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Net Environmental and Social Effects of Retrofitting Power Plants with Once-Through Cooling to Closed-Cycle Cooling

2011 TECHNICAL REPORT

Net Environmental and Social Effects of Retrofitting Power Plants with Once-Through Cooling to Closed-Cycle Cooling

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PRODUCT DESCRIPTION

The Electric Power Research Institute (EPRI) is investigating the implications of a potential U.S. Environmental Protection Agency (EPA) Clean Water Act §316(b) rulemaking that would establish “best technology available” (BTA) based on closed-cycle cooling retrofits for facilities with once-through cooling. This report focuses on the environmental and social impacts that can potentially result from a requirement for use of closed-cycle cooling systems.

Results and Findings

EPRI estimates that there are 428 facilities potentially subject to retrofit requirements, based on their use of greater than 50 million gallons per day (MGD) of once-through cooling water. These facilities generate approximately 312,000 MW of electricity, including 60,000 MW from 39 nuclear facilities and 252,000 MW from 389 fossil facilities. While closed-cycle cooling significantly reduces impingement mortality of fish and shellfish on cooling water intake structure screens as well as entrainment mortality of the early life stages of fish and other aquatic organisms through the condenser cooling water system, these systems can produce a variety of potentially adverse environmental and social impacts, depending on their location.

Closed-cycle cooling impacts that were evaluated included human health; terrestrial and aquatic resources; solid waste; and public safety, security, and quality of life as well as the permitting issues associated with these impacts. The quantified and monetized environmental and social impacts of closed-cycle cooling tend to be site specific and are a function of the water-body type, adjacent land use, fuel type, and nearby population density. Potential human health, terrestrial, social, noise, viewshed degradation, and safety impacts are dominant in urban and suburban areas, whereas terrestrial, ecological, and agricultural impacts are dominant in rural or undeveloped areas. Excluding consideration of greenhouse gas emissions and human health impacts for the majority of the 24 sites investigated in detail, the monetized impacts of closed-cycle cooling were found to exceed the fish impingement and entrainment mortality reduction benefits. However, considerable uncertainty remains for both monetized impacts and benefits, and methods are currently unavailable for monetization of some benefits as well as a number of impacts associated with closed-cycle cooling.

Challenges and Objective(s)

Section 316(b) of the Clean Water Act establishes statutory requirements for fish protection at cooling water intake structures (CWISs). In 2004 the U.S. EPA established a rule for implementing §316(b) for existing CWISs using >50 MGD. The rule was withdrawn by the EPA following a legal challenge and subsequent Second Circuit Court ruling. EPA has proposed a revised rule for existing facilities that included consideration of three additional options, two of which were based on closed-cycle cooling as BTA. The EPA plans to issue a final rule in mid-2012, and potentially, any of the four options could be selected for the final rule. Although closed-cycle cooling is commonly employed at new generating facilities, a retrofit of closed-cycle cooling at existing facilities can be challenging or impractical for a variety of reasons, including lack of space, location of existing facility infrastructure, local environmental issues, and economic reasons.

Applications, Values & Use

Information in this report is intended to provide the EPA with technical information for Clean Water Act §316(b) policy development and future rule compliance efforts by the power industry, resource and regulatory agencies, and the public.

Data in this report provide regulators, the industry, and other stakeholders with information on the environmental and social impacts of closed-cycle cooling as BTA. Additionally, this information is used in combination with companion reports on the cost, financial, and electric system impacts as well as the benefits of closed-cycle cooling as BTA.

Approach

Initially, seven “beta test” facilities were studied after gathering detailed information. These facilities underwent air quality modeling, noise modeling documentation of land use, and other analyses to evaluate the methodology planned for the overall study. Based on results, EPRI gathered detailed information on an additional 17 facilities (for a total of 24 facilities) that were selected based on the water-body type used for cooling water, size of facility, fuel type (nuclear or fossil), and climatic region. In addition, a questionnaire was sent out to the industry by distribution through a number of power generation industry trade organizations soliciting information on potential environmental issues associated with closed-cycle cooling retrofits, such as proximity to sensitive ecological habitat, protected species, and recreational areas as well as potential environmental permitting issues. The study also included an extensive literature review of potential closed-cycle cooling impacts. The information gathered was used with EPRI’s list of Phase II facilities to estimate potential impacts at the national level.

Key Words

Clean Water Act §316(b)
Cooling towers
EPA
Closed-cycle cooling
Cooling water intake structure (CWIS)
Fish protection

ABSTRACT

The U.S. Environmental Protection Agency (EPA) is currently developing revised regulations for power plant cooling water intake structures under §316(b) of the Clean Water Act. The EPA is considering technology-based aquatic life protection performance standards that may require closed-cycle cooling as "best technology available" (BTA) for existing thermoelectric facilities that currently use once-through cooling. This study provides information on potential environmental impacts associated with closed-cycle cooling. A variety of potential impacts are discussed that can occur with mechanical draft cooling towers. These include environmental impacts such as impacts to agriculture, wildlife, wetlands, native vegetation, or other ecological resources including impacts to protected species as well as social impacts such as aesthetics, noise, public safety, and health.

The study evaluated 24 representative facilities in some detail, and results determined that the significance of impacts varied widely, depending on the environment surrounding the facility. Facilities located in urban and suburban environments were dominated by social impacts, whereas facilities located in rural or undeveloped areas were dominated by environmental impacts. Where possible, impacts were quantified and/or monetized; however, other impacts are discussed only narratively.

Using the information from the analysis of the 24 representative facilities and a questionnaire issued to the industry, the Electric Power Research Institute (EPRI) provides estimates of potential national impacts should closed-cycle cooling be designated as BTA. EPRI estimates that there are 428 power facilities (39 nuclear and 389 fossil) potentially subject to a retrofit requirement, based on their use of greater than 50 million gallons per day of once-through cooling water. However, three facilities have both nuclear and fossil units. These 428 facilities generate approximately 312,000 MW of electricity, 60,000 MW from the 39 nuclear facilities and 252,000 MW from the 389 fossil facilities. Based on EPRI's list of facilities, estimates of impacts are extrapolated to a national level under the assumption that all of these facilities would be at risk of closed-cycle cooling retrofits. Additionally, potential environmental permitting issues that have the potential to affect the ability of some facilities to retrofit are discussed.

EXECUTIVE SUMMARY

This report is one of a series to inform the United States Environmental Protection Agency (USEPA) 316(b) rulemaking on the implications of designating closed-cycle cooling as "best technology available" (BTA) for cooling water intake structures. In January 2007, the U.S. Court of Appeals for the Second Circuit in Riverkeeper, Inc v. EPA remanded to the USEPA several important provisions of the Clean Water Act (CWA) §316(b) Phase II Rule (Rule). As a result, USEPA suspended the Rule pending further rulemaking. Among the remanded provisions was USEPA's determination of BTA. USEPA, in the Rule, allowed regulated facilities a number of compliance alternatives based on alternative fish protection technologies and operational measures rather than requiring closed-cycle cooling. The Second Circuit Decision determined the Rule improperly allowed consideration of environmental benefits relative to cost in determining that closed-cycle cooling was not BTA. The Second Circuit Decision provided reasons USEPA could consider as a basis to determine if closed-cycle cooling was BTA. These reasons included whether or not the industry could bear the cost of the technology, impacts to energy production and efficiency, and adverse environmental impacts associated with the technology.

In response to the Court's decision, the Electric Power Research Institute (EPRI) initiated a large-scale supplemental research program to gather, evaluate, and summarize information that would inform USEPA on the factors the Second Circuit determined could be considered. Specifically, the EPRI supplemental research program initially consisted of four projects that included:

1. Developing cost estimates for retrofitting existing Phase II facilities with closed-cycle cooling;
2. Determining the number of facilities that could potentially retire based on retrofit costs and reduced generation due to the retrofit energy penalty;
3. Estimating the potential electric system impacts as a result of potential facility retirements and retrofit energy penalties; and
4. Quantifying potential environmental and social impacts associated with closed-cycle cooling for comparison with the possible benefit of reducing impingement and entrainment losses.

The industry filed for Supreme Court review of the Second Circuit Decision as to whether cost could be considered relative to the benefits of BTA. In April 2009, the Supreme Court ruled that USEPA could consider the cost relative to the benefit in making the BTA determination. As a result of that determination, EPRI initiated a new study in 2010 to quantify the benefit of closed-cycle cooling relative to estimated costs generated from the initial four projects.

The subject of this report is to quantify the environmental and social impacts. Specifically, the study objective was to quantify and monetize (to the extent possible) the environmental and social impacts of closed-cycle cooling retrofits. Where it was not possible to quantify or monetize closed-cycle cooling retrofit impacts, qualitative information is provided to inform the rulemaking. Also considered in this study was a review of potential environmental permitting and licensing requirements. Closed-cycle cooling structures are relatively large and the use of wet closed-cycle cooling results in discharges to “waters of the United States,” air emissions, short term construction impacts, and waste generation. As a result, closed-cycle cooling retrofits can require a variety of federal, state, and local permits prior to construction. Such permits can impact the timing or overall feasibility of a closed-cycle cooling retrofit for any given site.

Study Approach

A comprehensive study of each of the over 400 facilities that have at least one unit with once-through cooling which would be subject to a Phase II rule is beyond the scope of this study. Therefore, the strategy for the project was to group the listed facilities according to critical variables and study at least one member in each group. The results would then be normalized to apply to the other facilities within the group or categories of facilities with similar characteristics (e.g., population). To estimate overall impacts on a national basis, the results for all groups would be summed.

The original study approach was to evaluate representative facilities selected based on fuel type (nuclear and fossil), waterbody type, and climatic region. During the second phase of this project, seven facilities were selected to test (Beta Test) the quantification methodology. These seven facilities were given alphabetic identifiers: Beta Test Plant (BTP) A, BTPB, BTPC, BTPD, BTPE, BTPCA1, and BTPCA2 (two facilities located in California). Following the completion of the Beta Test, 17 additional facilities (i.e., the Representative Facilities, or ‘RFs’), were selected and given identifiers RFF through RFV.

Key assumptions were that all facilities would retrofit with wet mechanical-draft cooling towers (the most commonly used cooling towers) and the study would rely on currently available data and information, with the exception of information generated from other aspects of EPRI’s Closed-cycle Cooling Research Program and the results obtained from an EPRI Questionnaire . As part of the Program, EPRI distributed a questionnaire (a copy is provided as Appendix D) to all facilities affected by the Phase II Rule. 209 facilities responded to at least a portion of the questionnaire and these results were used, when possible, in this report.

To estimate national impacts, the results of the Beta Test, evaluation of the RFs, and the EPRI Questionnaire results were normalized to the appropriate facility parameter (e.g., cooling water flow, population), if appropriate, and scaled to other facilities within each facility subset, where possible. National estimates were subtotaled by type of waterbody the plant withdraws from: salt or brackish waterbodies (termed Ocean/Estuaries/Tidal Rivers [O/E/TR] in this study); Great Lakes and small rivers (SR/GL); and larger rivers, reservoirs or lakes (LR/RL)

During the Beta Test and evaluation of RFs, estimated effects of retrofit to closed-cycle cooling were monetized where there was an appropriate basis to generate a willingness to pay (WTP) estimate, to create a standard unit of comparison for different types of impacts. Annual WTP values in 2007$ used in this report include:

- Terrestrial Resources: Loss of critical habitat = $200 per acre and $5,200 per acre (site-specific; only evaluated during the Beta Test)
- Terrestrial Resources: Drift effects on vegetation and soils = state-specific average annual rent per hectare of cropland (Section 4.2), based on U.S. Department of Agriculture data (only evaluated during the Beta Test)
- Water Resource Quantity and Quality: Debris removal = $1,132/ton trash calculated from existing data describing volunteer and government sponsored coastal and river clean-up programs
- Public Safety and Security: Fogging/Icing on Roadways: additional travel time = $8.91/hour, an average of U.S. Census Bureau and U.S. DOT data; additional cost of accidents due to fogging = $12,568/accident based on General Estimates System of the U.S. National Highway Traffic Safety Administration data
- Quality of Life: Noise – region-specific values based on median home sales and a 0.4 percent reduction in housing value for each 1 db increase in noise (Section 4.5.1)
- Quality of Life: Viewshed – homeowners - region-specific value based on median home sales and a 0.4 percent reduction in housing value associated with the introduction of a plume to a viewshed; recreational – region-specific values for a recreational visit and a 1.8 percent reduction in the value of each recreational visit due to the introduction of a plume (Section 4.5.2)
- Greenhouse Gas: Nuclear outage = $3.80 per ton of CO_2, the average price in the voluntary offset market
- Aquatic Biota: Impingement and entrainment = taxon- and region-specific values (provided in Appendix H) calculated using the methods outlined by USEPA in its 316(b) Phase II and III regional benefits assessment:
  - Commercial per pound WTP: $0.01 - $3.49
  - Recreational per pound WTP: $0.98 – 12.76
  - Forage per pound WTP: $0.01 – $0.35

Available resources for the project allowed detailed evaluations of 24 facilities that were selected to represent the Phase II population, estimated to be 39 nuclear and 389 fossil facilities for a total of 428 facilities (Appendix F). Because three of these facilities have both nuclear and fossil-fueled units at the same generating station, they were considered one facility. Therefore, results that were calculated using the total number of facilities are shown in relation to 425 Phase II facilities, rather than 428.

Results

A summary of results is provided below. A complete list of technical references associated with closed-cycle cooling impacts is provided in Section 7. While a number of potential cooling tower impacts were only discussed narratively, eight were selected for more detailed analysis and wherever possible were quantified and monetized and included:

1. Human Health
2. Terrestrial Resources
3. Water Resources
4. Solid Waste
5. Public Safety and Security
6. Quality of Life
7. Greenhouse Gases
8. Permitting Issues

In addition to the impacts, the "Aquatic Biota" that would benefit from a closed-cycle retrofit was estimated for the 24 representative facilities. A summary of results is provided for each topic.

Human Health

As a result of mechanical-draft evaporative cooling tower operation, water 'drift' emissions are generated. Drift consists of total dissolved solids (TDS) such as sodium, calcium, chloride, and sulfate ions contained in the water flowing through the cooling tower as well as organic matter (bacteria, spores, insect and vegetative material) that become entrained in the tower airflow through the force of the fans. There are two potential human health concerns from drift, fine particulates and pathogens.

Fine Particulates - Of particular concern to human respiratory health are particles (particulate matter or PM) that are less than 10 microns in diameter, referred to as PM_{10}. Emissions of PM_{10} are subject to environmental regulations intended to maintain or improve ambient air quality. USEPA further reduced the regulated particle size to less than 2.5 microns in diameter, or $PM_{2.5}$, and has developed and continues to refine regulations for particles of this size.

Mechanical-draft evaporative cooling towers in the study are assumed to use "drift eliminators" to limit the drift rate to 0.0005 percent of the circulating water flow rate and this figure was used in the modeling analysis. For the RFs modeled, fine particulates emitted ranged from 1.9 tons per year (tpy) (1.5 tpy PM_{10} and 0.6 tpy $PM_{2.5}$) to 877.8 tpy (352.5 tpy PM_{10} and 105.3 tpy $PM_{2.5}$). As expected, drift emissions were significantly greater for the higher salinity makeup water withdrawn from oceans, estuaries, and tidal rivers (i.e., average of 388.1 tpy/facility) compared to facilities withdrawing from freshwater (i.e., average of 17.1 tpy/facility). The population exposed to significant increases in PM_{10} and $PM_{2.5}$ ranged from 84 to 223,756 (Age 30+) and from 1 to 38,495 (Age 65+). Based on the analysis of the 24 RF, it is estimated that 29,800 tpy of particulates would be generated (13,500 tpy of PM_{10} and 4,200 tpy of $PM_{2.5}$) if all Phase II facilities were required to retrofit to mechanical-draft evaporative cooling towers.

Due to the lack of impact studies focused on human health effects related to cooling tower fine particulates, human health impacts are not reliably quantifiable. Any such impacts are likely to be extremely variable depending on the nature of the fine particulates in the source waterbody. However, human health risk estimates based on USEPA methodology were also made for comparison (Appendix G).

Pathogens – Another human health concern associated with cooling towers is the risk of disease caused by intake of aerosol sprays contaminated with *Legionella* sp. or other pathogens [17]. The Cooling Technology Institute has developed best practices that include halogenation to minimize *Legionella* in cooling systems. The current state of the science does not allow for quantification of the potential risks caused by *Legionella* [20] and other pathogens and therefore, this potential impact is neither quantified nor monetized in this report.

Terrestrial Resources

Terrestrial resources include both natural resources and human-generated resources. Natural terrestrial resources are lands that serve as habitats for plant and animal species or are used for other purposes (e.g., agriculture). Human-generated resources include homes, cars, and a variety of other man-made objects. The construction and operation of cooling towers systems could result in the short-term or long-term loss of natural resources as well as impact human-generated resources due to exposure to cooling tower emissions. Temporary losses would be restored and long-term losses would be avoided to the extent practicable. The types of impacts studied included:

- Long-term loss of wildlife habitat, wetlands, and critical habitat;
- Salt and mineral drift effects on vegetation and soils;
- Noise impacts on terrestrial wildlife;
- Impacts of fogging and icing on terrestrial vegetation; and
- Salt and mineral drift impacts to man-made objects.

Long-term Loss of Wildlife Habitat, Wetlands, and Critical Habitat

Based on the information collected and analyses performed, the loss of critical habitat associated with a national closed-cycle cooling retrofit requirement may be summarized as:

- Four of the 24 plants studied, or 17 percent, estimated potential loss of critical habitat from closed-cycle cooling retrofit; and
- Based on the EPRI Questionnaire, 29 of the 209 facilities responding indicated terrestrial or wetland resources would be impacted by closed-cycle cooling retrofit. Thus, unique, rare, or threatened habitats may be lost at up to 22 (or 11 percent) of the facilities surveyed.

Table ES-1
List of Impacts considered and either quantified, monetized and/or narratively discussed in the closed-cycle cooling retrofit study

Category	Quantified	Monetized	Narrative
Human Health			
Legionnaire's Disease			X
Exposure to Increased PM	X		X
Mortality and Morbidity from PM Exposure	X	X	X
Terrestrial Resources			
Long-term Loss of Non-unique, Non-rare Habitats	X		X
Long-term Loss of Unique, Rare Habitat	X	X	X
Salt/ Mineral Drift Impact to Native Vegetation	X		X
Salt / Mineral Drift Impact to Agricultural Soil	X	X	X
Noise Impact to Terrestrial Wildlife	X		X
Fogging/Icing Impacts on Terrestrial Vegetation	X		X
Bird, Bat, and Insect Collisions/ Entrainment into Cooling Tower			X
Salt Damage to Off-site Property	X		X
Water Resources			
Evaporative Water Loss (Potable Water)	X		X
Biocides and Trace Metal Discharge			X
Solid Waste			
Debris Removal	X	X	X
Solid Waste Generated by Cooling Tower			X
Public Safety / Security			
Icing of Roadways	X		X
Fogging of Roadways	X	X	X
Fogging/Icing at Airports	X		X
Fogging at Nuclear Facilities	X		X
Quality of Life			
Noise	X	X	X
Viewshed	X	X	X
Greenhouse Gas			
6- and 8-Month Outages at Nuclear Facilities	X	X	X
Additional CO_2 Associated with Energy Penalty			X
Change in Composition of Generating Fleet			X
Water Vapor as Greenhouse Gas	X		X
Aquatic Biota			
Impingement and Entrainment of Fish and Shellfish	X	X	X
Entrainment of Planktonic Organisms			X
Thermal Discharge Effects			X
Other			
Cumulative Impacts			X

Based on these two subsamples, between 47 and 72 of the Phase II facilities may experience potential loss of critical habitat as a result of closed-cycle cooling retrofit resulting in an average WTP estimate of $16,563. Thus, the national annual WTP to avoid this loss may range from approximately $775,000 to over $1.19 million. This estimate is highly uncertain due to the site-specific nature of the impacts.

Salt and Mineral Drift Effects on Vegetation and Soils

Salt/mineral drift emitted from mechanical-draft evaporative cooling towers were evaluated in terms of potential effects on native vegetation, soils and crops. The study findings suggest that potential impacts to forests and non-agricultural herbaceous vegetation such as visible leaf damage were likely at most of the RFs investigated in this study, representing both saline and fresh water sites. However, since impacts were found to be highly site-specific depending on the type of vegetation, location of the vegetation relative to the tower location, and tower emissions, and due to the lack of information to estimate WTP, salt/mineral drift effects were neither scaled nor monetized.

Noise Impacts on Wildlife

Based on a literature review, a threshold of 60 decibels A-scale (dBA) represents the noise level above which wildlife potentially can be adversely affected. This noise level is used by the U.S. Fish & Wildlife Service in California for several species of birds including the least bell’s vireo, California gnatcatcher and light-footed clapper rail. The acres of habitat exposed to a noise level greater than 60 dBA from cooling tower operation was estimated by modeling, and ranged from 111 to 208 acres for the seven Beta Test facilities. However, nationally this impact could not be quantified nor monetized. However, there are potential impacts at some facilities, which are further discussed under permitting issues.

Impacts of Fogging and Icing on Terrestrial Vegetation

The Nuclear Regulatory Commission (NRC) has identified potential detrimental effects to the terrestrial environment from increased fogging and icing associated with cooling tower operation. These effects include increased humidity-induced fungal or other phytopathological infections on local vegetation, or ice damage. The NRC suggests an order-of-magnitude approach to the analysis of impacts of fog or ice related to cooling tower operation and was the approach used in the analysis. Seasonal Annual Cooling Tower Impact (SACTI) modeling (see Section 4.4) results indicated that fogging at the rate of tens of hours/year is predicted to occur at eight of the 18 evaluated facilities (44.4 percent) and additionally, icing at this rate was predicted to occur at two of the facilities. Therefore, using the NRC guidelines, fogging and icing associated with cooling tower operation may cause detectable damage to vegetation, if present. At the national level the analysis was unable to monetize the WTP to avoid the damage due to site-specific variability in vegetation type (e.g., crops, critical habitat, and non-rare types) and lack of WTP data.

Human-Generated Terrestrial Resource Impacts

Salt deposition emitted from mechanical-draft evaporative cooling towers can damage automobiles and other metal surfaces, corrosion and shorting of electrical equipment, and spotting of windows and other surfaces. While in most cases, such impacts most likely occur within the facility property boundary, facilities using makeup water from oceans, estuaries and tidal rivers located in urban areas, may result in significant off-site property damage. Based on study results the critical rate of mineral deposition may occur at a distance up to 761 meters (2,500 feet) away from cooling towers for freshwater facilities and from 300 meters (980 feet) to more than 1,100 meters (3,600 feet) for facilities using saline or brackish water. These potential human-generated terrestrial resource impacts are not monetized due to a lack of economic data on which to base the WTP estimate and the lack of threshold effects data.

Water Resources

It is assumed that cooling tower discharges will meet applicable water quality standards. Using this assumption, three retrofit impacts were evaluated:

Evaporative Water Loss

Conversion to a closed-cycle cooling system will increase the evaporation rate compared to a once-through cooling system. Consumptive water loss from proposed closed-cycle cooling towers at modeled facilities is between ~400-900 gallons per megawatt (MW)-hr electricity generation for fossil-fueled facilities and approximately 750-1,050 gallons per MW-hr for nuclear facilities, which is over double the water loss estimated for once-through cooling. As shown in Table ES-2, nationally, the total estimated freshwater evaporative loss is estimated to be 500 billion gallons/yr (372 billion gallons/yr for facilities on large rivers, reservoirs and lakes other than the Great Lakes and 128 billion gallons/yr for facilities on the Great Lakes and small rivers). Note that permitting and/or the issue of obtaining additional water rights to maintain water levels for cooling lakes and ponds in southwestern arid portions of the United States such as Texas and Oklahoma are not evaluated in the study.

Source Water Debris Removal

The majority of once-through condenser cooled facilities remove and dispose of material collected on their intake structure traveling screens or that accumulate in front of the intakes. This includes natural material (logs, brush, leaves, sea weed, etc.) as well as man-made debris such as plastics, cans, paper, plastic can holders and other solid waste including the contribution of Combined Sewer Overflow wastes, especially in large urban areas. The National Oceanic and Atmospheric Administration (NOAA) consider this marine debris as one of the most widespread pollution problems in the world’s oceans, lakes and waterways. The reduction in the water volume withdrawn associated with closed-cycle cooling retrofits, and the associated reduction of man-made debris removed from the waterbody, was evaluated for characteristic facilities (Section 4.3.2). A national estimate of the amount of trash removed by the existing cooling water intake structures using responses to the EPRI Questionnaire and direct correspondence with some facilities estimated resulting in an estimate of 860 tons/yr of man-made debris removed by all once-through cooled facilities.

Table ES-2
National estimate of quantified environmental impacts should closed-cycle cooling be designated as best technology available

Impact Type	Large Freshwater Rivers, Freshwater Lakes (non-Great Lakes) and Freshwater Reservoirs	Great Lakes and Small Rivers	Oceans Estuaries and Tidal Rivers	Total Quantity
Human Health				
PM (tons/year)	2,000	800	27,100	29,800
PM_{10} (tons/year)	1,400	600	11,500	13,500
$PM_{2.5}$ (tons/year)	600	200	3,400	4,200
Exposed Population (Age 30+)	1,003,500	6,063,700	8,977,900	16,045,000
Exposed Population (Age 65+)	226,300	1,098,000	1,641,700	2,966,000
Terrestrial Resources				
Noise impacts on wildlife (# facilities)	96	39	22	157
Fogging/icing impacts on vegetation (# facilities)	115	59	0	174
Water Resources				
Active chlorine use (metric tons/year)	18,000	7,000		25,000
Evaporative water loss (billion gallons/year)	372	128	NA	500
Debris removal (tons of trash not removed/year)	338	241	281	861
Greenhouse Gas				
CO_2 Emitted (million tons) 6-month outage	74	22	67	163
CO_2 Emitted (million tons) 8-month outage	99	29	84	212

Totals may not equal due to rounding.

Table ES-3
Comparison of monetized environmental and social impacts with the benefits associated with a reduction in IM&E for 24 representative facilities

Representative Facility	Increased Man-Made Debris	Public Safety/ Increased Roadway Fogging [c]	Increased Noise [c]	Viewshed Degradation [a, c]	Decreased IM and E [d]	Net Annual Average WTP to Avoid Change to Closed-cycle Cooling [b,e]	Increased Greenhouse Gases [f]	Net WTP to Avoid Change to Closed-cycle Cooling [e]
BTCA1(1)	$18,600	<$50	$53,800	$189,300	($133,000)	$128,700	--	$128,700
BTPA	N/A	$0	$0	$300	($40,600)	($40,300)	--	($40,300)
BTPB(2)	$11,100	$100	$5,800	$8,600	($65,200)	$71,200	$428,800	$500,000
BTPC	$2,200	<$50	$0	$4,400	($241,700)	($235,100)	--	($235,100)
BTPD	$0	<$50	$16,200	$1,700	($400)	$17,500	--	$17,500
BTPE(3)	N/A	$0	$1,600	$100	($6,300)	($4,500)	$493,800	$489,300
BTCA2	$0	$2,800	$0	$157,800	($408,900)	($248,300)	$438,400	$190,100
RFF	$200	<$50	$0	$0	($569,800)	($569,600)	--	($569,600)
RFG	N/A	$200	$11,100	<$50	($6,200)	$5,100	--	$5,100
RFH	$0	$0	$19,600	$4,900	($47,400)	($22,900)	$411,200	$388,300
RFI	$46,600	$23,500	$0	$27,600	($8,100)	$89,600	--	$89,600
RFJ	<$50	<$50	$63,000	$0	($1,100)	$61,900	--	$61,900
RFK	$0	<$50	$0	$3,200	($91,900)	($88,700)	--	($88,700)
RFL	N/A	$400	$245,900	$0	($1,600)	$244,700	--	$244,700
RFM	$3,000	$0	$186,900	$0	($5,100)	$184,800	--	$184,800
RFN	N/A	$100	$73,900	$0	($500)	$73,500	--	$73,500
RFO	$0	$100	$0	<$50	($5,400)	($5,300)	--	($5,300)
RFP	N/A	$0	$14,700	<$50	($1,800)	$12,900	--	$12,900
RFQ	$45,600	<$50	$0	$0	($400)	$45,200	--	$45,200
RFR	$0	N/A	$0	<$50	($100)	($100)	--	($100)
RFS	$1,500	$100	$0	$1,000	($40,200)	($37,600)	$334,800	$297,200
RFT	$300	$0	$29,400	$0	($13,000)	$16,700	--	$16,700
RFU	$200	<$50	$0	$0	($200)	<$50	--	<$50
RFV	$400	<$50	$800	$100	($800)	$500	$214,300	$214,800

Table ES-3
Comparison of monetized environmental and social impacts with the benefits associated with a reduction in IM&E for 24 representative facilities (continued)

Notes:
1. Does not include $5,200 to off-site wetland.
2. Includes $110,800 for increased terrestrial habitat impacts.
3. Includes $80 for increased salt deposition.
a. Visual impacts include housing *and recreational* impacts.
b. Net willingness to pay without including human health or greenhouse gas emissions.
c. Impacts for these issues at RFM, RFN, RFO, RFP, RFQ, RFR, RFS, RFT, RFU, RFV were based on impacts for similar facilities; they were not modeled.
d. These values indicate the WTP to avoid IM&E-related losses, not the total monetized losses due to IM&E.
e. Note totals may not equal due to rounding.
f. Assumes a 6-month shutdown.

