooling water is based upon operational requirements of the boiler-generator-cooling system to optimize electric generation. Pumps are costly (in energy) to operate and are turned off when not needed. ("Excess pumping leads to a sub-optimal generation situation"). Generators operate as close to 100 percent as possible at all times (generally between 1,050 and 1,100 MW). The facility reports the average gross maximum generation (highest generation per month) to the state environmental regulatory agency (NPDES discharge monitoring report). "Except for cost of pumping" the facility faces no constraints on the quantity of water use. There is no way to alter water use at this facility other than to change the design of plant components. "Management" techniques could not be used to alter water use.

3. **Flow measurement:** Water cooling "use" calculations are done by estimation, based upon pumping capacity and hours of pump operation. Water use estimates are based on net reported generation estimates, even though the cooling is taking place for the gross amount of energy generated. Interviewee did not have any suggestions for determining the gross generation of plant or other facilities based on EIA-767. He agreed that on-site electric use could be significant as some plants (i.e., those with electrostatic precipitators). The "average" cfs flows reported in EIA-767 is an average of the summer and winter operations. Water "consumption (cfs)" estimate on EIA-767 is calculated as the difference between withdrawal and discharge (by direction on the form). Interviewee noted that "all of the water eventually ends up back in the river." Not clear how the withdrawal or discharge flows are measured. The operators monitor "screen velocity" to prevent fish kills at intakes per CWA 316B and keep it below 0.5 ft/second.

5. **Other issues:** The plant participates in a voluntary state water quantity monitoring program. They provided a copy of the 2003 form. This form reports estimated withdrawals in MGD as well as total (combined for all units) annual power generation. NPDES permits: temperature of discharge is "not even stated in permit"; gross generation is reported on NPDES form. Noted that plants farther up-river had to install cooling

towers because there is less flow upstream of input of secondary rivers. The interviewee could not provide any suggestions on how to increase survey returns. He did give example of "getting into trouble" by releasing information (unclear how). He was not optimistic about participation of power plant personnel in any type of voluntary survey.

APPENDIX C

SURVEY COVER LETTER, SURVEY FORMS AND TABLES

INTRODUCTION

This appendix presents the survey forms and tables that were used to conduct the survey component of this study. The eight cooling systems types that are designated in the Form EIA-767 were collapsed into three general categories for the purpose of the survey:

1. OX = Once-Through Cooling Systems;
2. RC = Recirculating Cooling Systems with Ponds and Canals; and
3. RX = Closed –Loop Cooling Systems with Cooling Towers.

The assignment of each cooling system type to a survey category is shown in Table B.1.

Table B.1 Assignment of Cooling Types to Survey Categories

Cooling System Type Description	Cooling System Type Code	Survey Category
Once through, fresh water	OF	OX
Recirculating with forced draft cooling tower(s)	RF	RX
Recirculating with induced draft cooling tower(s)	RI	RX
Once through, saline water	OS	OX
Recirculating with cooling pond(s) or canal(s)	RC	RC
Recirculating with natural draft cooling tower(s)	RN	RX
Once through with cooling pond(s) or canal(s)	OC	OX
Other types	OT	Not included

While the general form of the survey was the same for all survey categories, the “check-off” responses differed slightly for each category, resulting in three versions of the survey.

Several questions on each survey asked respondents to compare their own estimates of water use at their facility to a water use coefficient (gal/kWh) that had been calculated from the data available in the 2003 Form EIA-767, as well as to compare water use at their facility to that of others with similar cooling systems. These coefficients were presented in the form of a table. Because information for nuclear power generating facilities was last available in the 2000 Form EIA-767, a separate table was prepared for these facilities.

A cover letter was sent as an email attachment to all Form EIA-767 managers. The cover letter, three sets of surveys, and six coefficient tables appear on the following pages. Please note that these coefficients may not represent actual water use at these facilities.

Appendix C
COVER LETTER FOR EMAIL SURVEY

Subject Line: *Request for your participation in a study of power plant water use*

Contact Name
Power Plant Name/Plant Owner Name
City, State

Dear Contact Name:

I am writing to request your help in a study of power plant water use. This study is sponsored by National Institutes of Water Resources (NIWR) and is being conducted by researchers from Southern Illinois University Carbondale (SIUC). This research will examine how water is used, and the way that this water use is measured at power plants across the country.

You have received this email message and attached survey form because you are identified as the "contact person" on the Energy Information Administration's *Form EIA-767*, for the year 2003.

Attached to this email message is a short survey in the form of a Microsoft Word document. The questions on the survey ask about the measurement of generation and water use at your facility. A large table of power plant generation and water withdrawals is included with the survey, and you will also be asked to compare water use at your facility to that of other plants throughout the country.

If it would be more appropriate for another person at your facility to respond to this survey, please forward this email message and attachment to that person immediately. Or, if your utility operates more than one generating facility, please forward this message to the persons who are most knowledgeable about generation and water use measurement at each facility.

The survey will take about 15 or 20 minutes to complete. Please complete and return the survey to us as soon as possible. If you would prefer to respond using a paper copy of the survey, please let us know by sending a brief reply to this email. If you did not receive, or cannot open the survey attachment, copies of the survey are also available on the SIUC Geography Department website at: *http://www.geography.siu.edu/Research/research.html*

Your responses to this survey will be treated with confidentiality, and individual survey responses will not be attributed to either power utilities or responding individuals, without expressed written permission. The findings from this survey will be used in the development of water usage benchmarks for cooling systems at power generation facilities. A *Project Completion Report* will be prepared for NIWR, and will be available on SIUC Geography Department websites. Copies of the *Executive Summary* of this report will be emailed to all survey participants.

Your participation in this study will greatly enhance our ability to produce a meaningful analysis of thermoelectric water use in the U.S. However, participation in this study is voluntary, and you are under no obligation to participate. If for any reason your facility is unable to participate in this survey, please notify me immediately by sending a brief reply to this email. Your response will prevent us from sending you follow-up mailings requesting your participation.

If you have any questions about the survey or the research project, please contact me at (618) 453-6021, or by email at: wateruse@siu.edu. Thank you for taking the time to consider participating in this research study.

Sincerely,

Ben Dziegielewski, Professor
Department of Geography and Environmental Resources
Southern Illinois University Carbondale

This project has been reviewed and approved by the Southern Illinois University Human Subjects Committee. Questions concerning your rights as a participant in this research may be addressed to the Committee Chairperson, Office of Research and Development Administration, Southern Illinois University, Carbondale, IL 62901-4709; Phone: (618) 453-4533.

National Survey of Water Use at Thermoelectric Power Plants

A research project sponsored by the

National Institutes for
Water Resources

conducted by the

Department of Geography and
Environmental Resources
Southern Illinois University Carbondale

Purpose

This survey is one part of a research project to study power plant water withdrawals and consumptive use in the United States. The purpose of this research is to improve the understanding of power plant water use and to develop benchmarks that will facilitate water use evaluations by generation facility managers. A complete description of this project is available on the web site of the National Institutes of Water Resources: *http://water.usgs.gov/wrri/04grants/national/nationalindex.html*.

Instructions

This survey consists of 14 questions. Please read each question carefully and provide answers based upon your understanding of the water use operations at your generating facility and the power generation industry as a whole. Answer each question by checking the appropriate boxes or typing in a brief response. Please note that the number of pages may increase as you complete the questionnaire, but this will not affect our ability to properly record your answers.

A comments section is included at the end of this form, and any comments that you may have would be welcomed. *Please return your survey by saving the completed file and attaching it to a reply email message*.

If you have any questions about this survey or the research project, please contact Ben Dziegielewski at (618) 453-6021, or by email at: *wateruse@siu.edu.*

This project has been reviewed and approved by the Southern Illinois University Human Subjects Committee. Questions concerning your rights as a participant in this research may be addressed to the Committee Chairperson, Office of Research and Development Administration, Southern Illinois University, Carbondale, IL 62901-4709; Phone: (618) 453-4533. There is no penalty for not participating in this survey.

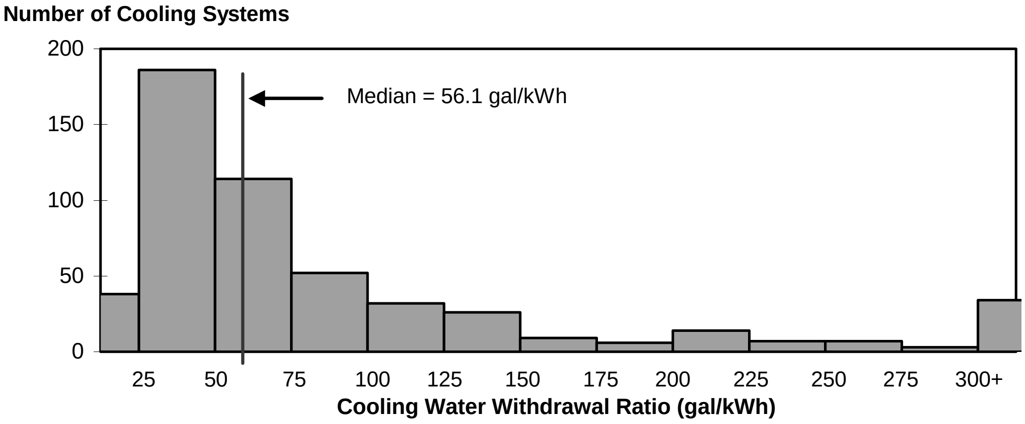
COOLING WATER WITHDRAWALS AND MEASUREMENT

Using the data reported in the *Form EIA-767* for the year 2003, the ratio of annual cooling water withdrawals (gallons) to net electric generation (kilowatt-hours) was calculated for the **584 *once-through cooling systems*** for which sufficient data was available. A table listing these ratios by power plant names and cooling systems IDs is available for viewing and download from:
http://info.geography.siu.edu/projects/ThermoSurvey/NationalSurveySupport.mht

More than half of these once-through cooling systems used between 25 and 75 gallons/kWh; however, there is a wide range of estimated ratios. The distribution of the number of systems by cooling system ratio appears in the chart below.

Where necessary, please refer to this chart and the table at the end of the survey to respond to the following questions.

Ratio of Annual Cooling Water Withdrawals to Generation at Power Plants Using Once-Through Cooling (2003)



Source: Department of Energy: Form EIA-767 (2003)

Q1. The Form EIA-767 requires facilities to report the average annual rate of cooling water withdrawals. How is this measure calculated or estimated for the cooling systems at your facility? (please check/write in one response)

☐ Measuring devices provide constant monitoring of flow rates, which are then averaged
☐ Cooling water system pump capacity is multiplied by the total annual time of operation
☐ Other (*please specify*):

____

Q2. Please find the withdrawal ratios for the cooling system(s) at your facility in the table of cooling system ratios that is available. Do the ratios that were calculated for your cooling systems appear to be correct?

☐ **Don't know**, we are not able to estimate the ratio of cooling water withdrawals to net generation at our facility
☐ **Yes**, the ratio(s) for our facility are consistent with our own estimates
☐ **No**, these ratios do not accurately represent cooling water use at our facility.

A more accurate estimate of the gallons of water withdrawals per kilowatt-hours of generation can be the determined by: (*please specify more accurate data or calculation method*):

____

Q3. Please refer to the chart on the previous page. Do the estimated cooling water withdrawal ratios for the cooling systems at your facility differ significantly from the 56.1 gal/kWh median value for once-through cooling systems? If so, what do you think are the principal reason(s) for this difference?

☐ **No**, the ratio(s) for our facility do not differ significantly from the median value
☐ **Yes**, the water withdrawals of the cooling system(s) at our facility differ significantly from the national average for once-through cooling system because: (*please specify*):

____

Q4. What plant- or system-specific characteristics or conditions do you think contribute to the wide range of once-through cooling system withdrawals ratios that are evident in the figure above and in the table of cooling water withdrawal ratios? (check all that apply and/or write in other relevant factors)

☐ Differences in the way that cooling water withdrawals are estimated or reported
☐ Differences in the ratio of net-to-gross generation at each facility
☐ Differences in the designed temperature rise of the condenser(s) in use at each facility
☐ Differences in maintaining optimal turbine "backpressure" that affect water flow
☐ Differences in the frequency and length of time of boiler/generator shutdowns
☐ Differences in other conditions/circumstances: (*please specify*):

____

Q5. Water consumption is defined in EIA-767 as the difference between cooling water withdrawal and discharge. Is it possible to measure or estimate cooling water consumption at your facility?

☐ **No,** it is not possible to measure or estimate consumptive use of water because: (*check all that apply or write in other applicable reasons*):

  ☐ No cooling water discharge measuring devices are available
  ☐ Estimates of discharge based upon equipment characteristics are not possible
  ☐ Other (*please specify*):

  ____

☐ **Yes,** cooling system water consumption was measured (or estimated) at our facility using the following method:

____

Q6. What are some of the possible sources of cooling water consumptive use at facilities using once-through cooling systems? (check all that apply and/or write in relevant factors)

☐ There is no measurable consumptive water use in once-through cooling systems
☐ Significant amounts of cooling water are diverted to other uses in some facilities where the diverted water is lost or evaporated
☐ Inaccurate estimation procedures for cooling systems discharge flow rates (used to calculate consumption) result in inflated estimates of consumptive use
☐ Frequent starting up and shutting down of the generators increases consumptive use because steam is vented to the atmosphere when the boiler is started up and shut down
☐ Other conditions/circumstances: (*please specify*)

____

Q7. Are there any non-cooling water needs at your facility that use water from the cooling system?

☐ **No,** all reported cooling water withdrawals are used only for generation process cooling
☐ **Yes,** there are some non-cooling diversions of water from the cooling water system.
These include: (*please describe and estimate quantity of each use*):

Use 1: _______________ Quantity: _____ mgd/yr
Use 2: _______________ Quantity: _____ mgd/yr
Use 3: _______________ Quantity: _____ mgd/yr

Q8. Form EIA-767 requires that power plants report NET GENERATION for each generator. How is NET GENERATION calculated for the generators at your facility? (please check one and/or write in response)

☐ Metering is available to measure both the gross generation and the service load energy for each generator
☐ Plant–level generation is metered as it is delivered to the grid. Generation for each generator is estimated based on hours of operation or other operational measures. Net generation is calculated by deducting a portion of the total plant service load from the estimated production of each generator.
☐ Service load energy is estimated and deducted from the metered gross generation of each generator unit
☐ Other measurement or estimation procedure (*please specify*):
____

Q9. Does your facility maintain a record of GROSS GENERATION for EACH generator at your POWER PLANT? If so, approximately what percent of gross generation on annual basis does net generation represent at your facility? (please check one and/or write in response)

☐ **Yes,** records of gross generation for each generator ARE available.
On an annual basis, net generation is equal to approximately   % of gross generation
☐ **No,** it is not possible to measure or record gross generation for each generator
☐ Other (*please specify*):
____

Q10. Does your facility measure and record the ANNUAL TOTAL WATER WITHDRAWALS for your facility?

☐ **Yes,** records of total water withdrawals ARE available.
☐ **No,** it is not possible to measure total withdrawals for our facility
☐ Other (*please specify*):
____

Q11. Are there any constraints to cooling water withdrawals at your plant? (please check all that apply)

☐ Volume limitations mandated under NPDES
☐ Temperature limitations mandated under NPDES
☐ Water withdrawals are fixed under State permitting requirements
☐ High summer water temperatures and/or low flows in the source may require generation reductions to prevent overheating
☐ Other limitation (*please specify*):

____

Q12. Do you currently use any "alternative" sources of water at your plant? (please check all that apply)

☐ **No**
☐ **Yes**, these include:
  ☐ Recycled water from ash ponds
  ☐ Municipal wastewater
  ☐ Brackish groundwater from oil/gas generation
  ☐ Water from mine dewatering operations
  ☐ Other alternative sources (*please specify*):

____

Q13. If water intake from your current source had to be reduced in response to severe weather conditions or regulatory restrictions, what actions could be taken at your plant to respond to these conditions? (please check all that apply and/or add additional alternatives)

☐ Reduce generation
☐ Install cooling towers
☐ Operate generators at less than optimal back pressure
☐ Obtain supplemental intake waters from other sources (including recycled water)
☐ Alter cooling water intakes and/or outflows structures to improve cooling system efficiencies
☐ Other adjustments (*please specify*):

____

RESPONDENT INFORMATION

Q14. What is the NAME and Plant ID number of your power plant?

Plant Name: _________
Plant ID #: __________

What is your title and water management responsibilities? ***(optional)***

Title: ____

Plant water management responsibilities: (*please check all that apply*)

☐ Complete Form EIA-767
☐ Complete NPDS forms
☐ Record water use data
☐ Manage cooling controls
☐ Monitor plant water use
☐ Make decisions on in-plant water management
☐ Other: ____

If you would be willing to discuss water use at your facility with us via phone or email, please enter your contact information below:

Name: _________

Phone: _________

Email: _________

COMMENTS AND SUGGESTIONS

Please use the space below to communicate any concerns or comments regarding this study, or contact Ben Dziegielewski at 618-453-6021, or by email at: wateruse@siu.edu .

Thank you for responding to this survey.

PLEASE SAVE YOUR COMPLETED SURVEY DOCUMENT
TO THE DESKTOP OF YOUR COMPUTER.

RETURN THE SURVEY BY ATTACHING IT TO A REPLY TO OUR COVER LETTER,
OR SEND A NEW MESSAGE TO: *wateruse@siu.edu.*

Once completed, the final project report for this study will be available on the research page of the SIUC Geography Department:: *http://info.geography.siu.edu/Research/research.html* .

Water Withdrawals, Generation and Unit Water Withdrawals: Power Plants with Once-Through Cooling Systems
- 2003 -

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Withdrawal Ratio (gallons/KWh)*
3	Barry	AL	1-3	409.7	3,345.5	44.7
3	Barry	AL	4-5	565.5	8056.1	25.6
7	Gadsden	AL	1-2	170.0	590.2	105.1
8	Gorgas	AL	10	433.6	4,871.5	32.5
8	Gorgas	AL	5-7	255.9	1,129.8	82.7
8	Gorgas	AL	8-9	288.9	1,946.9	54.2
10	Greene County	AL	1-2	324.4	3,553.3	33.3
47	Colbert	AL	1	1,231.8	7,192.9	62.5
50	Widows Creek	AL	1	1,510.3	9,521.2	57.9
56	Charles R Lowman	AL	1	78.8	582.4	49.4
170	Lake Catherine	AR	3	7.1	2.9	897.2
170	Lake Catherine	AR	4	306.3	468.8	238.5
173	Robert E. Ritchie	AR	1	36.2	12.4	>1,000.0[2]
173	Robert E. Ritchie	AR	2	10.3	0.0	>1,000.0[2]
202	Carl Bailey	AR	01	60.1	62.0	353.8
228	Contra Costa	CA	6	20.0	56.2	130.2
228	Contra Costa	CA	7	107.3	484.7	80.8
246	Humboldt Bay	CA	1	37.5	126.0	108.6
246	Humboldt Bay	CA	2	37.5	89.0	153.8
247	Hunters Point	CA	4	126.0	305.8	150.4
259	Morro Bay Power Plant	CA	1	67.9	3.8	>1,000.0[2]
260	Moss Landing Power Plant	CA	6	226.2	554.5	148.9
271	Pittsburg Power[2]	CA	2	5.2	0.7	2564.0
271	Pittsburg Power	CA	5	148.6	740.8	73.2
271	Pittsburg Power	CA	6	55.6	197.9	102.5
273	Potrero Power	CA	3	208.7	825.0	92.4
302	Encina	CA	1	22.0	114.5	70.0
302	Encina	CA	2	25.9	141.3	66.8
302	Encina	CA	3	35.5	203.5	63.8
302	Encina	CA	4	240.4	886.2	99.0
302	Encina	CA	5	234.0	1095.2	78.0
310	South Bay Power Plant	CA	1	398.1	406.3	357.6
315	AES Alamitos LLC	CA	1	873.1	124.2	>1,000.0[2]
330	El Segundo Power	CA	1	61.4	696.3	32.2
330	El Segundo Power	CA	3	224.9	696.3	117.9
335	AES Huntington Beach LLC	CA	1	305.0	1723.7	64.6
350	Ormond Beach	CA	1	698.0	1819.2	140.0
356	AES Redondo Beach LLC	CA	5	67.9	118.7	208.6

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Withdrawal Ratio (gallons/KWh)*
356	AES Redondo Beach LLC	CA	6	67.9	26.1	950.4
356	AES Redondo Beach LLC	CA	7	138.9	530.4	95.6
356	AES Redondo Beach LLC	CA	8	138.9	361.8	140.2
400	Haynes	CA	1	69.2	597.2	42.3
400	Haynes	CA	2	69.2	436.8	57.8
400	Haynes	CA	3	69.2	36.8	686.0
400	Haynes	CA	4	69.2	66.7	378.7
400	Haynes	CA	5	115.0	1020.4	41.1
400	Haynes	CA	6	115.0	308.2	136.2
404	Scattergood	CA	CW12	358.0	873.9	149.5
544	Devon Station	CT	7	46.5	267.0	63.6
546	Montville Station	CT	5	75.0	45.6	600.3
546	Montville Station	CT	6	245.6	203.5	440.6
548	NRG Norwalk Harbor	CT	1	33.0	136.3	88.3
548	NRG Norwalk Harbor	CT	2	34.9	147.2	86.5
562	Middletown	CT	2	66.6	56.5	430.2
562	Middletown	CT	3	109.9	321.8	124.6
568	Bridgeport Station	CT	BHC2	55.6	19.5	>1,000.0[2]
568	Bridgeport Station	CT	BHC3	266.3	2613.0	37.2
594	Indian River Operations	DE	1	108.6	379.4	104.4
594	Indian River Operations	DE	2	108.6	354.7	111.7
594	Indian River Operations	DE	3	157.7	674.1	85.4
609	Cape Canaveral	FL	1CWS	297.9	1701.8	63.9
609	Cape Canaveral	FL	2CWS	305.7	1724.1	64.7
610	Cutler	FL	5CWS	19.4	96.2	73.6
610	Cutler	FL	6CWS	67.9	293.8	84.3
617	Port Everglades	FL	1CWS	140.9	699.3	73.5
617	Port Everglades	FL	2CWS	109.2	566.9	70.3
617	Port Everglades	FL	3CWS	283.1	1571.4	65.8
617	Port Everglades	FL	4CWS	273.4	1566.3	63.7
619	Riviera	FL	3CWS	162.2	926.4	63.9
619	Riviera	FL	4CWS	255.3	1474.4	63.2
620	Sanford	FL	3CWS	87.9	379.7	84.5
628	Crystal River	FL	1	324.4	2494.5	47.5
628	Crystal River	FL	2	369.7	2849.5	47.4
634	P L Bartow	FL	1	327.0	2281.0	52.3
638	Suwannee River	FL	1	208.1	465.1	163.3
643	Lansing Smith	FL	1	217.1	1849.4	42.9
645	Big Bend	FL	OTC1	-	2117.5	-[1]
645	Big Bend	FL	OTC2	-	2018.5	-[1]
645	Big Bend	FL	OTC3	-	1986.7	-[1]
645	Big Bend	FL	OTC4	-	2482.7	-[1]
646	F J Gannon	FL	OTC1	-	122.1	-[1]
646	F J Gannon	FL	OTC2	-	132.1	-[1]
646	F J Gannon	FL	OTC3	-	555.0	-[1]

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Estimated Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Withdrawal Ratio (gallons/KWh)***
646	F J Gannon	FL	OTC4	-	445.9	-[1]
646	F J Gannon	FL	OTC5	-	73.3	-[1]
646	F J Gannon	FL	OTC6	-	1165.8	-[1]
658	Henry D King	FL	7	64.6	1.8	>1,000.0[2]
667	Northside Gen. Station	FL	1	113.7	1589.5	26.1
667	Northside Gen. Station	FL	2	122.1	1636.8	27.2
667	Northside Gen. Station	FL	3	104.0	1460.3	26.0
693	Vero Beach Municipal PP	FL	1	3.9	0.5	>1,000.0[2]
693	Vero Beach Municipal PP	FL	3	25.9	3.7	>1,000.0[2]
708	Hammond	GA	1	95.0	559.6	62.0
708	Hammond	GA	2	94.4	570.0	60.4
708	Hammond	GA	3	103.4	655.9	57.5
708	Hammond	GA	4	190.7	2755.1	25.3
710	Jack McDonough	GA	MCS1	193.9	1748.0	40.5
710	Jack McDonough	GA	MCS2	188.1	1727.0	39.7
715	McManus	GA	1	18.7	9.2	745.3
727	Mitchell	GA	1	148.6	546.2	99.3
728	Yates	GA	Y1CS	103.4	465.1	81.2
728	Yates	GA	Y2CS	109.9	476.2	84.2
728	Yates	GA	Y3CS	73.0	401.2	66.4
728	Yates	GA	Y4CS	76.9	599.2	46.8
728	Yates	GA	Y5CS	81.4	620.3	47.9
733	Kraft	GA	1	49.1	1355.6	13.2
734	Riverside	GA	1	48.5	0.1	>1,000.0[2]
764	Honolulu	HI	8	51.7	12.3	>1,000.0[2]
765	Kahe	HI	1-6	816.2	3393.0	87.8
766	Waiau	HI	3	46.5	47.2	359.9
766	Waiau	HI	5	88.5	97.0	333.2
766	Waiau	HI	7	176.4	417.9	154.1
856	E D Edwards	IL	1	371.0	514.7	263.0
863	Hutsonville	IL	02	84.7	710.2	43.5
864	Meredosia	IL	01	28.4	86.0	120.7
864	Meredosia	IL	02	30.4	88.3	125.5
864	Meredosia	IL	03	86.6	796.2	39.7
867	Crawford	IL	7	462.1	927.3	181.9
874	Joliet 9	IL	6	407.2	1661.9	89.4
883	Waukegan	IL	6	718.7	396.3	661.9
884	Will County	IL	3	643.0	975.8	240.5
886	Fisk Street	IL	19	187.4	1538.2	44.5
887	Joppa Steam	IL	1-4	378.7	5349.6	25.8
887	Joppa Steam	IL	5-6	173.2	2751.4	23.0
891	Havana	IL	1	1264.8	35.8	>1,000.0[2]
892	Hennepin Power Station	IL	1	229.4	1764.8	47.5
898	Wood River	IL	1	215.2	2752.3	28.5
963	Dallman	IL	31	156.4	408.9	139.6

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Estimated Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Withdrawal Ratio (gallons/KWh)***
963	Dallman	IL	33	84.7	957.1	32.3
976	Marion	IL	1-4	104.0	1490.3	25.5
981	State Line Energy	IN	3	232.7	1117.5	76.0
981	State Line Energy	IN	4	252.0	1869.5	49.2
983	Clifty Creek	IN	1	1137.4	1192.8	348.1
988	Tanners Creek	IN	U1	458.9	823.6	203.4
988	Tanners Creek	IN	U4	298.6	2462.5	44.3
990	Harding Street	IN	3	1.3	0.9	523.6
990	Harding Street	IN	4	1.3	0.5	>1,000.0[2]
994	AES Petersburg	IN	1	154.5	1710.9	33.0
995	Bailly	IN	78	243.0	2302.9	38.5
1008	R Gallagher	IN	1	108.6	742.3	53.4
1008	R Gallagher	IN	2	108.6	710.1	55.8
1008	R Gallagher	IN	3	108.6	764.9	51.8
1008	R Gallagher	IN	4	108.6	751.5	52.7
1010	Wabash River	IN	1	89.2	1090.1	29.9
1010	Wabash River	IN	2	89.2	599.6	54.3
1010	Wabash River	IN	3	89.2	593.6	54.8
1010	Wabash River	IN	4	89.2	492.9	66.0
1010	Wabash River	IN	5	102.1	640.9	58.2
1010	Wabash River	IN	6	212.6	1995.9	38.9
1012	F B Culley	IN	1	41.4	179.4	84.2
1012	F B Culley	IN	2	98.2	509.9	70.3
1012	F B Culley	IN	3	177.7	1805.2	35.9
1043	Frank E Ratts	IN	1CW	184.2	735.7	91.4
1047	Lansing	IA	2	6.5	1.0	>1,000.0[2]
1047	Lansing	IA	3	20.0	136.0	53.8
1047	Lansing	IA	4	87.9	1129.6	28.4
1048	Milton L Kapp	IA	1	3.2	1.6	716.6
1048	Milton L Kapp	IA	2	124.7	1184.8	38.4
1073	Prairie Creek	IA	1	229.4	988.9	84.7
1081	Riverside	IA	2	92.4	646.1	52.2
1082	Council Bluffs	IA	1	32.3	247.6	47.6
1082	Council Bluffs	IA	2	43.9	564.0	28.4
1082	Council Bluffs	IA	3	383.2	5334.7	26.2
1091	George Neal North	IA	2	245.6	1790.7	50.1
1091	George Neal North	IA	3	331.5	3570.5	33.9
1104	Burlington	IA	1	101.5	1276.8	29.0
1167	Muscatine Plant #1	IA	7	39.4	102.3	140.6
1167	Muscatine Plant #1	IA	8	63.3	276.8	83.5
1167	Muscatine Plant #1	IA	9	107.3	1032.8	37.9
1241	La Cygne	KS	1	394.2	4530.6	31.8
1241	La Cygne	KS	2	451.1	5225.9	31.5
1294	Kaw	KS	1	94.1	7.5	>1,000.0[2]
1295	Quindaro	KS	1	102.8	970.2	38.7

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Estimated Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Withdrawal Ratio (gallons/KWh)***
1357	Green River	KY	3	79.5	277.7	104.5
1357	Green River	KY	4	98.2	351.6	102.0
1361	Tyrone	KY	3	40.1	264.1	55.4
1363	Cane Run	KY	4	96.3	968.3	36.3
1363	Cane Run	KY	5	85.3	1035.9	30.1
1363	Cane Run	KY	6	146.1	1540.2	34.6
1364	Mill Creek	KY	1	7.1	1958.6	1.3
1374	Elmer Smith	KY	1	78.2	939.2	30.4
1374	Elmer Smith	KY	2	115.0	1548.2	27.1
1379	Shawnee	KY	1	1385.6	9037.7	56.0
1381	Kenneth C Coleman	KY	C1	270.1	976.3	101.0
1384	Cooper	KY	1	128.0	685.4	68.1
1384	Cooper	KY	2	255.3	1182.3	78.8
1385	Dale	KY	1	1.3	1201.2	0.4
1394	Willow Glen	LA	1	27.8	141.6	71.7
1394	Willow Glen	LA	2	39.4	182.4	78.9
1394	Willow Glen	LA	4	116.3	202.0	210.2
1394	Willow Glen	LA	5	100.8	263.7	139.6
1402	Little Gypsy	LA	1	140.2	479.5	106.7
1402	Little Gypsy	LA	2	210.7	394.6	194.9
1402	Little Gypsy	LA	3	230.1	459.2	182.9
1403	Nine Mile Point	LA	1	84.0	224.3	136.7
1403	Nine Mile Point	LA	3	82.7	136.3	221.5
1403	Nine Mile Point	LA	4	451.1	2318.2	71.0
1403	Nine Mile Point	LA	5	337.4	1897.6	64.9
1404	Sterlington	LA	3	1.3	363.9	1.3
1409	Michoud	LA	1	431.7	58.5	>1,000.0[2]
1496	Mason Stream	ME	2	0.6	0.2	>1,000.0[2]
1496	Mason Stream	ME	3	0.6	0.2	>1,000.0[2]
1496	Mason Stream	ME	4	1.9	0.2	>1,000.0[2]
1507	William F Wyman	ME	1	2.6	28.7	32.9
1507	William F Wyman	ME	2	2.6	31.6	29.8
1507	William F Wyman	ME	3	3.2	174.8	6.7
1507	William F Wyman	ME	4	6.5	998.6	2.4
1552	C P Crane	MD	1	384.5	1083.6	129.5
1553	Gould Street	MD	3	4.5	33.8	48.9
1554	Herbert A Wagner	MD	1	77.6	425.5	66.5[2]
1554	Herbert A Wagner	MD	4	77.6	425.5	66.5
1570	R Paul Smith Power Station	MD	3	40.7	76.2	195.1
1571	Chalk Point LLC	MD	1	261.1	1829.9	52.1
1571	Chalk Point LLC	MD	2	279.2	2050.7	49.7
1572	Dickerson	MD	1	116.3	925.7	45.9
1572	Dickerson	MD	2	119.6	834.3	52.3
1572	Dickerson	MD	3	129.9	991.4	47.8
1573	Morgantown Gen. Plant	MD	1	1204.7	4050.3	108.6

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Withdrawal Ratio (gallons/KWh)*
1573	Morgantown Gen. Plant	MD	2	1204.7	4079.8	107.8
1588	Mystic Gen. Station	MA	4	103.4	16.3	>1,000.0[2]
1588	Mystic Gen. Station	MA	5	113.7	10.2	>1,000.0[2]
1588	Mystic Gen. Station	MA	6	104.7	6.1	>1,000.0[2]
1588	Mystic Gen. Station	MA	7	382.6	1177.8	118.6
1589	New Boston Gen. Station	MA	1	120.2	199.1	220.3
1599	Canal	MA	1	208.7	2751.2	27.7
1599	Canal	MA	2	244.9	1832.4	48.8
1606	Mount Tom	MA	1	106.0	1075.7	36.0
1619	Brayton Point	MA	1	229.4	1630.6	51.4
1619	Brayton Point	MA	2	213.9	1849.7	42.2
1619	Brayton Point	MA	3	370.3	3929.1	34.4
1619	Brayton Point	MA	4	168.7	278.3	221.3
1626	Salem Harbor	MA	1	123.4	438.2	102.8
1626	Salem Harbor	MA	2	123.4	540.7	83.3
1626	Salem Harbor	MA	3	131.2	1066.8	44.9
1626	Salem Harbor	MA	4	227.5	332.4	249.8
1642	West Springfield	MA	3	1.3	98.3	4.8
1682	Cleary Food	MA	8	36.2	10.0	>1,000.0[2]
1695	B C Cobb	MI	1	231.4	6.2	>1,000.0[2]
1702	Dan E Karn	MI	1	303.1	1829.2	60.5
1710	J H Campbell	MI	1	677.3	2057.0	120.2
1720	J C Weadock	MI	7	242.4	1177.6	75.1
1723	J R Whiting	MI	1	185.5	730.7	92.7
1726	Conners Creek	MI	1	113.1	18.9	>1,000.0[2]
1731	Harbor Beach	MI	1	58.2	218.7	97.1
1733	Monroe	MI	1	376.8	4554.8	30.2
1733	Monroe	MI	2	376.8	4256.8	32.3
1733	Monroe	MI	3	376.8	4188.0	32.8
1733	Monroe	MI	4	376.8	5165.6	26.6
1740	River Rouge	MI	CWS	317.3	2780.5	41.7
1743	St Clair	MI	1	992.7	6500.1	55.7
1769	Presque Isle	MI	002	65.9	682.5	35.3
1769	Presque Isle	MI	003	73.7	844.7	31.8
1769	Presque Isle	MI	004	91.1	1468.1	22.7
1822	Mistersky	MI	5	25.9	70.6	133.7
1822	Mistersky	MI	7	52.3	172.7	110.6
1888	Fox Lake	MN	1	32.3	4.0	>1,000.0[2]
1888	Fox Lake	MN	3	52.3	131.7	145.1
1891	Syl Laskin	MN	CS1	133.8	643.3	75.9
1893	Clay Boswell	MN	CS1	143.5	848.5	61.7
1904	Black Dog	MN	1	228.1	1457.2	57.1
1912	High Bridge	MN	5	66.6	640.3	37.9
1912	High Bridge	MN	6	73.7	858.2	31.3
1927	Riverside	MN	200	56.9	921.9	22.5

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Estimated Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Withdrawal Ratio (gallons/KWh)***
1927	Riverside	MN	300	80.1	1669.7	17.5
2049	Jack Watson	MS	OTCW	182.2	1755.9	37.9
2050	Baxter Wilson	MS	1	137.7	220.0	228.4
2050	Baxter Wilson	MS	2	250.8	341.7	267.9
2053	Rex Brown	MS	CP	26.5	252.3	38.3
2079	Hawthorn	MO	5	214.6	4012.3	19.5
2079	Hawthorn	MO	9	23.9	60.8	143.5
2094	Sibley	MO	3	164.8	2474.0	24.3
2094	Sibley	MO	12	108.6	696.8	56.9
2098	Lake Road	MO	4	87.9	640.6	50.1
2103	Labadie	MO	1	291.5	4564.0	23.3
2103	Labadie	MO	2	281.1	4496.5	22.8
2103	Labadie	MO	3	208.1	3361.3	22.6
2103	Labadie	MO	4	260.4	4104.2	23.2
2104	Meramec	MO	1	109.9	751.6	53.4
2104	Meramec	MO	2	118.9	824.0	52.7
2104	Meramec	MO	3	133.1	1353.2	35.9
2104	Meramec	MO	4	199.1	2069.0	35.1
2107	Sioux	MO	1	252.0	2749.6	33.5
2107	Sioux	MO	2	319.9	3522.4	33.1
2167	New Madrid	MO	1	477.6	3663.9	47.6
2167	New Madrid	MO	2	504.1	3730.5	49.3
2168	Thomas Hill	MO	CW12	345.8	3576.9	35.3
2168	Thomas Hill	MO	CW3	431.7	5131.0	30.7
2187	J E Corette Plant	MT	2	55.6	1251.9	16.2
2226	Canaday	NE	1	18.1	87.1	75.9
2240	Lon Wright	NE	6	484.7	47.9	>1,000.0[2]
2240	Lon Wright	NE	7	606.2	48.3	>1,000.0[2]
2291	North Omaha	NE	1	624.3	408.4	558.0
2367	Schiller	NH	4	33.6	310.2	39.5
2367	Schiller	NH	5	38.1	319.0	43.6
2367	Schiller	NH	6	37.5	314.8	43.5
2378	B L England	NJ	1	90.5	605.7	54.5
2378	B L England	NJ	2	92.4	675.2	50.0
2384	Deepwater	NJ	1	82.7	13.1	>1,000.0[2]
2384	Deepwater	NJ	6	75.6	462.1	59.7
2390	Sayreville	NJ	04	15.5	16.4	345.5
2390	Sayreville	NJ	05	20.7	27.8	272.0
2403	PSEG Hudson Gen. Station	NJ	HU	442.1	2733.1	59.0
2404	PSEG Hudson Gen Station	NJ	KE	51.1	3.0	>1,000.0[2]
2408	PSEG Mercer Gen. Station	NJ	ME	561.6	2651.5	77.3
2411	PSEG Sewaren Gen.Station	NJ	SE	144.1	226.4	232.3
2480	Danskammer Gen. Station	NY	1	-	6.3	-[1]
2480	Danskammer Gen. Station	NY	2	2.6	15.6	60.6
2480	Danskammer Gen. Station	NY	3	95.0	995.8	34.8