Table ES-4
Monetized impacts should closed-cycle cooling be designated as best technology available of for various waterbody types

Type of Impact	Annual WTP to Avoid Impacts (2007$)	
Water Resources – Debris Removal		
Freshwater Large Rivers, Reservoirs and Lakes	$382,900	
Small Rivers and Great Lakes	$273,300	
Oceans Estuaries and Tidal Rivers	$317,900	
Sub-total	**$974,100**	
Public Safety – Roadway Fogging		
Freshwater Large Rivers, Reservoirs and Lakes	$7,300	
Small Rivers and Great Lakes	$29,800	
Oceans Estuaries and Tidal Rivers	$17,600	
Sub-total	**$54,700**	
Quality of Life - Noise		
Freshwater Large Rivers, Reservoirs and Lakes	$7,350,400	
Small Rivers and Great Lakes	$3,468,400	
Oceans Estuaries and Tidal Rivers	$5,322,800	
Sub-total	**$16,141,600**	
Quality of Life - Degraded Viewshed		
Freshwater Large Rivers, Reservoirs and Lakes	$281,100	
Small Rivers and Great Lakes	$373,600	
Oceans Estuaries and Tidal Rivers	$1,702,200	
Sub-total	**$2,356,900**	
Greenhouse Gas		
	6-Month Outage	8-Month Outage
Freshwater Large Rivers, Reservoirs and Lakes	$5,918,900	$7,891,900
Small Rivers and Great Lakes	$1,740,900	$2,321,200
Oceans Estuaries and Tidal Rivers	$5,359,000	$6,683,400
Sub-total	$13,018,800	$16,896,500
Cumulative Monetized Impacts [a]		
Freshwater Large Rivers, Reservoirs and Lakes	$13,940,600	
Small Rivers and Great Lakes	$5,886,000	
Oceans Estuaries and Tidal Rivers	$12,719,500	
Total Monetized Impact Estimate	**$32,546,100**[b]	

Totals may not equal due to rounding. [a] Assumes a 6-month outage for nuclear facilities.

[b] Cumulative total monetized impact is $33,736,100 if National terrestrial impact estimate is included.

The national-level WTP to avoid this consequence is shown in Table ES-4 and was estimated to be $974,100 ($382,900 for facilities on large freshwater rivers, lakes other than the Great Lakes and reservoirs, $273,300 for facilities withdrawing from small rivers and the Great Lakes and $317,900 for facilities located on oceans, estuaries and tidal rivers) as shown in Table ES-4.

Solid Waste

Mechanical-draft evaporative cooling towers and natural draft cooling towers are constructed with water basins at the bottom of the towers. These basins contain cooling tower makeup water withdrawn from the source waterbody and collect the water that passes down through the cooling tower fill. Sediments settle out in the basin and must periodically be removed for disposal. Estimates of the amount of sediments potentially generated and other relevant information (e.g., potential toxicity) were investigated using a specific cooling tower solid waste EPRI questionnaire submitted to the industry (separate from the more general EPRI Questionnaire described above). A total of 47 facilities responded to the questionnaire.

Based on the results, the type of tower (mechanical-draft evaporative cooling towers versus natural draft cooling towers) does not appear to correlate with the amount of sediment accumulated. However, sediment generation at nuclear facilities is approximately 70 percent less than that at fossil plants (150 cubic yards per basin per year [CY/basin/year] compared to 500 CY/basin/year, respectively). Most facilities responding to the questionnaire that analyzed the sediment indicated that it was non-toxic, and that it was disposed of on-site or in public landfills with no additional permitting. Due to high variability in responses and lack of WTP data no attempt was made to quantify or monetize this waste.

Public Safety and Security

Water vapor emitted from mechanical-draft evaporative cooling towers may produce adverse social impacts in surrounding areas, such as:

- Fogging and icing of roadways;
- Fogging interference with nuclear facility security systems; and
- Visible plume interference with air traffic at nearby airports.

Public Safety of Roadways and Airports

Based on analysis of RFs, for the national scale-up, the WTP to avoid fogging impacts was estimated for the once-through cooled facilities by applying the median annual WTP to avoid fogging calculated from the RFs (Table ES-3) for high and medium/low population with and without major nearby roads. The Phase II facilities were grouped by population based on U.S. census data and proximity to roadways based on responses to the EPRI Questionnaire and best professional judgment using aerial photography. The national-level WTP to avoid impacts caused by fogging is estimated to be $54,700 (Table ES-4) ($7,300 for facilities on large freshwater rivers, lakes other than the Great Lakes and reservoirs, $29,800 for facilities withdrawing from small rivers and the Great Lakes, and $17,600 for facilities located on oceans, estuaries, and tidal rivers.

Roadway icing was a potential issue for 38.9 percent of modeled facilities suggesting up to 165 facilities may encounter some icing problems if cooling towers were operated. Based on the modeled impacts, icing may occur between 0.3 hours/year and 23.12 hours/year (Section 4.4.1) at these facilities. A WTP to avoid impacts from roadway icing could not be developed because appropriate accident data associated with these conditions are not available.

National scale impacts at airports of fogging associated with closed-cycle cooling were neither quantified nor monetized due to inadequate data, however, this could be an issue for any facility located in close proximity to an airport.

Security of Nuclear Facilities

The potential impact to the line of sight for maintaining security surveillance at nuclear facilities due to fogging is an additional concern posed by on-site cooling towers. Based on the results of the characteristic facilities modeling, the additional hours of fogging per year within the Protected Area ranged from negligible to 10 hours; 0.1 hours – 6 hours of additional fogging per year was estimated within the Owner Controlled Area (see Section 4.4.3). The WTP to avoid these potential security issues at the nuclear facilities could not be monetized because there are insufficient data. However, there are 39 Phase II facilities with at least one nuclear unit which may experience some negative impacts on security from cooling tower plumes.

Quality of Life

Cooling towers generate noise from pumps, fans, and falling water in addition impacts to the viewshed due to their size, height, and visible plumes. These impacts can affect adjacent or nearby communities in urban and suburban areas as well as cause impairments to recreational use in parks or other recreational areas.

Noise

The impact associated with increased noise levels[1] from retrofitting to closed-cycle cooling is a function of the size of the tower, existing noise emissions sources on-site, the relative position of the cooling tower to these noise sources, off-site ambient noise, distance to and number of receptors (population), and topography.

Using the average annual WTP values calculated for the RFs in each geographic region, the annual WTP to avoid impacts associated with increased noise (two dbA or more) nationally at all once-through cooled facilities is estimated to be $16,141,600 ($7,350,400 for facilities on freshwater LR/RL, $3,468,400 for facilities on SR/GL and $5,322,800 for facilities on O/E/TR (Table ES-4).

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[1] A sound level of zero dB is the approximate threshold of human hearing and is the reference level against which the amplitude of other sound is compared. A two dB increase in ambient noise levels is assumed to represent a quantifiable change in the acoustic environment.

Viewshed

Viewshed deterioration is another quality of life issue associated with mechanical-draft evaporative cooling towers. The importance of this issue is generally related to the number of people who are exposed to the alternation in the viewshed as a result of the cooling tower size, height, and visible plume and the location of the tower relative to nearby seashores, parks or recreational areas. SACTI modeling was used to predict plume length and plume shadowing for the RFs. The estimated the median WTP to avoid viewshed impacts is related to population surrounding the facilities with the highest WTP in High population areas and much lower WTP in Medium/Low population areas ($15,400 and $8, respectively) (Section 4.5.2). Therefore, WTP to avoid viewshed impacts nationally was evaluated using the median annual WTP calculated for the RFs in two population groups (High and Medium/Low). See Appendix B for details of the methodology and Appendix E for a list of all Phase II facilities and their population category and source waterbody type. Using this approach, the results indicate that the national annual WTP to avoid potential viewshed degradation caused by the retrofit of all once-through cooling facilities is $2,356,900, including $1,026,600 estimated WTP for California facilities.

Greenhouse Gases

'Greenhouse gases' such as water vapor, carbon dioxide (CO_2), methane, nitrous oxide, and chlorofluorocarbons absorb and re-emit some of the Earth's outgoing thermal radiation and elevate the Earth's temperature. Excessive amounts of greenhouse gases in the atmosphere may increase the global temperature and possibly the amount of water vapor in the atmosphere. Increases in anthropogenic emissions of greenhouse gases have been implicated as promoters of 'climate change.' It is estimated that electric power generation accounts for approximately 40 percent of U.S. CO_2 emissions. Currently there is an international effort underway seeking to reduce greenhouse gas emissions. Thus, this impact represents the single exception to this study's focus on localized rather than regional impacts. This impact has been evaluated for nuclear facilities that would need to be taken off-line for closed-cycle system retrofitting. The larger question of retrofitting fossil-fueled plants and the impacts of converting these once-through cooled facilities on CO_2 emissions nation-wide has not been evaluated as part of this study because of the uncertainties in plant closure and replacement. It has been estimated by U.S. Department of Energy that the energy penalty associated with wet cooling towers is:

- 2.4 to 4.0 percent for the hottest months of the year; and
- 0.8 to 1.5 percent for the annual average temperature conditions.

The national replacement of this power with the existing mix of generation would result in additional CO_2 emissions greater than those calculated for the nuclear plant retrofit.

If required to retrofit, nuclear facilities which are all baseloaded (i.e., capacity utilization in excess of 75 percent) are estimated, on average, to require an extended outage of six months (EPRI best estimate) to complete a retrofit. During the retrofit outage, it is assumed that the replacement electric power generation needed will come from existing fossil-fueled facilities. Due to uncertainty of outage duration, an 8-month outage time was also considered. Assuming a 6-month outage, it is estimated 163 million tons of CO_2 would be generated for all once-through nuclear units with 74 million tons from facilities on LR/RL, 67 million tons from O/E/TR facilities and 22 million tons from facilities located on GL/SR (Table ES-2). Assuming an 8-month outage, it is estimated 212 million tons of CO_2 would be generated for all once-through nuclear units with 99 million tons from facilities on LR/RL, 84 million tons from O/E/TR facilities and 29 million tons from facilities located on GL/SR (Table ES-2). The estimated WTP to avoid this impact based on carbon markets using an average price of $3.80 per ton of CO_2 in 2007$ are $13,018,800 and $16,896,500 for 6- and 8-month outages, respectively, as shown in Table ES-4.

Permitting Issues

Due to the relatively large size of cooling towers and their potential environmental and social impacts, a variety of federal, state, and local permits may be required prior to construction. Potential permitting issues associated with closed-cycle cooling retrofits include, but are not limited to, air quality, environmental justice, threatened and endangered species, public heath, water quality, wetlands, consumptive water use, and other environmental issues. Such issues were evaluated for the 24 RFs in Section 4.6 and additionally through the questionnaire circulated to the industry through four major industry trade associations (Edison Electric Institute, Utility Water Act Group, National Rural Electric Cooperative and the American Public Power Association) in addition to EPRI members. The results of the 24 RF evaluations determined that for many power plants, at least one or more of the following topics are likely to be a concern:

- Air quality;
- Rare, threatened, and endangered species;
- Sensitive areas (e.g., wildlife management areas, refuges, critical dunes, etc.);
- Public health/water quality;
- Local ordinances and zoning (e.g., noise, night lighting, building height, etc.);
- Wetland disturbances; and
- Consumptive water use.
- Additionally, nuclear plants will need to adhere to NRC requirements.

Air Permitting Issues

Permitting issues associated with air quality for many parts of the United States would likely be significant, based on the results of the in-depth evaluation of 14 RFs (Section 4.6.1) and the responses to the EPRI Questionnaire. The Prevention of Significant Deterioration (PSD) program would apply to cooling towers at 50 percent of the RFs assessed and 13 of the 14 RFs would require Title V Operation Permits. Of the 209 responses to the EPRI Questionnaire, 40 percent of the facilities were located in a non-attainment area for air quality at the time of the questionnaire and 21 percent were located in or near a Class I area for air quality. Assuming these results are representative of all Phase II facilities, air quality permitting issues associated with a closed-cycle cooling retrofit may include:

- PSD program may apply at 213 facilities;
- Title V Operation Permits may be needed at 395 facilities;
- 170 facilities may be located in a non-attainment area for air quality; and
- 90 facilities may be located in or near a Class I area for air quality.

Protected Species

Protected species and/or critical habitat affected by retrofits were identified for potential permitting issues for 58 percent of the RFs and wetlands were identified at two additional facilities. Over 50 percent of the EPRI Questionnaire responses indicated that threatened, endangered, or otherwise protected species are known to exist on or in the vicinity of the facility. Additionally, 66 percent of EPRI Questionnaire facilities indicated that a sensitive receptor is located within 1 kilometer (3,280 feet) of the facility (e.g., landmarks, recreational areas, sensitive vegetation, protected species, new car lot, hospitals, and schools). This indicates that potentially 213-281 Phase II facilities may have permitting issues associated with protected species and/or critical habitat if they were to retrofit to closed-cycle cooling.

Noise

As estimated 54 percent of the facilities would likely have noise permitting issues based on the RF analysis while 44 percent (based on the EPRI Questionnaire) were located in areas with local noise ordinances. Results suggest that on a national scale between 187 and 230 Phase II facilities may have permit issues related to noise.

Building Height Ordinances

The RF analysis found two facilities were in areas with height ordinances while the questionnaire found approximately a quarter of the facilities reported height ordinances. It is estimated that between 35-107 facilities may need to meet permits for height.

Coastal Zone

Coastal zone regulations may require special permitting for three of the 24 RFs and over one-third of the EPRI Questionnaire respondents. It is estimated that between 53-140 facilities may require coastal zone permits.

Environmental Justice

Potential Environmental Justice issues (defined as potentially impacted areas with a minority population greater than 20 percent) exist for approximately 17 percent of the Phase II facilities, or 72 Phase II facilities based on the RF evaluation.

It is likely that most facilities that retrofit to closed-cycle cooling will encounter some permitting issues. This may result in significant additional costs to mitigate impacts and in some instances could potentially prevent the construction of cooling towers altogether.

Aquatic Biology

In contrast to the environmental and social impacts associated with closed-cycle cooling, there are two primary aquatic biological benefits. These are a reduction in cooling water intake structure impacts (impingement and entrainment) and a reduction in thermal impacts on organisms as a result of through-facility or thermal plume entrainment. It was the initial intent of this study to include a comparison of the national closed-cycle cooling environmental and social impacts to the national benefits that would be achieved based on the flow reduction of 93 percent or more that would be achieved with mechanical-draft evaporative cooling towers. However, preliminary analysis of the EPRI Impingement and Entrainment Database determined a poor correlation between flow and either impingement or entrainment. As a result, EPRI initiated a study based on the impingement and entrainment database to develop an estimate of the national benefit of a retrofit requirement.

Thermal Plume Reduction Benefit

Use of once-through condenser cooling does result in a temperature rise in the cooling water that can exceed the thermal tolerance of some aquatic organisms, especially during warm summer periods in some parts of the United States. The USEPA water quality standards regulatory program has established thermal discharge limits for the thermal discharge. Most generating facilities comply with those standards. However, the CWA at §316(a) provides a unique variance provision from the thermal criterion. Under this provision, facilities can apply for a thermal variance by demonstrating the protection and propagation of a balanced, indigenous community of fish and wildlife in and on the waterbody into which the discharge is made. Relative to the thermal discharge, this report assumes that once-through cooled facilities either comply with thermal mixing zone standards or have completed a CWA §316(a) Demonstration.

Impingement and Entrainment

By reducing condenser cooling water flow, the use of mechanical-draft evaporative cooling towers may result in a significant reduction in both impingement and entrainment. Potential reductions were calculated for the 24 RFs and two additional facilities to augment the O/E/TR category that was considered underrepresented because of the large number of facilities in the category and diversity of aquatic populations in these types of waterbodies. The quantified results are provided in Table ES-5. For facilities located on waterbodies with commercial fisheries, losses ranged from 30 lbs/yr to 620,100 lbs/yr. Recreational fishing losses existed at all 26 facilities and ranged from 40 lbs/yr to 284,000 lbs/yr. Foregone forage fish losses (i.e., non-commercial and non-recreational fish that may be a food source for commercial and recreational species) ranged from 6 lbs/yr to just under 3.6 million lbs/yr. The monetized losses for the 24 representative facilities are provided in Table ES-3 and ranged from $100/yr to $568,500/yr. However, it is important to note that approximately half of the RFs did not conduct entrainment studies and therefore these losses were neither quantified nor monetized.

This report does not estimate the national benefit of retrofits. EPRI has initiated an independent project to develop a national retrofit benefit estimate, the results of which will be reported separately along with a summary of the EPRI Impingement and Entrainment Database and specific information regarding the impingement and entrainment of protected species.

Table ES-5
Quantified impingement and entrainment losses for 24 representative and two additional facilities

Facility	IM and E	Equivalent Adults (# of eggs and larvae)	Foregone Commercial Yield (lbs)	Foregone Recreational Yield (lbs)	Foregone Forage (lbs)
BTPD	IM	(a)	(b)	228	2,079
BTPE	IM	82,601	(b)	2,513	7,435
RFG	IM	54,753	1,981	5,114	5,898
RFJ	IM	9,550	(b)	212	6
RFL	IM	57,960	(b)	1,153	7,991
RFM	IM	15,019	(b)	2,193	46,238
RFN	IM	4,752	(b)	235	7
RFO	IM	33,919	(b)	1,677	790
RFP	IM	531,623	(b)	747	2,538
RFQ	IM	11,441	(b)	71	23
RFR	IM	1,842	(b)	44	8
RFS	IM	1,834,837	(b)	35,569	159,173
RFU	IM	12,945	(b)	51	376
RFV	IM	7524	(b)	482	55
BTCA1	IM&E	10,645,075	8,701	5,793	174,284
BTPA	IM&E	1,387,237	34	15,008	52,808
BTPB	IM&E	83,820,000	18,784	19,761	96,156
BTPC	IM&E	3,435,466	72,762	228,277	330,432
BTCA2	IM&E	5,528,543	265,309	46,427	19,011
RFF	IM&E	77,345,402	620,131	284,166	3,596,037
RFH	IM&E	3,201,510	23,207	7,923	16,530
RFI	IM&E	106,288	(b)	917	45,293
RFK	IM&E	2,040,181	88,021	14,217	4,647
RFT	IM&E	475,987	431	836	37,918
RFW	IM&E	118,955,208	17,512	87,703	288,082
RFX	IM&E	1,416,538	6,623	4,482	18,625

a. Equivalent adult losses not calculated

b. No commercial fishery

Overall Conclusions

Based on this study, a number of conclusions can be drawn relative to environmental and social impacts of closed-cycle cooling retrofits, should they be designated as BTA for CWA §316(b).

- The quantified and monetized environmental and social impacts of closed-cycle cooling tend to be site-specific and are a function of the waterbody type, adjacent land use, fuel type, and nearby population density.

- Potential human health, terrestrial, social, noise, viewshed degradation, and safety impacts are dominant in urban and suburban areas while terrestrial ecological and agricultural impacts are dominant in rural or undeveloped areas.
- Giving no consideration to greenhouse gas emissions and human health effects, the net monetized closed-cycle cooling environmental and social impacts exceed the monetized benefits for just less than half the RFs. If monetized greenhouse gas impacts are included, only six of the 24 RFs had monetized benefits that exceeded monetized impacts of closed-cycle cooling.
- Considerable uncertainty remains for both monetized impacts and benefits and methods are currently unavailable for monetization of some benefits as well as a number of impacts associated with closed-cycle cooling.

LIST OF ACRONYMS

7Q10	7-day average low flow that has a recurrence interval of once in ten years
BTA	Best Technology Available
BTP	Beta Test Plant
CA	California
cfs	cubic feet per second
CO_2	carbon dioxide
CWA	Clean Water Act
CY	cubic yard
dB	decibel
DOT	Department of Transportation
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
ft	feet
gpcd	gallons per capita day
gpm	gallons per minute
IM	impingement mortality
IM&E	impingement mortality and entrainment
kg/ha/mo	kilogram per hectare per month
kg/ha/week	kilogram per hectare per week
kg/ha/year	kilogram per hectare per year
km	kilometer
lbs	pounds
lbs/kWh	pounds per kilowatt-hour
LR/RL	large rivers/reservoirs and lakes
MG	million gallons
MGD	million gallons per day

MGY	million gallons per year
MW	megawatt
NAAQS	National Ambient Air Quality Standards
NaCl	sodium chloride
NANSR	Nonattainment Area New Source Review
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NWI	National Wetlands Inventory
NWS	National Weather Service
O&M	operations and maintenance
O/E/TR	oceans/estuaries/tidal rivers
PM	particulate matter
$PM_{10-2.5}$	PM that measures between 10 and 2.5 microns in diameter
PM_{10}	PM that are less than 10 microns in diameter
$PM_{2.5}$	PM that are less than 2.5 microns in diameter
PSD	Prevention of Significant Deterioration
RF	Representative Facility
SACTI	Seasonal Annual Cooling Tower Impact
SIA	significant impact area
SIL	significant impact level
SR/GL	small rivers/Great Lakes
SSURGO	Soil Survey Geographic
TDS	total dissolved solids
tpy	tons per year
TSP	total suspended particulates
ug/m^3	micrograms per cubic meter
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish & Wildlife Service
WTP	willingness to pay

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INTRODUCTION

The January, 2007 decision of the U.S. Court of Appeals for the Second Circuit in *Riverkeeper, Inc v. EPA* remanded to the United States Environmental Protection Agency (USEPA) several important provisions of the Clean Water Act (CWA) §316(b) Phase II Rule (Rule). As a result, USEPA suspended the Rule pending further rulemaking. Among the remanded provisions was USEPA's determination of the best technology available (BTA). The Court found that USEPA's rejection of closed-cycle cooling as BTA and its authorization allowing selection from a suite of technologies and/or measures in place of closed-cycle cooling may have been improperly based on cost-benefit analyses (i.e., the costs of the selected options versus the environmental benefits that would be achieved). The Supreme Court subsequently overturned the Second Circuit Court's decision relative to use of cost-benefit. The Second Circuit Court also stated that the reasons that the USEPA could consider for rejecting closed-cycle cooling as BTA are the industry's ability to bear the cost of closed-cycle cooling retrofits, adverse environmental impacts of the technology, or impacts to energy production and efficiency.

In response to the Court's decision, the Electric Power Research Institute (EPRI) initiated a large-scale supplemental research program to gather, evaluate, and summarize information that would inform USEPA of potential impacts that could result if USEPA were to determine that closed-cycle cooling is BTA [1]. Specifically, the EPRI supplemental research program consists of four projects that are connected to each of the factors cited above:

1. Develop cost estimates for retrofitting existing Phase II facilities with closed-cycle cooling;
2. Quantify potential impacts to energy production and supply, including the number of facilities, units, and/or megawatts (MW) at risk of closure and the possible loss of MW capacity due to closed-cycle cooling retrofitting;
3. Quantify potential environmental and social effects associated with closed-cycle cooling for comparison with the possible benefit of reducing impingement and entrainment losses; and
4. Based on results of Project 2, assess potential impacts to electric system reliability.

The subject of this report is Project 3, which identifies the environmental and social effects of closed-cycle cooling and quantifies and/or monetizes, where possible, these impacts.

If Phase II facilities were to convert from open to closed-cycle cooling it would substantially reduce water withdrawal. The Phase II Rule assumed a relatively commensurate reduction in the loss of impinged and entrained fish and shellfish. With this benefit, however, there would likely be a significant number of other potentially adverse environmental effects caused by closed-cycle cooling systems. These potential effects are identified in this report. While the environmental tradeoffs between once-through and closed-cycle cooling systems have been widely discussed qualitatively, these tradeoffs have not been evaluated quantitatively. This project is intended to develop this information for facilities that would have been considered Phase II facilities under the remanded 316(b) Rule.

1.1 Assessment Approach

The goal of this project was to perform a quantitative comparison of potential environmental and social effects of once-through and closed-cycle cooling for the purpose of informing the USEPA during 316(b) rulemaking. The findings of this assessment are intended as input to the rulemaking process. The assessment approach was to:

- Select a subset of existing once-through cooled facilities that would represent the population currently utilizing once-through cooling that are potentially affected by the rulemaking;
- Identify potential direct environmental and social effects that are significant, measurable, and meaningful to society;
- Conceptually design site-specific closed-cycle cooling systems, based on current plant specifications and local conditions, and quantify design and operating characteristics (e.g., space requirements, emissions, etc.);
- Assess, quantify, and monetize, to the extent possible, the resulting effects; and
- Scale the measurable effects to a national level.

An overview of the proposed methodology was provided to USEPA in December 2007 [2]. A more detailed description of the methodology for identifying each environmental and social effect investigated is provided in this report.

This investigation was conducted in phases due to the large number of facilities involved, the number of potential effects, and the anticipated schedule for USEPA’s new rulemaking.

The first phase involved (1) identifying and prioritizing the environmental and social impacts to be quantified, (2) developing the quantification methodology, (3) developing a database of facilities subject to the USEPA existing facility rule which was eventually used to support national estimates of impacts, (4) creating a matrix of criteria for selecting characteristic facilities for evaluation, and (5) developing a questionnaire (EPRI questionnaire) to be distributed to all Phase II facilities to gather information on site-specific issues that could preclude cooling tower installation or create a unique set of potential environmental or social impacts.

The second phase of the project included (1) testing (Beta Test) the quantification methodology on a subset of seven facilities, (2) Beta Testing the proposed approach to scaling net environmental effects using California once-through cooling facilities and (3) distributing the EPRI questionnaire to all existing Phase II facilities and processing the responses.

This final report to the EPRI sponsors presents the results of the third and fourth phases of the project. In the third phase, 17 additional facilities were modeled for environmental and social effects. These results, along with the Beta Test results, are summarized in this report. Additionally, the results of the fourth phase of the project, the national extrapolation of impacts, are reported herein.

1.2 Organization of Report

The remainder of the report is organized as follows:

- Section 2 reviews the methodology and criteria used for the selection of the characteristic facilities discussed in this report. This section also introduces background information on each of the sites and their environmental settings. A summary of potential issues for the implementation of closed-cycle cooling at the facilities is presented as well;
- Section 3 provides an overview of the hypothetical closed-cycle cooling systems anticipated for each representative site. The design concept defaults to the use of mechanical-draft evaporative cooling towers for each of the facilities, as opposed to other types of cooling towers that are available (Section 5 discusses alternative cooling tower types);
- Section 4 presents a baseline impact assessment summary for the implementation of closed-cycle cooling at each of the representative sites. This includes an assessment of potential impacts to the following: human health (due to air emissions, drift, and plume), terrestrial resources, water consumption, solid waste, public safety and security, quality of life (noise and viewshed), permitting, greenhouse gas, and aquatic biota. These potential impacts are quantified and monetized where possible. Additionally, this section addresses any uncertainties or issues with the existing data identified or utilized during the preparation of this report;
- Section 5 summarizes the potential impacts associated with the use of alternative types of cooling towers relative to mechanical-draft evaporative cooling towers;
- Section 6 presents the quantification, monetization, and national scaling results; and
- Section 7 includes a list of references.