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Withdrawal Ratio (gallons/KWh)*
2480	Danskammer Gen. Station	NY	4	163.5	1391.4	42.9
2490	Arthur Kill Gen. Station	NY	2	352.2	519.4	247.5
2490	Arthur Kill Gen. Station	NY	3	300.5	154.3	711.0
2491	Charles Poletti	NY	C6	379.4	2635.1	52.5
2493	East River	NY	6	139.6	393.4	129.5
2493	East River	NY	7	39.4	180.0	79.9
2500	Ravenswood	NY	1	233.3	1015.7	83.8
2500	Ravenswood	NY	2	233.3	1466.8	58.1
2500	Ravenswood	NY	3	708.3	2204.0	117.3
2511	E F Barrett	NY	1	86.6	639.2	49.5
2511	E F Barrett	NY	2	84.7	697.3	44.3
2513	Far Rockaway	NY	4	63.3	263.8	87.6
2514	Glenwood	NY	4	66.6	251.0	96.8
2514	Glenwood	NY	5	78.2	294.0	97.1
2516	Northport	NY	1	238.5	2011.4	43.3
2516	Northport	NY	2	225.5	2070.0	39.8
2516	Northport	NY	3	213.3	1828.8	42.6
2516	Northport	NY	4	206.2	1597.1	47.1
2517	Port Jefferson	NY	3	129.9	739.8	64.1
2517	Port Jefferson	NY	4	109.9	659.4	60.8
2526	AES Westover	NY	7	34.3	241.7	51.7
2526	AES Westover	NY	8	41.4	600.2	25.2
2527	AES Greenidge LLC	NY	3	129.3	308.0	153.2
2535	AES Cayuga	NY	1	223.0	1145.0	71.1
2539	PSEG Albany Gen. Station	NY	1	60.7	16.7	>1,000.0[2]
2539	PSEG Albany Gen. Station	NY	2	60.7	27.7	801.8
2539	PSEG Albany Gen. Station	NY	3	60.7	19.3	>1,000.0[2]
2539	PSEG Albany Gen. Station	NY	4	60.7	38.3	578.7
2549	C R Huntley Gen. Station	NY	63	120.2	23.5	>1,000.0[2]
2549	C R Huntley Gen. Station	NY	64	120.2	1.7	>1,000.0[2]
2549	C R Huntley Gen. Station	NY	65	124.1	365.0	124.1
2549	C R Huntley Gen. Station	NY	66	124.1	383.0	118.3
2549	C R Huntley Gen. Station	NY	67	173.2	1154.4	54.8
2549	C R Huntley Gen. Station	NY	68	173.2	1205.9	52.4
2554	Dunkirk Gen. Station	NY	1	166.1	1827.2	33.2
2554	Dunkirk Gen. Station	NY	2	260.4	1785.7	53.2
2594	Oswego Harbor Power	NY	5	29.7	186.2	58.3
2594	Oswego Harbor Power	NY	6	28.4	208.7	49.7
2625	Bowline Point	NY	1	455.0	924.9	179.5
2625	Bowline Point	NY	2	455.0	249.9	664.5
2629	Lovett	NY	3	38.8	8.2	>1,000.0[2]
2629	Lovett	NY	4	142.2	933.8	55.6
2629	Lovett	NY	5	164.8	991.3	60.7
2642	Rochester 7	NY	001	144.8	1520.6	34.7
2718	G G Allen	NC	1	103.4	740.1	51.0

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Withdrawal Ratio (gallons/KWh)*
2718	G G Allen	NC	2	103.4	855.7	44.1
2718	G G Allen	NC	3	157.0	1713.8	33.4
2718	G G Allen	NC	4	170.6	1744.8	35.7
2718	G G Allen	NC	5	170.6	1587.8	39.2
2720	Buck	NC	3	90.5	204.0	161.9
2720	Buck	NC	4	50.4	139.7	131.7
2720	Buck	NC	5	107.3	868.4	45.1
2720	Buck	NC	6	107.3	905.9	43.2
2721	Cliffside	NC	1	46.5	128.3	132.4
2721	Cliffside	NC	2	44.6	129.3	125.9
2721	Cliffside	NC	3	72.4	182.7	144.6
2721	Cliffside	NC	4	73.7	204.7	131.4
2723	Dan River	NC	1	75.6	257.0	107.4
2723	Dan River	NC	2	75.6	259.7	106.3
2723	Dan River	NC	3	117.0	658.6	64.8
2727	Marshall	NC	1	196.5	2799.2	25.6
2727	Marshall	NC	2	207.5	2809.4	27.0
2727	Marshall	NC	3	324.4	4559.2	26.0
2727	Marshall	NC	4	375.5	5182.6	26.4
2732	Riverbend	NC	4	95.6	486.7	71.7
2732	Riverbend	NC	5	95.6	469.5	74.4
2732	Riverbend	NC	6	109.9	781.5	51.3
2732	Riverbend	NC	7	110.5	831.8	48.5
2790	R M Heskett	ND	C12	56.9	603.0	34.4
2817	Leland Olds	ND	1	119.6	1694.5	25.8
2817	Leland Olds	ND	2	171.9	2454.4	25.6
2823	Milton R Young	ND	CS1	126.7	1600.6	28.9
2823	Milton R Young	ND	CS2	343.2	3256.6	38.5
2824	Stanton	ND	1	130.5	1142.9	41.7
2828	Cardinal	OH	1	910.6	3835.8	86.6
2830	Walter C Beckjord	OH	1	69.8	457.6	55.7
2830	Walter C Beckjord	OH	2	80.1	487.2	60.0
2830	Walter C Beckjord	OH	3	95.0	803.0	43.2
2830	Walter C Beckjord	OH	4	109.2	899.1	44.3
2830	Walter C Beckjord	OH	5	168.0	1348.8	45.5
2830	Walter C Beckjord	OH	6	217.1	2356.5	33.6
2832	Miami Fort	OH	5	99.5	290.8	124.9
2832	Miami Fort	OH	6	129.9	1095.5	43.3
2835	Ashtabula	OH	1	186.1	771.7	88.0
2836	Avon Lake	OH	2	504.7	3836.0	48.0
2837	Eastlake	OH	1	578.4	6220.6	33.9
2838	Lake Shore	OH	1	190.7	654.6	106.3
2840	Conesville	OH	1	262.4	1278.8	74.9
2843	Picway	OH	5	60.1	402.5	54.5
2848	O H Hutchings	OH	GMR	96.9	997.9	35.5

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Withdrawal Ratio (gallons/KWh)*
2850	J M Stuart	OH	1	177.7	3573.1	18.2
2850	J M Stuart	OH	2	182.9	3768.8	17.7
2850	J M Stuart	OH	3	211.3	3784.7	20.4
2861	Niles	OH	1	45.2	489.0	33.8
2861	Niles	OH	2	58.2	614.2	34.6
2864	R E Burger	OH	3	208.7	16.7	>1,000.0[2]
2866	W H Sammis	OH	1	1194.3	1349.9	322.9
2872	Muskingum River	OH	1	767.8	990.9	282.8
2876	Kyger Creek	OH	1	1025.6	1415.9	264.4
2878	Bay Shore	OH	BSCS	659.2	3339.9	72.0
2952	Muskogee	OK	RIV	20.0	116.6	62.7
3098	Elrama Power Plant	PA	1	95.6	454.3	76.9
3098	Elrama Power Plant	PA	2	62.0	270.8	83.6
3098	Elrama Power Plant	PA	3	106.6	399.0	97.6
3113	Portland	PA	1	275.3	1810.8	55.5
3130	Seward	PA	A	46.5	51.6	329.1
3130	Seward	PA	B	124.7	662.1	68.8
3131	Shawville	PA	1	372.9	3300.8	41.2
3138	New Castle Plant	PA	3	53.0	522.2	37.0
3138	New Castle Plant	PA	4	47.8	446.7	39.1
3138	New Castle Plant	PA	5	36.8	432.9	31.1
3140	PPL Brunner Island	PA	1	122.8	2067.2	21.7
3140	PPL Brunner Island	PA	2	134.4	2563.4	19.1
3140	PPL Brunner Island	PA	3	292.1	4056.9	26.3
3148	PPL Martins Creek	PA	1	103.4	617.2	61.1
3152	WPS Energy Servs Sunbury Gen	PA	4	60.7	1603.8	13.8
3159	Cromby Gen. Station	PA	1	125.4	623.6	73.4
3159	Cromby Gen. Station	PA	2	228.8	255.9	326.3
3160	Delaware Gen. Station	PA	7	45.2	74.1	222.8
3160	Delaware Gen. Station	PA	8	43.9	76.1	210.9
3161	Eddystone Gen. Station	PA	1	248.2	1482.5	61.1
3161	Eddystone Gen. Station	PA	2	245.6	1432.9	62.6
3161	Eddystone Gen. Station	PA	3	302.5	341.1	323.7
3161	Eddystone Gen. Station	PA	4	213.9	268.9	290.3
3169	Schuylkill Gen. Station	PA	1	22.0	40.0	200.3
3178	Armstrong Power Station	PA	1	80.1	1099.5	26.6
3178	Armstrong Power Station	PA	2	76.3	1067.1	26.1
3181	Mitchell Power Station	PA	2	191.3	0.2	>1,000.0[2]
3287	McMeekin	SC	MCM1	145.4	1523.1	34.8
3295	Urquhart	SC	URQ1	98.9	622.0	58.0
3319	Jefferies	SC	1	36.2	8.0	>1,000.0[2]
3319	Jefferies	SC	2	36.2	8.3	1588.7[2]
3393	Allen Steam Plant	TN	1	602.3	4860.7	45.2
3396	Bull Run	TN	1	482.1	6213.3	28.3
3399	Cumberland	TN	1	1944.6	12671.8	56.0

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Withdrawal Ratio (gallons/KWh)*
3403	Gallatin	TN	1	922.2	7550.8	44.6
3405	John Sevier	TN	1	646.3	5088.4	46.4
3406	Johnsonville	TN	1	1185.3	7625.1	56.7
3407	Kingston	TN	1	1265.4	9454.2	48.9
3441	Nueces Bay	TX	7	1.3	74.1	6.4
3452	Lake Hubbard	TX	1	358.7	400.9	326.5
3453	Mountain Creek	TX	1	149.9	736.5	74.3
3454	North Lake	TX	1	214.6	873.5	89.7
3459	Sabine	TX	1	1275.7	363.3	>1,000.0[2]
3460	Cedar Bayou	TX	C1	199.7	989.0	73.7
3460	Cedar Bayou	TX	C2	266.3	1325.9	73.3
3460	Cedar Bayou	TX	C3	244.3	1227.7	72.6
3461	Deepwater	TX	C1	65.3	59.7	399.3
3466	P H Robinson	TX	C1	138.9	636.7	79.7
3466	P H Robinson	TX	C2	121.5	589.7	75.2
3466	P H Robinson	TX	C4	151.9	631.0	87.9
3468	Sam Bertron	TX	C1	22.0	85.1	94.3
3468	Sam Bertron	TX	C2	20.7	126.5	59.7
3468	Sam Bertron	TX	C3	46.5	223.7	75.9
3468	Sam Bertron	TX	C4	45.2	257.1	64.2
3476	Knox Lee	TX	CW	235.9	623.0	138.2
3489	Eagle Mountain	TX	1	33.6	617.4	19.9
3490	Graham	TX	1	261.7	762.6	125.3
3491	Handley	TX	1	606.8	1873.0	118.3
3497	Big Brown	TX	1	500.9	8462.6	21.6
3502	Lake Creek	TX	1	28.4	84.9	122.3
3504	Stryker Creek	TX	1	450.5	1091.4	150.7
3506	Tradinghouse	TX	1	595.2	2101.1	103.4
3508	Valley	TX	1	449.8	141.3	>1,000.0[2]
3507	Trinidad	TX	1	124.7	144.3	315.6
3527	San Angelo	TX	2	73.0	214.0	124.6
3548	Decker Creek	TX	1	334.1	904.4	134.8
3548	Decker Creek	TX	2	345.8	882.3	143.0
3549	Holly Street	TX	1	93.7	20.0	>1,000.0[2]
3549	Holly Street	TX	2	93.7	11.8	>1,000.0[2]
3549	Holly Street	TX	3	200.3	184.4	396.6
3549	Holly Street	TX	4	200.3	260.5	280.7
3576	Ray Olinger	TX	C1	53.6	76.9	254.7
3576	Ray Olinger	TX	C2	94.4	166.6	206.8
3576	Ray Olinger	TX	C3	57.5	374.2	56.1
3628	R W Miller	TX	1	86.6	2.3	>1,000.0[2]
3628	R W Miller	TX	2	115.0	137.5	305.3
3628	R W Miller	TX	3	210.7	362.2	212.3
3776	Glen Lyn	VA	5	115.7	448.9	94.1
3776	Glen Lyn	VA	6	146.7	1183.6	45.2

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Withdrawal Ratio (gallons/KWh)*
3788	Potomac River	VA	1	96.3	389.4	90.3
3788	Potomac River	VA	2	96.3	389.1	90.3
3788	Potomac River	VA	3	86.6	563.8	56.1
3788	Potomac River	VA	4	86.6	634.7	49.8
3788	Potomac River	VA	5	86.6	646.3	48.9
3796	Bremo Bluff	VA	3	48.5	530.9	33.3
3796	Bremo Bluff	VA	4	89.8	1086.9	30.2
3797	Chesterfield	VA	3	63.3	473.9	48.8
3797	Chesterfield	VA	4	88.5	956.3	33.8
3797	Chesterfield	VA	5	185.5	2199.9	30.8
3797	Chesterfield	VA	6	369.7	4652.0	29.0
3803	Chesapeake	VA	1	107.9	699.6	56.3
3803	Chesapeake	VA	2	107.9	738.0	53.4
3803	Chesapeake	VA	3	158.3	1203.0	48.0
3803	Chesapeake	VA	4	170.0	973.0	63.8
3804	Possum Point	VA	3	83.4	140.8	216.2
3804	Possum Point	VA	4	146.1	351.2	151.8
3809	Yorktown	VA	1	120.2	936.6	46.8
3809	Yorktown	VA	2	120.2	1161.0	37.8
3809	Yorktown	VA	3	525.4	2959.7	64.8
3936	Kanawha River	WV	1	367.7	1261.8	106.4
3938	Philip Sporn	WV	11	972.0	652.1	544.1
3945	Rivesville	WV	5	18.7	67.4	101.4
3945	Rivesville	WV	6	51.1	416.8	44.7
3946	Willow Island	WV	1	109.9	312.3	128.4
3946	Willow Island	WV	2	109.9	803.2	49.9
3947	Kammer	WV	1	526.1	1234.8	155.5
3954	Mt. Storm	WV	1	288.9	3308.9	31.9
3954	Mt. Storm	WV	2	338.6	4025.7	30.7
3954	Mt. Storm	WV	3	224.9	2347.2	35.0
3992	Blount Street	WI	1	31.0	98.3	115.2
3992	Blount Street	WI	2	43.3	452.0	35.0
4041	South Oak Creek	WI	303	262.4	1385.5	69.1
4041	South Oak Creek	WI	304	257.2	1287.0	72.9
4041	South Oak Creek	WI	305	264.3	1586.0	60.8
4041	South Oak Creek	WI	306	241.7	1691.3	52.2
4042	Valley	WI	401	78.2	581.4	49.1
4042	Valley	WI	402	76.9	545.8	51.4
4050	Edgewater	WI	5	162.9	2560.8	23.2
4072	Pulliam	WI	3	342.5	2361.4	52.9
4140	Alma	WI	G1	174.5	240.4	264.9
4143	Genoa	WI	1	151.2	2264.6	24.4
4271	John P Madgett	WI	G1	264.3	2306.9	41.8
4937	Thomas C Ferguson	TX	1	197.1	874.8	82.2
4938	Fort Phantom	TX	1	124.1	111.6	406.0

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Withdrawal Ratio (gallons/KWh)*
4938	Fort Phantom	TX	2	185.5	287.7	235.3
6017	Newton	IL	1	280.5	3253.2	31.5
6017	Newton	IL	2	285.7	3501.4	29.8
6034	Belle River	MI	C1	1995.0	3396.5	214.4
6034	Belle River	MI	C2	2501.1	4305.6	212.0
6055	Big Cajun 2	LA	2C3	292.8	3620.7	29.5
6064	Nearman Creek	KS	NCS	179.0	1620.6	40.3
6065	Iatan	MO	1	429.1	4961.2	31.6
6077	Gerald Gentleman	NE	1	352.9	5179.7	24.9
6077	Gerald Gentleman	NE	2	316.0	4602.9	25.1
6082	AES Somerset LLC	NY	1	234.0	5358.9	15.9
6096	Nebraska City	NE	1	463.4	4777.9	35.4
6124	McIntosh	GA	1	98.2	957.5	37.4
6146	Martin Lake	TX	1	1998.3	16484.4	44.2
6147	Monticello	TX	1	1274.4	13506.3	34.4
6155	Rush Island	MO	1	402.6	4314.3	34.1
6155	Rush Island	MO	2	343.2	3628.4	34.5
6156	New Haven Harbor	CT	NHC1	332.2	634.1	191.2
6179	Fayette Power Project	TX	1	315.4	4902.9	23.5
6179	Fayette Power Project	TX	2	316.7	4326.3	26.7
6179	Fayette Power Project	TX	3	244.3	3535.4	25.2
6705	Warrick	IN	4	168.0	2057.2	29.8
6705	Warrick	IN	1-3	302.5	3205.1	34.4
7286	Richard Gorsuch	OH	1	172.6	1185.5	53.1
7343	George Neal South	IA	4	303.7	3961.8	28.0
8002	Newington	NH	1	256.6	1955.7	47.9
8006	Roseton Gen. Station	NY	1	211.3	1566.0	49.3
8006	Roseton Gen. Station	NY	2	211.3	1677.0	46.0
8042	Belews Creek	NC	1	477.6	4268.1	40.8
8042	Belews Creek	NC	2	524.8	5662.7	33.8
8054	Gerald Andrus	MS	1	258.5	1998.6	47.2
8056	Waterford 1 & 2	LA	1	408.4	1502.5	99.2
8063	DeCordova	TX	1	305.7	1415.8	78.8
8226	Cheswick Power Plant	PA	1	258.5	3802.0	24.8
8906	Astoria Gen. Station	NY	2	9.7	59.9	59.1
8906	Astoria Gen. Station	NY	3	19.4	1195.7	5.9
8906	Astoria Gen. Station	NY	4	19.4	1084.3	6.5
8906	Astoria Gen. Station	NY	5	19.4	892.8	7.9
10075	Taconite Harbor Energy Cntr	MN	CS1	186.1	1491.9	45.5
10245	Burns Harbor Plant	IN	10	193.9	261.3	270.8
10485	Sparrows Point	MD	1	139.6	119.7	425.5
10675	AES Thames	CT	1HRC	124.1	1530.5	29.6
10676	AES Beaver Valley Partners	PA	1	107.3	1021.8	38.3
10849	Silver Bay Power	MN	CW1	133.1	701.3	69.3
50130	G F Weaton Power Station	PA	COOL	82.1	627.0	47.8

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Withdrawal Ratio (gallons/KWh)*
50406	Somerset Plant	ME	2	7.8	747.1	3.8
50481	Tenn. Eastman Operations	TN	RW	45.2	917.3	18.0
50488	PPG Riverside	LA	CSR	65.9	446.9	53.8
50491	PPG Natrium Plant	WV	7CIRC	63.3	749.0	30.9
50733	Gary Works	IN	SWPS2	120.9	783.3	56.3
55318	Indian River	FL	CWS	233.3	1220.2	69.8
			Totals/Weighted Average	**42,735,353.2**	**782,662.9**	**54.6**
					Simple Average	**100.0**
					Median	**56.1**

[1] Insufficient data available to calculate water use ratio.

[2] Ratios greater than 1,000 gallons/kWh are not included in summary statistics.

Water Withdrawals, Generation and Unit Water Withdrawals: Nuclear Power Plants with Once-Through Cooling Systems
- 2000 -

Power Plant ID	Power Plant Name	State	Cooling System Code	Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Use (gallons/KWh)*
204	Clinton Nuclear	IL	CW	628.0	6,888.8	33.3
360	San Onofre Nuclear	CA	2	1,194.5	8,524.2	51.1
360	San Onofre Nuclear	CA	3	1,194.5	9,633.8	45.3
566	Millstone	CT	3	1,338.5	10,108.0	48.3
880	Quad Cities Nuclear	IL	OF	1,106.4	12,388.7	32.6
1590	Pilgrim Nuclear	MA	27	446.5	5,512.3	29.6
2289	Fort Calhoun Nuclear	NE	1	523.8	3,892.7	49.1
2388	Oyster Creek Nuclear	NJ	OCCS	597.8	3,908.2	55.8
2410	Salem Nuclear	NJ	SA1	865.0	8,952.6	35.3
2410	Salem Nuclear	NJ	SA2	865.0	8,381.7	37.7
2589	Nine Mile Point Nuclear	NY	1	375.8	4,676.0	29.3
3251	HB Robinson	SC	2	431.8	6,237.1	25.3
3265	Oconee Nuclear	SC	CCW2	859.8	7,499.5	41.8
3265	Oconee Nuclear	SC	CCW3	853.9	6,577.8	47.4
3806	Surry Nuclear	VA	1	1,209.0	6,548.4	67.4
3806	Surry Nuclear	VA	2	1,209.0	6,539.5	67.5
4046	Point Beach Nuclear	WI	701	413.4	4,134.6	36.5
4270	Waterford #3 Nuclear	LA	W3-1	1,076.2	8,459.2	46.4
6011	Calvert Cliffs Nuclear	MD	1	1,556.2	6,449.6	88.1
6011	Calvert Cliffs Nuclear	MD	2	1,682.8	7,391.0	83.1
6014	Brunswick Nuclear	NC	1	674.4	6,746.5	36.5
6014	Brunswick Nuclear	NC	2	674.4	7,055.0	34.9
6038	McGuire Nuclear	NC	CCW1	1,378.4	9,995.0	50.3
6038	McGuire Nuclear	NC	CCW2	1,362.1	8,452.4	58.8
6045	St. Lucie Nuclear	FL	1CWS	349.3	7,514.2	17.0
6045	St. Lucie Nuclear	FL	2CWS	319.8	5,794.5	20.1
6099	Diablo Canyon Nuclear	CA	SW1	2,316.0	7,826.8	108.0
6110	James A Fitzpatrick	NY	C-1	518.1	6,024.8	31.4
6122	Ginna	NY	1	425.6	3,809.4	40.8
6145	Comanche Peak Nuclear	TX	1	2,789.2	18,476.9	55.1
6168	North Anna Nuclear	VA	1	1,045.4	7,214.4	52.9
6168	North Anna Nuclear	VA	2	1,080.1	8,018.9	49.2
8055	Arkansas Nuclear One	AR	1	966.9	6,410.1	55.1
8907	Indian Point 3 Nuclear	NY	C-3	901.3	8,432.2	39.0

National Survey of Water Use at Thermoelectric Power Plants

A research project sponsored by the

National Institutes for
Water Resources

conducted by the

Department of Geography and
Environmental Resources
Southern Illinois University Carbondale

Purpose

This survey is one part of a research project to study power plant water withdrawals and consumptive use in the United States. The purpose of this research is to improve the understanding of power plant water use and to develop benchmarks that will facilitate water use evaluations by generation facility managers. A complete description of this project is available on the web site of the National Institutes of Water Resources: *http://water.usgs.gov/wrri/04grants/national/nationalindex.html*.

Instructions

This survey consists of 14 questions. Please read each question carefully and provide answers based upon your understanding of the water use operations at your generating facility and the power generation industry as a whole. Answer each question by checking the appropriate boxes or typing in a brief response. Please note that the number of pages may increase as you complete the questionnaire, but this will not affect our ability to properly record your answers.

A comments section is included at the end of this form and any comments that you may have would be welcomed. *Please return your survey by saving the completed file and attaching it to a reply email message*.

If you have any questions about this survey or the research project, please contact Ben Dziegielewski at (618) 453-6021, or by email at: *wateruse@siu.edu.*

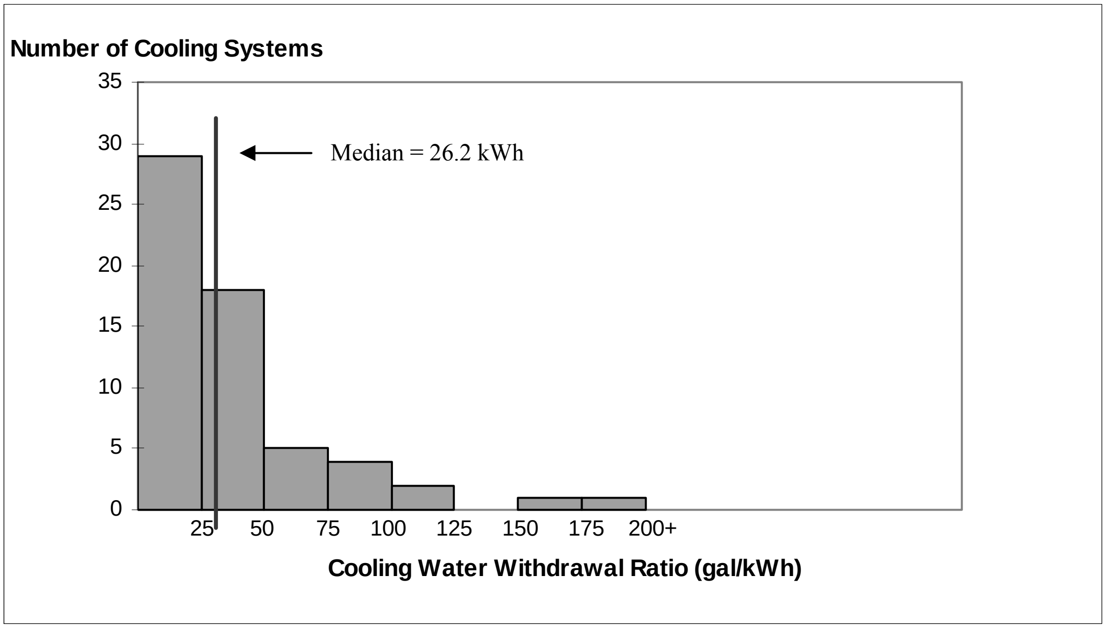
This project has been reviewed and approved by the Southern Illinois University Human Subjects Committee. Questions concerning your rights as a participant in this research may be addressed to the Committee Chairperson, Office of Research and Development Administration, Southern Illinois University, Carbondale, IL 62901-4709; Phone: (618) 453-4533. There is no penalty for not participating in this survey.

COOLING WATER WITHDRAWALS AND MEASUREMENT

Using the data reported in the *Form EIA-767* for the year 2003, the ratio of annual cooling water withdrawals (gallons) to net electric generation (kilowatt-hours) was calculated for the **63 *re-circulating cooling systems with ponds or canals*** for which sufficient data was available. A table listing these ratios by power plant names and cooling systems IDs is available for viewing and download from the Survey Support Web Page: *http://info.geography.siu.edu/projects/ThermoSurvey/NationalSurveySupport.mht*

While about half of these systems used less than 26 gallons/kWh, there is a wide range of estimated ratios. The distribution of the number of systems by cooling system ratio appears in the chart below. Where necessary, please refer to this chart and the table at the end of the survey to respond to the following questions.

Ratio of Annual Cooling Water Withdrawals to Generation at Power Plants Using Re-circulating Cooling Systems with Ponds or Canals (2003)



Source: Department of Energy: Form EIA-767 (2003) .

Q1. The Form EIA-767 requires facilities to report their average annual rate of cooling water withdrawals. How is this measure calculated or estimated for the cooling systems at your facility? (please check/write in one response)

☐ Measuring devices provide constant monitoring of flow rates, which are then averaged
☐ Cooling water system pump capacity is multiplied by the total annual time of operation
☐ Other (*please specify*):

____

Q2. Please find the withdrawal ratios for the cooling system(s) at your facility in the table that is available on the Survey Support Web Page (see above). Do the ratios that were calculated for your cooling systems appear to be correct?

☐ **Don't know**, we are not able to estimate the ratio of cooling water withdrawals to net generation at our facility
☐ **Yes**, the ratio(s) for our facility are consistent with our own estimates
☐ **No**, these ratios do not accurately represent cooling water use at our facility.

A more accurate estimate of the gallons of water withdrawals per kilowatt-hours of generation can be the determined by: (*please specify more accurate data or calculation method*):

____

Q3. Please refer to the chart on the previous page. Do the estimated cooling water withdrawal ratios for the cooling systems at your facility differ significantly from the 26.2 gal/kWh median value for re-circulating cooling systems with ponds and canals? If so, what do you think are the principal reason(s) for this difference?

☐ **No**, the ratio(s) for our facility do not differ significantly from the median value
☐ **Yes**, the water withdrawals of the cooling system(s) at our facility differ significantly from the national average for re-circulating cooling systems with ponds and canals because: (*please specify*):

____

Q4. What plant- or system-specific characteristics or conditions do you think contribute to the wide range of withdrawals ratios that are evident in the figure above and in the table of cooling water withdrawal ratios? (check all that apply and/or write in other relevant factors)

☐ Differences in the way that cooling water withdrawals are estimated or reported
☐ Differences in the ratio of net-to-gross generation at each facility
☐ Differences in the size of cooling pond relative to the amount of waste heat generated
☐ Differences in the design of cooling ponds, such as dikes that that ensure good mixing and cooling of the re-circulating water, or the distance between intake and outflow structures
☐ Differences in the designed temperature rise of the condenser(s) in use at each facility
☐ Differences in maintaining optimal turbine "backpressure" that affect water flow
☐ Differences in the frequency and length of time of boiler/generator shutdowns
☐ Differences in other conditions/circumstances: (*please specify*):

____

Q5. Water consumption is defined in EIA-767 as the difference between cooling water withdrawal and discharge. Is it possible to measure or estimate cooling water consumption at your facility?

☐ **No,** it is not possible to measure or estimate consumptive use of water because:
(*check all that apply or write in other applicable reasons*):
- ☐ No cooling water discharge measuring devices are available
- ☐ Estimates of discharge based upon equipment characteristics are not possible
- ☐ Other (*please specify*):

____

☐ **Yes,** cooling system water consumption was measured (or estimated) at our facility using the following method:

____

Q6. What are some of the possible sources of cooling water consumptive use at facilities using re-circulating cooling systems with ponds or canals? (check all that apply and/or write in relevant factors)

- ☐ There is no measurable consumptive use in re-circulating cooling systems with ponds or canals
- ☐ Significant amounts of cooling water are diverted to other uses in some facilities where the diverted water is lost or evaporated
- ☐ Inaccurate estimation procedures for cooling systems discharge flow rates (used to calculate consumption) result in inflated estimates of consumptive use
- ☐ Frequent starting up and shutting down of the generators increases consumptive use because steam is vented to the atmosphere when the boiler is started up and shut down
- ☐ Other conditions/circumstances: (*please specify*):

____

Q7. Are there any non-cooling water needs at your facility that use water from the cooling system?

☐ **No,** all reported cooling water withdrawals are used only for generation process cooling
☐ **Yes,** there are some non-cooling diversions of water from the cooling water system.
These include: (*please describe and estimate quantity of each use*):

Use 1: _______________ Quantity: _____ mgd/yr
Use 2: _______________ Quantity: _____ mgd/yr
Use 3: _______________ Quantity: _____ mgd/yr

Q8. Form EIA-767 requires that power plants report NET GENERATION for each generator. How is NET GENERATION calculated for the generators at your facility? (please check one and/or write in response)

☐ Metering is available to measure both the gross generation and the service load energy for each generator
☐ Plant–level generation is metered as it is delivered to the grid. Generation for each generator is estimated based on hours of operation or other operational measures. Net generation is calculated by deducting a portion of the total plant service load from the estimated production of each generator.
☐ Service load energy is estimated and deducted from the metered gross generation of each generator unit
☐ Other measurement or estimation procedure (*please specify*):

____

Q9. Does your facility maintain a record of GROSS GENERATION for EACH generator at your POWER PLANT? If so, approximately what percent of gross generation on annual basis does net generation represent at your facility? (please check one and/or write in response)

☐ **Yes,** records of gross generation for each generator ARE available.
On an annual basis, net generation is equal to approximately % of gross generation
☐ **No,** it is not possible to measure or record gross generation for each generator
☐ Other (*please specify*):

____

Q10. Does your facility measure and record the ANNUAL TOTAL WATER WITHDRAWALS for your facility?

☐ **Yes,** records of total water withdrawals ARE available.
☐ **No,** it is not possible to measure total withdrawals for our facility
☐ Other (*please specify*):

____

Q11. Are there any constraints to cooling water withdrawals at your plant? (please check all that apply)

☐ Volume limitations mandated under NPDES
☐ Temperature limitations mandated under NPDES
☐ Water withdrawals are fixed under State permitting requirements
☐ High summer water temperatures and/or low flows in the source may require generation reductions to prevent overheating
☐ Other limitation (*please specify*):

____

Q12. Do you currently use any "alternative" sources of water at your plant? (please check all that apply)

☐ **No**
☐ **Yes**, these include:
  ☐ Recycled water from ash ponds
  ☐ Municipal wastewater
  ☐ Brackish groundwater from oil/gas generation
  ☐ Water from mine dewatering operations
  ☐ Other alternative sources (*please specify*)

____

Q13. If water intake from your current source had to be reduced in response to severe weather conditions or regulatory restrictions, what actions could be taken at your plant to respond to these conditions? (please check all that apply and/or add additional alternatives)

☐ Reduce generation
☐ Install cooling towers
☐ Operate generators at less than optimal back pressure
☐ Obtain supplemental intake waters from other sources (including recycled water)
☐ Alter cooling water intakes and/or outflows structures to improve cooling system efficiencies
☐ Other adjustments (*please specify*)

____

RESPONDENT INFORMATION

Q14. What is the NAME and Plant ID number of your power plant?

Plant Name: _____________
Plant ID #: _______________

What is your title and water management responsibilities? ***(optional)***

Title: ____

Plant water management responsibilities: (*please check all that apply*)

- ☐ Complete Form EIA-767
- ☐ Complete NPDS forms
- ☐ Record water use data
- ☐ Manage cooling controls
- ☐ Monitor plant water use
- ☐ Make decisions on in-plant water management
- ☐ Other

____

If you would be willing to discuss water use at your facility with us via phone or email, please enter your contact information below:

Name: ____
Phone: ____
Email: ____

COMMENTS AND SUGGESTIONS

Please use the space below to communicate any concerns or comments regarding this study, or contact Ben Dziegielewski at 618-453-6021, or by email at: wateruse@siu.edu .

Thank you for responding to this survey.

PLEASE SAVE YOUR COMPLETED SURVEY DOCUMENT
TO THE DESKTOP OF YOUR COMPUTER.

RETURN THE SURVEY BY ATTACHING IT TO A REPLY TO OUR COVER LETTER,
OR SEND A NEW MESSAGE TO: *wateruse@siu.edu*.

The project completion report for this study will be available on the research page of the SIUC Geography Department: *http://info.geography.siu.edu/Research/research.html* .

Water Withdrawals, Generation and Unit Water Withdrawals: Power Plants using Re-circulating Cooling Systems With Ponds and Canals
- 2003 -

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Use (gallons/KWh)*
113	Cholla	AZ	1	12.9	2,631.0	1.8
477	Valmont	CO	1	5.2	1,453.6	1.3
621	Turkey Point	FL	CP	580.4	3,224.4	65.7
876	Kincaid Generation LLC	IL	1	822.1	3,185.0	94.2
879	Powerton	IL	5	306.3	3,429.0	32.6
879	Powerton	IL	6	367.7	4,812.9	27.9
889	Baldwin Energy Complex	IL	1	32.3	13,090.4	0.9
1416	Arsenal Hill	LA	CW	1.3	88.2	5.3
1417	Lieberman	LA	CW	268.2	110.4	>200.0[1]
2330	Fort Churchill	NV	1	92.4	993.2	34.0
2442	Four Corners	NM	1	25.9	2,570.6	3.7
2706	Asheville	NC	1	0.6	1,183.3	0.2
2706	Asheville	NC	2	0.6	1,234.6	0.2
2709	Lee	NC	3	8.4	1,108.5	2.8
2713	L V Sutton	NC	1	9.0	343.2	9.6
2713	L V Sutton	NC	2	9.7	400.0	8.8
2713	L V Sutton	NC	3	12.3	2,144.9	2.1
2716	W H Weatherspoon	NC	1	12.3	165.4	27.1
2716	W H Weatherspoon	NC	2	12.9	186.8	25.3
2716	W H Weatherspoon	NC	3	15.5	321.9	17.6
2951	Horseshoe Lake	OK	CP	9.0	624.8	5.3
2956	Seminole	OK	CP	9.7	2,882.4	1.2
3251	H B Robinson	SC	1	120.2	1,069.1	41.0
3457	Lewis Creek	TX	1	1.3	2,132.8	0.2
3470	W A Parish	TX	C2	30.4	62.7	176.8
3470	W A Parish	TX	C1	36.8	77.6	173.3
3470	W A Parish	TX	C3	59.5	217.2	99.9
3470	W A Parish	TX	C4	198.4	885.6	81.8
3470	W A Parish	TX	C5	416.2	4,565.8	33.3
3470	W A Parish	TX	C6	441.4	4,842.4	33.3
3601	Sam Gideon	TX	CP1	170.0	137.6	>200.0[1]
3601	Sam Gideon	TX	CP2	170.0	121.2	>200.0[1]
3601	Sim Gideon	TX	CP3	280.5	890.9	114.9
3611	O W Sommers	TX	2	0.6	291.9	0.8
3611	O W Sommers	TX	1	0.6	447.8	0.5
3612	V H Braunig	TX	2	0.6	160.5	1.5
3612	V H Braunig	TX	1	0.6	259.7	0.9
3612	V H Braunig	TX	3	1.3	584.3	0.8
6025	Collins	IL	1	3.2	560.6	2.1

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Use (gallons/KWh)*
6035	Greenwood	MI	1	0.6	588.6	0.4
6042	Manatee	FL	CP	759.4	5,336.5	51.9
6043	Martin	FL	CP	915.8	6,038.9	55.4
6073	Victor J Daniel Jr	MS	BCCF	3.2	6,026.9	0.2
6095	Sooner	OK	CP	19.4	7,200.0	1.0
6098	Big Stone	SD	1	4.5	3,325.0	0.5
6106	Boardman	OR	1CS	11.6	4,329.4	1.0
6113	Gibson	IN	4	371.6	3,649.4	37.2
6113	Gibson	IN	2	371.6	3,964.0	34.2
6113	Gibson	IN	1	371.6	4,216.5	32.2
6113	Gibson	IN	5	371.6	4,436.9	30.6
6113	Gibson	IN	3	371.6	4,532.0	29.9
6136	Gibbons Creek	TX	1	326.4	3,426.0	34.8
6138	Flint Creek	AR	CW	354.2	3,247.3	39.8
6178	Coleto Creek	TX	1	509.9	4,260.4	43.7
6181	J T Deely	TX	2	3.2	2,642.2	0.4
6181	J T Deely	TX	1	3.9	3,214.8	0.4
6190	Rodemacher	LA	1	160.3	737.7	79.3
6190	Rodemacher	LA	2	264.3	2,885.9	33.4
6213	Merom	IN	1CW	429.1	3,074.6	50.9
6243	Dansby	TX	1	71.7	257.4	101.7
7902	Pirkey	TX	CW	453.7	4,770.1	34.7
8059	Comanche	OK	7253	2.6	478.6	2.0
10333	Central Power & Lime	FL	1	144.1	865.2	60.8
Totals/Weighted Average				**3,735,542.6**	**146,627.1**	**25.5**
Simple Average						**31.4**
Median						**26.2**

[1] Estimated ratios greater than 200 gallons/kWh are not included in summary statistics.