In addition, there are eight appendices providing detailed information, including:

- Appendix A provides detailed facility information, design and operating characteristics of the closed-cycle cooling systems for each site (sizes, emissions, water consumption, etc.), and data used in the impact assessment for each facility;
- Appendix B provides details of the methods used in the evaluations, including the conceptual design methodology and baseline impact assessment techniques;
- Appendix C contains figures depicting the impact model output;
- A blank EPRI Questionnaire is provided in Appendix D;
- A consolidated list of Phase II facilities used in the environmental assessment is provided in Appendix E. This list was used for scaling impacts to the national level;
- Appendix F is the master list of all the once-through cooled facilities using greater than 50 MGD for the Closed-cycle Cooling Research Program;
- A human health risk assessment evaluation potential risks based on conservative USEPA methods is provided in Appendix G; and
- Appendix H provides the methodology used to estimate impingement mortality and entrainment (IM&E) and summarizes the results of the quantification and monetization process for each representative facility.

2

SELECTION, DESCRIPTION AND ENVIRONMENTAL SETTING OF BETA TEST PLANTS AND REPRESENTATIVE FACILITIES

2.1 Facility List

A list of what would have been considered Phase II facilities (note the Rule has been remanded but these facilities are assumed to be subject to the current rulemaking) that utilize once-through cooling for at least one unit, listed alphabetically by name, is provided in Appendix E. The EPRI facility database consists of information from the currently suspended CWA §316(b) Phase II Rule Record, Department of Energy database, working knowledge of individual facilities, and information provided by the utilities through a questionnaire (a sample of which is provided in Appendix D) or through contacting individual facilities. This information is stored in a centralized data management system (EPRI System) for the purposes of this study. The list also provides baseline information for each facility, including identification (facility code) number, state where located, MW generating capacity, fuel classification, cooling water flow, surrounding population classification, and source waterbody type.

The grouping and selection methodology used to identify Beta Test Plants (BTPs) and Representative Facilities (RFs) is described in the next section.

2.2 Selection Methodology and Criteria

The goal of this project is to evaluate the environmental effects of retrofitting those Phase II facilities that do not currently have closed-cycle cooling for all of their steam-electric generating units. Environmental effects of closed-cycle cooling include air emissions, noise, aesthetics, fogging and icing, water consumption, loss of terrestrial habitats, etc. These adverse environmental effects were also scaled nationally. The national benefit of closed-cycle cooling (i.e., the reduction of fish and shellfish mortality that currently occurs with once-through cooling systems) is the subject of a separate EPRI study. Phase II facilities are located in different climatic regions, withdraw cooling water from different waterbody types, and have different surrounding land uses. A comprehensive study of each of the over 400 facilities that have at least one unit with once-through cooling is beyond the scope of this study. Therefore, the strategy for this project was to:

- Group each listed facility according to three critical variables, which were selected on the basis of their influences on closed-cycle cooling retrofits and associated environmental and social effects;

- Study at least one member in each group and then normalize the results to apply to the other facilities within the same group, or;
- Normalize the results from all characteristic facilities and apply the results to categories of facilities such as population (e.g., low [rural], medium [suburban], high [urban]); and
- Sum the results for all the groups and categories to evaluate overall impacts on a national basis.

For the purposes of this study, all Phase II facilities that rely solely on closed-cycle cooling were removed from further consideration prior to sorting.

The critical variables originally used to sort/group the Phase II facilities are described below. The combinations of these variables result in grouping the facilities into separate categories for further analysis.

2.2.1 Climatic Region

The wet-bulb temperature at a given location effects wet cooling tower size and performance efficiency. Facilities of comparable design located in regions with lower wet-bulb temperatures generally require smaller cooling towers than those located in regions with higher wet-bulb temperatures [3]. Therefore, the environmental and social effects of closed-cycle cooling are affected by wet-bulb temperature region. Section 3 provides further discussion of cooling tower design and operation and how design relates to wet-bulb temperature.

Facilities were sorted into three separate wet-bulb temperature regions. Each region is defined by wet-bulb temperatures (at a one percent annual exceedance level) falling into the following ranges:

- Less than or equal to 76°F;
- Between 76°F-79°F; and
- Greater than or equal to 79°F.

These divisions were selected to achieve a relatively even distribution of facilities for each climatic region. The climatic regions and facility locations within the contiguous United States are illustrated in Figure 2-1.

2.2.2 Fuel Type

The primary fuel types used to generate electricity are nuclear and fossil (mostly coal, natural gas, and petroleum distillate). Coal-fired units provided the majority (approximately 59 percent) of all electricity generated in 2006, followed by nuclear units (17 percent), natural gas-fired units (11 percent), and oil-fired units (two percent) [4][1]. Hydropower and other miscellaneous energy sources account for the remainder of power generation (approximately 11 percent).

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[1] Electricity generation distribution by fuel type is somewhat different when Phase II facilities that already have cooling towers are considered. Coal, nuclear, natural gas and petroleum facilities generate 56.4, 33.8, 8.6, and 1.1 percent, respectively, of all electricity generated at Phase II facilities [6].

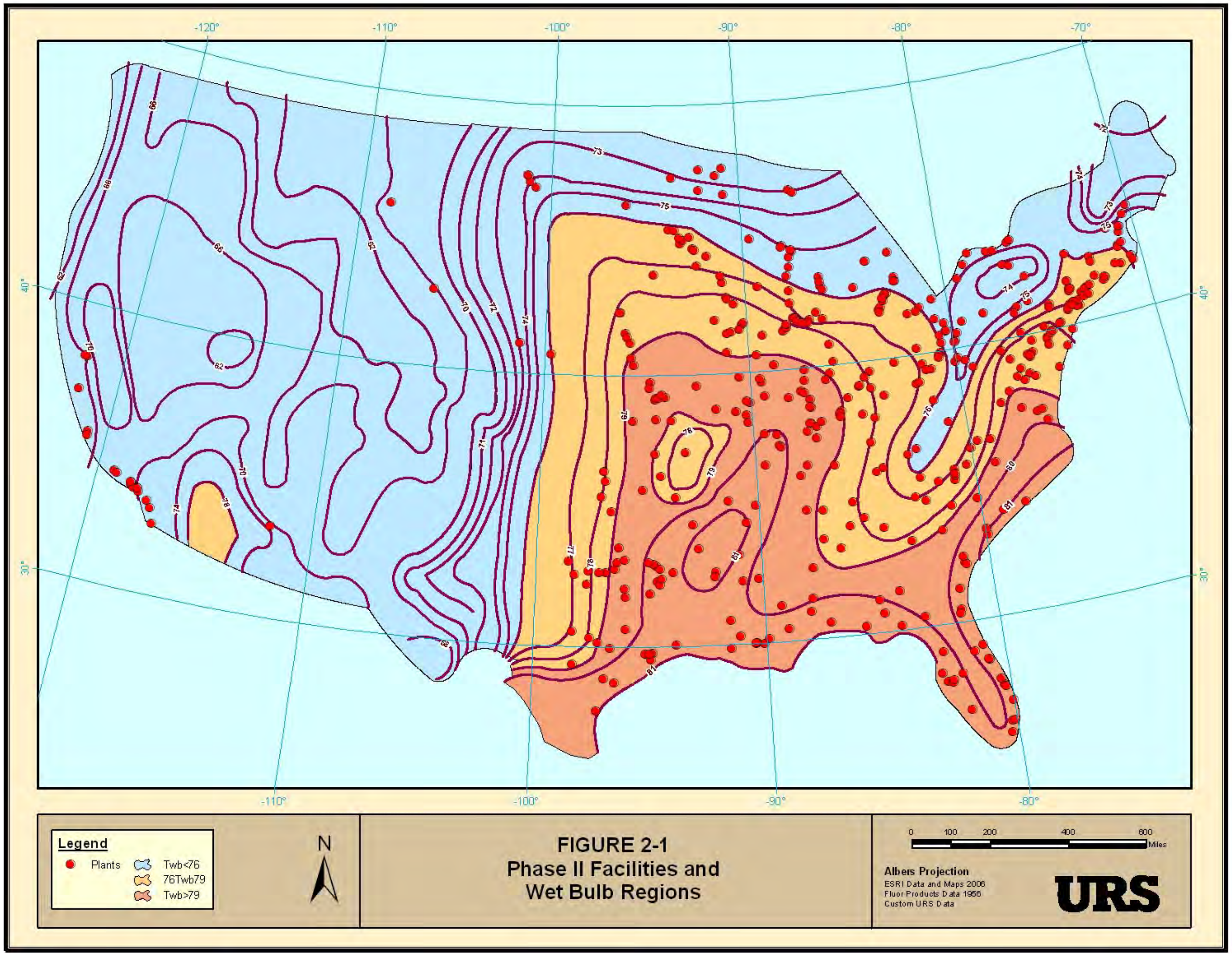

Figure 2-1
Location of Phase II facilities and wet-bulb regions in the contiguous United States

Although there are some differences in potential environmental and social effects associated with retrofitting closed-cycle cooling at nuclear and fossil facilities, these differences do not warrant separate categories based on fuel type. However, nuclear facilities have larger capacity, use higher amounts of water per MW and operate as baseload facilities. For example, nine percent of all Phase II facilities are nuclear, however nuclear facilities account for 20 percent of all Phase II cooling water flow at design conditions. Nuclear facilities account for an even higher percent of the Phase II cooling water flow, when both cooling water flow and capacity utilization are considered. Therefore, nuclear facilities were selected for modeling in approximate proportion based on cooling water flow and capacity utilization.

2.2.3 Source Waterbody Type

The currently suspended Phase II Rule established Performance Standards based on waterbody type. The waterbody type groupings provided therein were: Freshwater Rivers and Streams; Lakes and Reservoirs; Great Lakes; Estuaries and Tidal Rivers; and Oceans.

The Phase II Rule waterbody grouping lends itself to this investigation, as these waterbody types will help to assure that:

- A range of source water total dissolved solids (TDS) is represented. TDS affects the cycles of concentration of the cooling tower, tower size (to a small degree), and particulate emissions;
- A range of fish and shellfish species and life stages and, thus, a range of susceptibility to IM&E, are represented. For example, most freshwater fish species have adhesive eggs or are nest builders. The Great Lakes contain many unique fish species as compared to other fresh waterbody types. Estuarine and marine waters tend to have more species that are broadcast spawners with a higher susceptibility of young life stages to entrainment; and
- A range of geographic, environmental and social settings is represented. The Lakes and Reservoirs grouping includes many facilities in drier, rural locations on small waterbodies whereas many of the other groups are on large waterbodies in densely populated areas.

A review of the Phase II facilities was undertaken to determine if there would be a relatively even distribution in terms of number of plants in each waterbody type, and to ensure that all potential effects would be investigated completely. This review found that:

- Relatively few facilities used ocean water as makeup; therefore, the Oceans category and the Estuaries and Tidal Rivers category were grouped together;
- The river grouping for two wet-bulb categories were divided into small and large river groups because of the very large number of facilities. This grouping is consistent with USEPA’s application of entrainment standards to facilities using more than five percent of the annual average flow, which would tend to be smaller rivers and would allow a complete assessment of issues such as water consumption in the Phase II Rule; and
- Relatively few facilities used lake water with wet-bulbs of <76°F; therefore, this category was combined with those in the 76°F-79°F range.

Therefore, this study grouped the facilities into the following waterbody types:

- Ocean/Estuaries and Tidal Rivers;
- Great Lakes;
- Large Freshwater River[2];
- Small Freshwater River[3]; and
- Lake/Cooling Pond/Reservoir.

2.2.4 Representative Phase II Facilities

Appendix E provides a list of Phase II facilities that utilize once-through cooling for at least one of the generating units; facilities and generating units that utilize closed-cycle cooling have been removed from the list. For the purposes of this study, this list was finalized on November 9, 2010. Based on the available information on that date, EPRI estimates there are 428 facilities which utilize once-through cooling for at least one unit. Three generating stations are listed twice because they have both nuclear and fossil-fueled units.

Table 2-1 distributes the 428 facilities that were evaluated to select plants for modeling into the appropriate categories.

Table 2-1
Distribution of phase II facilities with once-through cooling systems

Wet-Bulb Regions	T_{wb} ≤ 76°F	76°F< T_{wb}< 79°F	T_{wb} ≥ 79°F	Sums
Ocean/Estuaries and Tidal Rivers	20	51	46	117
Large River/Reservoirs & Lakes	31	82	80	193
Small River/Great Lakes	42	51	25	118
Sums	93	184	151	**428**

This approach to select facilities was intended to represent the full range of geographic and environmental conditions. Nuclear powered plants were also selected in order to represent their special characteristic in proportion to their capacity and flow. Also, because several of the waterbody types contained a disproportionately higher number of fossil facilities, additional facilities were selected for these categories for a more proportional distribution.

The following criteria were used when selecting characteristic facilities.

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[2] Some impounded rivers may be classified as reservoirs under the suspended Phase II Rule based on retention time within the impoundment. This study will assume that facilities located on rivers and river reservoirs are classified as rivers unless data are readily available to demonstrate the system meets the retention time requirements.

[3] Small freshwater rivers are defined for the purpose of this study as rivers with an average annual flow of less than 10,000 cubic feet per second (cfs).

1. Facilities with very low capacity utilization rates were not selected because of the higher likelihood that the facility would retire rather than retrofit;
2. Facilities that were lacking critical information (e.g., recent IM&E or other data) were not selected;
3. Facilities were selected to cover a range in population density (e.g., high, medium and low);
4. Of the remaining facilities, those considered likely to participate in the study (e.g., membership in the EPRI Technical Advisory Committee[4]) were given preference because of their likelihood of providing critical data in a timely manner; and
5. Preliminarily selected facilities were contacted to determine their willingness to participate in the study and their ability to provide critical data in a timely manner. If a plant declined to participate, an alternate facility within the same category was selected.

2.3 BTPs and RFs

During the second phase of this project, seven facilities were selected to test (Beta Test) the quantification methodology. Criteria for selection included geography, waterbody type, and data availability. These BTPs are listed in Table 2-2. Note that facility names are not provided. A second goal of the Beta Test was to test the extrapolation methods using California facilities. Therefore, two facilities were selected from California and identified as BTCA1 and BTCA2.

BTPs were selected that represented major fuel types, climatic regions, waterbody types, and population. The following table shows basic information for the BTPs and their locations. Willingness to participate and provide necessary site-specific data and information was a major factor in selection of the BTPs due to the need for information necessary to complete that phase of the project on schedule.

Following the completion of the Beta Test, 17 additional facilities (i.e., the RFs), were selected from the remaining categories. Multiple facilities were selected from categories containing a large number of facilities (e.g., Ocean/Estuaries and Tidal Rivers; Large Rivers, Reservoirs and Lakes). These facilities are listed in Table 2-3. Throughout the evaluation, data were updated and refined as information became available. Therefore, the data provided in Appendix E, which were used for the national scale up (Section 6), may differ slightly from those found in Tables 2-2 and 2-3. The data presented in Tables 2-2 and 2-3 were used in the Beta Test phase and evaluation of RFs (Section 4).

Population categories shown in Tables 2-2 and 2-3 are based on the census tracts within which the facilities are located and the Year 2000 population expressed in population per square mile (people/mi^2). The population categories were divided into the following groups: Low (<100 people/mi^2), Medium (100-1,000 people/mi^2) and High (>1,000 people/mi^2). Some census tracts are large and may not account for population distribution within the census tract. Of the facilities studied, four (17 percent) are listed as High, 12 (50 percent) are considered Medium, and eight (33 percent) are in Low population category based on this classification method. The population classification for the Phase II facilities is 21 percent High, 36 percent Medium, and 43 percent Low. Thus, the studied facilities under represent the High and Low population categories and over represent the Medium.

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[4] EPRI Technical Advisory Committee represents 29 companies that include some of the largest utilities in the nation who own and operate a substantial percentage of the Phase II facilities.

Table 2-2
Facility information and associated categories for BTPs

Facility	Location or U.S. Region	Climatic Region (Wet-Bulb Temp.)	Fuel	Capacity (MW)	Cooling Water Flow (MGD)	Source Waterbody	Population Category[a]
BTCA1	Los Angeles County, CA	< 76°F	Natural Gas	1,950	1,181	Estuary	High
BTPA	Southeast	> 79°F	Coal	1,837 [b]	1,119 [b]	Freshwater Tidal River	Low
BTPB	Great Lakes Region	76°F – 79°F	Nuclear	2,161	2,369	Great Lakes	Medium
BTPC	Northeast	76°F – 79°F	Coal	705[b]	937 [b]	Estuary	Low
BTPD	Southeast	76°F – 79°F	Coal	2,090	1,463.04	Reservoir	Medium
BTPE	Northeast	76°F – 79°F	Nuclear	2,186	2,281	Reservoir	Medium
BTCA2	San Diego County, CA	< 76°F	Nuclear	2,150	2,335	Ocean	Low

[a] High >1,000 per sq mile, Medium 100-1,000 per sq mile, Low <100 per sq mile

[b] Only for those units utilizing once-through cooling.

Table 2-3
Facility information and associated categories for RFs

Facility	Location or U.S. Region	Climatic Region (Wet-Bulb Temp)	Fuel	Generating Capacity (MW)	Cooling Water Flow Rate (MGD)	Source Waterbody	Population Category[a]
RFF	Midwest	76°F – 79°F	Coal, petroleum coke	849	810	Great Lakes	Medium
RFG	Midwest	76°F – 79°F	Coal	1,222	741	Large River	Medium
RFH	Southeast	> 79°F	Nuclear	2,060	1,921	Estuary	Medium
RFI	Midwest	76°F – 79°F	Coal	584	550	Small River	High
RFJ	South	> 79°F	Natural gas, fuel oil	500	639	Lake	Medium
RFK	Northeast	76°F – 79°F	Oil, natural gas	380	294	Ocean	High
RFL	Midwest	> 79°F	Natural gas, coal	460	340	Large River	High
RFM	Southeast	> 79°F	Coal	864[b]	549[b]	Lake	Medium
RFN	Northern Plains	< 76°F	Coal	140[b]	156[b]	Lake	Medium
RFO	Midwest	76°F – 79°F	Coal	360	252	Large River	Low
RFP	Midwest	76°F – 79°F	Coal	1,139	484	Lake	Low
RFQ	Northeast	< 76°F	Oil, natural gas	353[b]	224[b]	Large River	Medium

Table 2-3
Facility information and associated categories for RFs (continued)

Facility	Location or U.S. Region	Climatic Region (Wet-Bulb Temp)	Fuel	Generating Capacity (MW)	Cooling Water Flow Rate (MGD)	Source Waterbody	Population Category[a]
RFR	Southeast	> 79°F	Coal	125	173	Small River	Medium
RFS	Midwest	76°F – 79°F	Nuclear	1,824	1,356	Large River	Low
RFT	Great Lakes Region	< 76°F	Coal	1,414	1,111	Great Lakes	Medium
RFU	Northern Tier	< 76°F	Coal	202	144	Large River	Low
RFV	Southeast	76°F – 79°F	Nuclear	1,100	720	Lake	Low

[a] High >1,000 per sq mile, Medium 100-1,000 per sq mile, Low <100 per sq mile

[b] Only for those units utilizing once-through cooling.

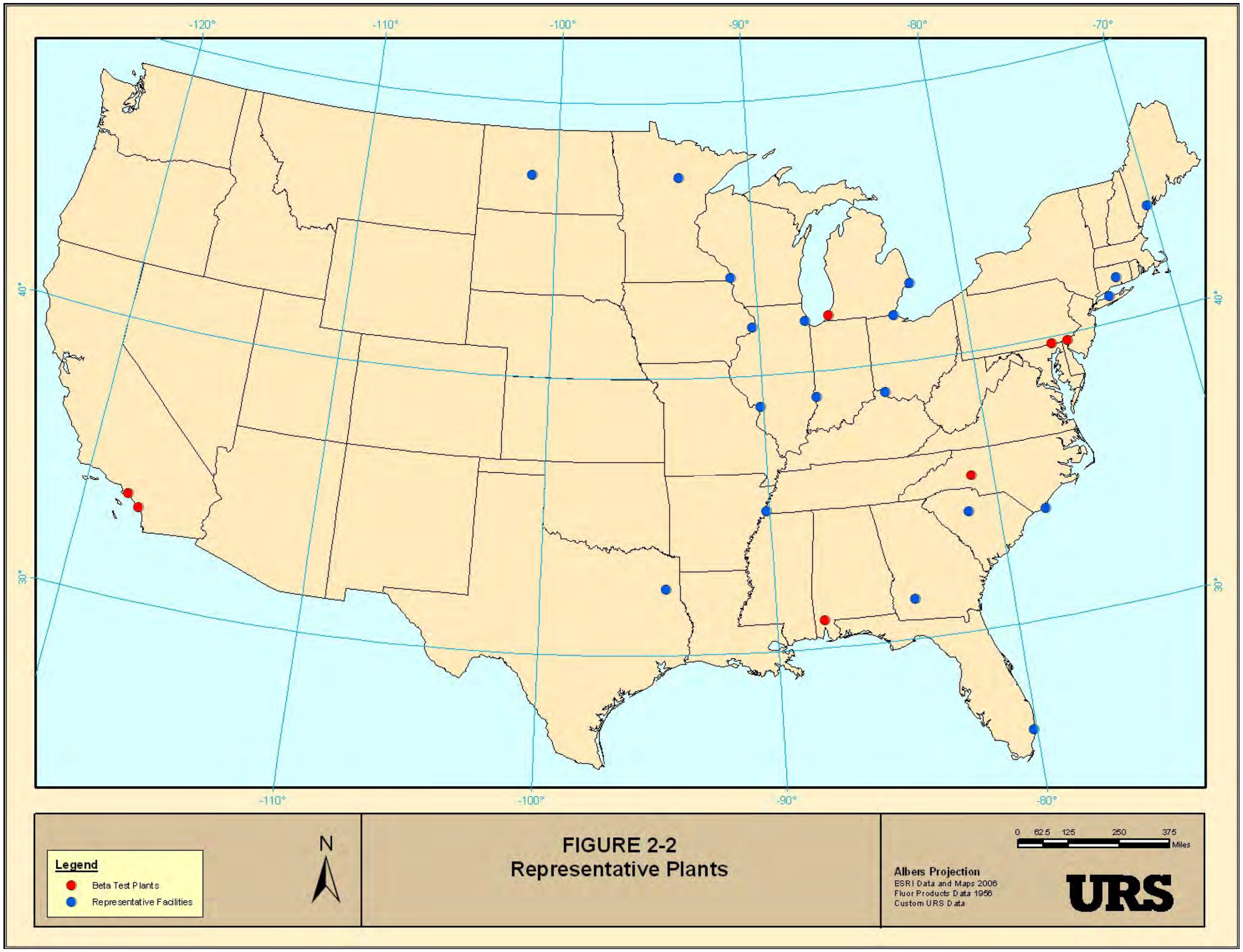

Figure 2-2
Location of BTPs and RFs

3

CLOSED-CYCLE COOLING SYSTEM DESIGN

This section discusses the process used to develop a conceptual closed-cycle cooling system design for each of the 24 selected sites. The basic components of a closed-cycle cooling system consist of:

- Circulating water pumps (may also use booster pumps for cooling tower pumping head);
- Main condenser;
- Cooling tower with basin;
- Makeup water pumps and cooling tower discharge (blowdown) pipeline; and
- Interconnecting piping network.

This section presents the conceptual design of cooling towers, and default design assumptions made for other closed-cycle cooling system components. These assumptions are used in this evaluation, unless constraints identified for a particular facility necessitated that an alternate assumption be made.

This section provides the following:

- Background information on cooling tower operating principles and terminology;
- Descriptions of alternate cooling tower designs;
- A list of design assumptions used for evaluation (including the assumption that mechanical-draft evaporative cooling towers will be the cost-effective cooling tower type used at each facility);
- Applications of cooling towers at each of the BTPs and RFs; and
- A discussion of those aspects of closed-cycle cooling system operation that are associated with its potential environmental and social effects, including cooling tower air emissions and water consumption.

Additional site-specific information is provided in Appendix A.

Section 5 compares the mechanical-draft evaporative cooling tower with alternate cooling tower types (e.g., size/dimensions/footprint, capital and operations and maintenance [O&M] costs, energy penalty, etc.), advantages or drivers that would lead a facility to choose an alternative other than mechanical-draft evaporative cooling towers (e.g., cost, water availability, O&M, potential environmental effects, etc.), assesses the potential application of the cooling tower alternatives at the BTPs, and assesses the relative potential environmental and social effects of using a cooling tower type other than mechanical-draft evaporative cooling towers at a Phase II facility.

3.1 Cooling Tower Operating Principles

The primary heat-dissipating component of a closed-cycle cooling system is the cooling tower. The cooling tower functions as a mechanism to reject waste heat associated with any type of power generating cycle to the atmosphere. Waste heat may be rejected via latent heat transfer, associated with a phase change such as evaporation, or sensible heat transfer, which is associated with an incremental change in temperature of the air or water medium, or a combination of both latent and sensible heat transfer. Transfer of latent heat is significantly more efficient than transfer of sensible heat, since a great deal more heat is liberated in a liquid-to-vapor phase change in comparison to an incremental temperature change within a phase.

When using evaporative cooling systems for latent heat transfer, the ambient wet-bulb temperature is the primary environmental performance-limiting factor. Dry-bulb temperature may be measured using a regular thermometer, whereas wet-bulb temperature is measured using a thermometer with a wet wick or “sock” on the bulb end over which ambient air is passed. As the moisture in the sock evaporates, the end of the bulb cools to an end point, which is a measure of wet-bulb temperature. The dry- and wet-bulb temperatures together provide an indication of the relative humidity of the ambient air, and the larger the difference between these two temperatures, the lower the relative humidity (or “drier” the air). At the other extreme, when the relative humidity is 100 percent, the dry- and wet-bulb temperatures are, by definition, equal. When the ambient air is relatively dry, more efficient evaporation can take place because the air has more capacity to take in moisture (and the latent heat along with it). Dry-bulb temperatures also affect the moisture-holding capacity, as warmer air can hold more moisture than cooler air. This combination of factors allows for delineating wet-bulb regions. Areas that experience higher wet-bulb temperatures more frequently throughout the year tend to be in hotter and more humid regions of the country, such as in Southeastern states, although most of the East and Midwest experiences these conditions during the summer months. In these areas, it takes a larger cooling tower to achieve the same amount of cooling than in a lower wet-bulb area.

For sensible heat transfer (the mechanism for dry cooling systems), the ambient dry-bulb temperature is the environmental performance-limiting factor, since water vapor is not being transferred along with the heat. A discussion of the overall implications of wet vs. dry cooling systems is provided by EPRI and the California Energy Commission [7].

3.2 Cooling Tower Terminology

The following terminology is uniquely associated with cooling towers and may be used in this report.

Recirculation–Meteorological conditions (particularly wind direction), location, and orientation of cooling towers typically cause some portion of the warm, moist exhaust air to reenter the cooling tower air inlet. This is referred to as recirculation. It reduces operating efficiency by increasing the effective wet-bulb temperature [8]. Rectilinear cooling towers perform more efficiently when their longitudinal axis is oriented with the wind direction. Given that the wind blows from different directions at different times of the day and year, and since cooling is most challenging during the summer, cooling towers typically are oriented in the predominant summer wind direction.

Interference–Interference is similar to recirculation, except that the warm, moist air from one tower enters the air inlet of another nearby cooling tower. In general, when two or more cooling towers are located side by side, a distance equal to at least the length of the towers needs to be maintained between towers to minimize interference [8].

Hot-water temperature–This is the temperature of the water entering the cooling tower that carries the heat load from the condenser. The hot-water temperature depends mostly on the amount of heat transferred in the condenser and the cooling water flow rate.

Cold-water temperature–This is the temperature of the water after it has passed through the cooling tower and dissipated the heat load to the atmosphere. The cold-water temperature depends on a variety of factors, including the state of the incoming air, prevalence and direction of wind, and the design, location, and orientation of the cooling towers.

Range–The cooling tower range is defined as the actual difference between the entering and leaving water temperatures (i.e., hot-water temperature minus cold-water temperature). Cooling tower size varies directly with range.