Water Withdrawals, Generation and Unit Water Withdrawals: *__Nuclear__ Power Plants using Re-circulating Cooling Systems With Ponds and Canals*

- 2000 -

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Use (gallons/KWh)***
6022	Braidwood Nuclear	IL	OC	35.0	18,822.3	0.7
6026	La Salle County Nuclear	IL	OC	59.8	18,785.8	1.2
6251	South Texas Nuclear	TX	CWS2	1,131.8	10,543.4	39.2

National Survey of Water Use at Thermoelectric Power Plants

A research project sponsored by the

National Institutes for
Water Resources

conducted by the

Department of Geography and
Environmental Resources
Southern Illinois University Carbondale

Purpose

This survey is one part of a research project to study power plant water withdrawals and consumptive use in the United States. The purpose of this research is to improve the understanding of power plant water use and to develop benchmarks that will facilitate water use evaluations by generation facility managers. A complete description of this project is available on the web site of the National Institutes of Water Resources: *http://water.usgs.gov/wrri/04grants/national/nationalindex.html*.

Instructions

This survey consists of 14 questions. Please read each question carefully and provide answers based upon your understanding of the water use operations at your generating facility and the power generation industry as a whole. Answer each question by checking the appropriate boxes or typing in a brief response. Please note that the number of pages may increase as you complete the questionnaire, but this will not affect our ability to properly record your answers.

A comments section is included at the end of this form and any comments that you may have would be welcomed. *Please return your survey by saving the completed file and attaching it to a reply email message*.

If you have any questions about this survey or the research project, please contact Ben Dziegielewski at (618) 453-6021, or by email at: *wateruse@siu.edu.*

This project has been reviewed and approved by the Southern Illinois University Human Subjects Committee. Questions concerning your rights as a participant in this research may be addressed to the Committee Chairperson, Office of Research and Development Administration, Southern Illinois University, Carbondale, IL 62901-4709; Phone: (618) 453-4533. There is no penalty for not participating in this survey.

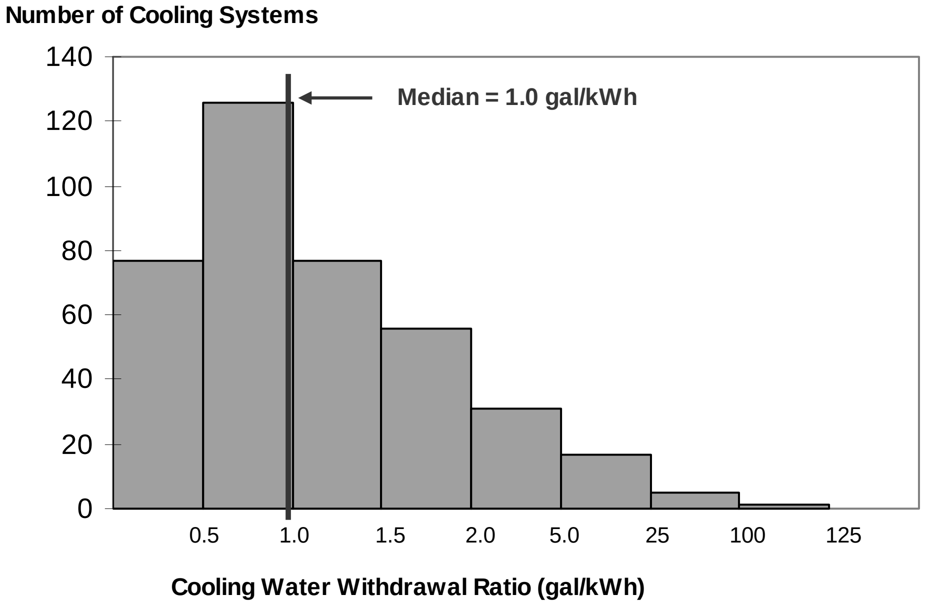
COOLING WATER WITHDRAWALS AND MEASUREMENT

Using the data reported in the *Form EIA-767* for the year 2003, the ratio of annual cooling water withdrawals (gallons) to net electric generation (kilowatt-hours) was calculated for the **429 *closed-loop cooling systems with cooling towers*** for which sufficient data was available. A table listing these ratios by power plant names and cooling systems IDs is available for viewing and download from the Survey Support Web Page: *http://info.geography.siu.edu/projects/ThermoSurvey/NationalSurveySupport.mht*

More than half of these once-through cooling systems used less than1.0 gallons/kWh, however, there is a wide range of estimated ratios. The distribution of the number of systems by cooling system ratio appears in the chart below.

Where necessary, please refer to this chart and the table at the end of the survey to respond to the following questions.

Ratio of Annual Cooling Water Withdrawals to Generation at
Power Plants Using Closed-Loop Cooling Systems with Cooling Towers (2003)



Source: Department of Energy: Form EIA-767 (2003) .

Q1. The Form EIA-767 requires facilities to report their average annual rate of cooling water withdrawals. How is this measure calculated or estimated for the cooling systems at your facility? (please check/write in one response)

☐ Measuring devices provide constant monitoring of flow rates, which are then averaged
☐ Cooling water system pump capacity is multiplied by the total annual time of operation
☐ Other (*please specify*)

____

Q2. Please find the withdrawal ratios for the cooling system(s) at your facility in the table that is available on the Survey Support Web Page (see above). Do the ratios that were calculated for your cooling systems appear to be correct?

☐ **Don't know**, we are not able to estimate the ratio of cooling water withdrawals to net generation at our facility
☐ **Yes**, the ratio(s) for our facility are consistent with our own estimates
☐ **No**, these ratios do not accurately represent cooling water use at our facility.

A more accurate estimate of the gallons of water withdrawals per kilowatt-hours of generation can be the determined by: (*please specify more accurate data or calculation method*):

____

Q3. Please refer to the chart on the previous page. Do the estimated cooling water withdrawal ratios for the cooling systems at your facility differ significantly from the 1.0 gal/kWh median value for closed-loop cooling systems with cooling towers? If so, what do you think are the principal reason(s) for this difference?

☐ **No**, the ratio(s) for our facility do not differ significantly from the median value
☐ **Yes**, the water withdrawals of the cooling system(s) at our facility differ significantly from the national average for closed-loop cooling systems with cooling towers because: (*please specify*):

____

Q4. What plant- or system-specific characteristics or conditions do you think contribute to the wide range of cooling system withdrawal ratios that are evident in the figure above and in the table of cooling water withdrawal ratios? (check all that apply and/or write in other relevant factors)

☐ The estimation/measurement of makeup water is imprecise and could be in error
☐ There are large differences in the blow-down rates of different cooling towers
☐ Some differences in cooling tower designs result in different amounts of water drift
☐ Differences in water quality require different blow-down rates for optimal system performance
☐ Differences in the ratio of net-to-gross generation at each facility
☐ Differences in the designed temperature rise of the condenser(s) in use at each facility
☐ Differences in maintaining optimal turbine "backpressure" that affect water flow
☐ Differences in the frequency and length of time of boiler/generator shutdowns
☐ Differences in other conditions/circumstances: (*please specify)*

____

Q5. Water consumption is defined in EIA-767 as the difference between cooling water withdrawal and discharge. Is it possible to measure or estimate cooling water consumption at your facility?

☐ **No,** it is not possible to measure or estimate consumptive use of water because:
(*check all that apply or write in other applicable reasons*):
- ☐ No cooling water discharge measuring devices are available
- ☐ Estimates of discharge based upon equipment characteristics are not possible
- ☐ Other (*please specify*):

____

☐ **Yes,** cooling system water consumption was measured (or estimated) at our facility using the following method:

____

Q6. What are some of the possible sources of cooling water consumptive use at facilities using cooling systems with cooling towers (check all that apply and/or write in relevant factors)?

- ☐ Water that is evaporated in cooling towers escapes into the atmosphere
- ☐ Drift of water droplets from the cooling tower is considered consumptive use
- ☐ Significant amounts of cooling water are diverted to other uses in some facilities where the diverted water is lost or evaporated
- ☐ Frequent starting up and shutting down of the generators increases consumptive use because steam is vented to the atmosphere when the boiler is started up and shut down
- ☐ Other conditions/circumstances: (*please specify*)

____

Q7. Are there any non-cooling water needs at your facility that use water from the cooling system?

☐ **No,** all reported cooling water withdrawals are used only for generation process cooling
☐ **Yes,** there are some non-cooling diversions of water from the cooling water system.
These include: (*please describe and estimate quantity of each use*)

Use 1: ________________ Quantity: _____ mgd/yr
Use 2: ________________ Quantity: _____ mgd/yr
Use 3: ________________ Quantity: _____ mgd/yr

Q8. Form EIA-767 requires that power plants report NET GENERATION for each generator. How is NET GENERATION calculated for the generators at your facility? (please check one and/or write in response)

☐ Metering is available to measure both the gross generation and the service load energy for each generator

☐ Plant–level generation is metered as it is delivered to the grid. Generation for each generator is estimated based on hours of operation or other operational measures. Net generation is calculated by deducting a portion of the total plant service load from the estimated production of each generator.

☐ Service load energy is estimated and deducted from the metered gross generation of each generator unit

☐ Other measurement or estimation procedure (*please specify*):

____

Q9. Does your facility maintain a record of GROSS GENERATION for EACH generator at your POWER PLANT? If so, approximately what percent of gross generation on annual basis does net generation represent at your facility? (please check one and/or write in response)

☐ **Yes,** records of gross generation for each generator ARE available.
On an annual basis, net generation is equal to approximately _______ % of gross generation

☐ **No,** it is not possible to measure or record gross generation for each generator

☐ Other (*please specify*):

____

Q10. Does your facility measure and record the ANNUAL TOTAL WATER WITHDRAWALS for your facility?

☐ **Yes,** records of total water withdrawals ARE available.

☐ **No,** it is not possible to measure total withdrawals for our facility

☐ Other (*please specify*)

____

Q11. Are there any constraints to cooling water withdrawals at your plant? (please check all that apply)

☐ Volume limitations mandated under NPDES
☐ Temperature limitations mandated under NPDES
☐ Water withdrawals are fixed under State permitting requirements
☐ High summer water temperatures and/or low flows in the source may require generation reductions to prevent overheating
☐ Other limitation (*please specify*):

____

Q12. Do you currently use any "alternative" sources of water at your plant? (please check all that apply)

☐ **No**
☐ **Yes**, these include:
  ☐ Recycled water from ash ponds
  ☐ Municipal wastewater
  ☐ Brackish groundwater from oil/gas generation
  ☐ Water from mine dewatering operations
  ☐ Other alternative sources (*please specify*):

____

Q13. If water intake from your current source had to be reduced in response to severe weather conditions or regulatory restrictions, what actions could be taken at your plant to respond to these conditions? (please check all that apply and/or add additional alternatives)

☐ Reduce generation
☐ Operate generators at less than optimal back pressure
☐ Obtain supplemental intake waters from other sources (including recycled water)
☐ Other adjustments (*please specify*):

____

RESPONDENT INFORMATION

Q14. What is the NAME and Plant ID number of your power plant?

Plant Name: _______________

Plant ID #: _________________

What is your title and water management responsibilities? ***(optional)***

Title: ____

Plant water management responsibilities: (*please check all that apply*)

☐ Complete Form EIA-767
☐ Complete NPDS forms
☐ Record water use data
☐ Manage cooling controls
☐ Monitor plant water use
☐ Make decisions on in-plant water management
☐ Other

____

If you would be willing to discuss water use at your facility with us via phone or email, please enter your contact information below:

Name: __________

Phone: __________

Email: ___________

COMMENTS AND SUGGESTIONS

Please use the space below to communicate any concerns or comments regarding this study, or contact Ben Dziegielewski at 618-453-6021, or by email at: wateruse@siu.edu .

Thank you for responding to this survey.

PLEASE SAVE YOUR COMPLETED SURVEY DOCUMENT
TO THE DESKTOP OF YOUR COMPUTER.

RETURN THE SURVEY BY ATTACHING IT TO A REPLY TO OUR COVER LETTER,
OR SEND A NEW MESSAGE TO: *wateruse@siu.edu*.

Once completed, the final project report for this study will be available on the research page of the SIUC Geography Department: *http://info.geography.siu.edu/Research/research.html* .

Water Withdrawals, Generation and Unit Water Withdrawals: Power Plants with Closed-Loop Cooling Systems with Cooling Towers
- 2003 -

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Use (gallons/KWh)*
3	Barry	AL	U6C	4.5	629.4	2.6
3	Barry	AL	U7C	4.5	669.9	2.5
26	E C Gaston	AL	5	18.7	5,968.6	1.1
51	Dolet Hills	LA	CW	500.2	4,798.9	38.0
59	Platte	NE	1	1.3	639.1	0.7
87	Escalante	NM	1	205.5	1,864.5	40.2
108	Holcomb	KS	CW1A	3.2	2,570.1	0.5
116	Ocotillo	AZ	1	0.6	76.1	3.1
117	West Phoenix	AZ	CC5	1.3	726.8	0.6
117	West Phoenix	AZ	CC4	0.6	395.9	0.6
118	Saguaro	AZ	1	0.6	55.9	4.2
126	Irvington	AZ	1	0.6	136.0	1.7
126	Irvington	AZ	3	-	186.3	-[1]
126	Irvington	AZ	4	1.3	639.3	0.7
127	Oklaunion	TX	1	6.5	4,700.8	0.5
130	Cross	SC	1	5.2	4,303.3	0.4
130	Cross	SC	2	5.2	3,910.8	0.5
136	Seminole	FL	2	5.8	4,880.9	0.4
136	Seminole	FL	1	5.2	4,687.5	0.4
141	Agua Fria	AZ	1	-	108.1	-[1]
141	Agua Fria	AZ	2	-	80.8	-[1]
141	Agua Fria	AZ	3	0.6	213.3	1.1
147	Kyrene	AZ	K-7	1.3	236.7	2.0
160	Apache Station	AZ	2	1.9	1,299.6	0.5
160	Apache Station	AZ	3	1.9	1,430.5	0.5
160	Apache Station	AZ	1	0.6	136.6	1.7
165	GRDA	OK	2	6.5	3,580.7	0.7
165	GRDA	OK	1	6.5	3,498.5	0.7
169	Harvey Couch	AZ	2	-	10.4	-[1]
207	St Johns River Power Park	FL	1	21.3	4,706.1	1.7
207	St Johns River Power Park	FL	2	21.3	5,076.2	1.5
271	Pittsburg Power	CA	7	11.6	1,026.4	4.1
298	Limestone	TX	C2	7.8	5,552.5	0.5
298	Limestone	TX	C1	7.8	6,609.0	0.4
331	Etiwanda Generating Station	CA	3	1.9	145.6	4.9
389	El Centro	CA	3	-	58.2	-[1]
389	El Centro	CA	4	0.6	187.7	1.3

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Estimated Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Use (gallons/KWh)***
420	Broadway	CA	B3	-	156.9	-[1]
465	Arapahoe	CO	3	1.9	279.0	2.5
469	Cherokee	CO	1	8.4	822.8	3.7
470	Comanche	CO	1	8.4	2,223.3	1.4
492	Martin Drake	CO	5	0.6	270.4	0.9
492	Martin Drake	CO	6	1.3	551.6	0.9
492	Martin Drake	CO	7	1.9	1,070.3	0.7
525	Hayden	CO	H1	2.6	1,264.1	0.7
562	Middletown	CT	4	8.4	71.3	43.0
564	Stanton Energy Center	FL	1	3.9	3,098.3	0.5
564	Stanton Energy Center	FL	2	3.9	2,957.1	0.5
594	Indian River Operations	DE	4	8.4	1,096.3	2.8
599	McKee Run	DE	3	0.6	102.3	2.3
602	Brandon Shores	MD	1	7.8	3,928.3	0.7
603	Benning	DC	16	5.2	20.7	91.0
603	Benning	DC	15	5.2	33.1	57.0
628	Crystal River	FL	4	59.5	5,430.3	4.0
628	Crystal River	FL	5	59.5	5,430.3	4.0
641	Crist	FL	7	9.0	3,334.8	1.0
641	Crist	FL	6	9.7	2,043.6	1.7
658	Henry D King	FL	8	0.6	7.3	32.1
663	Deerhaven Generating Station	FL	T1	2.6	217.8	4.3
688	Arvah B Hopkins	FL	2	1.9	586.7	1.2
688	Arvah B Hopkins	FL	1	0.6	171.3	1.4
693	Vero Beach Municipal Power	FL	4	0.6	14.1	16.7
703	Bowen	GA	1CT	9.0	4,296.4	0.8
703	Bowen	GA	3CT	9.0	6,004.0	0.6
703	Bowen	GA	4CT	9.0	6,481.4	0.5
703	Bowen	GA	2CT	9.0	4,179.2	0.8
728	Yates	GA	Y7CS	20.0	1,629.4	4.5
728	Yates	GA	Y6CS	20.0	2,137.2	3.4
891	Havana	IL	6	1264.8	2366.3	195.1[2]
897	Vermilion	IL	1	3.2	965.4	1.2
990	Harding Street	IN	70	11.0	2,612.6	1.5
994	AES Petersburg	IN	3	9.7	3,248.7	1.1
994	AES Petersburg	IN	4	7.8	3,853.8	0.7
997	Michigan City	IN	12	5.2	2,405.7	0.8
1077	Sutherland	IA	1	0.6	305.0	0.8
1077	Sutherland	IA	2	0.6	420.8	0.6
1233	Judson Large	KS	4	0.6	309.1	0.8
1240	Gordon Evans Energy Center	KS	1	0.6	150.9	1.6
1240	Gordon Evans Energy Center	KS	2	1.3	495.1	1.0
1242	Murray Gill	KS	1	-	2.5	-[1]
1242	Murray Gill	KS	2	-	21.5	-[1]
1242	Murray Gill	KS	4	1.3	93.0	5.1

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Estimated Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Use (gallons/KWh)***
1242	Murray Gill	KS	3	1.3	104.6	4.5
1250	Lawrence Energy Center	KS	L235	3.9	347.6	4.1
1252	Tecumseh Energy Center	KS	8	1.9	858.2	0.8
1252	Tecumseh Energy Center	KS	7	1.3	496.3	1.0
1336	Garden City	KS	S-2A	-	80.9	-[1]
1353	Big Sandy	KY	U1CT	12.3	1,760.5	2.5
1355	E W Brown	KY	1	2.6	599.1	1.6
1355	E W Brown	KY	2	3.9	972.7	1.5
1355	E W Brown	KY	3	5.8	2,525.7	0.8
1356	Ghent	KY	4	13.6	2,758.5	1.8
1356	Ghent	KY	3	11.6	2,265.5	1.9
1356	Ghent	KY	2	14.9	2,981.2	1.8
1356	Ghent	KY	1	16.8	3,448.0	1.8
1364	Mill Creek	KY	2	7.1	1,714.8	1.5
1364	Mill Creek	KY	3	16.8	2,691.4	2.3
1364	Mill Creek	KY	4	16.8	2,931.9	2.1
1382	HMP&L Station 2 Henderson	KY	H	7.1	1,842.9	1.4
1393	R S Nelson	LA	4	1.3	873.1	0.5
1393	R S Nelson	LA	3	1.9	437.7	1.6
1393	R S Nelson	LA	1	1.9	762.5	0.9
1393	R S Nelson	LA	2	1.9	814.8	0.9
1393	R S Nelson	LA	6	6.5	3,340.4	0.7
1443	Louis Doc Bonin	LA	1	-	8.2	-[1]
1443	Louis Doc Bonin	LA	2	-	66.5	-[1]
1443	Louis Doc Bonin	LA	3	0.6	256.1	0.9
1564	Vienna Operations	MD	8	2.6	90.9	10.4
1571	Chalk Point LLC	MD	4	2.6	808.8	1.2
1571	Chalk Point LLC	MD	3	3.2	1,222.3	1.0
1682	Cleary Flood	MA	9	0.6	79.0	3.0
1702	Dan E Karn	MI	3	14.2	202.6	25.6
1832	Erickson Station	MI	1	1.3	915.2	0.5
1893	Clay Boswell	MN	CS4	6.5	4,130.3	0.6
1893	Clay Boswell	MN	CS3	3.9	2,291.8	0.6
2049	Jack Watson	MS	CT	9.7	3,428.4	1.0
2132	Blue Valley	MO	1	1.9	111.8	6.3
2132	Blue Valley	MO	2	1.3	136.1	3.5
2240	Lon Wright	NE	8	0.6	332.9	0.7
2277	Sheldon	NE	1	1.3	566.4	0.8
2277	Sheldon	NE	2	1.3	766.2	0.6
2322	Clark	NV	1	1.3	100.5	4.7
2322	Clark	NV	3	1.3	163.5	2.9
2322	Clark	NV	2	1.3	171.2	2.8
2324	Reid Gardner	NV	3	1.3	733.6	0.6
2324	Reid Gardner	NV	2	1.3	751.5	0.6
2324	Reid Gardner	NV	1	1.3	827.0	0.6