Approach–The approach is defined as the difference between the cold-water temperature and the entering air wet-bulb temperature [9]. Cooling tower size varies inversely with approach and it is not practical to design for an approach that is less than 5°F since, in reality, the lowest achievable cold-water temperature is ambient wet-bulb temperature *plus* 5°F [8].

Cooling efficiency–This is defined as:

$$\frac{range}{approach + range}.$$

Cooling efficiency is typically 50 percent to 70 percent [10].

Heat load–This is the total heat to be removed from the circulating water by the cooling tower per unit time, and is the product of the mass flow rate of water entering the cooling tower and the cooling tower range. For a given range, approach and wet-bulb temperature, the tower size varies directly and linearly with heat load.

Fill–Fill material increases contact area and time between air and water. The two basic types of fill are splash and film [3]. Splash-type fill causes the water to cascade down parallel splash bars and breaks the water stream into smaller water droplets. Film-type fill causes water to flow in thin films over vertically oriented sheets of fill [3]. California redwood and Douglas fir were the fill materials of choice until recently, when the use of lighter weight and more durable synthetics like polyvinyl chloride and fiberglass captured the cooling tower market.

Cell–A cooling tower cell is a subdivision of a cooling tower that functions as an independent unit with regard to air and water flow; cells are bounded by exterior walls (or partition walls between adjacent cells). Cells are arranged normally in a single row (in-line), a double row (with back-to-back cells), or in a circular array. Towers with back-to-back cells tend to be somewhat taller than in-line cell towers to compensate for their lowered efficiency due to reduced per-cell air inlet area.

Drift–This is circulating water that is lost from the tower as liquid droplets entrained in the exhaust air stream; cooling towers can be designed with drift 'eliminators' that can control the loss to as low as 0.0005 percent of the circulating water flow rate.

Capacity–This is the flow rate that the cooling tower will cool through a specified range, at a given approach and wet-bulb temperature.

Fogging–This refers to the visibility and path of the heated air/vapor stream that exits the cooling tower; if visible and close to the ground, then it is referred to as fog, and if visible and elevated, then it is referred to as a plume.

3.3 Cooling Tower Types

There is a variety of cooling tower designs that may be used to retrofit facilities that currently utilize once-through cooling systems. These cooling towers may be grouped by a variety of factors, including (in descending order of significance):

- By method of heat transfer: wet, dry or wet/dry (hybrid) towers;
- By air flow method: natural draft, mechanical forced draft, mechanical induced draft;
- By air flow direction: counter- or cross-flow; and
- By arrangement: rectilinear (in-line or back-to-back) or round [9].

Since the type of cooling tower selected will have the greatest impact on its size and operation (and, consequently, potential environmental and social effects), brief descriptions of wet, dry, and hybrid towers follow.

Due to their lower overall capital cost and operational flexibility, it is anticipated that most facilities, if required to retrofit existing once-through systems with closed-cycle cooling towers, would choose mechanical-draft evaporative cooling towers. The use of cooling tower designs other than mechanical-draft evaporative cooling towers (as well as cooling lakes or ponds[1]) will most likely be limited to few sites that have specific constraints, such as limited water availability or sensitive receptors. A detailed comparison of alternative types of cooling relative to retrofits has been performed by EPRI in its *Closed-Cycle Retrofit Study* [11]. However, for this study, it is assumed that the site conditions are amenable to the use of mechanical-draft evaporative cooling tower, unless information is identified to the contrary.

Details on the methodology used to size the cooling towers for the modeled sites are provided in Appendix B.

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[1] Cooling lakes or ponds require significant property acreage that is assumed to be unavailable at most sites.

3.3.1 Mechanical-Draft Evaporative Cooling Towers

A wet mechanical-draft evaporative cooling tower typically consists of multiple rectangular cells arranged in an array. Each cell houses ‘fill’ material, which functions to increase the area and time of contact between the water and air. Water cascades down the interior ‘fill’ while ambient air is forced or drawn (induced) by fans against (‘counter-flow’ design) or across (‘cross-flow’ design) the flow of water and then exhausted out the top of the cells; a portion of the water evaporates into the air stream, cooling the remainder of the water. Wet cooling is based on a combination of latent and sensible heat transfer. Present day designs use counter-flow design with induced-draft fans located on top of each cell [3].

3.3.2 Wet Natural-Draft Cooling Towers

Wet natural-draft cooling towers typically are designed as a single large round cell with the air exhaust stack in the distinctive shape of a hyperboloid. The hyperboloid geometry has been found to improve performance efficiency and minimize use of materials. Airflow through this type of tower is produced by the density differential between the heated air (less dense) inside the stack and the relatively cooler (more dense) ambient air outside the tower [8]. Water flows/cascades downward, warming the air that comes into contact with it. Warmer air is more buoyant and therefore rises, creating a lower pressure zone at the base of the tower and inducing additional cooler ambient air to flow in through the base of the tower. This type of cooling tower has not been built in the United States on a large scale in over 20 years, although one is under construction at Brayton Point in southeastern Massachusetts.

3.3.3 Dry Cooling Towers

Dry cooling towers use ambient air to condense and cool turbine exhaust steam either directly or, by using a secondary circulating water loop, indirectly. Dry cooling is based on sensible heat transfer only.

Direct dry cooling systems typically use large air-cooled condensers that use finned heat exchange tube bundles that may be sloped at some angle up to 60 degrees from horizontal (A-frame) in order to reduce the footprint size. The steam enters a manifold at the top and flows down through the bundles, is condensed into liquid and cooled, and then returned to the boiler circuit. The ambient air is forced or induced by fans across the bundles and the warmed air is exhausted to the atmosphere. The steam and condensate do not come into direct contact with the coolant air.

Indirect dry cooling systems couple a dry natural- or mechanical-draft cooling tower with a steam surface condenser. The tube bundles are mounted inside the cooling tower. The circulating water is pumped from the condenser through the bundles (i.e., does not flow down through ‘fill’) and is cooled by the ambient air, which then exhausts through the top of the tower. The cooled circulating water flows back to the condenser to condense the steam exhausted from the turbine. Again, there is no direct contact between the air and the circulating water.

3.3.4 Hybrid Wet/Dry Cooling Towers

Hybrid wet/dry cooling towers[2] typically consist of an air-cooled condensing unit as the top portion of the tower, and a wet mechanical draft cooling tower portion below [8][3]. The tower is coupled with a steam surface condenser. The heated circulating water first enters the top dry portion of the tower where sensible heat transfer takes place resulting in a slightly lowered temperature. The water then flows out from the tube bundles and cascades down the wet portion of the tower where latent heat transfer takes place. The cooled water is then pumped from the cooling tower basin to the condenser to condense the steam exhausted from the turbine. There is no direct contact between the air and the circulating water in the air condenser portion of the tower, but there is in the wet portion.

3.4 Closed-Cycle Cooling Tower System Design Assumptions

This section provides a list of assumptions for designing closed-cycle cooling systems and sizing hypothetical cooling towers for the BTPs and RFs. The sizing methodology is discussed in further detail in Appendix B. Unless exceptions are noted for identified site-specific factors or for practical reasons, the following simplifying design assumptions were made for all BTPs and RFs.

- Mechanical-draft evaporative cooling towers are used;
- Cooling tower approach is 10°F;
- Cooling tower range is equal to the temperature rise for each unit’s condenser(s);
- A separate cooling tower is assigned to each generating unit (towers may be combined for multiple smaller units for economy of scale);
- The design wet-bulb temperature is the value with a one percent exceedance on an annual basis (or approximately a five percent exceedance during the summer months) for the location;
- Design wind direction used is the primary wind directions with 2.5 percent summer dry-bulb temperature, as reported by American Society of Heating, Refrigerating and Air-Conditioning Engineers Technical Committee [12];
- Condenser cooling water flow rate and heat load will remain unchanged after the cooling tower retrofit;
- Salt water towers are sized slightly larger than freshwater towers to compensate for the different vapor pressure, density, and specific heat;

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[2] Hybrid wet/dry cooling towers are sometimes referred to as plume-abatement cooling towers since they are capable of operating without a visible plume by using a combination of dry and wet cooling.

[3] A variation of this configuration is a parallel hybrid cooling system, which relies on a combination of a direct dry cooling tower and a wet surface condenser with associated wet cooling tower. While this system is gaining more favor for new units where water conservation and efficiency are both of high concern, the cost of installing such a system would not make it a likely candidate for retrofit on existing facilities.

- All cooling towers are equipped with drift eliminators and the drift rate will be the circulating water flow rate times 0.0005 percent;
- Where possible, cooling towers are located as closely as possible to the facility's existing cooling water intake structure;
- The cooling towers are located on the existing site property to minimize, if possible, potential environmental and social effects; no new land acquisitions are assumed[4];
- Booster pumps are used ahead of the cooling towers to avoid the need to modify the existing circulating water pumps and the condensers due to higher operating pressures;
- Cooling tower basins extend 4 feet (ft) out from the cooling tower cells and are 6 ft in depth; the tower footprint dimensions include a basin allowance;
- Cooling tower evaporation is estimated as 0.1 percent of the circulating water flow rate per degree of range;
- The actual cycles of concentration (i.e. the TDS concentration in the circulating water divided by the TDS concentration in the makeup water) are site-specific. In the absence of direct plant input, for the purposes of this study, eight cycles of concentration were used for freshwater facilities; 1.5 cycles of concentration for ocean water-using facilities;
- Blowdown losses are calculated based on assumed cycles of concentration for each waterbody type (see Appendix A), and can be returned to the waterbody through the current outfall of the once-through cooling water discharge;
- Makeup water pumps to replace evaporation, drift, and blowdown losses can be located in the existing intake structure(s); and
- The intake structure can be modified to isolate the existing circulating water pumps from the waterbody so that they can be used in a closed-cycle mode.

3.5 Facility Cooling Towers

3.5.1 BTP Cooling Towers

The number of cells and footprint of the mechanical-draft evaporative cooling towers required at each BTP unit currently designed with once-through cooling is given in the following table. The sizes were provided by GEA Power Cooling, Inc., a cooling tower vendor, based on the assumptions cited above [13]. Additional information for the cooling towers is provided in Appendix A.

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[4] In conjunction with the New York State Pollutant Discharge Elimination System permit renewal for Dynegy's Danskammer Generating Station, based on a hearing report issued by Administrative Law Judge Daniel P. O'Connell, the New York Department of Environmental Conservation Deputy Commissioner Carl Johnson issued a Decision on May 24, 2006 that cooling towers would not fit on the site property. Petitioners in the adjudicatory hearing included Riverkeeper, Inc., Scenic Hudson, Inc., and National Resource Defense Council Inc. who proposed that the Plant be retrofitted with a closed-cycle cooling system. As a prerequisite to the Decision, an Interim Decision (May 13, 2005) based on an earlier hearing, deemed that the use of properties other than the site or the use of piers or barges in the Hudson River shall not be considered in determining whether a closed-cycle cooling system can be located on the site.

Table 3-1
Number of cells and footprint of hypothetical mechanical-draft evaporative cooling towers for BTPs

BTP	Unit	Number of Cells/Arrangement	Foot Print, ft
BTCA1	U1	14/Back-to-back	344 x 104
	U2		
	U3	22/Back-to-back	602 x 116
	U4		
	U5	14/Back-to-back	386 x 116
	U6	14/Back-to-back	386 x 116
BTPA	5 units	Five cooling towers:	
		5/In-line	278 x 62
		6/In-line	296 x 56
		10/Back-to-back	278 x 104
		10/Back-to-back	278 x 116
		18/Back-to-back	494 x 104
BTPB	2 units	Four cooling towers:	
		24/Back-to-back	710x104
		26/Back-to-back	656x104
		24/Back-to-back	656 x 104
		24/Back-to-back	656 x 104
BTPC[a]	3 units	Three cooling towers:	
		5/In-line	248 x 62
		7/In-line	344 x 62
		20/Back-to-back	548 x 104
BTPD	4 units	Four cooling towers:	
		12/Back-to-back	296 x 104
		12/Back-to-back	296 x 104
		20/Back-to-back	548 x 104
		20/Back-to-back	548 x 104
BTPE	2 units	Five cooling towers:	
		22/Back-to-back	602 x 104
		22/Back-to-back	602 x 104
		22/Back-to-back	602 x 104
		22/Back-to-back	602 x 104
		20/Back-to-back	548 x 104
BTCA2	U2	Two 32-cell towers; Back-to-back	Each 872 x 116
	U3	Three 22-cell towers; Back-to-back	Each 602 x 116

[a] This table provides the sizes of closed-cycle cooling towers required to remove the full heat load from Units 1-3. However, towers of this size cannot be located at the proposed location. Towers sized by a consultant over 15 years ago for helper cooling towers are shown in Figure A-20 (Appendix A) for the purpose of assessing impacts. The two inline cooling towers for Units 1 and 2 have been combined into a single back-to-back tower in Figure A-20.

3.5.2 RFs

The number of cells and footprint of the mechanical-draft evaporative cooling towers required for the 17 RFs currently designed with once-through cooling is given in the following table.

Table 3-2
Number of cells and footprint of hypothetical mechanical-draft evaporative cooling towers for RFs

Representative Facility	Unit	Number of Cells/Arrangement	Foot Print, ft
RFF	4 units	Four cooling towers:	
		14/Back-to-back	358 x 108
		14/Back-to-back	358 x 108
		14/Back-to-back	358 x 108
		20/Back-to-back	508 x 108
RFG	6 units	Four cooling towers:	
		14/Back-to-back	358 x 108
		16/Back-to-back	408 x 108
		12/Back-to-back	308 x 108
		18/Back-to-back	458 x 108
RFH	2 units	Six cooling towers:	
		22/Back-to-back	558 x 108
		22/Back-to-back	558 x 108
		22/Back-to-back	558 x 108
		22/Back-to-back	558 x 108
		24/Back-to-back	608 x 108
		24/Back-to-back	608 x 108
RFI[a]	2 units	Two cooling towers:	
		8/In-line	408x 58
		22/In-line	1108 x 58
RFJ	4 units	Two cooling towers:	
		20/Back-to-back	508 x 108
		26/Back-to-back	658 x 108
RFK[b]	2 units	One cooling tower:	558 x 108
		22/Back-to-back	
RFL	5 units	Two cooling towers:	
		24/Back-to-back	608 x 108
		22/Back-to-back	558 x 108
RFM	3 units	Three cooling towers:	
		14/Back-to-back	358 x 108
		14/Back-to-back	358 x 108
		14/Back-to-back	358 x 108

Table 3-2
Number of cells and footprint of hypothetical mechanical-draft evaporative cooling towers for RFs (continued)

Representative Facility	Unit	Number of Cells/Arrangement	Foot Print, ft
RFN	2 units	One cooling tower:	
		12/Back-to-back	308 x 108
RFO[c]	1 unit	One cooling tower:	
		18/Back-to-back	458 x 108
RFP	2 units	Two cooling towers:	
		18/Back-to-back	458 x 108
		18/Back-to-back	458 x 108
RFQ	2 units	One cooling tower:	
		16/Back-to-back	408 x 108
RFR	1 unit	One cooling tower:	
		10/Back-to-back	258 x 108
RFS	2 units	Four cooling towers:	
		26/Back-to-back	658 x 108
		26/Back-to-back	658 x 108
		26/Back-to-back	658 x 108
		26/Back-to-back	658 x 108
RFT	6 units	Four cooling towers:	
		20/Back-to-back	508 x 108
		20/Back-to-back	508 x 108
		18/Back-to-back	458 x 108
		26/Back-to-back	658 x 108
RFU	1 unit	One cooling tower:	
		10/Back-to-back	258 x 108
RFV	1 unit	Three cooling towers:	
		16/Back-to-back	408 x 108
		16/Back-to-back	408 x 108
		18/Back-to-back	458 x 108

[a] These towers were sized and located by a facility consultant.

[b] Locating a cooling tower at this site is not feasible. This tower has been sized and located (on unavailable land) to facilitate evaluation of environmental impacts only.

[c] Locating a cooling tower at this facility may not be feasible. This tower has been located to facilitate evaluation of environmental impacts only.

The cooling tower sizes were estimated using methodology developed by Maulbetsch [14] based on the assumptions cited above. Site-specific information is provided in Appendix A.

3.6 Engineering Factors that Affect Ease of Retrofit

In addition to the space requirements associated with the installation of cooling towers, other engineering factors must be considered in the assessment of whether a closed-cycle cooling retrofit is feasible and, if so, whether the retrofit would be relatively easy, moderate, or difficult. In general, the more difficult the retrofit, the higher the associated capital cost. A separate EPRI supplemental research program includes an independent evaluation of the degree of retrofit difficulty for approximately 125 facilities. The following is a list of primary factors that would influence the feasibility or the ease/difficulty of retrofit.

- Suitable space on-site for locating a cooling tower and need to relocate existing facilities;
- Distance between the cooling tower and the main facility and difficulty of tie-ins to existing structures and components, including auxiliary power for new loads;
- Interference from existing underground and overhead utilities;
- Suitability of site geology and topography;
- Need to reinforce condensers or water supply tunnels;
- Need for plume abatement;
- Drift deposition on- or off-site;
- Need for noise reduction;
- Need to bring in alternate sources of makeup water;
- Requirements to modify balance-of-plant equipment; and
- Need to re-optimize the cooling water system.

Other issues that could affect costs include required outage time, permitting procedures and, for nuclear facilities, Nuclear Regulatory Commission (NRC) requirements.

As previously stated, EPRI sent out a questionnaire (a copy is provided as Appendix D) to all facilities affected by the Phase II Rule. One of the questions asked was: “Does your facility have contiguous open space on your property or adjacent ‘off-site’ open space that can be used to support cooling tower construction? (Y, N, DK).” 196 responses were received, of which 128 responded with a ‘Y’ (Yes), 38 responded with an ‘N’ (No), 18 responded with a ‘DK” (Don’t Know) and 12 were left blank. Based on this sample, 23 percent of the facilities that could definitively respond to the question (166 facilities) indicated that there is insufficient space to site a cooling tower on- or off-site.

A determination of cooling tower feasibility at a site must be based on a detailed site-specific study and examination of pipe runs, tie-ins, and other issues. As previously noted, EPRI has another supplemental research program that includes an independent evaluation of the degree of retrofit difficulty for approximately 125 facilities.

3.7 Cooling Tower Emissions

Evaporation and ‘drift’ are the primary emissions from a typical cooling tower that could result in potential environmental effects on receptors. Evaporation adds water vapor to the atmosphere. The drift droplets will contain the same type and concentration of TDS, such as sodium, calcium, chlorides, and sulfates, as contained in the water flowing through the cooling tower. The drift droplets will also contain organic matter (e.g., bacteria, spores, insects, and plant material) entrained into the towers by the fans. Additionally, the drift droplets contain the same chemical impurities as the water circulating through the tower; these impurities can be converted to airborne emissions. The amount of drift emissions is directly proportional to cycles of concentration and source water TDS.

Large drift droplets settle out of the tower exhaust air stream and deposit near the tower. This process can lead to wetting, icing, salt deposition, and related problems such as damage to equipment or to vegetation. Other drift droplets may evaporate before being deposited in the area surrounding the tower. Of particular concern to human health are particles (particulate matter or PM) with diameters of 10 microns and less (PM_{10}) and 2.5 microns and less ($PM_{2.5}$). These air contaminants are important because they are associated with respiratory and cardiovascular diseases and USEPA has established National Ambient Air Quality Standards (NAAQS) for these contaminants intended to maintain or improve ambient air quality.

To reduce the drift from cooling towers, drift eliminators are usually incorporated into the tower design to remove as many droplets as practical from the air stream before exiting the tower. The drift eliminators used in cooling towers rely on inertial separation caused by direction changes while passing through the eliminators. The most efficient drift eliminator currently available can limit the drift rate to 0.0005 percent of the circulating water flow rate.

A commonly referenced document published by USEPA, called “AP-42, Compilation of Air Pollutant Emission Factors,” is often used to estimate air emissions using an emission factor approach. An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Section 13.4 of AP-42, Fifth Edition provides emission factors for wet cooling towers [15].

Table 13.4-1 of AP-42, Fifth Edition lists an emission factor for PM_{10} from an induced draft wet cooling tower; however, the factor has an “E” rating. An E rated factor is best characterized as “Poor”, which is the lowest level of confidence, only one step above U for Unrated. An E rated factor is developed from average and below average rated test data from a very few number of facilities, which may not represent a random sample of the industry. There may also have been variability within the source category population tested.

The AP-42 factors were developed based on a limited number of emission tests performed between 1983-1990 and are therefore based on older technology not representative of current manufacturers’ guaranteed drift rates or expected drift droplet size distributions. Instead of using the E rated factor in Table 13.4-1, AP-42 recommends a method to estimate a *conservatively high* [italics per USEPA] PM_{10} emission factor by (a) multiplying the total liquid drift factor by the TDS fraction in the circulating water and (b) assuming that, once the water evaporates, all remaining solid particles are within the PM_{10} size range. However, this method has been challenged as unrealistically conservative. For this study, drift drop size spectrum data and plausible assumptions about the density and shape of the particles remaining following evaporation of the drift droplets are used to estimate PM size.

A discussion of the methodology and assumptions for calculating PM_{10} emission rates from mechanical-draft evaporative cooling towers, based on a representative drift droplet size distribution and TDS concentration in the circulating water, is provided in Appendix B.

Annual emissions for selected facility are summarized in Table 3-3.

Table 3-3
Calculated PM emissions summary with 0.0005% drift eliminator for BTPs and RFs based on potential to emit

Facility	Annual Emissions (tons per year [tpy])		
	PM	PM_{10}	$PM_{2.5}$
Great Lakes			
BTPB	32.7	24.6	10.1
RFF	9.9	7.7	3.2
RFT	13.6	10.7	4.5
Large Rivers			
RFG	100.6	41.3	12.1
RFL	11.2	8.2	3.3
RFM	6.1	4.8	2.0
RFO	4.6	3.4	1.4
RFQ	2.7	2.1	0.9
RFS	17.7	13.9	5.8
RFU	2.6	1.9	0.8
Small Rivers			
RFI	10.5	7.6	3.0
RFR	3.5	2.4	0.9
Lakes and Reservoirs			
BTPD	17.0	13.3	5.6
BTPE	43.4	31.1	12.4
RFJ	12.2	8.8	3.5
RFN	1.9	1.5	0.6
RFP	8.8	6.4	2.6
RFV	9.4	7.3	3.1

Table 3-3
Calculated PM emissions summary with 0.0005% drift eliminator for BTPs and RFs based on potential to emit (continued)

Facility	Annual Emissions (tons per year [tpy])		
	PM	PM_{10}	$PM_{2.5}$
Ocean/Estuaries and Tidal Rivers			
BTCA1	440.5	176.9	52.9
BTCA2	877.8	352.5	105.3
BTPA	170.3	82.8	25.8
BTPC	235.2	100.4	28.2
RFH	504.3	218.4	60.5
RFK	100.6	41.3	12.1

Table 3-3, shows that annual emissions can vary significantly. Emissions from facilities using brackish (e.g., BTPC, RFK) or salt water (e.g., BTCA2, BTCA1, RFH, RFK) for tower makeup can have high emissions, while facilities using freshwater (BTPB, BTPD, BTPE, RFF, RFI, RFJ, RFL, RFM, RFN, RFO, RFP, RFQ, RFR, RFS, RFT, RFU and RFV) have relatively low emissions. This may not be the case for all fresh waterbodies (RFG) depending on site-specific water quality. These emissions represent potential to emit, which is based on certain worst-case assumptions. The worst-case assumptions used in this study are full year operation, maximum TDS values in the makeup water, and maximum design cycles of concentration. Actual emissions may be lower than the potential to emit. For the air permitting analysis, emissions were based on potential to emit unless there was an enforceable permit condition restricting plant operations. For the impact assessment, potential to emit was reduced proportionally with estimated hours of operation.

3.8 Cooling Tower Water Consumption

Evaporation (and, to a much lesser degree, drift) from cooling towers consumes water. Another much smaller amount of water is lost due to excess evaporation from the warmer cooling tower blowdown plume; this loss was not estimated in this report. In-stream evaporation due to the once-through discharge plume is estimated in Section 4. Consumptive water loss is primarily important for freshwater facilities where water availability can be an issue during periods of low flow or droughts.

Evaporation of part of the water cascading down a cooling tower provides the bulk of the cooling for the remaining water. The evaporation rate, in gallons per minute (gpm), from a closed-cycle cooling tower may be estimated as:

0.1% x condenser cooling water flow rate (gpm) x cooling tower range (in °F) [9].

Drift rate from towers is the *circulating water flow rate x 0.0005%,* which is the drift rating of the most efficient, currently available drift eliminators.

Therefore the total water consumption due to cooling towers is:

Water consumption = evaporation rate + drift rate.

Consumptive water use from operating hypothetical cooling towers at the BTPs and RFs is given in the following table.

Table 3-4
Consumptive water use from cooling tower operation

Facility	Evaporation Rate (gpm)	Drift Rate (gpm)	Consumptive Loss Rate due to Cooling Towers (gpm)	Estimated Annual Average Consumptive Loss from Cooling Towers (gal/MW-hr)
BTCA1	16,343	4	16,347	495
BTPA	15,760	4	15,764	620
BTPB	28,246	7	28,254	767
BTPC	7,013	3	7,016	597
BTPD	16,798	5	16,803	482
BTPE	31,200	8	31,208	848
BTCA2	31,880	8	31,888	890
RFF	6,199	2.8	6,202	589
RFG	13,026	2.4	13,028	673
RFH	29,342	6.7	29349	939
RFI	5,868	1.9	5870	603
RFJ	5,430	2.2	5432	670
RFK	3,570	1.0	3571	592
RFL	7,703	2.1	7705	744
RFM	6,900	1.7	6,902	418
RFN	1,528	0.5	1,529	655
RFO	3,850	0.9	3851	642
RFP	9,250	1.7	9,252	519
RFQ	3,100	0.8	3100	517
RFR	1,770	0.5	1770	625
RFS	30,330	5.1	30,335	1049
RFT	16,449	3.9	16452	696
RFU	1,900	0.5	1901	606
RFV	13,328	2.7	13330	820

The net consumptive loss in converting a once-through cooling system to closed-cycle cooling must also account for the loss due to excess evaporation induced by the warmer discharge plume from the once-through cooled system. The calculation methodology and results are presented in Appendix B.

The following figure shows the estimated evaporative loss from cooling towers per megawatt-hour (MW-hr) of generation (gallons/MW-hr) plotted against each facility’s design wet-bulb temperature (in °F). This figure does not account for evaporative losses associated with once-through cooling systems.

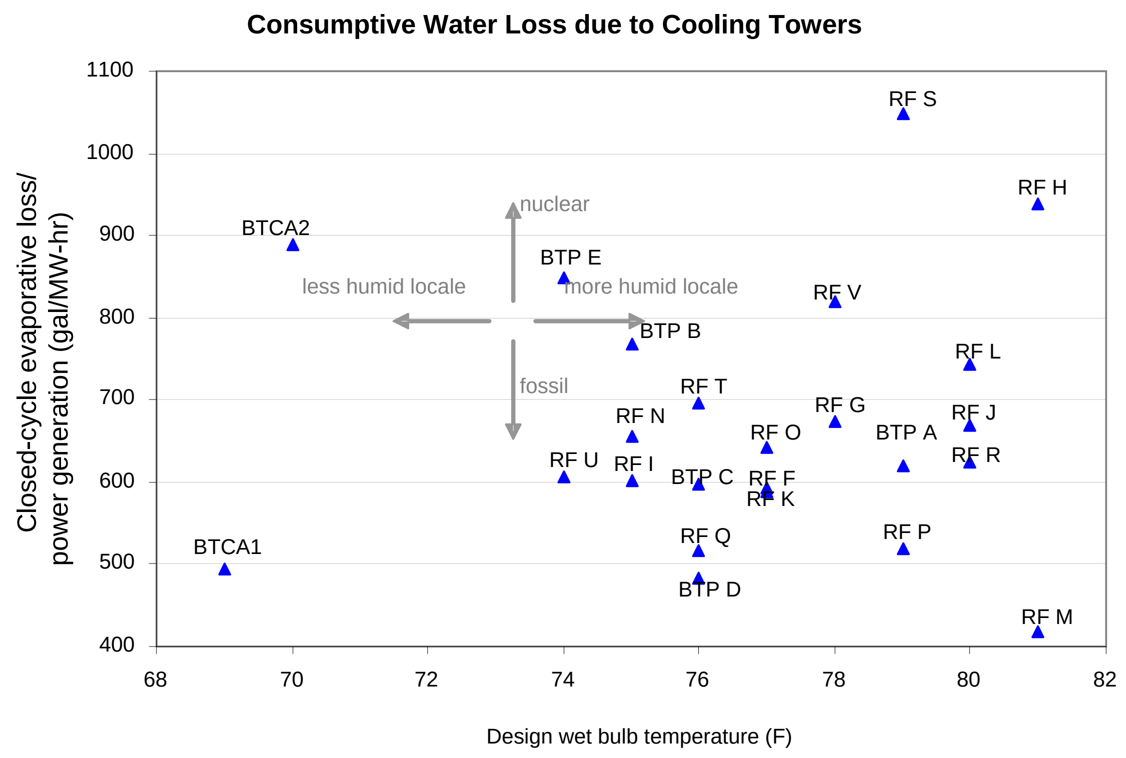

Figure 3-1
Consumptive water loss due to cooling towers

In general, evaporative loss rate per electricity generation is higher from nuclear stations (between 750-1,050 gals/MW-hr) than from fossil-fuel stations (approximately 400-750 gals/MW-hr).