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Estimated Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Use (gallons/KWh)***
2324	Reid Gardner	NV	4	1.3	1,777.4	0.3
2341	Mohave	NV	1	16.2	9,755.6	0.6
2378	B L England	NJ	3	1.3	163.6	2.9
2444	Rio Grande	NM	7	1.9	137.3	5.2
2444	Rio Grande	NM	6	1.9	187.8	3.8
2444	Rio Grande	NM	8	1.9	462.4	1.5
2446	Maddox	NM	051C	1.3	499.4	0.9
2450	Reeves	NM	1	-	38.9	-[1]
2450	Reeves	NM	2	-	46.9	-[1]
2450	Reeves	NM	3	-	71.4	-[1]
2451	San Juan	NM	2	4.5	2,043.9	0.8
2451	San Juan	NM	1	4.5	2,476.3	0.7
2451	San Juan	NM	4	4.5	3,370.5	0.5
2451	San Juan	NM	3	4.5	3,442.0	0.5
2454	Cunningham	NM	122C	0.6	710.7	0.3
2454	Cunningham	NM	121C	0.6	166.4	1.4
2709	Lee	NC	2	6.5	305.0	7.7
2709	Lee	NC	1	6.5	309.3	7.6
2712	Roxboro	NC	4	5.2	4,111.7	0.5
2721	Cliffside	NC	5	8.4	3,701.4	0.8
2828	Cardinal	OH	3	9.0	3,427.1	1.0
2832	Miami Fort	OH	7-8	22.6	6,242.6	1.3
2840	Conesville	OH	4	25.9	4,903.9	1.9
2850	J M Stuart	OH	4	16.2	3,959.7	1.5
2872	Muskingum River	OH	5	7.1	3,345.2	0.8
2951	Horseshoe Lake	OK	8CT	2.6	282.7	3.3
2952	Muskogee	OK	5CT	12.3	3,822.2	1.2
2952	Muskogee	OK	6CT	11.0	3,200.4	1.3
2952	Muskogee	OK	4CT	10.3	3,200.7	1.2
2953	Mustang	OK	1CT	1.9	2.8	249.5[2]
2963	Northeastern	OK	3314	5.2	3,528.9	0.5
2963	Northeastern	OK	3313	5.2	3,572.1	0.5
2963	Northeastern	OK	3302	1.3	788.4	0.6
2964	Southwestern	OK	8001	1.3	17.7	26.7
2964	Southwestern	OK	8002	1.3	19.3	24.5
2964	Southwestern	OK	8003	1.9	742.3	1.0
2965	Tulsa	OK	1402	0.6	193.4	1.2
3008	Mooreland	OK	1	0.6	2.6	92.4
3115	Titus	PA	1	5.2	1,208.9	1.6
3118	Conemaugh	PA	1	9.0	6,895.8	0.5
3118	Conemaugh	PA	2	8.4	6,724.5	0.5
3122	Homer City Station	PA	A	14.9	4,999.9	1.1
3136	Keystone	PA	1	18.7	5,852.3	1.2
3148	PPL Martins Creek	PA	3	73.0	1,094.1	24.4
3149	PPL Montour	PA	1	20.7	10,125.6	0.7

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Use (gallons/KWh)*
3179	Hatfields Ferry Power Station	PA	1	6.5	4,993.0	0.5
3179	Hatfields Ferry Power Station	PA	2	6.5	5,503.6	0.4
3280	Canadys Steam	SC	CAN3	3.2	782.7	1.5
3319	Jefferies	SC	3	16.8	1,997.3	3.1
3438	J L Bates	TX	1	2.6	331.7	2.8
3439	Laredo	TX	1	1.3	72.6	6.5
3442	La Palma	TX	4	1.9	67.3	10.5
3455	Parkdale	TX	1	-	12.2	-[1]
3456	Newman	TX	4	1.3	618.3	0.8
3456	Newman	TX	1	0.6	278.8	0.8
3456	Newman	TX	2	0.6	275.1	0.9
3456	Newman	TX	3	0.6	457.6	0.5
3464	Greens Bayou	TX	C5	2.6	253.8	3.7
3469	T H Wharton	TX	C2	-	55.3	-[1]
3482	Jones	TX	151C	1.9	892.4	0.8
3482	Jones	TX	152C	1.9	1,083.8	0.7
3484	Nichols	TX	142C	0.6	189.7	1.2
3484	Nichols	TX	143C	0.6	527.6	0.4
3484	Nichols	TX	141C	0.6	258.4	0.9
3485	Plant X	TX	115C	2.6	376.4	2.5
3485	Plant X	TX	114C	1.3	729.9	0.6
3494	Permian Basin	TX	5	0.6	40.0	5.9
3494	Permian Basin	TX	6	3.2	1,802.7	0.7
3500	Collin	TX	1	99.5	98.9	367.4[2]
3526	Rio Pecos	TX	5	-	8.0	-[1]
3526	Rio Pecos	TX	6	0.6	79.9	3.0
3561	Bryan	TX	6	0.6	15.8	14.9
3613	W B Tuttle	TX	1	-	1.3	-[1]
3613	W B Tuttle	TX	3	-	1.3	-[1]
3613	W B Tuttle	TX	4	-	15.2	-[1]
3644	Carbon	UT	1	1.3	520.2	0.9
3644	Carbon	UT	2	1.9	851.1	0.8
3648	Gadsby	UT	1	-	17.6	-[1]
3648	Gadsby	UT	2	-	40.5	-[1]
3648	Gadsby	UT	3	-	100.1	-[1]
3775	Clinch River	VA	1	9.0	1,452.1	2.3
3845	Transalta Centralia Gen	WA	70	1.3	87.0	5.4
3845	Transalta Centralia Gen	WA	CW21	10.3	5,685.8	0.7
3845	Transalta Centralia Gen	WA	CW22	10.3	5,375.8	0.7
3935	John E Amos	WV	1	9.0	5,087.2	0.6
3935	John E Amos	WV	3	17.4	8,391.1	0.8
3935	John E Amos	WV	2	9.0	5,040.8	0.7
3943	Fort Martin Power Station	WV	2	5.8	3,663.5	0.6
3943	Fort Martin Power Station	WV	1	5.8	4,195.1	0.5
3944	Harrison Power Station	WV	1	12.9	8,638.8	0.5

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Estimated Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Use (gallons/KWh)***
3944	Harrison Power Station	WV	2	11.6	8,048.6	0.5
3948	Mitchell	WV	1	22.6	4,770.3	1.7
4158	Dave Johnston	WY	CW44	3.9	2,065.5	0.7
4162	Naughton	WY	2	2.6	1,465.3	0.6
4162	Naughton	WY	3	4.5	2,064.8	0.8
4162	Naughton	WY	1	1.9	1,269.0	0.6
4266	Spencer	TX	1	-	2.2	-[1]
4940	Riverside	OK	1501	2.6	935.9	1.0
4940	Riverside	OK	1502	3.9	999.4	1.4
4941	Navajo	AZ	1A-1B	7.8	5,354.7	0.5
4941	Navajo	AZ	2A-2B	8.4	5,881.5	0.5
4941	Navajo	AZ	3A-3B	7.1	5,087.5	0.5
6002	James H Miller Jr	AL	3-4	9.0	9,570.8	0.3
6002	James H Miller Jr	AL	1-2	9.7	9,688.8	0.4
6004	Pleasants Power Station	WV	2	10.3	3,836.7	1.0
6004	Pleasants Power Station	WV	1	10.3	3,947.3	1.0
6009	White Bluff	AR	2	9.7	4,431.8	0.8
6009	White Bluff	AR	1	6.5	5,462.1	0.4
6013	Olive	CA	01	2.6	35.0	26.9
6018	East Bend	KY	2	347.7	4,816.0	26.4
6019	W H Zimmer	OH	1	645.0	9,224.3	25.5
6021	Craig	CO	C1	3.9	2,913.9	0.5
6021	Craig	CO	C3	3.9	3,242.4	0.4
6021	Craig	CO	C2	3.9	3,375.0	0.4
6030	Coal Creek	ND	9	11.6	8,953.2	0.5
6031	Killen Station	OH	2	7.8	4,271.4	0.7
6041	H L Spurlock	KY	1	3.2	2,051.1	0.6
6041	H L Spurlock	KY	2	3.2	3,527.2	0.3
6052	Wansley	GA	1	51.7	6,017.9	3.1
6055	Big Cajun 2	LA	2C2	8.4	4,219.7	0.7
6055	Big Cajun 2	LA	2C1	8.4	3,998.6	0.8
6061	R D Morrow	MS	2	1.3	1,312.8	0.4
6061	R D Morrow	MS	1	1.3	1,329.7	0.4
6068	Jeffrey Energy Center	KS	1	22.0	4,770.3	1.7
6071	Trimble County	KY	1	8.4	3,674.7	0.8
6076	Colstrip	MT	3	9.7	5,690.8	0.6
6076	Colstrip	MT	4	8.4	4,941.5	0.6
6076	Colstrip	MT	2	3.9	2,431.5	0.6
6076	Colstrip	MT	1	3.9	2,151.5	0.7
6090	Sherburne County	MN	1	19.4	4,894.3	1.4
6094	Bruce Mansfield	PA	2	17.4	4,967.1	1.3
6094	Bruce Mansfield	PA	1	21.3	6,074.1	1.3
6094	Bruce Mansfield	PA	3	16.8	4,993.2	1.2
6112	Fort St Vrain	CO	1	3.2	3,917.3	0.3
6165	Hunter	UT	1	5.8	3,346.9	0.6

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Use (gallons/KWh)*
6165	Hunter	UT	3	5.8	3,475.8	0.6
6165	Hunter	UT	2	5.2	3,120.8	0.6
6166	Rockport	IN	CT1	33.6	8,250.0	1.5
6170	Pleasant Prairie	WI	801	8.4	7,935.5	0.4
6177	Coronado	AZ	U2CW	3.9	2,797.0	0.5
6177	Coronado	AZ	U1CW	3.9	2,986.0	0.5
6183	San Miguel	TX	SM-1	303.7	2,704.4	41.0
6193	Harrington	TX	061C	5.2	2,770.0	0.7
6193	Harrington	TX	062C	5.2	2,877.6	0.7
6193	Harrington	TX	063C	3.9	2,404.4	0.6
6194	Tolk	TX	171C	5.2	4,188.1	0.5
6194	Tolk	TX	172C	5.2	4,243.0	0.4
6195	Southwest Power Station	MO	1	2.6	1,341.1	0.7
6204	Laramie River Station	WY	3	6.5	4,540.7	0.5
6204	Laramie River Station	WY	1	5.2	4,026.7	0.5
6204	Laramie River Station	WY	2	5.2	4,534.5	0.4
6246	Putnam	FL	CT	108.6	1,238.1	32.0
6248	Pawnee	CO	1	4.5	3,903.2	0.4
6250	Mayo	NC	1	13.6	4,082.6	1.2
6254	Ottumwa	IA	1	6.5	4,781.6	0.5
6257	Scherer	GA	3	14.9	5,511.7	1.0
6257	Scherer	GA	1	12.3	4,277.8	1.0
6257	Scherer	GA	4	15.5	6,214.9	0.9
6257	Scherer	GA	2	11.6	4,205.9	1.0
6264	Mountaineer	WV	1	12.9	9,738.2	0.5
6469	Antelope Valley	ND	CC1	5.2	3,443.2	0.5
6469	Antelope Valley	ND	CC2	5.2	3,554.1	0.5
6481	Intermountain Power Project	UT	1HRC	9.7	6,630.6	0.5
6481	Intermountain Power Project	UT	2HRC	9.0	6,922.7	0.5
6558	D G Hunter	LA	2	9.0	7.4	446.3[2]
6558	D G Hunter	LA	3	26.5	10.8	895.3[2]
6639	R D Green	KY	G2	3.9	1,642.3	0.9
6639	R D Green	KY	G1	3.9	1,685.0	0.8
6641	Independence	AR	1	213.9	5,110.7	15.3
6664	Louisa	IA	101	6.5	4,426.4	0.5
6768	Sikeston Power Station	MO	1	5.2	1,757.8	1.1
6772	Hugo	OK	1	5.2	2,657.6	0.7
6823	D B Wilson	KY	W1	5.8	2,920.4	0.7
7030	Twin Oaks Power One	TX	CT-1	4.5	1,177.3	1.4
7210	Cope	SC	COP1	3.9	2,818.4	0.5
7296	State Line Combined Cycle	MO	HRC	-	331.0	-[1]
7350	Coyote Springs	OR	CW01	1.3	984.1	0.5
7350	Coyote Springs	OR	CW02	1.3	701.6	0.7
7710	H Allen Franklin Combined Cycle	AL	U1C	0.6	402.3	0.6
7710	H Allen Franklin Combined Cycle	AL	U2C	-	173.6	-[1]

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Estimated Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Use (gallons/KWh)***
7790	Bonanza	UT	1-1	7.1	3,516.5	0.7
7897	E B Harris Electric Gen. Plant	AL	U1C	0.6	274.9	0.9
7897	E B Harris Electric Gen. Plant	AL	U2C	0.6	145.1	1.6
8066	Jim Bridger	WY	CW74	5.8	3,674.4	0.6
8066	Jim Bridger	WY	CW71	5.8	3,834.5	0.6
8066	Jim Bridger	WY	CW72	5.8	3,884.6	0.5
8066	Jim Bridger	WY	CW73	4.5	3,099.7	0.5
8069	Huntington	UT	2	6.5	3,747.2	0.6
8069	Huntington	UT	1	5.8	3,466.0	0.6
8102	General James M Gavin	OH	1	40.1	8,200.2	1.8
8219	Ray D Nixon	CO	1	2.6	1,681.9	0.6
8222	Coyote	ND	C1	4.5	2,744.9	0.6
8223	Springerville	AZ	2	4.5	2,924.7	0.6
8223	Springerville	AZ	1	3.2	3,035.5	0.4
8224	North Valmy	NV	1	3.9	1,892.5	0.7
10002	ACE Cogeneration Facility	CA	CT	1.9	744.5	1.0
10043	Logan Generating Plant	NJ	DAE01	1.9	1,253.0	0.6
10071	Cogentrix Portsmouth	VA	UNIT1	1.3	279.6	1.7
10071	Cogentrix Portsmouth	VA	UNIT2	1.3	292.1	1.6
10143	Colver Power Project	PA	EBE	1.3	777.8	0.6
10362	Muskogee Mill	OK	1	18.1	517.7	12.8
10377	Cogentrix Hopewell	VA	UNIT1	1.3	259.6	1.8
10377	Cogentrix Hopewell	VA	UNIT2	1.3	268.2	1.8
10378	Cogentrix Southport	NC	UNIT1	1.3	134.9	3.5
10378	Cogentrix Southport	NC	UNIT2	1.3	136.5	3.5
10384	Cogentrix Dwayne Collier Battle Cogen	NC	UNIT1	1.3	450.9	1.0
10384	Cogentrix Dwayne Collier Battle Cogen	NC	UNIT2	1.3	454.7	1.0
10495	Rumford Cogeneration	ME	COOLTW	32.3	758.1	15.6
10566	Chambers Cogeneration LP	NJ	CT	3.9	1,706.1	0.8
10670	AES Deepwater	TX	DAE001	17.4	635.9	10.0
10671	AES Shady Point	OK	1	3.2	1,963.6	0.6
10672	Cedar Bay Generating LP	FL	1	1.9	1,842.3	0.4
10673	AES Hawaii	HI	CT	9.0	1,559.4	2.1
10864	ADM Cedar Rapids	IA	NCT	0.6	845.8	0.3
50184	Weyerhaeuser Columbus MS	MS	COLTWR	0.6	190.4	1.2
50216	Watson Cogeneration	CA	16	1.3	347.8	1.4
50304	Shell Deer Park	TX	CPS	0.6	596.7	0.4
50397	P H Glatfelter	PA	5-6	0.6	528.5	0.4
50398	International Paper Savanna Mill	GA	9CT	0.6	439.1	0.5
50406	Somerset Plant	ME	1	0.6	747.1	0.3
50637	Potlatch Idaho Pulp Paper	ID	4TG	0.6	497.8	0.5
50658	Covanta Fairfax Energy	VA	CT1	17.4	622.4	10.2
50707	TCP 272	CO	COOLTW	0.6	163.8	1.4
50888	Northhampton Generating LP	PA	CT1	1.3	838.9	0.6
50976	Indiantown Cogen Facility	FL	DA	2.6	2,419.1	0.4

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Use (gallons/KWh)*
52007	Mecklenburg Cogen Facility	VA	CS1	120.9	384.3	114.8
52088	Texas City Power Plant	TX	CT	1.3	345.9	1.4
54035	Westmoreland-LG&E Roanoke Val	NC	CT1	1.3	1,301.1	0.4
54081	Cogentrix of Richmond	VA	UNIT2	2.6	506.7	1.9
54081	Cogentrix of Richmond	VA	UNIT1	2.6	790.1	1.2
54091	Mansfield Mill	LA	HRSGCT	75.0	716.1	38.2
54091	Mansfield Mill	LA	MILLCT	1.3	716.1	0.7
54304	Birchwood Power Facility	VA	1F	7.1	1,355.9	1.9
54547	Sithe Independence Station	NY	CW6	2.6	459.2	2.1
54547	Sithe Independence Station	NY	CW5	2.6	498.1	1.9
54817	Cleburne Cogeneration Project	TX	1 HRC	1.3	550.8	0.9
55010	Cogentrix LSP Cottage Grove	MN	UNIT1	1.3	196.4	2.4
55011	Cogentrix Whitewater Cogen Facility	WI	UNIT1	1.3	194.7	2.4
55063	Batesville Generation Facility	MS	CCW1	0.6	277.0	0.9
55065	Mustang Station	TX	CT	-	954.9	-[1]
55076	Red Hills Generating Facility	MS	AA021	4.5	3,317.3	0.5
55086	Gregory Power Facility	TX	MCT	-	496.7	-[1]
55123	Magic Valley Generating Station	TX	CT	1.9	2,584.1	0.3
55129	Desert Basin	AZ	HRC	148.6	1,120.5	48.4
55131	Kendall County Generation Facility	IL	C1	2.6	31.9	29.6
55146	Green Country Energy LLC	OK	UNIT1	1.3	283.3	1.7
55146	Green Country Energy LLC	OK	UNIT2	1.3	288.9	1.6
55146	Green Country Energy LLC	OK	UNIT3	1.3	298.1	1.6
55153	Guadalupe Generating Station	TX	CT2	2.6	670.3	1.4
55153	Guadalupe Generating Station	TX	CT1	2.6	783.5	1.2
55168	Bastrop Energy Center	TX	CTOWER	3.9	566.1	2.5
55173	Acadia Energy Center	LA	CT 2	2.6	315.2	3.0
55173	Acadia Energy Center	LA	CT 1	2.6	439.0	2.1
55176	Eastex Cogeneration Facility	TX	GEA CT	0.6	243.2	1.0
55177	South Point Energy Center	AZ	CW	1.9	1,049.4	0.7
55178	Aries Power Project	MO	CT	3.9	279.7	5.1
55179	Rathdrum Power LLC	ID	UNIT1	1.3	411.5	1.1
55187	Channelview Cogen Plant	TX	ACW	2.6	919.0	1.0
55197	Caledonia	MS	UNIT 1	1.3	29.6	15.9
55197	Caledonia	MS	UNIT 2	1.3	31.9	14.8
55197	Caledonia	MS	UNIT 3	1.3	37.8	12.5
55206	Corpus Christi Energy Center	TX	CW	3.2	477.0	2.5
55215	Odessa Ector Gen, Station	TX	CTW1	3.9	879.9	1.6
55217	Los Medanos Energy Center	CA	CT	2.6	1,147.4	0.8
55221	Wrightsville Power Facility	AR	COOLTW	-	37.0	-[1]
55225	Oneta Energy Center	OK	CW-1	0.6	71.4	3.3
55231	Liberty Electric Power Plant	PA	CT	0.6	251.1	0.9
55259	Whiting Clean Energy	In	CT	-	120.2	-[1]
55269	Southaven	MS	UNIT2	1.3	44.3	10.7
55269	Southaven	MS	UNIT3	1.3	30.7	15.4