4

IMPACT ASSESSMENT

This section provides an assessment of both potential adverse and beneficial environmental and social effects of closed-cycle cooling retrofits, based on the methodology provided in Appendices B and H, including the construction and operation of hypothetical mechanical-draft evaporative cooling towers discussed in Section 3. Potential adverse effects are compared to the beneficial effects from reduced cooling water flow and quantified where possible. The effects are also monetized, where there was an appropriate basis to generate a willingness to pay (WTP) estimate, to create a standard unit of comparison for different types of impacts.

The first step in the process was to establish assessment categories having the greatest likelihood of producing potentially significant impacts as a consequence of retrofitting. A first-order assessment matrix process was used to identify the most important environmental and social issues [2]. Ten assessment categories were established with the recognition that potential effects not considered significant enough to warrant inclusion in this base analysis, or for which data were not available for a quantitative assessment, could be considered in site-specific cases. Following selection of the assessment categories, relative and qualitative judgments of the magnitude of the potential effects (e.g., high, moderate, or low) were made. A rationale based on existing literature and best professional judgment produced an assessment of more likely effects that would be analyzed further (ranks of high or moderate) and less likely effects that would be eliminated from further analysis (ranks of low or not applicable).

As a result of this process, the following environmental and social issues associated with closed-cycle cooling were selected for quantification in this study:

Beneficial

- Aquatic biota.

Adverse

- Human health related to air emissions;
- Terrestrial resources;
- Water resource quantity and quality;
- Public safety and security;
- Quality of life related to noise;
- Quality of life related to visual impacts;
- Environmental permitting;
- Environmental justice; and
- Greenhouse gases.

Potentially significant site-specific impacts from closed-cycle cooling that were not quantified in the study include: short-term construction impacts; Legionnaires disease; insect, bird and bat collisions and/or entrainment into cooling tower fans; removal/disposal of sediments that accumulate in the cooling tower basin; off-property damage from salt drift; and removal and disposal of excavated materials from construction. Also not quantified were cumulative potential impacts from power plants in close proximity. The details of the approach to quantify the potential effects are discussed below and in Appendix B.

As previously discussed, scaling methods were tested (Beta Test) and reported using a subset of seven facilities [16]. The results of the Beta Test were used to refine and focus the impact assessment and scaling as discussed in this report.

4.1 Human Health

Potential human health issues are driven by possible health impacts resulting from additional air emissions from mechanical-draft evaporative cooling towers. Section 3.7 describes the emission of ‘drift’ from wet cooling towers, its connection to emission of PM_{10} or $PM_{2.5}$, and the use of drift ‘eliminators’ to reduce these emissions.

4.1.1 Pathogens

Other human health concerns associated with cooling towers include increased cases of disease caused by aerosol spray contaminated with *Legionella* sp. or other pathogens [17, 18], such as *Salmonella*, *Shigella*, *Pseudomonas aeruginosa*, thermophilic fungi, and free-living amoebae [17]. The Cooling Technology Institute has developed best practices that include halogenation to minimize *Legionella* in cooling systems [19]. Findings from recent epidemiological and experimental studies and the current state of the science does not allow for quantification of the potential risks caused by *Legionella* [20] and other pathogens. Therefore, this potential impact is not studied in this report. However, this may be a serious health concern for sensitive populations (e.g., the elderly).

4.1.2 PM_{10} and $PM_{2.5}$

4.1.2.1 Quantification

The AERMOD dispersion model was used to predict mechanical-draft evaporative cooling tower drift emissions for BTPs and RFs. A description of the AERMOD model, inputs, and assumptions are included in Appendix B. The AERMOD meteorological data requirements were met using readily available National Weather Service (NWS) data. The modeled maximum 24-hour and annual average concentrations around each of the modeled facilities are provided in Appendix C.

The population exposed to a significant increase in the levels of PM_{10} and $PM_{2.5}$ was determined by averaging the individual receptor levels within a given census block group with the changes approximating 0.1 of the significant impact level (SIL) for 24-hour maximum and average annual concentrations of PM_{10} and $PM_{2.5}$, on the local population surrounding the facilities. For this assessment, the number of households and the age breakdown in each block group was identified from 2000 census data. The results of this analysis are provided in Table 4-1. Impacts were modeled for all seven of the BTPs and eight of the RFs. Facilities not modeled were located in medium and low population areas where any impacts are likely to be small[1].

Potential upper bounds for possible human health impacts may be estimated through human health risk assessment. The USEPA provides risk assessment methodology in its document, "Particulate Matter Health Risk Assessment for Selected Urban Areas" [21], which relies heavily on the information and conclusions presented in the USEPA's final assessment of the available PM health effects literature [22]. However, EPRI research indicates USEPA's methods and their application in this closed-cycle cooling analysis results in very conservative risk estimates at the high end of the upper bound. Due to the lack of impact studies focused on human health effects related to cooling tower fine particulates, human health impacts are not reliably quantifiable. Any such impacts are likely to be extremely variable depending on the nature of the fine particulates in the source waterbody. Therefore, only the population exposed to a significant increase in the levels of PM_{10} and $PM_{2.5}$ is reported here. For comparison, human health risk estimates based on USEPA methodology, and the associated WTP to avoid them, are provided in Appendix G as a highly conservative estimate of the upper bound.

Table 4-1
Estimated population exposed to a significant increase in PM_{10} and $PM_{2.5}$

	Exposed Population (Age 30+)	Exposed Population (Age 65+)
BTCA1 - Los Angeles Co., CA	19,377	9,576
BTPA - Southeast	183	41
BTPB - Midwest	6,746	1,523
BTPC - Northeast	39,290	8,823
BTPD - Southeast	535	99
BTPE - Northeast	7,554	1,282
BTCA2- Orange Co., CA	84[a]	1
RFF - Midwest	15,139	3,498
RFG - Midwest	1,809	288
RFH - Southeast	23,407	5,397
RFI - Midwest	223,756	38,495
RFJ - South	5,784	1,206
RFK - Northeast	148,269	25,105
RFL - Midwest	20,614	5,717
RFS - Midwest	1,651	400

[a] No census data was found for nearby military base.

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[1] The objective of the study was to scale impacts. Since it is not possible to scale zero, not all low impact facilities were modeled.

4.1.2.2 Monetization

WTP to avoid potential human health impacts was based on the incremental increase in mortality and morbidity associated with increased exposure to PM. Since these measures of risk cannot be reliably quantified, the WTP to avoid human health risks cannot be reliably monetized. However, Appendix G provides a conservative estimate of the upper bound using USEPA methods for comparison purposes. Based on USEPA methods the WTP to avoid potential human health impacts is very significant ranging between $2,100 and $682,000.

4.1.2.3 Uncertainties

The uncertainties and omissions that affect the air modeling include:

- Meteorological Data Set–A single year of offsite NWS data were used in these analyses. In permitting situations, a five-year data set is required. Results will typically vary by approximately 20 percent from year to year over a five-year period. Therefore, the results presented in this study may not represent maximum potential impacts;
- Tower Location–The actual placement of the cooling towers in relationship to the property boundary and other existing structures could greatly affect the model results;
- Facility Plot Plan–Heights of existing structures and exact location of the facility fence line were estimated based on aerial photographs;
- Project Emissions–Information on unit operating restrictions was not available. In the absence of such information, full-year operation was assumed for permitting. Any limitations on long-term operations will have a direct linear impact on the predicted long-term results; and;
- All BTPs and RFF, RFG, RFH, RFI, RFJ, RFK and RFL were modeled for PM emissions. For the remaining RFs, which were located in low population areas, the PM concentrations were estimated using model results from similar facilities. This adds uncertainty to the results.

4.2 Terrestrial Resources

4.2.1 Long-Term Loss of Wildlife Habitat, Wetlands, & Critical Habitat

For this report, terrestrial resources were identified as wildlife habitats that include tidal or non-tidal wetlands, including critical habitats supporting rare, threatened, and endangered species. The construction of one or more cooling towers and their associated piping systems and system operation could result in the short-term or long-term loss of these resources. Temporary losses would be restored and long-term losses would be avoided to the extent practicable.

For the Beta Test, the most current site-specific information available was reviewed for each BTP to determine the location and extent of on-site and nearby terrestrial and wetland resources. Sources included national and state databases, geographic information system mapping, aerial photography, National Wetlands Inventory (NWI) maps, and published facility reports. This information is provided in Appendix A. If possible, cooling towers (see Section 3) were located to avoid these terrestrial and wetland resource areas. In cases where impacts were unavoidable, the likely area of long-term disturbance by the cooling tower footprint, buffer zones, and access roads was quantified (Appendix A).

Not all potential adverse impacts to terrestrial resources are addressed, including:

- Birds and bats colliding with cooling towers;
- Bird and bat entrainment into cooling towers; and
- Beneficial or protected insect (e.g. ladybugs, pollinators, endangered butterflies) entrainment into cooling towers.

Available information suggests that collisions with mechanical-draft evaporative cooling towers are not as likely compared with much larger natural-draft towers [23]. Increased mortality associated with collisions is expected during spring and fall migrations when visibility can be poor at times (e.g., at night) [17, 24]. Mortality from collisions is taxon-specific: warblers, kinglets, and fringillids appear to be more susceptible than ducks and gulls. Additionally, insect entrainment and/or impingement are expected to be more significant an impact for fan-assisted dry towers [25], given the large banks of fans used in this technology. Data relative to this issue for mechanical-draft evaporative cooling towers and other cooling towers were not found, but the parallels to aquatic impingement and entrainment are obvious.

Additional information related to avian taxa interaction with mechanical-draft evaporative cooling towers was solicited through the EPRI questionnaire. The results of this survey indicate that little or no data on avian taxa interaction with mechanical-draft evaporative cooling towers are available.

4.2.1.1 Quantification

Unavoidable long-term losses of terrestrial resources were quantified for each BTP. Potential impacts are summarized in Table 4-2. It was assumed that long-term losses associated with the cooling tower construction would require permits and/or approvals by the appropriate local, state, and federal agencies. Also, due to the magnitude of closed-cycle cooling retrofit projects, they are generally subject to public stakeholder review and comment. This is discussed in further detail in Section 4.6.

4.2.1.2 Monetization of Beta Test Sites

The loss of wildlife habitat that would be unavoidably impacted by cooling tower construction and operation represents an adverse impact associated with retrofitting to closed-cycle cooling. The costs and benefits associated with potential terrestrial impacts are primarily borne by landowners. However, some are experienced by society as a whole. The costs and benefits experienced by society as a whole are referred to as externalities. In this section, WTP to avoid the loss of positive externalities as the result of cooling tower construction and operation are estimated.

Table 4-2
Summary of closed-cycle cooling impacts to terrestrial resources at BTPs

Facility	Land Disturbed (acres)[a]	Habitat Impacts (acres)			Wetlands Impacts[c, d] (acres)	Critical Habitat Impacts (acres)	Footprint Impact Description[e]
		Upland Forest	Upland Herb./Scrub-Shrub	Open Water (Non-wetland)[b]			
BTCA1	6.55	0.0	0.94	1.68	0.0	0.0	Developed areas & on-site open water.
BTPA	6.92	0.5	0.0	0.0	3.64-forested 2.78-emergent scrub-shrub	0.0	Disturbed forested & emergent/scrub-shrub wetlands
BTPB	23.0	21.3	0.0	1.7	0.0	21.3-Critical Dune Area (forested dune)	Critical dune area/threatened and endangered forested habitat & on-site open water
BTPC	2.14	0.0	0.61	0.31	0.0	0.0	Developed areas and on-site open water.
BTPD	19.91	18.8	1.11	0.0	0.0	0.0	Developed areas and forested habitat.
BTPE	7.0	0.0	0.15	0.0	0.04-emergent	0.0	Existing cooling tower locations and on-site open water.
BTCA2	13.34	0.0	0.17	0.45	0.0	0.17-Rare Coastal Bluff Scrub	Developed areas, on-site open water and coastal bluff scrub area.

[a] "Land Disturbance" is the total area disturbed for proposed cooling tower locations and perimeter buffer, which includes vegetated areas, open waters, wetlands, and developed and/or paved areas.

[b] Potential open water (non-wetland) impacts are based on NWI mapped excavated ponds and aerial photo interpretation.

[c] Potential wetland impacts are associated with wetlands likely to be regulated only. NWI wetlands that are non-jurisdictional as wetlands, such as artificial pond/lagoons, were not included.

[d] Potential wetland impacts are based on the NWI mapping as well as aerial photo interpretation where necessary.

[e] Does not include any offsite wetland impacts.

In creating and implementing multiple private programs designed to preserve land in its natural state, society has revealed a WTP to maintain positive externalities that flow from private land. The existence of government sponsored programs designed to achieve the same goal coupled with the assumption that governments are an agent acting on behalf of society is consistent with this revealed WTP. Where available, these market data were used to estimate the WTP to preserve specific rare habitats that would be converted to industrial land use. Detailed methods are provided in Appendix B.

Because the majority of these “preservation transactions” are related to the protection of rare habitats, this analysis focused on the estimation of a per-unit WTP for the preservation of positive externalities flowing from rare habitats. WTP to avoid the loss of externalities flowing from common habitats was not estimated because the available market data do not support such an analysis.

Potential wetland impacts were not monetized because federal, and some state, regulations require that these losses be mitigated by creation of new wetlands or restoration of existing wetlands. As such, there is no net loss of wetland services associated with cooling tower construction in wetlands.

All facilities were screened to identify potential impacts to unique, rare, or threatened habitats associated with retrofitting to closed-cycle cooling. Impacts were determined to be unavoidable at three of the BTPs. These potential impacts include:

- The construction of cooling towers at BTPB would result in the conversion of 21.3 acres of forested dune habitat to an industrial land use;
- The construction of cooling towers at BTCA2 would result in the conversion of 0.17 acres of coastal scrub-shrub to an industrial land use; and
- Abandonment of once-through cooling at BTCA1 would greatly diminish the flushing of water through a nearby 25-acre wetland. This could potentially degrade the wetland indirectly because water quality would deteriorate without this flushing action.

Table 4-3 provides a monetization of potentially adverse impacts to unique, rare, or threatened habitats at the three BTPs based on available WTP estimates. At facilities where no such impacts were anticipated, WTP was reported as zero.

4.2.1.3 Qualitative Assessment of Habitat Loss

As a result of the Beta Test, it was determined that the loss of non-unique/rare habitats could not be monetized and therefore, these impacts were only qualitative assessed for each of the RFs. Unique/rare habitats could be monetized; however, losses of these habitats were avoided if possible, and any unavoidable losses were very site-specific and could not be scaled to other facilities. It was therefore determined that loss of unique habitats would also only be identified for each of the RFs, but not monetized. Table 4-4 is a summary of the qualitative impacts to terrestrial habitats for each RF.

Table 4-3
Annual monetized impacts to BTP critical terrestrial habitats

Facility	Type of Critical Terrestrial Habitat	Acres Impacted	Annual WTP per Acre (2007$)	Annual WTP to Avoid Habitat Degradation (2007$)
BTCA1	Wetland (Off-site)	25	$200[a]	$5,200[b]
BTPB	Forested Dune	21.3	$5,200[c]	$110,800
BTCA2	Rare Coastal Bluff Scrub	0.17	N/A[d]	N/A[d]

[a] Based on Southern California's Wetlands Recovery Project data [26].

[b] This estimate has a high level of uncertainty associated with it since the degree of wetland degradation that may occur is unknown.

[c] Based on Schneider [27]; unknown potential interactions between WTP and surrounding development levels create uncertainty in this estimate.

[d] The WTP to avoid the loss of coastal scrub-shrub habitat at BTCA2 is expected to be positive, however, it could not be quantified due to a lack of information on which to base the WTP estimate.

Note WTP values are rounded to the nearest $100.

4.2.2 Salt and Mineral Drift Effects on Vegetation and Soils

4.2.2.1 Quantification

Salt and mineral drift from mechanical-draft evaporative cooling towers may adversely affect native vegetation, soils, and crops. The Beta Test quantified potential effects on vegetation, soils, and crops using two methodologies (See Appendix B) as described below:

- Method 1 used the model outputs of deposition rates in kilogram per hectare per month (kg/ha/mo) of sodium chloride (NaCl) and other mineral salts to compare with threshold values in the literature indicating when vegetative cover may be damaged by salt deposition; and
- Method 2 quantified the amount of salt that would be deposited on various agricultural soil types and identified expected yield reductions associated with that salt deposition, which were then monetized. Salt or mineral drift from mechanical-draft evaporative cooling towers at each BTP was determined using the methods described in Appendix B. Salt drift deposition were overlain on maps showing specific soil types, crops, and native vegetation derived from Soil Survey Geographic (SSURGO) and National Land Cover Data databases (Appendix C). Potential effects of salt deposition were analyzed separately for arid and non-arid regions. All BTPs are located in non-arid regions, where deposition of salt on plant leaves can reduce agricultural productivity in both the short- and long-term. In arid regions, the primary long-term effect driving productivity reductions is the accumulation of salts in the soil.

Table 4-4
Qualitative impacts to terrestrial habitats for RFs

Facility	Land Disturbed (acres)	Habitat Impacts			Wetlands Impacts[b, c]	Critical Habitat	Footprint Impact Description[d]
		Upland Forest	Upland Herb./Scrub-Shrub	Open Water (Non-wetland)[a]			
RFF	5.85			X	X		Existing developed areas, includes emergent/scrub-shrub wetlands, uplands, and on-site open water.
RFG	5.61		X	X	X		Existing uplands, emergent/scrub-shrub wetlands, and on-site open water.
RFH	12.33	X	X		X	X	Existing developed areas, upland forest habitat, and forest/emergent wetlands. Potential mature longleaf pine habitat for State and Federally–listed Red-cockaded woodpecker.
RFI	3.81		X	X			Existing developed areas and on-site open waters.
RFJ	4.43	X	X		NA		Upland forest and herbaceous scrub-shrub habitat. NWI wetlands mapping was not available.
RFK	2.01	X					Upland forest habitat adjacent to developed areas.
RFL	4.22		X		X		Existing developed areas and emergent/scrub-shrub wetlands.
RFM	3.83		X	X	X		Existing developed areas, on-site open waters, and upland herbaceous/scrub-shrub habitat.
RFN	1.38		X				Upland herbaceous/scrub-shrub habitat.

Table 4-4
Qualitative impacts to terrestrial habitats for RFs (continued)

Facility	Land Disturbed (acres)	Habitat Impacts			Wetlands Impacts[b, c]	Critical Habitat	Footprint Impact Description[d]
		Upland Forest	Upland Herb./Scrub-Shrub	Open Water (Non-wetland)[a]			
RFO	1.80		X				Existing developed areas and herbaceous/scrub-shrub upland habitat.
RFP	3.34		X				Existing maintained and agricultural areas.
RFQ	1.74		X		X		Upland herbaceous/scrub-shrub habitat, on-site open waters and emergent/scrub-shrub wetlands.
RFR	1.23	X	X				Upland herbaceous/scrub-shrub and forest habitat.
RFS	11.44	X	X				Upland herbaceous/scrub-shrub and forest habitat
RFT	7.58		X	X			On-site open waters, existing developed areas and upland herbaceous/scrub-shrub habitat.
RFU	1.01		X				Existing developed areas and small areas of upland herbaceous/scrub-shrub habitat.
RFV	5.62	X	X				Existing developed areas and upland habitats.

[a] Potential open water (non-wetland) impacts are based on NWI mapped excavated ponds and aerial photo interpretation.

[b] Potential wetland impacts are associated with wetlands likely to be regulated only. NWI wetlands that are non-jurisdictional as wetlands, such as artificial pond/lagoons, were not included.

[c] Potential wetland impacts are based on the NWI mapping as well as aerial photo interpretation where necessary.

[d] Does not include any offsite wetland impacts.

The modeled distribution of mineral drift rates at each facility using Method 1 were compared to order-of-magnitude thresholds of impacts derived from the NRC [28]. The ranges used represent no impact, possible visible leaf damage (moderate), and potential damage sufficient to require mitigation actions (high). Table 4-5 shows the acres of vegetation exposed to various ranges of salt drift.

Table 4-5
Potential salt mineral drift impacts to vegetation for BTPs

Facility	Moderate Level (10-100 kg/ha/mo)		High Level (>100 kg/ha/mo)	
	Woody (acres)	Herbaceous/Scrub-Shrub (acres)	Woody (acres)	Herbaceous/Scrub-Shrub (acres)
BTCA1	1.8	13.3	0.0	0.0
BTPA	66.2	67.9	0.0	8.8
BTPB	238.7	0.0	14.5	0.0
BTPC	0.0	14.4	0.0	0.0
BTPD	0.0	0.0	0.0	0.0
BTPE	12.9	0.0	0.0	0.0
BTCA2	0.0	438.0	0.0	26.1

The hectares of crops exposed to various ranges of salt drift using Method 2 are shown in Table 4-6.

4.2.2.2 Monetization

The Beta Test showed that deposition of salt on native vegetation and agricultural lands is an adverse impact associated with the retrofit to closed-cycle cooling. However, potential adverse impacts to native vegetation cannot be monetized due to a lack of economic data on which to base the WTP estimate.

Potential adverse impacts from salt deposited on agricultural soil types, along with the expected yield reductions, were monetized assuming agricultural costs are sunk and non-recoverable over the relevant time horizon. Therefore, the average annual lost revenue is the appropriate measure of annual WTP to avoid productivity reductions (See Appendix B). Average annual lost revenue was estimated by multiplying lost productivity by the area of agricultural land impacted and the average annual rent per hectare of cropland for each respective state [29]. The monetized impact based on the WTP to avoid salt deposition is presented in Table 4-6.

Table 4-6
Average annual monetized impacts to agricultural lands near BTPs

Facility	Hectares of Agricultural Land Impacted	Average Salt Deposition Rate (kg/ha/week)	Average Yield Reduction (%)[b]	Average Annual Rent per Hectare of Cropland (2007$)	Average Annual WTP to Avoid Salt Deposition (2007$)
BTCA1	0			$840	$0
BTPA	0			$100	$0
BTPB	0			$180	$0
BTPC	0			$160	$0
BTPD	0			$130	$0
BTPE	26	1.5[a]	1.84	$120	$80
BTCA2	0			$840	$0

[a] Weekly salt deposition ranged from 0.5 to 2.5 kg/ha.
[b] Assumes a crop rotation of corn and soybeans.
Note monetary values are rounded to the nearest $10.

4.2.2.3 Qualitative Assessment of Salt Drift

Salt drift impacts from mechanical-draft evaporative cooling towers to native vegetation are difficult to quantify and the impacts cannot be monetized due to a lack of suitable economic data. Impacts of salt deposition to agricultural lands can be quantified and monetized. However, since there was a WTP to avoid salt and mineral drift effects on agricultural lands at only one of the seven Beta Test sites, and the amount was so low, salt drift impacts were qualitatively discussed for RFs that would use high TDS makeup water in Table 4-7.

Table 4-7
Salt drift impacts at RFs using high TDS makeup water

Facility Using High TDS Makeup Water	Potential Impacts to Agricultural Lands	Potential Impacts to Woody Vegetation	Potential Impacts to Herbaceous/Scrub-Shrub Vegetation
RFH		X	X
RFI			X
RFJ		X	X
RFK		X	X

As indicated in Table 4-7, salt drift impacts from RFs using high TDS makeup water may potentially impact woody or herbaceous/scrub-shrub vegetation surrounding the facilities. No agricultural lands were identified within or adjacent to the RF facility properties.

4.2.3 Noise Impacts on Terrestrial Wildlife

4.2.3.1 Quantification

The noise impact threshold of >60 dBA is used by the U.S. Fish & Wildlife Service (USFWS) in California for the Least Bell's vireo, California gnatcatcher, and light-footed clapper rail [30]. Therefore, this threshold was used to represent the noise level where wildlife may be adversely impacted in this study. The acres of habitat modeled to receive greater than 60 dBA from the cooling towers at the BTPs are provided in Table 4-8, below. Some of these habitats may contain threatened and endangered species. For example, the coastal California gnatcatcher may likely inhabit some of the 207 acres impacted by noise surrounding BTCA2. However, without specific census data, it was not possible to quantify how much, and to what degree, the population may be impacted.

Table 4-8
Potential noise impacts to terrestrial wildlife for BTPs

Facility	Area with >60 dBA Potential Terrestrial Wildlife Noise Impacts (acres)	Description of Habitat for >60 dBA Potential Terrestrial Wildlife Noise Impact Areas
BTCA1	208	Herbaceous/Scrub-Shrub, Landscape Tree Areas, Open Water, and Developed Area
BTPA	186	Forested Wetlands, Emergent Wetlands, Upland Forested, Herbaceous/Scrub-Shrub, Open Water, and Developed Areas
BTPB	111	Forested Dune (Protected Critical Dune Area), Open Water, and Developed Areas
BTPC	154	Estuarine Wetlands, Herbaceous/Scrub-Shrub, Upland Forested, Maintained Grass, Open Water, and Developed Areas
BTPD	188	Upland Forested, Herbaceous /Scrub-Shrub, Maintained Grass/ROW, and Developed Areas
BTPE	171	Upland Forested, Herbaceous/Scrub-Shrub, Maintained Grass/ROW, Open Water, and Developed Area
BTCA2	207	Herbaceous/Scrub-Shrub, Southern Coastal Bluff Scrub Community, Beach/Dune, and Developed Areas

4.2.3.2 Monetization

Retrofitting to closed-cycle cooling may result in potential noise impacts to wildlife, including threatened and endangered species. However, this impact cannot be monetized due to a lack of economic data on which to base the WTP estimate.

The results of the Beta Test suggested that closed-cycle cooling noise might impact wildlife, including threatened and endangered species. However, this impact is difficult to quantify and available economic data do not support a WTP estimate. Therefore, noise impacts were addressed qualitatively as they relate to permitting for the 17 other RFs (Section 4.6.3).

4.2.4 Impacts of Fogging and Icing on Terrestrial Vegetation

The NRC has identified possible detrimental effects associated with increased fogging and icing on local vegetation from humidity-induced increases in fungal or other phytopathological infections or ice damage as a potential impact to the terrestrial environment from cooling towers [28]. The NRC suggests an order of magnitude approach to analyze operational impacts from fog or ice:

- Fogging or icing of vegetation on the order of a few hours per year is generally not severe;
- Fogging or icing on the order of tens of hours per year may cause detectable damage to vegetation; and
- Fogging or icing occurring for hundreds of hours per year could be severe enough to suggest the need for design changes, depending on the amount of land impacted and the uniqueness of the terrestrial ecosystems expected to be exposed.

The potential rates of fogging and icing were calculated using SACTI modeling (see Section 4.4). Using the results in Table 4-15 and converting to a rate of hours/year from days/year, fogging at the rate of tens of hours/year is predicted to occur at eight of the 18 evaluated facilities (44.4 percent): RFF, RFG, RFI, RFL, RFN, RFO, RFQ, and RFS. Additionally, icing of this degree was predicted to occur at RFF and RFI.

Using the NRC [28] guidelines, fogging and icing associated with cooling towers may cause detectable damage to vegetation, if present, near these RFs. However, a WTP to avoid this damage was not estimated due to the site-specific variability in vegetation type (e.g., crops, critical habitat, and non-rare types) and lack of economic data to base the WTP estimate.

4.2.5 Other Terrestrial (Social) Impacts

Other adverse effects of salt deposition from mechanical-draft evaporative cooling towers include damage to automobiles and other metal surfaces, corrosion and shorting of electrical equipment, and spotting of windows and other surfaces. These potential impacts may be most severe within the property boundary because of the rapid deposition of salt drift. However, for facilities where the towers are located near the property boundary, and those facilities using high TDS makeup water and/or are located in urban areas (e.g., BTCA1), this may be a significant offsite issue.

There is no consensus on the level of salt deposition rate that is detrimental to manmade surfaces. However, it has been recommended that electric power supply insulators be cleaned when a level of 0.03 mg/cm^2 of mineral deposition is reached in order to prevent flashover events [31]. Mineral accumulation will occur if surfaces are not manually washed or rinsed by precipitation. Assuming one week is a reasonable period of time for most areas of the continental

United States to have no significant precipitation, the critical rate of mineral deposition is 0.03 mg/cm^2/week. This critical rate of mineral deposition may occur at a distance up to 760 meters away from cooling towers for freshwater plants and from 300 meters to more than 1,100 meters at facilities using saline or brackish water (based on salt deposition modeling at BTPs; Table 4-9). Thus mineral deposition impacts to electrical equipment have the potential to occur outside of the property boundary.

These potential impacts were not monetized due to a lack of economic data on which to base the WTP estimate and the lack of threshold effects data.

Table 4-9
Maximum modeled distance from cooling towers with salt deposition rates greater than 0.03 mg/cm^2/week for BTPs

Facility	Waterbody Type	MW	Flow (MGD)	Distance from Cooling Tower to Deposition Threshold (meters)[a]
Freshwater				
BTPD	Lake	2,110	1,463	0[b]
BTPE	Reservoir	2,186	2,160	100
BTPB	Great Lakes	2,161	2,369	760
Saline and Brackish Water				
BTPA	Tidal River	1,837	1,119	300
BTPC	Estuary	705	837	700
BTCA1	Estuary	1,950	1,181	800
BTCA2	Ocean	2,150	2,335	1,100

[a] Threshold = 0.03 mg/cm^2/week of salt deposition.
[b] No modeled distance exceeded 0.03 mg/cm^2/week of salt deposition.

4.2.6 Uncertainty

4.2.6.1 Quantification

When developing methodologies for quantifying the impacts, a key criterion was to use readily available data that were consistent and comparable for each facility. The sources of uncertainty associated with the quantification of terrestrial resources are described below.

- Wetland habitats identified at the facilities were initially identified from NWI maps. Since these maps were prepared from the interpretation of dated aerial photography (primarily from the 1980s) with little ground-verification, they do not necessarily reflect current site conditions. The NWI information was supplemented with information visible on the most recent aerial photos readily available for each facility. Field delineations of jurisdictional wetlands were not used to produce a more accurate quantification of potential impacts;
- The quantification of long-term losses of terrestrial habitats was based on conceptual cooling tower footprints and an assumed perimeter buffer;
- Information regarding rare, threatened, and endangered species habitats was identified using existing facility reports (e.g., permit application reviews, environmental impact reports) and reports on known nearby critical habitats. No current habitat surveys or species inventories were performed specifically for this study;
- Vegetation and crop cover types impacted by drift deposition could not be identified by species or crop type using existing information. For cropland impacts, predicted salt deposition rates (kilogram per hectare per year [kg/ha/yr]) were coupled with an experimentally derived relationship between crop yield and salt deposition to estimate productivity losses [28]. These were values assuming a soybean and corn crop rotation. The guideline values are based on an extensive literature, but are generalized. The actual extent of damage to vegetated cover types near the cooling towers may be different. Additionally, the SACTI model used to predict cooling tower drift provides output as NaCl and other mineral salts. The NRC threshold values are for NaCl only; and
- Potential noise impacts to wildlife were based on a threshold of 60 dBA which is used by the USFWS in California for the Least Bell's vireo, coastal California gnatcatcher, and light-footed clapper rail [30]. However, it is uncertain which wildlife species present within the 60 dBA or higher noise impact area would also be sensitive to levels <60 dBA or what species are more resilient to noise changes and may tolerate levels at or >60 dBA. Detailed noise analyses specific to the wildlife utilizing the facility properties and the adjacent areas were limited to literature review rather than field studies.

4.2.6.2 Monetization

The $5,200 per acre annual WTP estimate for coastal dune preservation used for assessing possible impacts identified at BTPB may overstate actual WTP. The transaction upon which the assessment was based related to a large, undeveloped shoreline parcel. WTP to preserve the same habitat in the vicinity of industrial or commercial/residential areas may be less than $5,200 per acre.

Potential WTP to avoid potential impacts to 0.17 acres of coastal bluff scrub habitat at BTCA2 and longleaf pine habitat for State and Federally–listed red-cockaded woodpecker at RFH were not estimated. Estimates of WTP to avoid potential terrestrial impacts to preserve non-unique habitats were not generated. These omissions would bias estimates of closed-cycle cooling impacts in a downward direction.

The primary uncertainty associated with WTP estimates associated with salt deposition is the ability of farmers to mitigate potential impacts by altering production processes and/or switching to more salt tolerant crops. The assessment of WTP associated with impacts to non-arid regions assumed that the potential impacts to any one operation are of a magnitude such that losses are less than the cost associated with mitigating behavior. To the extent that farmers can mitigate potential impacts, average annual WTP has been overestimated.

The potential agricultural impacts associated with salt deposition at rates below 0.5 kg per hectare per week were omitted, thereby underestimating WTP.

4.2.6.3 Qualitative Assessment

As a result of the Beta Test, it was determined that the loss of non-unique habitats could not be monetized. While loss of rare habitats could be monetized when suitable transactions data exists, those estimates are very site-specific and cannot be scaled to other facilities. It was therefore determined that unique and non-unique habitat loss would be qualitatively discussed for each of the RFs. With a qualitative approach, a greater level of uncertainty existed during the assessment, including.

- Wetland habitats identified at the facilities were initially identified from NWI maps, which as described previously, do not necessarily reflect current sites conditions. The NWI information was supplemented with information visible on the most recent aerial photos readily available for each facility. Wetlands were identified on-site and within the proposed cooling tower footprint. Field delineations of jurisdictional wetlands were not used to produce a more accurate quantification of potential impacts;
- The long-term losses of terrestrial habitats were identified and qualitatively discussed for conceptual cooling tower footprints and an assumed perimeter buffer, by utilizing recent aerial photos the RFs;
- Information regarding rare, threatened, and endangered species habitats was obtained utilizing the facility questionnaires and existing facility reports, if available (e.g., Proposal for Information Collection, generic environmental impact statement, and environmental impact reports). No current habitat surveys or species inventories were performed specifically for this study;
- Vegetation and crop cover types impacted by drift deposition could not be identified by species or crop type using existing information. Only the facilities with high TDS were considered for the qualitative assessment; and
- Potential noise impacts to wildlife were not evaluated for the RF qualitative assessment. The data needed for detailed noise analyses specific to the wildlife utilizing the facility properties and the adjacent areas (e.g., species, potential numbers of receptors, and threshold of effects) were not available for this study.

These assumptions and omissions would bias estimates of closed-cycle cooling impacts in a downward direction.

4.3 Water Resource Quantity and Quality

Retrofitting the currently operating once-through cooled Phase II facilities with closed-cycle cooling may result in two adverse impacts on water resources that were evaluated in this study:

1. The net increase in evaporation of water resulting in a decrease in the availability of water in the Waters of the United States. In turn, this could potentially lower water surface elevations in the waterbodies, decrease the availability of potable water, littoral habitats and, in tidal river and estuaries, increase salt wedge intrusion; and
2. A net decrease in the removal of trash such as plastics, cans, and other flotsam that is collected and disposed of as part of cooling water intake structure maintenance.

These two impacts are discussed further in the sections below. However, not all possible adverse impacts associated with water quality were investigated in detail for this report. These potential water quality impacts include:

- The conversion to closed-cycle cooling will require the use of biocides such as chlorine. Although once-through cooling may also require biocides, a study in the Netherlands found the consumption of active chlorine in wet cooling towers with fresh water makeup averages 200 kg/MW/yr compared to 85 kg/MW/yr for once-through cooling systems [32]. Thus, conversion to closed-cycle cooling has the potential to more than double chlorine use;
- A wide range of other hazardous substances including corrosion and scaling inhibitors will be added to cooling towers with some residual discharged with the blowdown. These commonly include sulfuric acid, sodium bisulfite, and dispersants containing phosphonic acid and potassium hydroxide; and
- Closed-cycle cooling also results in the concentration of contaminants that may be present in the source waterbody. Evaporation of water in closed-cycle cooling systems commonly results in concentration factors two to 10 times ambient levels, with the result that many constituents in the discharge water may approach or exceed water quality standards. This is of particular concern on impaired waterbodies. There has been an increased concern with TDS in fresh water systems. For example, the Pennsylvania Water Quality Board has proposal to amend 25 Pa. Code Chapter 95 to establish new effluent standards for new sources of wastewaters containing high TDS. The proposed regulation would set monthly average limits of 500 mg/L TDS, 250 mg/L total chlorides, and 250 mg/L total sulfates. Cooling tower blowdown would likely exceed these limits on some impacted rivers. The available technologies for treating TDS at high concentrations include reverse osmosis and evaporation (with or without crystallization). These systems are costly, energy intensive, and generate large quantities of residual solid waste for disposal.

It is assumed that any future cooling tower blowdown must meet water quality standards established for receiving waterbodies either at the end of pipe, after mixing or at the edge of a mixing zone. Thus, these water quality impact issues associated with cooling tower blowdown were not quantified or monetized in this report, which would bias the estimates of closed-cycle cooling impacts in a downward direction. However, the NPDES process may effect cooling tower feasibility at some locations and add to the overall cost of closed-cycle cooling retrofits. Finally, additional regulated and non-regulated chemicals are likely to be discharged to waters of the United States as a result of closed-cycle cooling retrofits.

4.3.1 Evaporative Water Loss

The installation of mechanical-draft evaporative cooling towers in a closed-cycle cooling system will increase the evaporation rate compared to once-through cooling water discharges. The evaporation rate due to proposed mechanical-draft evaporative cooling towers *in excess* of the current once-through evaporation rates were estimated for BTPs, except at those facilities that utilize high salinity water sources for condenser cooling water. The evaporation rate due to proposed mechanical-draft evaporative cooling towers in excess of the current once-through evaporation rates were estimated for four additional RFs located on small rivers, a lake, and on a large river in a low wet bulb region as discussed below. Details on methods are provided in Appendix B.

4.3.1.1 Quantification

The in-stream evaporative water loss estimates for five BTPs and four RFs are given in Table 4-10. Calculated in-stream evaporative water losses at these facilities compare well with typical water consumption estimates [33, 34, 35]. Average in-stream evaporative loss ranges from approximately 300 to 13,100 gpm.

Table 4-10
Estimated average in-stream evaporation due to thermal discharge from once-through cooling for BTPs and four RFs

Facility[a]	Source Waterbody	Estimated Annual Average In-stream Evaporation Rate (gpm)[b]	Estimated Evaporation Rate Converted to Different Metrics		
			gal/MW-hr[c]	Evaporative Loss as Percent of Circulating Water Used[d]	Percent of Induced Temperature Rise Dissipated by Evaporation[e]
BTPA	Tidal River (O/E/TR)	8,500	309	1.01%	60%
BTPB	Great Lakes (SR/GL)	9,600	352	0.84%	66%
BTPC	Estuary (O/E/TR)	800	233	0.48%	61%
BTPD	Lake (LR/RL)	6,700	238	0.82%	55%
BTPE	Reservoir (LR/RL)	13,100	369	0.9%	67%
RFI	Small River (SR/GL)	1,900	335	0.79%	61%

Table 4-10
Estimated average in-stream evaporation due to thermal discharge from once-through cooling for BTPs and four RFs (continued)

Facility[a]	Source Waterbody	Estimated Annual Average In-stream Evaporation Rate (gpm)[b]	Estimated Evaporation Rate Converted to Different Metrics		
			gal/MW-hr[c]	Evaporative Loss as Percent of Circulating Water Used[d]	Percent of Induced Temperature Rise Dissipated by Evaporation[e]
RFJ	Lake (LR/RL)	400	350	0.68%	62%
RFR	Small River (SR/GL)	300	312	0.89%	60%
RFU	River (LR/RL)	600	224	0.70%	58%

[a] In-stream evaporative loss calculations were not performed for facilities that use Ocean water (BTCA2 and BTCA1).

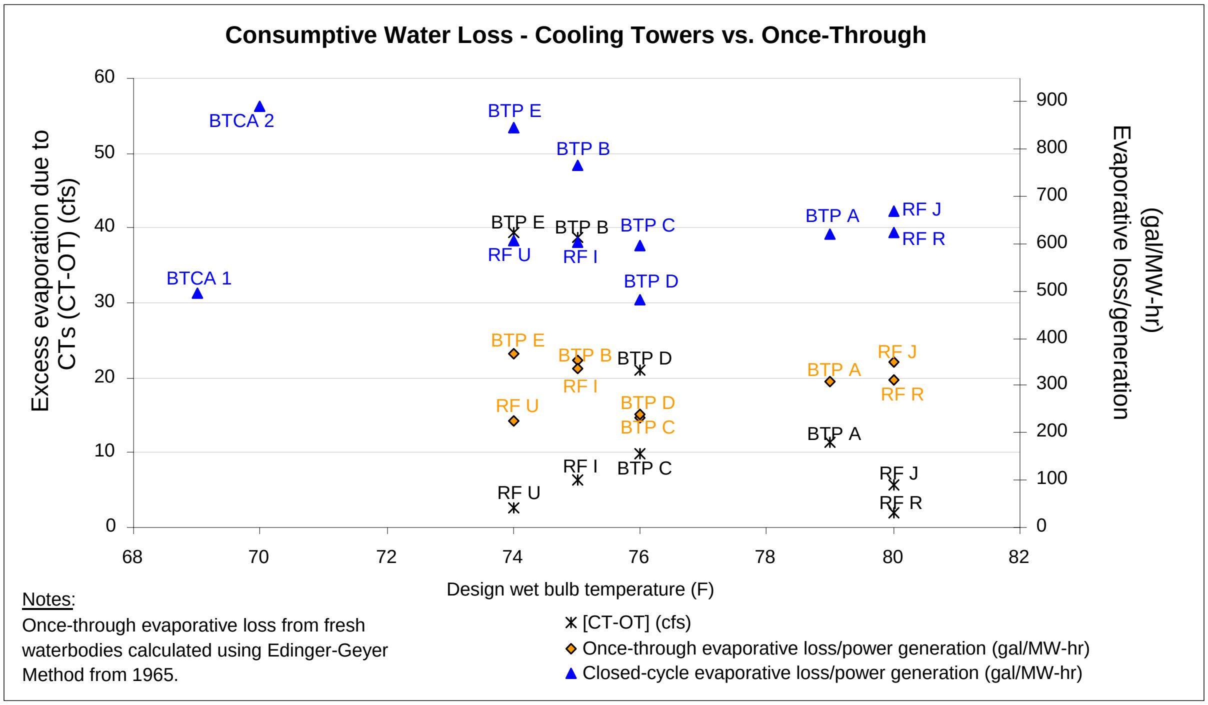
[b] Uses average capacity utilization rate for period 2002-2006.

[c] 300 gal/MWh estimated for fossil plants and 400 gal/MWh estimated for nuclear plants [33].

[d] One percent estimated nationwide [33].

[e] 60-64 percent estimated for the Chesapeake Bay [34]; 63 percent estimated for oceans [35].

Figure 4-1 compares evaporative water loss due to once-through and closed-cycle systems for the five BTPs and four RFs.



Notes:
Once-through evaporative loss from fresh waterbodies calculated using Edinger-Geyer Method from 1965.

Figure 4-1
Consumptive water loss-cooling towers vs. once-through

In general, the difference in evaporation between once-through cooling and closed-cycle cooling is greater in lower wet-bulb locations. Therefore, retrofitting once-through facilities with cooling towers could increase consumptive loss of water in already drier locations.

The evaporative loss due to the installation of mechanical-draft evaporative cooling towers may result in reductions in the availability of potable water, a decrease in water surface elevation on rivers and lakes and corresponding loss of aquatic and riparian habitats and recreational uses, and a decrease in the assimilative capacity of the river. On small tidal rivers and estuaries, excess evaporative loss may result in the upstream movement of the salt-wedge. The magnitude of these possible impacts would correspond to the percent of the water loss relative to the in-flow. Table 4-11 shows the excess evaporative loss due to the installation of mechanical-draft evaporative cooling towers expressed as equivalent daily water use (number of people) and percent of typical low surface water flow at each site. Note that all of the BTPs are located on large waterbodies and rivers where evaporative loss is less likely to be a significant issue.

Table 4-11
Additional consumptive water due to closed-cycle cooling retrofit at BTPs

Facility[a]	Excess Water Consumption Due to Closed-cycle Cooling Retrofit (gal/day and cfs)	Equivalent Daily Water Use (No. of people)[b]	Source Waterbody Low Flow (cfs)	Low Flow Reference	Excess Water Consumption as Percent of Low Flow (%)
BTPA	7,344,000 (11.4 cfs)	56,600 – 98,000	4,767	Minimum monthly mean river flow	0.24
BTPB	25,066,600 (38.8 cfs)	193,000 – 334,000	5,690	Estimated surface water flow into lake	0.68
BTPC	6,355,600 (9.8 cfs)	NA [c]	1,810	7Q10 for the river	0.54
BTPD	14,870,900 (23 cfs)	114, 500 – 198,500	311	Current license for the facility; Minimum average daily flow releases from lake.	7.4
BTPE	25,518,200 (39.5 cfs)	196,500 – 340,000	1,500	Minimum monthly average flows from upstream reservoir	2.63

[a] Consumptive water use due to once-through systems from facilities using marine water was not evaluated.
[b] Residential water use is 75 to 130 gallons per capita day (gpcd) [10].
[c] Non-potable water consumed.
7Q10 is the 7-day average low flow that has a recurrence interval of once in ten years.
Note calculated values are rounded.

Additional evaporative loss from mechanical-draft evaporative cooling towers may be exacerbated during drought conditions. The declaration of drought conditions by a state or regional water resources authority is driven by regional or local stream flows or water surface elevations. The increase in consumptive water use resulting from cooling towers may increase the frequency of drought declarations in the watersheds of the source waterbodies. This change in frequencies was quantified for the two BTPs withdrawing water from impounded rivers (BTPD and BTPE), which serve as public water supply reservoirs. Users of these reservoirs are impacted by water use restrictions during droughts. The method used to quantify potential impacts to drought declarations is provided in Appendix B. The results are presented in Table 4-12 below.

Table 4-12
Percent increase in drought frequency due to BTP consumptive water use[a]

Facility	Impoundment/ River	Drought Watch[b]	Drought Warning[c]	Drought Emergency[d]
BTPD	Lake/River	1.3%	1.0%	1.0%
BTPE	Reservoir/River	0.2%	0.2%	0.4%

[a] Drought declarations (watch, warning, emergency) [36].
[b] Declared when stream flow is at a 75 percent or greater historic exceedance probability.
[c] Declared when stream flow is at a 90 percent or greater historic exceedance probability.
[d] Declared when stream flow is at a 95 percent or greater historic exceedance probability.

Potential impacts of net evaporative loss for BTPs are summarized below:

- BTPA draws water from the tidal portion of a river and the net evaporative loss is minimal compared to minimum monthly mean flows. No measurable impacts are expected;
- BTPB draws water from one of the Great Lakes, and the net evaporative loss is minimal compared to surface flow into the Lake. No measurable impacts are expected;
- BTPC is located on the upper estuary and the net evaporative loss is minimal compared to minimum monthly mean flows. No measurable impacts are expected;
- BTPD consumptive water use is 7.4 percent of minimum average flow releases from a large man-made lake. Institutional mechanisms in place to regulate lake water elevation mitigate any change in pool elevation. However, water consumption will increase the frequency of drought restrictions; and
- BTPE draws water from a large impounded river reservoir and the net evaporative loss is 2.6 percent of minimum monthly average flows. Flow in the Reservoir is also controlled by hydroelectric power releases (inflow to reservoir from the upstream dam and regulated minimum outflow from reservoir at the downstream dam), a pumped storage facility operation, and the consumptive water use of public water suppliers. These controlled inflows and outflows, and consumptive water uses of others, could influence the impact of consumptive water loss associated with cooling tower operation.

The Beta Test concluded that the in-stream adverse impacts were not significant at the BTPs; however lakes and small rivers were not represented in the Beta Test. Therefore, one lake facility (RFJ) in Texas, two facilities on small rivers (RFI and RFR), and one additional large river facility in a low wet bulb region (RFU) were investigated to calculate the additional consumptive water due to closed-cycle cooling retrofit. The results, presented in Table 4-13, show potential water consumption due to closed-cycle cooling retrofit to be minimal relative to the water flow. No flow data were found for RFJ, a lake-reservoir site in Texas. Facilities in Texas and Oklahoma need to add makeup water during high winter-spring flows to replenish the cooling lakes and reservoirs in these drier parts of the United States. The additional consumptive water loss at RFJ of 1.1 million gallons per day may make the retrofit to closed-cycle cooling problematic on this waterbody.

Table 4-13
Additional consumptive water due to closed-cycle cooling retrofit at four RFs

Facility	Excess Water Consumption Due to Closed-cycle Cooling Retrofit (gal/day and cfs)	Equivalent Daily Water Use (No. of people)[b]	Source Waterbody Low Flow (cfs)	Low Flow Reference	Excess Water Consumption as Percent of Low Flow (%)
RFI	2,643,800 (4.1 cfs)	NA[a]	1,755	7Q10 at Lockport	0.23
RFJ	1,120,300 (1.7 cfs)	8,600-14,900	N/A		Unknown
RFR	498,200 (0.8 cfs)	9,800 – 17,000	1,310	Minimum flow at Albany, GA	0.06
RFU	1,725,100 (2.4 cfs)	13,300-23,000	5,860	Lowest daily flow recorded Missouri River below Garrison Dam	0.04

[a] Non-potable water consumed
[b] Residential water use is 75 to 130 gpcd [10].
7Q10 is the 7-day average low flow that has a recurrence interval of once in ten years.
Note calculated values are rounded.

4.3.1.2 Monetization

The consumptive water losses associated with converting once-through cooling systems to closed-cycle cooling represent a potential adverse impact. This monetization analysis was limited to estimating the WTP to avoid changes that could affect society's enjoyment of recreational activities such as boating, rafting, fishing, and general water based recreation (See Appendix B for further explanation). If water consumption is great enough to change water levels in a waterbody, these recreational activities could be affected; it is assumed if water consumption is not great enough to change water levels, then WTP to avoid water consumption is zero. Because measurable water level changes would not be expected on large waterbodies (oceans, estuaries, large rivers, or the Great Lakes), this analysis, particularly for the RFs, focused on small rivers and reservoirs.

Based on the site conditions (water management controls) and estimated excess water consumption expressed as a percent of low flow at the five BTPs and four RFs evaluated, it was determined that no measurable change in water levels would be associated with the conversion from once-through cooling systems to closed-cycle cooling. Therefore, the WTP to avoid consumptive water loss at all the evaluated BTPs and RFs is zero.

4.3.1.3 Uncertainty

Water consumption calculations resulted in the findings that closed-cycle cooling has approximately double the evaporative loss of once-through cooling. The main assumptions associated with the calculations that translate into uncertainty in this result include:

- Edinger-Geyer method may not be valid for all regions;
- Calculations were performed at average monthly and annual scales. The daily and hourly fluctuations in atmospheric conditions (wind speed, intake water temperature, and dew point temperature) within the monthly cycle may be as small at 10 percent or as large as 200 percent depending on the variable and location;
- Evaporation rate from cooling towers (i.e., the product of 0.1 percent times the degree range times the water flow rate) was assumed to be equivalent at all towers and locations;
- It was assumed that the heat load on condensers and circulating water flow rate would remain the same after the retrofit;
- It was assumed that the limited period used for calculation is representative;
- The approach temperature for all towers was assumed to be 10°F; and
- All towers are assumed to be mechanical-draft evaporative cooling towers. Evaporative losses would be different for other types of towers.

The primary uncertainty associated with the monetization is that this WTP is based upon potential changes in stream flows or water levels. WTP to avoid consumptive water loss was estimated to be zero because situations where *in-situ* water levels are likely to change in a meaningful manner were not identified. If, in times of low supply, increased consumptive water use reduces the availability of water for other uses such as drinking water or irrigation, WTP is underestimated.

In the driest regions of the country, existing water allocation agreements and regulations would require any additional water withdrawals for cooling towers to be offset. These regulatory constraints would mitigate or eliminate many of the potential ecological changes and so WTP would remain near zero because there would be minimal environmental change. However, the acquisition of water rights by the cooling tower operator would represent potentially large component of the cost associated with constructing and operating a cooling tower. These costs, which can range up to $7,500 per acre-foot, would need to be accounted for in a cost-benefit analysis.

4.3.2 Source Waterbody Debris Removal

Many Phase II facilities retain and dispose of material collected on their intake structure traveling screens. This includes natural material (e.g., leaves, sea weed, etc.) as well as man-made debris such as plastics, cans, paper, plastic can holders, and other trash including the contribution of Combined Sewer Overflow wastes, especially in large urban areas. National Oceanic and Atmospheric Administration (NOAA) considers this marine debris as one of the most widespread pollution problems in the world's oceans, lakes, and waterways [37]. The reduction in the water volume withdrawn associated with closed-cycle cooling retrofit reduces not only the amount of fish removed, but also the amount of man-made debris (trash) currently removed from the waterbody, thereby potentially increasing the overall waste load transported past the facility, eventually littering the shoreline. Other trash commonly found in waterways (e.g., plastic bags and six-pack can holders) has been implicated in choking sea turtles, waterfowl, and other wildlife.

4.3.2.1 Quantification

The estimated amounts of trash removed by the existing cooling water intake structures, converted to a common unit of tons per year (tpy), are reported in Table 4-14. This information was collected from the EPRI Questionnaire and represents a best estimate by the reporting facilities [38].

4.3.2.2 Monetization

A decrease in the amount of trash removed from waterways represents an adverse impact associated with the retrofit to closed-cycle cooling. A lower-bound monetization of society's WTP to avoid a reduction in the removal of trash is presented in Table 4-14. Detailed methods are provided in Appendix B.

In creating and implementing multiple volunteer programs designed to remove trash from waterbodies, society has revealed a WTP to remove trash from waterbodies and place that trash into the proper trash stream. The existence of government-sponsored programs designed to achieve the same goal, coupled with the assumption that governments are an agent acting on behalf of society, is consistent with this revealed WTP. The per-unit WTP for trash removal was based on an average of four volunteer and government programs across the country.

The annual WTP to avoid reductions in trash removal was estimated as the product of the tons of trash that would no longer be removed from waterbodies and placed into the proper waste stream, the percent reduction in trash removal, and the average revealed WTP to remove a ton of trash from waterbodies and shorelines. It was assumed that the reduction in the amount of trash removed by the intake screens is directly proportional to the estimated flow reduction with closed-cycle cooling.

The results of the analysis are provided Table 4-14.

Table 4-14
Average annual impacts and WTP to avoid impacts associated with trash removal for BTPs and RFs

Facility	Tons of Trash Removed Annually	Percent Reduction Associated with Closed-cycle Cooling[a]	Annual WTP to Avoid Reduction in Trash Removal (2007$)
BTCA1	17.5	94	$18,600
BTPA	Not Available	96	N/A
BTPB	10	98	$11,100
BTPC	2	99	$2,200
BTPD	Minimal	98	$0
BTPE	Not Available	98	N/A
BTCA2	Minimal	94	$0
RFF	0.15	99	$200
RFG	Not Available	97	N/A
RFH	Minimal	93	$0
RFI	42	98	$46,600
RFJ	0.04	98	<$50
RFK	0	95	$0
RFL	Not Available	98	N/A
RFM	2.75	98	$3,000
RFN	Not Available	98	N/A
RFO	0	97	$0
RFP	Not Available	97	N/A
RFQ	41.25	98	$45,600
RFR	0	98	$0
RFS	1.375	97	$1,500
RFT	0.25	98	$300
RFU	0.15	98	$200
RFV	0.36	97	$400

Note WTP values are rounded to the nearest $100.
[a] Does not include service water; therefore the percent reduction is overestimated.