Power Plant ID	Power Plant Name	State	Cooling System Code	Estimated Water Pumpage (mgd)	Annual Generation (Million KWH)	*Unit Water Use (gallons/KWh)*
55269	Southaven	MS	UNIT1	1.3	42.4	11.1
55270	Jackson Michigan Power Plant	MI	COOLTW	-	22.1	-[1]
55282	Arlington Valley Energy Facil.	AZ	CT	2.6	541.8	1.7
55293	Morgan Energy Center	AL	CWS	0.6	26.7	8.8
55299	Channel Energy Center	TX	CT	3.9	527.7	2.7
55306	Gila River Power Station	AZ	CT-1	82.7	322.8	93.5
55314	Union Power Station	AR	CT-1	13.6	413.7	12.0
55327	Baytown Energy Center	TX	CT	4.5	1,497.2	1.1
55328	Hermiston Power Project	OR	CSW 1	3.2	941.4	1.3
55333	Delta Energy Center	CA	CT	3.9	1,885.5	0.8
55334	Holland Energy Facility	IL	CIRC	-	37.6	-[1]
55357	Brazos Valley Generating Facility	TX	CT1	1.9	490.5	1.4
55358	Cottonwood Energy Project	TX	110CLG	2.6	27.6	34.2
55358	Cottonwood Energy Project	TX	120CLG	2.6	51.6	18.3
55358	Cottonwood Energy Project	TX	130CLG	2.6	58.8	16.0
55358	Cottonwood Energy Project	TX	140CLG	2.6	67.6	14.0
55364	Mirant Sugar Creek PP	IN	CW	-	56.4	-[1]
55382	Murray Energy Facility	GA	1CW	100.2	192.7	185.9[2]
55404	Carville Energy LLC	LA	CTW	1.9	474.3	1.5
55418	Hot Spring Energy Facility	AR	1CW	5.2	421.2	4.5
55467	Ouachita Generating Plant	LA	UNIT3	1.3	168.7	2.8
55467	Ouachita Generating Plant	LA	UNIT2	1.3	190.6	2.5
55467	Ouachita Generating Plant	LA	UNIT1	1.3	194.3	2.4
55516	Fayette Energy Facility	PA	CW	7.1	72.3	35.9
55528	Redhawk	AZ	CTWR-2	4.5	585.3	2.8
55528	Redhawk	AZ	CTWR-1	4.5	771.5	2.1
55620	Perryville Power Station	LA	1	1.3	837.0	0.6
55736	Hanging Rock Energy Facility	OH	2CCW	13.6	97.8	50.6
55736	Hanging Rock Energy Facility	OH	1CCW	13.6	105.2	47.1
55821	Curtis H Stanton Energy Center	FL	1	1.9	226.2	3.1
55965	Wansley Combined Cycle	GA	U6C	1.9	283.9	2.5
55965	Wansley Combined Cycle	GA	U7C	1.9	320.5	2.2
Totals/Weighted Average				**1,836,162.2**	**828,906.8**	**2.2**
					Simple Average	**4.8**
					Median	**1.0**

[1] Insufficient data available to calculate water use ratio.

[2] Ratios greater than 100 gallons/kWh are not included in summary statistics

Water Withdrawals, Generation and Unit Water Withdrawals: <u>Nuclear</u> Power Plants with Closed-Loop Cooling Systems with Cooling Towers
- 2000 -

Power Plant ID	**Power Plant Name**	**State**	**Cooling System Code**	**Water Pumpage (mgd)**	**Annual Generation (Million KWH)**	***Unit Water Use (gallons/KWh)***
371	Columbia Generating	WA	1	21.3	9,226.5	0.8
649	Vogtle Nuclear	GA	UT1	31.7	9,196.6	1.3
649	Vogtle Nuclear	GA	UT2	31.7	10,337.8	1.1
1060	Duane Arnold Nuclear	IA	1	8.5	4,455.7	0.7
1729	Fermi Nuclear	MI	N71	47.0	8,253.3	2.1
1925	Prairie Island Nuclear	MN	1	584.6	4,536.4	47.0
2589	Nine Mile Point Nuclear	NY	2	48.5	7,981.9	2.2
6001	Joseph M Farley Nuclear	AL	SW-2	48.8	7,363.0	2.4
6008	Palo Verde Nuclear	AZ	1	22.4	10,966.6	0.7
6008	Palo Verde Nuclear	AZ	2	20.5	9,525.3	0.8
6015	Harris Nuclear	NC	1	34.6	6,878.0	1.8
6022	Braidwood Nuclear	IL	OC	34.9	18,822.3	0.7
6023	Byron Nuclear	IL	RN1	50.1	9,291.9	2.0
6026	La Salle County Nuclear	IL	OC	59.8	18,785.8	1.2
6036	Catawba Nuclear	SC	RC1	54.4	8,923.0	2.2
6036	Catawba Nuclear	SC	RC2	52.6	8,981.4	2.1
6040	Beaver Valley Nuclear	PA	2BVN	42.5	6,228.9	2.5
6051	Edwin I Hatch	GA	2	28.8	6,900.3	1.5
6072	Grand Gulf Nuclear	MS	1C	29.3	10,694.6	1.0
6103	Susquehanna Nuclear	PA	2	20.9	9,347.2	0.8
6153	Callaway Nuclear	MO	1	20.9	9,991.8	0.8
6251	South Texas Nuclear	TX	CWS2	1,131.8	10,543.4	39.2
6462	River Bend Nuclear	LA	1	15.3	7,353.0	0.8

APPENDIX D

REVIEW OF SURVEY RESPONSES

This appendix provides a summary of the responses to electronic mail survey. The responses have been edited slightly to preserve the anonymity of individual respondents as described in the research protocol. In several cases apparently the tables that accompanied the surveys were not forwarded to the respondent and/or they were not aware that these tables were available from the survey web site. Some responses, which were received without the survey forms are included at the back of this appendix.

THERMOELECTRIC POWER PLANT SURVEY RESPONSES

Q1. The Form EIA-767 requires facilities to report their average annual rate of cooling water withdrawals. How is this measure calculated or estimated for the cooling systems at your facility? (please check/write in one response)

☐ Measuring devices provide constant monitoring of flow rates, which are then averaged
☐ Cooling water system pump capacity is multiplied by the total annual time of operation
☐ Other (*please specify*):

____

Cooling Type	***Measured***	***Estimated***	***Other***
Once through	0	14	0
Re-circulating with Ponds	1	2	0
Towers	14	3	4

Other Responses:

Cooling towers surveys

- At our site we meter all of the water coming onto the plant site settling basins. We measure the water we treat - provide an estimate of settling pond evaporation - and the resulting balance is the estimate for cooling water withdrawals.
- Blow down flows + calculated evaporative losses.
- Flow totalizer
- Metered well pumps
- We have flow meters on the makeup clarifiers. However, historically the flow reported to the state environmental regulatory agency is a mathematical calculation done by the engineer. We report the same flow every month. This would be more accurate if we reported the actual flow. I discussed this with the engineer - he said that we had to report as we are unless we go through an official notification.

Q2. Please find the withdrawal ratios for the cooling system(s) at your facility in the table of cooling system ratios that is available. Do the ratios that were calculated for your cooling systems appear to be correct?

☐ **Don't know**, we are not able to estimate the ratio of cooling water withdrawals to net generation at our facility
☐ **Yes**, the ratio(s) for our facility are consistent with our own estimates
☐ **No**, these ratios do not accurately represent cooling water use at our facility.

A more accurate estimate of the gallons of water withdrawals per kilowatt-hours of generation can be the determined by: (*please specify more accurate data or calculation method*):

____

Cooling Type	***Don't know***	***Yes***	***No***
Once Through	1	10	3
Re-circulating with Ponds	0	0	1
Towers	0	15	8

"NO" response comments:

Once-through

- *(same response for two plants)* Certain assumptions regarding number of pumps in operation and number of hours per year of operation appear to be incorrect. These assumptions and methodologies for calculating these flows are currently under review by our performance engineer. The most accurate way to determine this flow data would be to have dedicated flow meters on each independent cooling flow system as well as a method for logging this data.
- Sum (pump run time X pump capacity) / sum generation.

Ponds

- Table not found. We calculate 1.314 gallons/kWh. *(note: Survey Table reported a value of 1.3 for this cooling system)*
- Could not find the Table. The EIA 767 report is accurate. If you got the data from that report it would be accurate.
- Actual water use for 2000 was 1.13 gal/kWh. EIA767 guidance requires circulating water flow and not withdrawal making the comparison inaccurate.

Towers

- I have reviewed our EIA-767 data for 2003 and calculated the withdrawal ratios as 1.033 for cooling system #1 and 1.04 for cooling system #2. *(note: Survey Table reported a value of 0.7 for both of these cooling systems)*
- We withdraw water whether we are operating or not - which makes this ratio high.
- Include generation from both plant units and compare to total plant water intake. (See attached table with calculation of correct withdrawal ratios for this and other power plants operated by this utility.)

- Estimated water pump = 2.7 mgd and annual generation =1,317.9 million KWh which would give us a ratio of 0.77
- *(same response for two plants)* Include generation from both plant units and compare to total plant water intake. (See attached table with calculation of correct withdrawal ratios for this and other Colorado Xcel Energy power plants.)
- Include generation from all four plant units and compare to total plant water intake. (See attached table with calculation of correct withdrawal ratios for this and other power plants operated by this utility.)
- Inaccurate data was reported. 28.8 MGD is the absolute maximum withdrawal for the entire cooling water system with no unit downtime. 10,316.9 million MWH is the correct generation for the Independence Station. We cannot separately measure the cooling water used for both units.
- Table not included for me to review.

Q3. Please refer to the chart on the previous page. Do the estimated cooling water withdrawal ratios for the cooling systems at your facility differ significantly from the 56.1 gal/kWh median value for once-through cooling systems (26.2 gal/kWh median value for re-circulating cooling systems with ponds and canals; the 1.0 gal/kWh median value for closed-loop cooling systems with cooling towers)? If so, what do you think are the principal reason(s) for this difference?

☐ **No**, the ratio(s) for our facility do not differ significantly from the median value

☐ **Yes**, the water withdrawals of the cooling system(s) at our facility differ significantly from the national average for once-through cooling system because: (*please specify*):

____

Cooling Type	***No***	***Yes***	***No Response***
Once Through	8	4	---
Re-circulating with Ponds	0	3	---
Towers	18	5	---

Ponds

- This power plant uses three large reservoirs for cooling so makeup intake rates are very low.
- My ratio for 2004 was 38.2 gal/kWh. The difference may not be statistically significant but it is significant percent wise.
- Normally intermittent river diversion to the Main Cooling Reservoir is used instead of circulating water flow to calculate water withdrawal and use.

Towers

"NO not significantly different" response comments

- *(same response for three plants)* Response is based on correct calculation of withdrawal ratio for this plant. See above.
- Response is based on correct calculation of withdrawal ratio for this plant. See above. Is 0.303 considered significantly lower? If so our response would change to Yes. Reason is that this is a minimal discharge facility with very effective water management practices. . *(note: Survey Table reported a value of 0.7 for this cooling system)*
- Is 0.319 considered significantly lower? If so our response would change to Yes. Reason is that this facility utilizes very effective water management practices. . *(note: Survey Table reported a value of 0.3 for this cooling system)*
- Is 0.435 considered significantly lower? If so our response would change to Yes. Reason is that this facility is a zero discharge plant and utilizes very effective water management practices. . *(note: Survey Table reported a value of 0.4 for this cooling system)*
- Response is based on correct calculation of withdrawal ratio for this plant. See above.
- My calc for 2003 came out to be 0.93

"YES differ significantly" response comments

- Because we withdraw water even if we are not operating the units.
- Each system is unique. Some closed loop systems may not really be a closed loop. Many must meet thermal limitations since the unit might discharge back to a river or lake. Other systems are designed to be zero-discharge. Others still may include scrubbers or other systems that make the overall cycle much more water efficient than other systems. In our case the unit is a zero-discharge design with an effective liquid waste treatment system that supplies water to a dry scrubber which gives our unit a very good water use efficiency. Cooling water withdrawal ratios may not necessarily translate into actual water consumption. Again, in our unit's case we use well water to a true closed loop cooling system utilizing a cooling tower blowing down to a series of wastewater basins where the lower quality water is utilized to slake lime and for mixing a lime slurry for the dry scrubber. Other systems cooling water withdrawal rates are likely measuring water pumped from a river or lake into an open loop system supported by a cooling tower where a high percentage is blowdown back to the original source of supply (river or lake).

Q4. What plant- or system-specific characteristics or conditions do you think contribute to the wide range of **once-through cooling system** *withdrawals ratios that are evident in the figure above and in the table of cooling water withdrawal ratios? (check all that apply and/or write in other relevant factors)*

☐ Differences in the way that cooling water withdrawals are estimated or reported
☐ Differences in the ratio of net-to-gross generation at each facility
☐ Differences in the designed temperature rise of the condenser(s) in use at each facility
☐ Differences in maintaining optimal turbine "backpressure" that affect water flow
☐ Differences in the frequency and length of time of boiler/generator shutdowns
☐ Differences in other conditions/circumstances: (*please specify*)

____

Estimated or Reported	Net-to-gross ratio	Condenser design	Optimal backpressure	Shutdown time	Other conditions
11	2	6	3	7	6

(N=14)

Other Conditions:

- Once through cooling for other plant processes
- *(same response for two plants)* Our performance engineer feels that base load units in general will tend to have a lower ratio than the norm. Cyclical units will be in the range of 56 and peaking units will tend to have a higher number. That is because operators tend to run more of the circulating water pumps than is required to meet the heat rejection associated with the load and the operators of base load units typically have fewer options to exercise in this regard.
- Differences in the interpretation of what constitutes cooling water. Most facilities appropriate water at their intake structures that is used for purposes other than cooling water (ash pulling; wet scrubber make-up water; etc.)
- Differences in Inlet Water Temperature
- Use of Condensate Coolers in summer months affects usage in summer months. Pumps are shut down during cooler months to avoid sub-cooling.

Q4. What plant- or system-specific characteristics or conditions do you think contribute to the wide range of **re-circulating cooling systems with ponds** *withdrawals ratios that are evident in the figure above and in the table of cooling water withdrawal ratios?*
(check all that apply and/or write in other relevant factors)

☐ Differences in the way that cooling water withdrawals are estimated or reported
☐ Differences in the ratio of net-to-gross generation at each facility
☐ Differences in the size of cooling pond relative to the amount of waste heat generated
☐ Differences in the design of cooling ponds, such as dikes that that ensure good mixing and cooling of the re-circulating water, or the distance between intake and outflow structures
☐ Differences in the designed temperature rise of the condenser(s) in use at each facility
☐ Differences in maintaining optimal turbine "backpressure" that affect water flow
☐ Differences in the frequency and length of time of boiler/generator shutdowns
☐ Differences in other conditions/circumstances: (*please specify*)

____

Estimated or Reported	Net-to-gross ratio	Pond Size	Pond design	Condenser design	Optimal backpressure	Shutdown time	Other conditions
3	1	1	1	1	1	2	1

(N=3)

Other Conditions:

- Agricultural water storage rights, variable irrigation releases. Variable reservoir inflows due to weather conditions and water rights. Variable depletion of reservoir capacities due to consumption, releases, and weather conditions, and increased inflows to restore low water levels.

Q4. What plant- or system-specific characteristics or conditions do you think contribute to the wide range of **closed-loop cooling systems with towers** *withdrawal ratios that are evident in the figure above and in the table of cooling water withdrawal ratios? (check all that apply and/or write in other relevant factors)*

☐ The estimation/measurement of makeup water is imprecise and could be in error
☐ There are large differences in the blow-down rates of different cooling towers
☐ Some differences in cooling tower designs result in different amounts of water drift
☐ Differences in water quality require different blow-down rates for optimal system performance
☐ Differences in the ratio of net-to-gross generation at each facility
☐ Differences in the designed temperature rise of the condenser(s) in use at each facility
☐ Differences in maintaining optimal turbine "backpressure" that affect water flow
☐ Differences in the frequency and length of time of boiler/generator shutdowns
☐ Differences in other conditions/circumstances: (*please specify)*

____

Imprecise estimation or measurement	Blow down rates	Tower Design	Water quality	Net - to- gross ratio	Condenser design	Optimal back pressure	Shut down time	Other conditions
13	17	8	20	5	12	7	11	5

(N=23)

Other Conditions:

- Some plants have a zero discharge requirement
- Cooling system design -- once through closed loop etc. Plant water system design -- zero liquid discharge
- Most were described in the previous question. Big questions would be what is the definition of cooling system withdrawal ratios, and are data applied consistently such that calculated withdrawal ratios are comparing 'apples to apples' or is this an 'apples to oranges' comparison. I'd estimate that the later case explains the wide data spread since water rejects heat consistently regardless of plant design or location and since there isn't that wide of spread in thermal efficiencies between the units.
- Recovery systems installed at the facility, use of on-site wells, water used in auxiliary systems at the plant (e.g., lime spray dryers), ambient conditions at the facility location (humid vs. dry climate, warm vs. cool climate), design of plant in how it incorporates service water (auxiliary water) used to cool plant equipment
- Estimate may include other uses such as ash sluicing or service water
- Errors in calculation possible also.

Q5. Water consumption is defined in EIA-767 as the difference between cooling water withdrawal and discharge. Is it possible to measure or estimate cooling water consumption at your facility?

☐ **No,** it is not possible to measure or estimate consumptive use of water because:
(*check all that apply or write in other applicable reasons*):

- ☐ No cooling water discharge measuring devices are available
- ☐ Estimates of discharge based upon equipment characteristics are not possible
- ☐ Other (*please specify*):

____

☐ **Yes,** cooling system water consumption was measured (or estimated) at our facility using the following method:

____

Cooling Type	***No***	***No devices***	***Can't estimate***	***Other***	***Yes***
Once Through	9	4	1	4	4
Re-circulating with Ponds	1	1	0	1	2
Towers	4	5	0	0	18

Once Through

"No, Other" response comments

- All once-through cooling water is used for condensing of steam to condensate and therefore there is no measurable consumption.
- *(same response for two plants)* We have no consumptive use of water
- No significant water consumption is assumed.

"Yes" response comments

- Measurement at outfall weirs
- Rough evaporative estimate
- Cooling water pumps flow curves and latest test data.
- Water balance

Ponds

"No, Other" response comments

- At flows of 1,071 mgd it would be hard to find any significant difference in the intake and discharge flow.