4.3.2.3 Uncertainty

4.3.2.3.1 Quantification

The sources of uncertainty associated with the quantification of changes in trash removal include:

- Information on the quantity of trash at several facilities was lacking. This biases quantification estimates in a downward direction;
- The percentage of trash was an estimate and not specifically measured. The estimate assumed that the reduction in trash is directly proportional to reduction in circulating water flow; and
- A best professional judgment conversion of 275 pounds per cubic yard of trash was used. This may vary based on the composition of the trash.

4.3.2.3.2 Monetization

The per-unit WTP for trash removal was based on an average of four volunteer and government programs across the country. There are two elements to estimating the costs of those programs: (1) the actual expenditure of administering the program and (2) the value of the volunteer's time. Administration costs for two of the volunteer programs were not available and economists have not reached a consensus as to the appropriate estimates of the value of time for activities such as volunteering to pick up trash. The value of travel time was used as a proxy, but this value is likely low for theoretical reasons. For these two reasons, the WTP for trash removal is likely underestimated.

4.3.3 Solid Waste

4.3.3.1 Questionnaire Responses

The installation of cooling towers will also generate additional solid waste in the form of cooling tower sediment. Estimates of the amount of sediments potentially generated and other relevant information (e.g., potential toxicity) was investigated using a specific solid waste EPRI questionnaire submitted to the industry. This questionnaire was independent of the questionnaire submitted to Phase II facilities. A total of 47 facilities with operating cooling towers responded to this solid waste questionnaire. A synopsis of the responses to the survey regarding cooling tower sediment is provided below:

Frequency of inspections and sediment removal

Most facilities perform regular inspections of the cooling tower basins, typically during planned outages that allow dewatering of the basins. On average, facilities remove sediment on a once per three-year-period; the range of cleaning frequencies spans from once per month to once per 10 years.

Quantity of sediment generated/removed

The average amount of sediment generated/removed by responders to the questionnaire is approximately 200 cubic yards (CY) (between approximately 170 and 200 tons, depending on solids content) per year per cooling tower basin for mechanical-draft evaporative cooling towers[2]. Of the information received on 47 facilities, 11 utilize mechanical-draft evaporative cooling towers and 19 utilize natural-draft evaporative cooling towers. Seventeen facilities did not indicate the type of cooling tower. The quantity of sediment generated did not appear to be driven by the type of tower. Eight of the responding facilities are nuclear facilities; 22 are fossil facilities; the others did not indicate the type of primary fuel. Disregarding all other influencing factors, sediment generation at nuclear facilities is approximately 150 CY/basin/year (between approximately 130 and 150 tons/basin/year), and approximately 500 CY/basin/year (between approximately 425 and 500 tons/basin/year) at fossil facilities[3]. Anecdotal evidence suggests that this higher sediment generation may be related to higher levels of air borne PM at fossil plants.

Hazardous/non-hazardous sediment

Approximately one-half of the facilities analyze cooling tower sediment using the Toxic Characteristics Leaching Procedure; others do not perform routine analyses. Of those facilities that analyze cooling tower basin sediment, all but one facility stated that the cooling tower sediment is non-hazardous.

Sediment disposal methods and permitting

Most facilities disposed of the cooling tower sediment on-site, typically in the coal combustion by-products area (e.g., in ash ponds). Other facilities disposed of the sediment at a public landfill. No additional permitting is required of most facilities; for other facilities, cooling tower sediment disposal is approved under the coal combustion by-products site-operating permit or landfill permit.

A conversion to closed-cycle cooling will result in the generation of additional solid waste on the order of 150 CY/basin/year at nuclear facilities, and 500 CY/basin/year at fossil facilities. This sediment will require transport and disposal. The sediment generated by a small number of these facilities may be hazardous.

4.3.3.2 Uncertainty

Facilities responding to the survey were not retrofits but facilities with operating cooling towers. It is not clear how representative in terms of waterbody type and other factors these facilities are

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[2] The questionnaire did not differentiate the basis for sediment removal quantities—whether for each cooling tower basin or for the entire facility. Therefore, it was conservatively assumed that the sediment quantity provided is for a single basin for the cleaning cycle. If the sediment volumes reported are totals for all cooling tower basins, the quantities from most facilities would reduce to one-half or to one-third per single basin per cleaning cycle. In this case, the sediment-related additional effort would be even less significant.

[3] Includes all cooling tower types.

relative to Phase II facilities. Also, 19 of the facilities had natural draft towers, rather than mechanical-draft evaporative cooling towers, and other facilities did not specify which type. There is uncertainty regarding the sediment accumulation differences between the two tower types. The direction of the potential bias is not known.

4.4 Public Safety and Security

Water vapor emitted from mechanical-draft evaporative cooling towers may produce adverse environmental impacts in surrounding areas as a result of fogging from visible plumes or icing from plume condensation. This section addresses safety concerns and security issues resulting from:

- Fogging and icing of roadways;
- Visible plume interference with air traffic at nearby airports; and
- Fogging interference with nuclear facility security systems.

Other possible issues related to visible plumes from cooling towers, such as shadowing and viewshed impacts, are addressed in Section 4.5.

The facilities included in this study were evaluated for potential fogging, icing, and visible plume impacts using the Seasonal Annual Cooling Tower Impact (SACTI) model, Version 11-01-90. SACTI is a validated and recognized cooling tower plume model that has been applied in numerous studies across the United States. The model was developed by Argonne National Laboratory at the request of EPRI to address potential impacts from cooling towers such as plume visibility, ground level fogging, ground level icing, and plume shadowing. It is based on studies conducted by Argonne National Laboratory to evaluate the performance of numerous cooling tower plumes and drift models. SACTI model outputs are shown in Appendix C.

4.4.1 Public Safety on Roadways and at Airports

4.4.1.1 Quantification

For each facility modeled, SACTI was used to calculate the probable frequency of ground level plume fogging and icing for each cooling tower design and location. The annual results based on one year of metrological data are presented in Appendix C.

Fogging was predicted to occur at 13 of the 14 facilities modeled and icing was predicted at six facilities. The amount and likelihood of fogging impacts to roadways at each facility was calculated as the product of the number of hours of fog on the roadways and the number of commutes per day on those roads. The number of fog events and their duration was estimated using methods described in Appendix B. The width of the plume was approximated based on the cooling tower configuration and the relative angle of the plume and the roadway. The annual average daily traffic (commutes per day) for affected roads was obtained from Department of Transportation (DOT) data for each respective state. The analysis assumed the average rate of travel under normal conditions appropriate for the roadway. Table 4-15 provides the estimate of additional roadway icing and fogging. Note that in some cases, fog and ice did not affect roadways.

Table 4-15
Data describing incidences of Fog and Ice on roadways from cooling tower operation for BTPs and RFs

Facility[a]	Road Impacted by Ice or Fog	Commutes per Day[b]	Roadway Icing		Roadway Fogging			
			Events per Year	Duration of Event (hours)	Events per Year	Duration of Event (hours)	Days per Year	Width of Fog Plume (miles)
BTCA1	Route 22	191,000	0		2	0.02	0.0017	0.25
	I-405	649,000	0		1	0.02	0.0008	0.25
	Route 1	77,500	0		1	0.02	0.0008	0.5
BTPB	Interstate Hwy	39,222	4	0.3	2	0.6	0.0500	0.25
	Interstate Hwy	39,222	0		2	2.6	0.2167	0.25
BTPC	Interstate Hwy	64,966	3	0.1	3	0.08	0.0100	0.1
BTPD	U.S. Route	19,000	0		3	0.09	0.0113	0.2
	U.S. Route	19,000	0		1	0.09	0.0038	0.35
	U.S. Route	19,000	0		2	0.62	0.0517	0.2
	U.S. Route	19,000	0		2	2.79	0.2325	0.2
BTCA2	I-5	276,000	0		5	0.25	0.0521	0.75
	I-5	276,000	0		2	0.75	0.0625	0.75
	I-5	276,000	0		1	5.95	0.2479	0.75
RFF	Local Rd	2,278	8	1.42	9	2.11	0.7921	0.20
RFG	U.S. Route	11,900	0		23	1.47	1.4129	0.36
RFI	Interstate Hwy	158,250	11	1.00	33	1.91	2.6321	1.02
	Local Road	31,500	17	1.36	39	2.36	3.8392	1.46
	Local Street	14,900	0		39	1.06	1.7183	1.54
RFJ	State Road	12,030	0		13	0.44	0.2392	0.43
RFK	State Road	28,597	0		6	1.20	0.2996	0.15
RFL	State Road	15,850	0		17	0.80	0.5683	1.27
RFN[c]	Local Route	1,550	0		27	0.62	0.6954	1.09
	Interstate Hwy	7,600	0		8	0.31	0.1045	0.30
RFO[c]	Local Route	720	0		5	0.29	0.0596	0.16
	Local Route	4,500	5	0.60	19	0.91	0.7171	0.75

Table 4-15
Data describing incidences of Fog and Ice on roadways from cooling tower operation for BTPs and RFs (continued)

Facility[a]	Road Impacted by Ice or Fog	Commutes per Day[b]	Roadway Icing		Roadway Fogging			
			Events per Year	Duration of Event (hours)	Events per Year	Duration of Event (hours)	Days per Year	Width of Fog Plume (miles)
RFQ[c]	Local Road	NA	0		23	3.61	3.4559	0.57
	State Route	18,100	0		7	0.35	0.1025	0.17
RFR[c]	Local Highway	NA	0		7	0.51	0.1479	0.44
RFS[c]	Local Route	3,650	4	1.63	5	3.81	0.7937	0.55
RFU[c]	State Route Alt.	1,425	7	0.31	13	0.51	0.2736	0.52
RFV[c]	Local Route	2,400	0		5	0.33	0.0695	0.22

[a] The roadway analysis for BTPA, BTPE, RFH, RFM, RFP, and RFT predicted that no major roads would be impacted by fog or ice.

[b] NA indicates no data estimating the average commutes per day were available for the roadway impacted by icing or fogging. Available data were based on annual average daily traffic from DOT for the state which each facility resides.

[c] Fog and ice impacts for these facilities were estimated based on modeling from similar facilities.

Visible plumes interfering with air traffic at nearby airports was determined based on plume length estimates (Appendix C). The results showed that the vapor plume from mechanical-draft evaporative cooling towers at BTCA1 crosses a nearby armed forces runway. This suggests that mechanical-draft evaporative cooling towers may not be viable at BTCA1. Since plume-abatement (hybrid) towers are not proven with saline water and dry cooling towers would not fit on this site, these designs of cooling towers are not available at BTCA1.

4.4.1.2 Monetization

The possibility of increased roadway fogging and icing during certain times of the year are potential adverse environmental effects associated with cooling towers. The monetization of these potential impacts was based on a WTP to avoid roadway fogging and icing associated with cooling tower operation. WTP to avoid fogging was estimated; however, appropriate accident data were not available to estimate WTP to avoid icing. Detailed methods are provided in Appendix B.

The results of the estimation of WTP to avoid public safety issues associated with cooling tower operation are summarized in Table 4-16 for BTPs and RFs.

Table 4-16
Annual monetized impacts associated with roadway fogging for BTPs and RFs

Facility[a]	Total Additional Travel Time (hours)	Total Baseline Accidents	WTP to Avoid Additional Travel Time (2007$)	WTP to Avoid Increased Cost of Accidents (2007$)	Total Annual WTP to Avoid Fogging (2007$)
BTCA1	0.67	0.0002	$10	<$5	$10
BTPB	7.10	0.0026	$60	$30	$100
BTPC	0.18	0.0001	<$5	<$5	<$5
BTPD	3.12	0.0011	$30	$10	$40
BTCA2	203.72	0.0750	$1,800	$900	$2,800
RFF	0.97	0.0004	$10	<$5	$10
RFG	16.32	0.0060	$140	$80	$220
RFI	1,736.20	0.6395	$15,500	$8,000	$23,500
RFJ	3.39	0.0012	$30	$20	$50
RFK	3.47	0.0013	$30	$20	$50
RFL	31.15	0.0115	$300	$100	$400

Table 4-16
Annual monetized impacts associated with roadway fogging for BTPs and RFs (continued)

Facility[a]	Total Additional Travel Time (hours)	Total Baseline Accidents	WTP to Avoid Additional Travel Time (2007$)	WTP to Avoid Increased Cost of Accidents (2007$)	Total Annual WTP to Avoid Fogging (2007$)
RFN[d]	3.84	0.0014	$30	$20	$50
RFO[d]	6.59	0.0024	$60	$30	$90
RFQ[b, d]	0.86	0.0003	$10	<$5	$10
RFR[c, d]	NA	NA	NA	NA	NA
RFS[d]	4.33	0.0016	$40	$20	$60
RFU[d]	0.55	0.0002	$10	<$5	$10
RFV[d]	0.10	0.0000	<$5	$0	<$5

[a] The roadway analysis for BTPA, BTPE, RFH, RFM, RFP, and RFT predicted that no major roads would be impacted by fog or ice.

[b] Fogging impacts at RFQ may be underestimated because an estimate of average commutes per day was not available to monetize the impacts of fogging on the local road, which was one of two roads impacted.

[c] Fogging impacts at RFR could not be monetized because an estimate of average commutes per day was not available for the local highway.

[d] Fog and ice impacts for these facilities were estimated based on modeling from similar facilities.

Note WTP values rounded; totals may not equal due to rounding.

Impacts due to fogging on the runway at a nearby Armed Forces Reserve Center are not monetized. As mentioned above, the presence of the runway suggests that mechanical-draft evaporative cooling towers may not be viable at BTCA1.

4.4.2 Uncertainty

4.4.2.1 Quantification

The SACTI model was used to estimate potential impacts from cooling towers such as plume visibility, ground level fogging, ground level icing, and plume shadowing. One year of meteorological data was used and, therefore, interannual variability is not represented. The SACTI model includes many assumptions which results in “conservative” estimates with respect to the effects on the surrounding environment. The SACTI model uses a simplistic method for calculating ground level icing, which is a very complex process that requires super cooled moisture conditions to be present before ground level icing can occur. The model simply assumes if the air temperature is at or below freezing and there is a fogging condition possible then rime icing is predicted. The model predicts a potential for ground level icing which may poorly correlate to the actual development of this condition. The model does not consider plume density. The model assumes if temperature and moisture conditions result in a saturation condition then the entire plume has condensed even if the edges of the plume are barely saturated and evaporating, making the plume more transparent.

Although SACTI contains algorithms for cooling water towers arranged singly or in clusters, it can evaluate only 30 cells in a single run. Proposed cooling towers at the BTPs exceeded this limitation; as a result, for the Beta Test modeling, each facility was split into multiple model runs as a “work around”. The results for the multiple runs were combined. The 30 cell limit was also reached or exceeded for additional facilities modeled, except for RFK. Several test evaluation runs using the SACTI model confirmed that multi-tower plume interaction is an important factor. Therefore, for facilities that exceeded the allowed number of cells in this phase of the study, the following approach was used. All dual arrays were modeled as single arrays and the total number of cells was reduced. This preserved the configuration of the towers in terms of number of towers, length, and alignment of towers to allow for plume interactions between the towers. The test evaluation run used an example facility, with a multiple tower configuration, which limited the number of cells to a value less than 30. The analysis compared results using a “split-run” modeling approach (Beta Test) and a “representative configuration” modeling approach. Results indicated slightly better agreement when using the “representative configuration” than the “split-run” method. Both the “split-run” and “representative configuration” modeling methods have merits, depending on a facility’s exact configuration. However, since the “representative configuration” produced more conservative results, this methodology was selected for the RFs. This will tend to bias closed-cycle cooling impacts in a downward direction.

All BTPs and RFF, RFG, RFH, RFI, RFJ, RFK and RFL were modeled for fogging and icing. For the remaining RFs, which were located in low population areas, the impacts were estimated using modeling results from similar facilities. This adds uncertainty to the results.

4.4.2.2 Monetization

The WTP estimate associated with changes to public safety omits several potential impacts. These include potential delays and safety issues related to airport operation, and fog related impacts associated with line of sight dependant security operations. WTP for roadway fogging is best characterized as a partial estimate in that it omits potential increases in the frequency of accidents, delays related to car-to-car interactions, and potential impacts on secondary roadways. In addition, fog is often associated with other poor weather conditions and the impact of the fog alone is difficult to discern. Each omission biases the WTP estimate in a downward direction.

4.4.3 Security at Nuclear Facilities

The potential impact to the line of sight at nuclear facilities due to fogging is an additional concern posed by on-site cooling towers.

The land on which a nuclear power plant is built and the surrounding land owned by the utility is referred to as the Owner Controlled Area. Much of the Owner Controlled Area can be accessed without special authorization. The Protected Area is a relatively small subsection of the Owner Controlled Area with a higher level of security. The Protected Area is generally enclosed within two fences. The inner fence is equipped with an intrusion detection system; the outer fence reduces the number of false intrusion alarm triggers.

When possible, the hypothetical cooling towers were located such that the predominant wind would carry the plume and fog away from the relatively small Protected Area that is under active visual surveillance. Nevertheless, a potential closed-cycle cooling retrofit with any one of the wet cooling tower types would likely cause some fogging within the Protected Area during certain weather conditions. The additional number of hours of fogging that may be expected within the Protected Area and the Owner Controlled Area at representative nuclear facilities due to the closed-cycle cooling retrofit is summarized below:

The additional hours of fogging per year within the Protected Area:

- BTPB – 5 to 10 hours;
- BTPE – 0 to 1 hour;
- BTCA2 – 0.1 to 0.8 hour;
- RFH – negligible;
- RFS – negligible; and
- RFV – negligible.

The additional hours of fogging per year within the Owner Controlled Area:

- BTPB – 2.5 to 6 hours;
- BTPE – 0.2 to 0.5 hour;
- BTCA2 – 0.1 to 0.7 hour;
- RFH – approximately 3.5 hours;
- RFS – approximately 5.5 hours; and
- RFV – less than 1 hour.

Fog related impacts to security at nuclear facilities are not monetized because there were insufficient data to estimate WTP for marginal security changes at nuclear facilities.

4.5 Quality of Life

4.5.1 Noise

Increased noise levels associated with retrofitting to closed-cycle cooling are determined by individual noise assessments for each of the 14 modeled facilities using the Cadna/A® Model. This is a three-dimensional acoustic model commonly used to predict noise levels at power plants. Details of the model assumptions and inputs are presented in Appendix B. Ambient noise levels in the vicinity of the plants were estimated based upon adjacent land uses and known noise sources using actual community noise measurement data from similar environs. Future noise contours were modeled with the proposed mechanical-draft evaporative cooling towers (See Appendix C). These contours depict the total noise environment including the background noise level, existing plant operations, and cooling tower operations. Figures that display the change in community noise levels between the baseline (i.e., existing) condition and the future condition, including cooling towers, are likewise shown in Appendix C.

4.5.1.1 Quantification

The population exposed to increased levels of noise is determined by superimposing isopleths of changes of two dBA or more on local population maps surrounding the BTPs and RFs. The number of houses in each zip code was identified from 2000 census data. The estimated noise level increases and number of homes affected are shown in Table 4-17. Perceptible changes in noise levels are not expected at any recreational sites surrounding the facilities studied.

4.5.1.2 Monetization

An increase in noise due to cooling tower operation is an adverse environmental impact. This impact was monetized using an estimate of society's WTP to avoid increased noise. This analysis assumed the quality of the acoustic environment is capitalized into the value of the housing stock, and that a two-decibel (dB)[4] increase in ambient noise levels represents a quantifiable change in the acoustic environment. The facilities were modeled assuming an average ambient background noise. Thus, during quieter periods of the day, the increase in ambient noise levels produced by the mechanical-draft evaporative cooling towers will be several dB higher. The resulting decrease in the value of the local housing stock is a component of the WTP estimate. Note that WTP among non-local users of recreational sites may not be capitalized into local housing stocks. This non-local increment to WTP was estimated on a site-specific basis. Median housing values for 2007, provided by City-Data.com (http://www.city-data.com/), were based on home sales for the zip code each BTP or RF resides whenever possible.

The WTP by local residents to avoid noise increases from new cooling towers was estimated using hedonic methods. These methods infer people's WTP for various attributes by evaluating their home purchasing decisions. Details are provided in Appendix B.

Table 4-17 summarizes monetization data for possible noise impacts associated with retrofitting to closed-cycle cooling using the WTP estimates associated with potential noise impacts to households.

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[4] A sound level of zero dB is the approximate threshold of human hearing and is the reference level against which the amplitude of other sound is compared.

Table 4-17
Annual monetized impact associated with increased noise for BTPs and RFs

Facility	# of Homes	Incremental Noise Increase Over Ambient (dB)	Median Home Sales (2007$)	Annual WTP to Avoid Noise Degradation (2007$)
BTCA1	57	2	$800,000	$19,500
BTCA1	67	3	$800,000	$34,300
			BTCA1 Total	$53,800
BTPA	0	2	$105,000	$0
			BTPA Total	$0
BTPB	14	2	$140,000	$800
BTPB	20	3	$140,000	$1,800
BTPB	9	4	$140,000	$1,100
BTPB	7	7	$140,000	$1,500
BTPB	2	10	$140,000	$600
			BTPB Total[a]	$5,800
BTPC	0	2	$130,000	$0
			BTPC Total	$0
BTPD	17	2	$400,000	$2,900
BTPD	10	3	$400,000	$2,600
BTPD	21	6	$400,000	$10,800
			BTPD Total	$16,200
BTPE	18	2	$210,000	$1,600
			BTPE Total	$1,600
BTCA2[b]	0	2	$450,000	$0
			BTCA2 Total	$0
RFF	0	2	$162,069	$0
			RFF Total	$0
RFG	153	2	$152,745	$10,000
RFG	1	3	$152,745	$100
RFG	4	8	$152,745	$1,000
			RFG Total	$11,100
RFH	244	2	$188,437	$19,600
			RFH Total	$19,600
RFI	0	2	$251,223	$0
			RFI Total	$0
RFJ	369	2	$104,769	$16,500
RFJ	152	3	$104,769	$10,200
RFJ	210	4	$104,769	$18,800
RFJ	29	5	$104,769	$3,200
RFJ	17	6	$104,769	$2,300
RFJ	51	7	$104,769	$8,000
RFJ	7	8	$104,769	$1,300
RFJ	11	9	$104,769	$2,200

Table 4-17
Annual monetized impact associated with increased noise for BTPs and RFs (continued)

Facility	# of Homes	Incremental Noise Increase Over Ambient (dB)	Median Home Sales (2007$)	Annual WTP to Avoid Noise Degradation (2007$)
RFJ	2	10	$104,769	$400
			RFJ Total	$63,000
RFK	0	2	$593,555	$0
			RFK Total	$0
RFL	6,396	2	$90,000	$245,900
			RFL Total	$245,900
RFM	930	2	$73,480	$29,200
RFM	3,349	3	$73,480	$157,700
			RFM Total[c]	$186,900
RFN	640	2	$174,353	$47,700
RFN	235	3	$174,353	$26,300
			RFN Total[c]	$73,900
RFO	0	2	$130,248	$0
			RFO Total[c]	$0
RFP	74	2	$88,887	$2,800
RFP	108	3	$88,887	$6,200
RFP	51	4	$88,887	$3,900
RFP	20	5	$88,887	$1,900
			RFP Total[c]	$14,700
RFQ	0	2	$258,758	$0
			RFQ Total[c]	$0
RFR	0	2	$75,945	$0
			RFR Total[c]	$0
RFS	0	2	$160,766	$0
			RFS Total[c]	$0
RFT	289	2	$235,272	$29,000
RFT	2	4	$235,272	$400
			RFT Total[c]	$29,400
RFU	0	2	$60,046	$0
			RFU Total[c]	$0
RFV	8	4	$117,303	$800
			RFV Total[c]	$800

[a] Does not include new development adjacent to the property.
[b] Does not include residents on a nearby military base.
[c] Noise impacts for these facilities were estimated based on modeling from similar facilities.
Note WTP values rounded to the nearest $100; totals may not equal due to rounding.

4.5.1.3 Uncertainty

4.5.1.3.1 Quantification

Uncertainty associated with noise analysis is based on many factors and is very difficult to assess. A critical variable is the accuracy and variability of radiated sound energy from noise sources. The source noise levels used in this analysis are based on manufacturers' published data, accepted sound prediction calculations based upon known performance characteristics, and empirical data. However, source sound levels from identical components may vary due to manufacturing tolerances, changes in the manufacturing process, and maintenance practices. Another key variable is the accuracy of acoustical predictions. All sound prediction models are based on approximations to model source to receiver propagation. The accuracy of these approximations can vary for specific propagation path conditions. Other variables include site sound level measurement uncertainty due to localized conditions such as topography, weather, existing ambient noise, and sample size.

The assessment of uncertainty as applied to acoustic predictions is compounded by the logarithmic nature of the dB. Sound levels do not add linearly. For example, if one piece of equipment is three dBA louder than average and another is three dBA quieter than average, the logarithmic average of these two pieces of equipment is louder than the linear average. Standard methods of assessing uncertainty are based on linear methods.

For these reasons, conservative estimates of source noise levels were used. This may bias the prediction of background noise levels in an upward direction, somewhat over-estimating the ambient noise levels. This in turn will tend to underestimate the change in noise level over background predicted for the mechanical-draft evaporative cooling towers.

All BTPs and RFF, RFG, RFH, RFI, RFJ, RFK and RFL were modeled for noise. For the remaining RFs, which are located in low population areas, the impacts were estimated using modeling results from similar facilities. This adds uncertainty to the results.

Some states and/or local jurisdictions have ambient noise regulations. In those cases, noise mitigation measures may be required. Because of the nature of cooling towers, mitigation methods are limited. Sound barriers may not be effective due to the height of the tower structures. Sound barriers could also restrict airflow to the cooling towers, which hinders their ability to perform. Although barriers could be made large enough to avoid interferences with air flow, sound barriers may not be practical for many facilities. One feasible mitigation method for cooling towers is low speed fans. These fans generally increase the blade count and angle to permit similar volumes of airflow at lower RPM, and use quiet motors. This method of mitigation can be successful but is also extremely expensive. Another potential source mitigation measure is the use of reduced fan speed during the cooler periods of the day. These periods coincide with periods of increased noise sensitivity. Fans operating at half speed reduce source noise levels by approximately eight dB. Mitigation at the receptor comes in two forms: property line sound barriers and upgrades to the structure. Property line sound barriers may work well in limited situations depending on the geometries involved. However, such barriers have their own set of adverse impacts. Due to their size and visibility, noise abatement barriers could result in visual or other impacts; quantification of those impacts is beyond the scope of this study.

Another method for receptor mitigation is installing upgrades to the impacted offsite structures, such as multi-pane windows and in-wall sound insulation. These methods mitigate noise levels inside the receptor structure, but provide no reduction in noise on the property surrounding the structure.

4.5.1.3.2 Monetization

The primary uncertainty associated with this analysis relates to perceptibility. The studies relied upon generally assess the relationship between relatively large changes in ambient noise levels and housing prices; a WTP per dB was then calculated as total change in WTP divided by total change in noise level. The literature does not contain studies that actually assess WTP for a two dB change in noise levels. This uncertainty may bias WTP estimates in an upward direction. However, change in noise was estimated assuming average background noise levels. During the quieter periods of the day the dB change in noise levels produced by the tower at a particular location would be higher than two dB.

In some cases, regulations may require engineering solutions that mitigate or prevent noise. In such cases, there may be no environmental change for which to estimate WTP.

4.5.2 Viewshed

Viewshed deterioration is another quality of life issue sometimes associated with potential closed-cycle cooling-related environmental effects. For this analysis, the SACTI model is used to predict plume length and plume shadowing. A description of the SACTI model and model inputs are provided in Appendix B.