Ponds

"Yes" response comments

- Measurement at intake minus measurement at discharge
- A factor is used and multiplied by the net generation to determine consumption.

Towers

"Yes" response comments

- We measure withdrawal and discharge flow and totalize it and subtract discharge from withdrawal
- *(same response for four plants)* Measurement at intake minus measurement at discharge
- Measurement at intake equals consumption because this is a zero discharge facility.
- All water at our facility is provided from groundwater wells. We have accurate metering devices on all wells and therefore have accurate data on total plant water consumption. Additionally we have metering devices on cooling tower blowdown and good historical data on what fraction of total water pump is for potable use - boiler water makeup - and cooling tower consumption. Generally speaking we assume that 95% of all water pumped is for cooling tower make up. Therefore the maximum theoretical error in our cooling tower figures is 5%. At a 5% error the effect would be that the cooling tower consumed 100% of all water pumped - which is impossible. Therefore our cooling water data reported is expected to be quite accurate.
- Overall Plant Water Balance
- Measurement at intake minus measurement at discharge
- Using discharge monitoring reports - but it doesn't solely measure cooling tower discharge - other minor sources are included.
- Total facility water consumption is calculated based upon the facility withdrawal from the river less the facility discharge back to the river. This amount includes boiler water makeup and other facility water consumption in addition to the cooling tower consumption. Cooling tower makeup rate (gpm) and blowdown rate (gpm) are monitored but are not totalized. Cooling tower makeup rate varies based upon cooling tower conditions (make is intermittent) and, as such, cannot be used to calculate an accurate consumption estimate.
- We perform a water balance for the generating station and calculate the consumption as outlined in question 1.
- Measure blow down flow + calculated evaporative losses.
- Flow meters at inlet and outlet
- All cooling water withdrawal is consumed. Withdrawal is metered.
- heat balance and mass balance
- We have the ability to measure how much water enters the plant site and how much water is discharged from the site (intake - discharge)
- Total Withdrawal (zero discharge facility)

Towers

"No" response comments

- We have a questionable CT blowdown flow meters due to the configuration of piping. We are working to remedy.

Q6. What are some of the possible sources of cooling water consumptive use at facilities using once-through cooling systems? (check all that apply and/or write in relevant factors)

- ☐ There is no measurable consumptive water use in once-through cooling systems
- ☐ Significant amounts of cooling water are diverted to other uses in some facilities where the diverted water is lost or evaporated
- ☐ Inaccurate estimation procedures for cooling systems discharge flow rates (used to calculate consumption) result in inflated estimates of consumptive use
- ☐ Frequent starting up and shutting down of the generators increases consumptive use because steam is vented to the atmosphere when the boiler is started up and shut down
- ☐ Other conditions/circumstances: (*please specify*)

____

Cooling Type	No measurable use	Diverted to other uses	Inaccurate measurement	Vented during start ups	Other conditions
Once Through	6	6	5	3	0
Re-circulating with Ponds	1	1	0	0	1

Ponds

- Forced and natural evaporation.

Q6. What are some of the possible sources of cooling water consumptive use at facilities using cooling systems with cooling towers (check all that apply and/or write in relevant factors)?

☐ Water that is evaporated in cooling towers escapes into the atmosphere
☐ Drift of water droplets from the cooling tower is considered consumptive use
☐ Significant amounts of cooling water are diverted to other uses in some facilities where the diverted water is lost or evaporated
☐ Frequent starting up and shutting down of the generators increases consumptive use because steam is vented to the atmosphere when the boiler is started up and shut down
☐ Other conditions/circumstances: (*please specify*)

____

Cooling Type	Tower evaporation	Drift	Diverted to other uses	Vented during start ups	Other conditions
Towers	23	16	6	10	6

(N=23)

Other conditions:

- We blowdown the cooling towers even when not operating.
- Water quality into the plant and plant design affecting the blowdown rate.
- Evaporation is by far the predominant effect typically accounting for well over 90% of total cooling tower consumption (in our case under summer time conditions we run around 94% evaporation). Blowdown will vary based on design of cooling tower and quality of make up water but on our system this accounts for roughly 6%. Drift is so insignificant so as to be almost not worth mentioning at something like 0.1% - if that. In an extreme case -I suppose that frequent start up and shut down could increase plant BOILER WATER consumption - but this has nothing to do with cooling water consumption. Overall plant water use should drop dramatically for a unit that does not run in base load. Boiler water consumption on any unit ought to be a tiny fraction of cooling water consumption and if the unit is off line - cooling water consumption ought to be very, very low - if not zero. Makes no sense to say that frequent start up and shut down would increase cooling water consumption.
- Blowdown to control cycles to prevent corrosion/scaling of the condenser
- Ash handling consumption
- All of the items listed consume water to some extent. Being zero liquid discharge, our facility uses cooling water blowdown as brine concentrator feed, which recycles 90% of the water back into the plant. Except for some steam loss and leakage this water gets back to the cooling system.
- (Start-up/shut-down losses) not typically an issue.

Q7. Are there any non-cooling water needs at your facility that use water from the cooling system?

☐ **No,** all reported cooling water withdrawals are used only for generation process cooling
☐ **Yes,** there are some non-cooling diversions of water from the cooling water system.
These include: (*please describe and estimate quantity of each use*)

Use 1: ________________ Quantity: ______ mgd/yr
Use 2: ________________ Quantity: ______ mgd/yr
Use 3: ________________ Quantity: ______ mgd/yr

Cooling Type	***No***	***Yes***
Once Through	6	8
Re-circulating with Ponds	2	1
Towers	11	12

Once Through

Uses	*Quantities*
Unknown	----
Processing/washing	4,247,471,000 gal yr
Boiler make up	0.041 mgd
bearing cooling water	5 mgd
Ash Sluicing	0.47 mgd
Co-Gen steam supply to DuPont	1.4 mgd
Supply water to boiler water make up	25 mgd
filtered water	1 mgd
FGDS (Scrubber)	unknown
chemical plant use	14 mgd

Ponds

Uses	*Quantities*
Irrigation releases	420,000,000 gal yr
Lime spray dryer scrubber makeup	53,000,000 gal yr
Lawn irrigation, wash down, misc.	1,000,000 gal yr

Towers

Uses	***Quantities***
Yes response, No specified use	-----
Steam Cycle Make-up	0
Cooling tower blowdown is used in the scrubber as process water.	0.32
Demineralized Water Production	1
Ash Sluice	1 mgd
Boiler seals	15.8 million gallons/year
AMU dust control	0.004
Cooling system blowdown water is recycled in the scrubber.	0.16
boiler make up	0.036
Ash water from cooling tower blowdown	26.28 million gallons/year
Ash system	315 million gallons/year
Ash system	1000 gpm estimated -- 525 mgd/yr
Scrubber dilution water from cooling tower blowdown	315.36 million gallons/year
quencher make up	0.526
Liquid CO2 Production	Don't know
Fire water backup	Not measured
Fire protection	Not measured
Cooling tower blowdown is used as quench water in the boiler blowdown flash tank.	0.43
Washdown	100 gpm estimated -- 52 mgd/yr
Facility Wash Down; Fire Protection	Don't know
Coal system washdown	46 million gallons/year

Q8. Form EIA-767 requires that power plants report NET GENERATION for each generator. How is NET GENERATION calculated for the generators at your facility? *(please check one and/or write in response)*

☐ Metering is available to measure both the gross generation and the service load energy for each generator
☐ Plant–level generation is metered as it is delivered to the grid. Generation for each generator is estimated based on hours of operation or other operational measures. Net generation is calculated by deducting a portion of the total plant service load from the estimated production of each generator.
☐ Service load energy is estimated and deducted from the metered gross generation of each generator unit
☐ Other measurement or estimation procedure (*please specify*)
:

Cooling Type	***Both metered***	***Generation estimated***	***Service load estimated***	***Other***
Once Through	12	0	1	1
Re-circulating with Ponds	3	0	0	0
Towers	21	1	0	1

Once Through

- Generator gross load is measured. Plant level generation is metered as it is delivered to the grid. Service load is estimated by taking the difference.

Towers

- Gross. Net and station power is metered.
- Metering available for *net* generation only.

Q9. Does your facility maintain a record of GROSS GENERATION for EACH generator at your POWER PLANT? If so, approximately what percent of gross generation on annual basis does net generation represent at your facility? (please check one and/or write in response)

☐ **Yes,** records of gross generation for each generator ARE available.
On an annual basis, net generation is equal to approximately % of gross generation
☐ **No,** it is not possible to measure or record gross generation for each generator
☐ Other (*please specify*)
:

Cooling Type	***Yes***	***No***	***Other***
Once Through	12	0	1
Re-circulating with Ponds	3	0	0
Towers	22	1	1

Reported ratio of net to gross generation by cooling type

Once Through	***Re-circulating with Ponds***	***Towers***
100	94.67	92
95.675	94	93
95.675	One did not specify %	91.85
95		91.17
92 to 93%		92.11
Approx. 94		98.64
95		93.72
10		93
Four did not specify %		91.23
		94.98
		94.2
		95
		97.2
		95
		93
		89
		87.5
		928% service power)
		93
		93
		Two did not specify

Other specification:

Once through

- This ratio is considered sensitive and proprietary information.

Towers

- 8% service power (= 92% gross)
- gross generation is calculated, but we do not keep records

Q10. Does your facility measure and record the ANNUAL TOTAL WATER WITHDRAWALS for your facility?

☐ **Yes,** records of total water withdrawals ARE available.
☐ **No,** it is not possible to measure total withdrawals for our facility
☐ Other (*please specify*)
:

Cooling Type	***Yes***	***No***	***Other***
Once Through	8	5	1
Re-circulating with Ponds	3	0	0
Towers	18	1	4

Other specification:

Once through

- Pumping Capacity

Towers

- Withdrawals are recorded for the state of Arkansas for water conservation purposes - but it is calculated based off of a capacity factor
- what we report for withdrawal is actually total water withdrawals *(this was a comment attached to a yes response)*
- estimates based on pumps in operation

Q11. Are there any constraints to cooling water withdrawals at your plant? (please check all that apply)

☐ Volume limitations mandated under NPDES
☐ Temperature limitations mandated under NPDES
☐ Water withdrawals are fixed under State permitting requirements
☐ High summer water temperatures and/or low flows in the source may require generation reductions to prevent overheating
☐ Other limitation (*please specify*)

:

Cooling Type	***NPDES vol***	***NPDES temp***	***State permit***	***Seasonal temp***	***Other***
Once Through	3	7	2	2	2
Re-circulating with Ponds	0	0	1	1	2
Towers	2	4	4	0	9

“Other”

Once Through
- None
- Pumping Capacity

Ponds
- Contractual and water rights
- Texas Colorado River flow limitation

Towers
- none
- Don’t have any
- Contractual and water rights (*six responses*)
- pump capacity

Q12. Do you currently use any "alternative" sources of water at your plant? (please check all that apply)

☐ **No**
☐ **Yes**, these include:
  ☐ Recycled water from ash ponds
  ☐ Municipal wastewater
  ☐ Brackish groundwater from oil/gas generation
  ☐ Water from mine dewatering operations
  ☐ Other alternative sources (*please specify*)

:

Cooling Type	***No***	***Ash ponds***	***wastewater***	***brackish***	***mines***	***other***
Once Through	11	0	0	1	0	3
Re-circulating with Ponds	2	0	0	0	0	1
Towers	9	14	5	2	0	3

One "once through" respondent that answered "no" also answered "brackish"
One "Towers" respondent answered both "yes" and "no" but did no specify an alternative water source.
One "Towers" respondent answered neither "yes" nor "no" but did specify an alternative water source.

<u>*"Other":*</u>

Once Through
- Deep wells
- Groundwater
- City water (treated for boiler make-up)

Ponds
- Valmont Station uses City water for boiler makeup and potable uses (*answered "no"*)
- Direct rainfall (approximately 42" per year) on the 7,000 acre Main Cooling Reservoir

Towers
- groundwater for backup cooling for specific equipment
- City water, Recycle water sample table, Recycled tertiary-treated water from municipal wastewater treatment plant, Well water
- Groundwater monitoring wells.
- Well water – typically over 90% of water use
- City water, Recycle water sample table
- Shallow well water
- Leachate from Ash Management Unit; Water from stormwater sediment pond
- Well water

Q13. If water intake from your current source had to be reduced in response to severe weather conditions or regulatory restrictions, what actions could be taken at your plant to respond to these conditions? (please check all that apply and/or add additional alternatives)

☐ Reduce generation
☐ Install cooling towers
☐ Operate generators at less than optimal back pressure
☐ Obtain supplemental intake waters from other sources (including recycled water)
☐ Alter cooling water intakes and/or outflows structures to improve cooling system efficiencies
☐ Other adjustments (*please specify*)

:

Cooling Type	***Reduce gen***	***Install towers***	***Sub-optimal back pressure***	***Supplemental intake***	***Alter structures***	***Other***
Once Through	12	3	3	1	1	
Re-circulating with Ponds	2	1	0	1	0	2
Towers	15	2	5	6	---	6

"Other":

Once Through

- Running turbine with increased back pressure 1) is very inefficient; wastes fuel; increases stack emissions; 2) will greatly shorten the life of the turbine due to increased moisture and temperatures in latter stages.
- Do not have authority to make policy

Ponds

- Water exchanges or purchases to meet irrigation release demands or supplement stream flows. With full reservoirs supply is sufficient for operations for several months with interrupted inflows.
- The STP diversion facility is within the tidal reaches of the Gulf of Mexico. Operating procedures outline actions during drought conditions where reservoir water quality is sacrificed to maintain reservoir level.

Towers

- Send more ash pond discharge back to ash water storage tanks for reuse, increase cycles in cooling towers
- Water would be released from Steamboat Lake where one year's worth of water is stored for plant use.
- Increase cycles of concentration in cooling towers, Increase chemical feed
- Generation would be restricted or shut down.
- Modify pretreatment chemistry (higher softening). Modify cooling water chemistry and treatment. Run higher cycles of concentration in cooling tower.
- not known

Q14. What is your title and water management responsibilities? ***(optional)***

Title:

Once Through	**Re-circulating Ponds**	**Cooling Towers**
Air Program Coordinator	Environmental Analyst	Assistant CFC Plant Superintendent
Area Superintendent, Power/Brine	Environmental Supervisor	Chemical Supervisor
Environmental Compliance Specialist	Senior Environmental Compliance Engineer	Chemist III
Environmental Coordinator		Engineer
Operations Superintendent		Environmental Analyst
Performance Engineer		Environmental Coordinator
Plant Engineer		Environmental Specialist
Senior Lead Environmental Analyst		Executive Manager Power Production
Senior Plant Engineer		Results Engineer
Special Projects Chemist		Senior Environmental Analyst
Station Engineer		Senior Lead Chemist
Vice President		Team Leader

Plant water management responsibilities: (*please check all that apply*)

☐ Complete Form EIA-767
☐ Complete NPDES forms
☐ Record water use data
☐ Manage cooling controls
☐ Monitor plant water use
☐ Make decisions on in-plant water management
☐ Other

:

Cooling Type	***767***	***NPDES***	***Record***	***Manage***	***Monitor***	***Decide***	***Other***
Once Through	13	5	7	2	6	4	0
Re-circulating with Ponds	3	2	1	0	2	1	0
Towers	18	7	13	7	11	8	4

Other Towers

- Monitor plant performance

Other Comments:

Towers Comment #1
Additional non-cooling water needs at the facility (Q7) also include waste ash pub mills (not separately measured from cooling towers), lime spray dryers (dependent on unit size, removal rate, and system efficiency) and service water (not separated from circulating water cooling towers).

Towers Comment #2
Independence is a two-unit facility. The cooling water is known for the entire plant but we can't quantify individual unit totals - so the annual generation for this facility should be 10,316.9 million MWH. Also - see comments in other questions for corrected numbers. The system was reported as EN on the survey but the attached table makes it appear that the numbers are for only one unit.

NON-SURVEY EMAIL RESPONSES

Several plant managers and engineers responded to the survey request by telephoning the PI, or by emailing written comments that generally described water use and reporting at their facilities. No attempt was made to record the telephone feedback. Of the written email responses, only one is reproduced in this appendix. The text has been edited to retain the anonymity of the respondent.

Rec'd via email 8/26/05

Mr. Dziegielewski,

I am responsible for compliance and reporting of UTILITY NAME water use in accordance with our surface water withdrawal permits issued by the STATE AGENCY. Rather than responding individually to your questionnaire for each of our plants, I will respond in general and identify exceptions. I'll be happy to discuss any questions you may have regarding these responses.

First, some background on the state of water use and regulation in STATE: Over the past 15 years, STATE awareness of water resources issues has increased dramatically - regulatorily, politically and publicly - as a result of a water war among CONTINGENT STATES, and two periods of extended severe drought. As the withdrawer of the largest amount of water in the state, UTILITY NAME has been closely following these issues and has examined our own impact, processes and tracking methods. Most of those involved have only recently begun to realize the difference between water withdrawals and water consumption. To illustrate the significance of this difference, UTILITY NAME withdrawals in 2003 averaged 2,614 MGD, but only 164 MGD was not immediately returned to the source. Beginning in 2003 at STATE AGENCY's request, we agreed to annually voluntarily report our consumptive use, in addition to the past requirements to report withdrawals. Since our NPDES permits do not require monitoring of discharge flow rates and we typically have no meters installed to do so, we have reached agreement with STATE AGENCY on consumptive use determination methodology (which may vary from plant to plant, depending on specific design configurations).

Your list includes these UTILITY NAME plants:
Once-through cooling: FIVE PLANT ID's LISTED
Closed-loop cooling: FIVE PLANT ID's LISTED
Nuclear closed-loop: TWO PLANT ID's LISTED

The following responses apply to all plants and categories unless otherwise noted:

1. Withdrawals are intake pump nameplate ratings multiplied by pump run time. This number represents withdrawal for all uses at the plants - not just cooling water.
2. The withdrawal and generation numbers are close enough to leave as is, but the ratios can be misleading. Once-thru Plants XXX and XXX are old, less efficient and rarely generate. They should probably be omitted from your survey since their cooling water flow will remain at full flow when the unit is on standby, or when flow is needed to prevent condenser biofouling. None of your numbers for the closed-loop plants, including nuclear, considered return flows (i.e., cooling tower blowdown), which reduce the unit water use 25 to 60 percent.
3. With the exceptions above, the ratios are in the ball park.
4. The wide range of numbers is likely dominated by reporting/tracking differences or, as in #2, once-thru plants with constant pumping during variable or low generation periods.
5. STATE AGENCY agrees with the following consumption determination methods: Once-through plants' consumption is considered zero since the negligible water loss is much less than one percent of the cooling water flow, which itself is conservatively calculated. Consumptive use of closed-loop systems is conservatively calculated by multiplying plant capacity factor times the engineered maximum cooling tower evaporation potential.
6. All other consumptive use is negligible compared to the evaporation and drift from the cooling towers.
7. The reported withdrawals include all uses at the plant. We do not track those flows.
8. Not conversant in net generation calculations, but they are tracked very accurately.
9. Ditto for gross generation.
10. Daily withdrawals are reported each month to STATE AGENCY. Average monthly and annual consumption is reported each year.
11. STATE withdrawal permits have limits for average monthly and maximum 24-hour withdrawals. Some on smaller rivers have restrictions during low river flows. None have ever caused load cuts to comply with the withdrawal permit.
12. Three of our plants use less than 1 MGD of ground water for process water make-up. There are no other alternative sources, and none have alternative cooling water sources.
13. See #11.
14. See plant listing above. I track, report, analyze, and advise plant managers on water use. They make the decisions and operate the plant.

Again, feel free to call me for clarification.

RESPONDENT NAME
TITLE
CONTACT INFORMATION