4.5.2.1 Quantification

The percent duration of vapor plumes of various lengths and plume shadow over the one-year model period is shown in Appendix C for modeled facilities. A lower bound estimate of the population that can view a significant visible plume was determined by superimposing percent duration of vapor plumes of various lengths over maps surrounding the modeled facilities. The maps indicate the block groups impacted, the number of households in each block group, and the proportion of the time the plume is visible. The estimated percent of the year that the plume is visible and the numbers of households affected are shown in Table 4-18.

Similar methods were used to identify recreational sites from which a significant plume, defined as a plume shadow, would be visible and the proportion of the year with potentially impacted viewsheds. See Appendix B for methodology.

4.5.2.2 Monetization

Viewshed deterioration is an adverse impact associated with mechanical-draft evaporative cooling tower operation. This impact is monetized using society’s WTP to avoid this deterioration. In this analysis, the quality of the viewshed for local residents was assumed to be capitalized into the value of the housing stock and that the introduction of a plume represents a perceptible decrease in the quality of the viewshed that would reduce property values. Local residents' WTP to avoid seeing the plume is based on the same economic methods discussed for the monetization of noise impacts (Section 4.5.1.2), i.e., hedonic pricing methods. Median housing values for 2007, provided by City-Data.com, were based on home sales for the zip code each BTP or RF resides, whenever possible. Detailed methods are provided in Appendix B.

Table 4-18 summarizes the input data and WTP estimates associated with potential impacts to households at each site. The variable "number of homes" understates the true population that experiences viewshed deterioration. This is because:

- It is conservatively assumed that the plume must be directly overhead of the household for the plume to be visible; and
- All homes within one-quarter mile of fossil-fueled facilities are assumed to have an impacted viewshed from the existing stacks and stack plumes, thus, the viewshed is assumed to be unchanged even though the vapor plume from the mechanical-draft evaporative cooling towers can be significantly larger and lower to the ground.

Table 4-18
Annual monetized impact of viewshed degradation for BTPs and RFs

Facility	# of Homes	Minimum Average Percent of Year Visible[a]	Median Home Sales (2007$)	Annual WTP to Avoid Viewshed Degradation (2007$)
BTCA1	35,727	0.4	$800,000	$109,900
BTCA1	7,178	1.2	$800,000	$66,200
BTCA1	845	2	$800,000	$13,000
			BTCA1 Total	$189,100
BTPA	280	1.1	$105,000	$300
			BTPA Total	$300
BTPB	1,036	1.25	$140,000	$1,700
BTPB	914	3.75	$140,000	$4,600
			BTPB Total	$6,400
BTPC	4,946	0.70	$130,000	$4,300
			BTPC Total	$4,300
BTPD	328	1.10	$400,000	$1,400
			BTPD Total	$1,400

Table 4-18
Annual monetized impact of viewshed degradation for BTPs and RFs (continued)

Facility	# of Homes	Minimum Average Percent of Year Visible[a]	Median Home Sales (2007$)	Annual WTP to Avoid Viewshed Degradation (2007$)
BTPE	46	1.25	$210,000	$100
			BTPE Total	$100
BTCA2	0[b]		$450,000	$0
			BTCA2 Total	$0
RFF	0	N/A	$162,100	$0
			RFF Total	$0
RFG	1	1.10	$152,700	<$50
			RFG Total	<$50
RFH	875	1.25	$188400	$2,000
RFH	54	1.75	$188,400	$200
RFH	93	2.75	$188,400	$500
RFH	203	3.25	$188,400	$1,200
RFH	50	3.75	$188,400	$300
RFH	93	4.25	$188,400	$700
			RFH Total	$4,900
RFI	323	0.8	$251,200	$600
RFI	1,191	1.0	$251,200	$2,900
RFI	1,260	1.1	$251,200	$3,300
RFI	498	1.2	$251,200	$1,400
RFI	157	1.4	$251,200	$500
RFI	95	1.8	$251,200	$400
RFI	1,192	1.9	$251,200	$5,500
RFI	1,310	2.4	$251,200	$7,600
RFI	571	3.6	$251,200	$5,000
RFI	17	7.8	$251,200	$300
			RFI Total	$27,600

Table 4-18
Annual monetized impact of viewshed degradation for BTPs and RFs (continued)

Facility	# of Homes	Minimum Average Percent of Year Visible[a]	Median Home Sales (2007$)	Annual WTP to Avoid Viewshed Degradation (2007$)
RFJ	0	N/A	$104,800	$0
			RFJ Total	$0
RFK	85	1.25	$593,600	$600
RFK	132	1.75	$593,600	$1,300
RFK	102	2.25	$593,600	$1,300
			RFK Total	$3,200
RFL	0	N/A	$90,000	$0
			RFL Total	$0
RFM	0	2.0	$73,500	$0
			RFM Total[c]	$0
RFN	0	2.0	$174,400	$0
			RFN Total[c]	$0
RFO	14	0.9	$130,200	<$50
RFO	12	1.2	$130,200	<$50
RFO	1	1.8	$130,200	<$50
			RFO Total[c]	<$50
RFP	5	1.0	$88,900	<$50
RFP	1	1.1	$88,900	<$50
RFP	3	1.2	$88,900	<$50
			RFP Total[c]	<$50
RFQ	0	2.0	$258,800	$0
			RFQ Total[c]	$0
RFR	8	1.2	$75,900	<$50
			RFR Total[c]	<$50
RFS	6	1.2	$160,800	<$50
RFS	58	1.3	$160,800	$100

Table 4-18
Annual monetized impact of viewshed degradation for BTPs and RFs (continued)

Facility	# of Homes	Minimum Average Percent of Year Visible[a]	Median Home Sales (2007$)	Annual WTP to Avoid Viewshed Degradation (2007$)
RFS	6	1.4	$160,800	<$50
RFS	1	1.5	$160,800	<$50
RFS	15	1.6	$160,800	<$50
RFS	9	1.7	$160,800	<$50
RFS	4	1.8	$160,800	<$50
RFS	23	2	$160,800	$100
RFS	9	2.1	$160,800	<$50
RFS	1	2.2	$160,800	<$50
RFS	9	2.3	$160,800	<$50
RFS	123	2.5	$160,800	$500
RFS	30	2.7	$160,800	$100
			RFS Total[c]	$1,000
RFT	0	2	$235,300	$0
			RFT Total[c]	$0
RFU	0	2	$60,000	$0
			RFU Total[c]	$0
RFV	66	1.1	$117,300	$100
RFV	32	1.7	$117,300	$100
			RFV Total[c]	$100

[a] Directly overhead of the household.

[b] Does not include residents on nearby military base.

[c] Viewshed impacts for these facilities were estimated based on impacts from similar facilities.
Note WTP values rounded to the nearest $100; totals may not equal due to rounding.

WTP among *non-local* users of recreational sites may not be capitalized into local housing stocks. Similar to noise impacts, WTP to avoid possible impacts to non-local users of recreational areas were estimated based upon incremental changes to consumer surplus associated with varying site attributes (e.g., visible plumes or not). For this application, “non-local” is defined as those visitors whose property is not impacted by the cooling tower vapor plume. For state parks and state beaches, which typically have over 50,000 visitors annually, it was assumed that 100 percent of visitors are non-local. Visitors to a national refuge are also assumed to be non-local because access to the refuge is very limited and not likely driven by proximity. For neighborhood parks, non-local use is assumed to be zero (i.e., visual impacts to neighborhood parks are assumed to be entirely capitalized into the housing values as discussed above). The values of a recreational visit to a California state beach and to potentially impacted state parks were based on literature values, including average recreational use values for 21 activities based on geographic region [39, 40].

The economic literature does not contain consumer surplus changes associated with the introduction of a plume to a recreational site. In lieu of these data, and consistent with the housing analysis, the WTP to avoid degradation in the recreational site was assumed to be 1.8 percent of the value of each recreational visit. Site-specific attendance data for the identified parks were obtained from the park systems. Detailed methods are provided in Appendix B.

Table 4-19 summarizes the visual degradation and the monetized value based on WTP to avoid potential impacts to the recreational sites for the BTPs. No state parks with significant shadowing were identified at the RFs. The hours of plume shadowing and minimum percent of the year visible understates the true population that experiences viewshed deterioration. This is because, except for BTCA2, it is conservatively assumed that the plume must be directly overhead and/or casting a shadow on the park for the plume to be visible. Because BTCA2 is on the shoreline directly adjacent to the beach and the view of the plume would be unobstructed by trees or other objects, values represent the total time a visible plume is present, not just the time the plume casting a shadow over the park.

4.5.2.3 Uncertainty

4.5.2.3.1 Quantification

The uncertainty associated with the SACTI model is discussed in Section 4.4.2.1 and in greater detail in Appendix B. Because the SACTI model may over-predict plume height and length, a conservative approach to population impacts was used in that the visible impact was only considered to occur when the plume is located directly overhead of the receptor for at least one percent of the year or greater. Far larger populations will actually see the plume lower to the horizon. The plume at this angle may obstruct view of lakes, oceans, and other scenic vistas, which would be of considerable concern to homeowners. This will bias the estimates of closed-cycle cooling impacts in a lower direction.

Table 4-19
Annual monetized impacts associated with viewshed degradation of recreation sites

Facility Name	Park Name	Average Annual Hours of Plume Shadowing[a]	Minimum Percent of Year Visible[a]	Annual Attendance[b]	Recreational Activities Available[c]	Average Recreational Value/Visit (2007$)	Annual WTP to Avoid Viewshed Degradation (2007$)
BTCA1	National Refuge	2.32	0.03	2,000	Wildlife viewing	$32	$0
	State Beach	1.26	0.01	3,892,782	Fishing and swimming	$17	$200
BTPB	State Park	80	0.91	52,000	Picnicking, swimming, hiking, cross country skiing, hunting, fishing	$36	$300
	State Park	14.7	0.17	1,670,000	Camping, swimming, hiking, picnicking, hunting, fishing, cross country skiing	$37	$1,900
BTPC	State Park	10.44	0.12	162,215	Sightseeing, picnicking, horseback riding	$40	$100
	State Park	8.53	0.10	51,914	Biking, hiking, picnicking	$33	<$50
BTPD	State Park	8.87	0.10	523,008	Camping, picnicking, swimming, boating, fishing,	$34	$300

Table 4-19
Annual monetized impacts associated with viewshed degradation of recreation sites (continued)

Facility Name	Park Name	Average Annual Hours of Plume Shadowing[a]	Minimum Percent of Year Visible[a]	Annual Attendance[b]	Recreational Activities Available[c]	Average Recreational Value/Visit (2007$)	Annual WTP to Avoid Viewshed Degradation (2007$)
BTPE	State Park	3	0.03	60,819	Hiking, horseback riding, picnicking, camping	$40	<$50
BTCA2	State Beach	18.8	0.21	605,618	Fishing and swimming	$17	$400
	State Beach[d]	1,583.81	18.08	2,778,764	Fishing and swimming	$17	$157,400

[a] Directly overhead and/or casting a shadow on the park except for BTCA2.

[b] Attendance data from state resource agencies.

[c] Recreational activities from identified government agencies, including California State Parks [41, 42, 43]

[d] Modeling output was based on plume visibility rather than plume shadowing.
Monetary values are rounded.

4.5.2.3.2 Monetization

The economic literature does not contain reliable housing diminution estimates for the introduction of a plume to a viewshed. While an informed opinion was made regarding potential WTP, a primary uncertainty associated with the estimate of WTP to avoid a change to the viewshed is the estimate of housing diminution associated with the introduction of a plume.

In addition, potential WTP among all households for whom the generating station is already a component of the viewshed is omitted; this includes houses potentially shaded by the plume. This omission tends to bias WTP estimates in a downward direction. Likewise the obstruction of lake, oceans, and other scenic vistas when the plume is low to the horizon are omitted, which also bias WTP estimates in a downward direction.

Also, there may be considerable uncertainty associated with WTP among non-local recreational participants. Because of that uncertainty, an estimate of a lower bound on annual WTP was attempted.

4.6 Permitting

Potential permitting issues associated with retrofitting to closed-cycle cooling are discussed in this section. Air permitting is discussed separately because of the complexity of the permitting process related to air quality.

4.6.1 Air Permitting

Construction of cooling towers at an existing facility would trigger various federal and/or state air quality permitting requirements. The applicability of these regulations depends on:

- Major source status of existing facility;
- Cooling tower potential to emit; and
- Area attainment status.

Each of the regulations is discussed below. Applicability is pollutant-specific, therefore, a project could require a Prevention of Significant Deterioration (PSD) permit for one pollutant (e.g., PM_{10}) and a Nonattainment Area New Source Review (NANSR) permit for another (e.g., $PM_{2.5}$).

4.6.1.1 Permit Requirements

Prevention of Significant Deterioration (PSD)

The PSD program is a federal permitting program which applies to major new sources or major modifications at existing major sources located in attainment areas. For this study, PSD applicability will vary depending on the facility fuel type (i.e., fossil or nuclear), cooling tower potential to emit, and the area attainment status.

Existing fossil-fueled plants have a potential to emit pollutant criterion of >100 tpy and, therefore, would be considered to be an existing major source. The installation of cooling towers at these facilities will be subject to PSD review if the project potential to emit of PM_{10} is greater than 15 tpy or $PM_{2.5}$ is greater than 10 tpy (these emission increase thresholds are considered the Significant Emission Rate). Nuclear facilities are not one of the listed PSD source types; therefore, their major source threshold is 250 tpy. If nuclear facilities do not have existing cooling towers, their emission rates are typically less than this threshold and they are not existing major sources. Therefore, for a cooling tower project at a nuclear facility to be subject to PSD review, the cooling tower project potential to emit would need to exceed 250 tpy for PM_{10} or $PM_{2.5}$.

The main technical requirements of PSD are:

- Demonstrate that the project will incorporate best available control technology;
- Evaluate existing ambient air quality;
- Demonstrate that the project will not cause or significantly contribute to an exceedance or violation of the PSD increments and National Ambient Air Quality Standards (NAAQS);
- Determine the potential impacts of the project on soils, vegetation, and visibility at Class I areas; and
- Determine potential air quality impacts resulting from indirect growth associated with the project.

Nonattainment Area New Source Review (NANSR)

Annual and 24-hour NAAQS for PM_{10} includes only those particles with aerodynamic diameter smaller than 10 microns. In 1997, USEPA established annual and 24-hour NAAQS for $PM_{2.5}$ for the first time. In 2006, USEPA revised the 24-hour NAAQS for $PM_{2.5}$. The EPA issued $PM_{2.5}$ designations based on the 2006 $PM_{2.5}$ 24-hour NAAQS on October 8, 2009. The attainment status for each of the pollutant types for the 14 facilities for which detailed air modeling was performed is listed in Table 4-20.

Table 4-20
Area PM Attainment status and annual emission estimates (from Table 3-4)

Facility Name	Area Pollutant Attainment Status		Annual Emissions Estimate (tpy)		
	PM_{10}	$PM_{2.5}$	PM (TSP)	PM_{10}	$PM_{2.5}$
BTCA1	Nonattainment	Nonattainment	440	177	53
BTPA	Attainment	Attainment	170	83	26
BTPB	Attainment	Attainment	33	24.6	10.1
BTPC	Attainment	Nonattainment	235	100	28
BTPD	Attainment	Attainment	17	13	6
BTPE	Attainment	Nonattainment	43	31	12
BTCA2	Attainment	Attainment	878	353	105
RFF	Attainment	Attainment	10	8	3

Table 4-20
Area PM Attainment status and annual emission estimates (from Table 3-4) (continued)

Facility Name	Area Pollutant Attainment Status		Annual Emissions Estimate (tpy)		
	PM_{10}	$PM_{2.5}$	PM (TSP)	PM_{10}	$PM_{2.5}$
RFG	Attainment	Attainment	101	41	12
RFH	Attainment	Attainment	504	218	61
RFI	Attainment	Attainment	11	8	3
RFJ	Attainment	Attainment	12	9	4
RFK	Attainment	Nonattainment	101	41	12
RFL	Attainment	Attainment	11	8	3

PM = particulate matter; TSP = total suspended particulates; tpy = tons per year

USEPA has set the *de minimus* emissions threshold for direct emissions of $PM_{2.5}$ at 100 tpy. Therefore, in a $PM_{2.5}$ nonattainment area, a cooling tower addition would be subject to NANSR if emissions exceed 100 tpy. For minor $PM_{2.5}$ emissions sources located in nonattainment areas (i.e., potential to emit less than 100 tpy), the facility may be subject to a dispersion modeling-based test in addition to the emissions-based test. Individual states can have more stringent nonattainment requirements and lower thresholds than the Federal NANSR. New Jersey, for example, has developed guidance requiring projects with a potential to emit greater than 15 tpy to demonstrate, using dispersion modeling, that maximum predicted impacts are less than the SILs[5] [44].

The main requirements of NANSR are:

- Demonstrate that the project will incorporate lowest achievable emission rate;
- Secure emission offsets at the appropriate offset ratio, which is likely 1:1;
- Demonstrate that the project will not cause or significantly contribute to an exceedance or violation of the NAAQS; and
- Demonstrate, via an analysis of alternative sites, sizes, and production processes, including pollution prevention measures and environmental control techniques, that the benefits of the newly constructed, reconstructed, or modified equipment significantly outweigh the environmental and social costs imposed as a result of the location, construction, reconstruction or modification and operation of such equipment.

For this study, three of the seven BTPs and one of the seven RFs are located in designated $PM_{2.5}$ nonattainment areas: BTCA1, BTPC, BTPE, and RFK. Referencing Table 3-4, only BTCA2 would have $PM_{2.5}$ emissions greater than 100 tpy; therefore, NANSR would only apply to the other facilities if dispersion modeling were required and predicted impacts were greater than the SILs.

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[5] Significant Impact Levels, or SILs, are a set of ambient impact levels used to determine whether a new source or modification would “significantly” affect an area. For $PM_{2.5}$, the SILs established by the final rule published in the Federal Register Wednesday, October 20, 2010 at 40 CFR 51.166(k)(2) are 0.3 µg/m^3 for the annual standard and 1.2 µg/m^3 for the 24-hour standard except in Class I areas where the SILs are 0.06 µg/m^3 and 0.07 µg/m^3, respectively.

State Minor Source Permits

For those projects not subject to PSD or NANSR requirements, a state minor source preconstruction permit would most likely be required. Program applicability and requirements vary from state to state. Individual state programs were not reviewed as part of this study.

Title V Operation Permit

Title V of the Clean Air Act Amendments of 1990 requires that all major stationary sources of air pollutants obtain a permit to operate. A facility is considered “major” if it has individual pollutant emissions over certain thresholds. Applicability is based on total facility emissions, not just the subject cooling tower project. If one pollutant is greater than its threshold, then the entire facility is subject to the permit to operate program.

Part 70 is the section in the Code of Federal Regulations where Title V is detailed. “Title V Permit” and “Part 70 Permit” “Major Source (Operating) Permit” are used interchangeably. The purpose of a Part 70 Permit is to gather all applicable air pollution requirements for a major stationary source into one site-specific, legally enforceable operating permit. A Part 70 permit is renewable every five years.

In general, the Part 70 Permit is meant to incorporate existing applicable state and federal requirements. It is not intended to create new requirements. However, the Part 70 Permit will often include monitoring requirements (e.g., testing, recordkeeping, etc.) that did not appear in previous permits and/or are not explicitly required under existing regulations. These monitoring requirements are forms of “periodic monitoring,” a required part of the Clean Air Act's Title V operating permits program. Periodic monitoring includes actions deemed necessary for the facility to demonstrate compliance with rules or permit conditions.

Summary of Air Permit Requirements

The required permits for the subset of facilities evaluated are summarized in Table 4-21.

4.6.1.2 Best Available Control Technology/Lowest Achievable Emission Rate Control Technology Requirements

To reduce the drift from cooling towers, drift eliminators are usually incorporated into the tower design to remove as many droplets as practical from the air stream before exiting the tower. The drift eliminators used in cooling towers rely on inertial separation caused by direction changes while passing through the eliminators. The most efficient drift eliminator currently available can limit drift to 0.0005 percent of the circulating water flow rate. This efficiency was assumed for this evaluation and therefore, the cooling towers would comply with best available control technology/lowest achievable emission rate requirements of PSD/NANSR.

Table 4-21
Summary of air permit program applicability for BTPs and seven RFs

Facility Name	Permit Program	Pollutant		
		PM (TSP)	PM_{10}	$PM_{2.5}$
BTCA1	PSD	N/A	N/A	N/A
	NANSR	N/A	Y	Y
	State Minor Source			
	Title V	Y	Y	Y
BTPA	PSD	Y	Y [c]	Y [c]
	NANSR	N/A		
	State Minor Source			
	Title V	Y	Y	Y
BTPB	PSD			
	NANSR	N/A		
	State Minor Source	Y	Y	Y
	Title V	N	N[a]	N[a]
BTPC	PSD	Y	Y	N/A
	NANSR	N/A		Note b
	State Minor Source			Y
	Title V	Y	Y	Y
BTPD	PSD			
	NANSR	N/A		
	State Minor Source	Y	Y	Y
	Title V	Y	Y	Y
BTPE	PSD	Y[c]	Y[c]	N/A
	NANSR	N/A		Y
	State Minor Source			
	Title V	Y	Y	Y

Table 4-21
Summary of air permit program applicability for BTPs and seven RFs (continued)

Facility Name	Permit Program	Pollutant		
		PM (TSP)	PM_{10}	$PM_{2.5}$
BTCA2	PSD	Y	Y	Y
	NANSR	N/A		
	State Minor Source			
	Title V	Y	Y	Y
RFF	PSD	N	N	N
	NANSR	N/A	N	N
	State Minor Source			
	Title V	Y	Y	Y
RFG	PSD	Y	Y[c]	Y[c]
	NANSR	N/A	N	Note b
	State Minor Source			
	Title V	Y	Y	Y
RFH	PSD	Y	Y	Y[c]
	NANSR	N/A	N	N
	State Minor Source			
	Title V	Y	Y	Y
RFI	PSD	N	N	N
	NANSR	N/A	N	Note b
	State Minor Source			
	Title V	Y	Y	Y
RFJ	PSD	N	N	N
	NANSR	N/A	N	N
	State Minor Source			
	Title V	Y	Y	Y

Table 4-21
Summary of air permit program applicability for BTPs and seven RFs (continued)

Facility Name	Permit Program	Pollutant		
		PM (TSP)	PM_{10}	$PM_{2.5}$
RFK	PSD	Y	Y[c]	N/A
	NANSR	N/A	N	Note b
	State Minor Source		Y	Y
	Title V	Y	Y	Y
RFL	PSD	N	N	N
	NANSR	N/A	N	Note b
	State Minor Source			
	Title V	Y	Y	Y

[a] This designation assumes existing facility is a minor source with respect to Title V.
[b] Potential to emit is less than USEPA-designated 100 tpy threshold.
[c] Tower emissions exceed Significant Emission Rate at an existing Title V Major Source

4.6.1.3 Dispersion Modeling Results

As stated above, the PSD and NANSR regulations require a demonstration that a new project will not cause or significantly contribute to an exceedance or violation of the PSD increments and NAAQS. For this report, the USEPA AERMOD dispersion model was used to estimate possible maximum ambient impacts attributable to the hypothetical new cooling towers. A discussion of the dispersion modeling methodology can be found Appendix B.

The results of the analysis for all seven of the BTPs and seven of the RFs that underwent AERMOD dispersion modeling are provided in Table 4-22. Facilities not modeled were located in medium and low population areas where any potential impacts are likely to be small[6]. This table lists the maximum predicted PM_{10} and $PM_{2.5}$ concentrations for each facility, along with the pollutant-specific SILs, the NAAQS, and the PSD Class II Area Increments.

The SILs are a set of ambient impact levels used to determine whether a new source or modification will “significantly” affect an area. These SILs are interpreted by the USEPA as representing the ambient impact level below which no further analysis of the new source’s impacts is required. The primary purpose of comparing a new source’s modeled impacts to the SILs is to determine if additional dispersion modeling is warranted and, if so, to establish the source’s significant impact area (SIA). If a project’s maximum predicted impact exceeds the SILs in an attainment area, a compliance demonstration is typically required. This would include the modeling of major background sources located within the source’s pollutant-specific SIA as well as other sources outside the SIA, which could significantly interact within the proposed source’s SIA. In a nonattainment area, if predicted impacts are above the SILs, then the project is subject to NANSR (i.e., lowest achievable emission rate, offsets, alternatives analysis). The air permit can be denied if potential impacts remain above the SILs.

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[6] The objective of the study was to scale impacts. Since it is not possible to scale zero, not all low impact facilities were modeled.

Table 4-22
Summary of AERMOD ambient concentration modeling for BTPs and seven RFs

Site Name	Pollutant	Averaging Period	Maximum Predicted Conc. (µg/m^3)	SIL (µg/m^3)	NAAQS (µg/m^3)	Class II Area PSD Increment (µg/m^3)
BTCA1	PM_{10}	24-hour	51.49	5	150[b]	30
	$PM_{2.5}$	24-hour	15.38	1.2[a]	35[c]	9[f]
		Annual	3.91	0.3[a]	15[d]	4[f]
BTPA	PM_{10}	24-hour	16.09	5	150[b]	30
	$PM_{2.5}$	24-hour	3.97	1.2[a]	35[c]	9[f]
		Annual	0.75	0.3[a]	15[d]	4[f]
BTPB	PM_{10}	24-hour	2.76	5	150[b]	30
	$PM_{2.5}$	24-hour	1.13	1.2[a]	35[c]	9[f]
		Annual	0.33	0.3[a]	15[d]	4[f]
BTPC	PM_{10}	24-hour	52.0	5	150[b]	30
	$PM_{2.5}$	24-hour	14.1	1.2[a]	35[c]	9[f]
		Annual	3.25	0.3[a]	15[d]	4[f]
BTPD	PM_{10}	24-hour	7.86	5	150[b]	30
	$PM_{2.5}$	24-hour	0.64	1.2[a]	35[c]	9[f]
		Annual	0.12	0.3[a]	15[d]	4[f]
BTPE	PM_{10}	24-hour	4.47	5	150[b]	30
	$PM_{2.5}$	24-hour	1.78	1.2[a]	35[c]	9[f]
		Annual	0.63	0.3[a]	15[d]	4[e]
BTCA2	PM_{10}	24-hour	25.84	5	150[b]	30
	$PM_{2.5}$	24-hour	6.50	1.2[a]	35[c]	9[e]
		Annual	1.96	0.3[a]	15[d]	4[e]
RFF	PM_{10}	24-hour	1.87	5	150[b]	30
	$PM_{2.5}$	24-hour	0.78	1.2[a]	35[c]	9[e]
		Annual	0.19	0.3[a]	15[d]	4[e]
RFG	PM_{10}	24-hour	1.54	5	150[b]	30
	$PM_{2.5}$	24-hour	0.64	1.2[a]	35[c]	9[e]
		Annual	0.12	0.3[a]	15[d]	4[e]
RFH	PM_{10}	24-hour	42.37	5	150[b]	30
	$PM_{2.5}$	24-hour	9.62	1.2[a]	35[c]	9[e]
		Annual	1.93	0.3[a]	15[d]	4[e]

Table 4-22
Summary of AERMOD ambient concentration modeling for BTPs and Seven RFs (continued)

Site Name	Pollutant	Averaging Period	Maximum Predicted Conc. (µg/m^3)	SIL (µg/m^3)	NAAQS (µg/m^3)	Class II Area PSD Increment (µg/m^3)
RFI	PM_{10}	24-hour	1.05	5	150[b]	30
	$PM_{2.5}$	24-hour	0.42	1.2[a]	35[c]	9[e]
		Annual	0.07	0.3[a]	15[d]	4[e]
RFJ	PM_{10}	24-hour	1.80	5	150[b]	30
	$PM_{2.5}$	24-hour	0.72	1.2[a]	35[c]	9[e]
		Annual	0.18	0.3[a]	15[d]	4[e]
RFK	PM_{10}	24-hour	18.64	5	150[b]	30
	$PM_{2.5}$	24-hour	5.45	1.2[a]	35[c]	9[e]
		Annual	0.53	0.3[a]	15[d]	4[e]
RFL	PM_{10}	24-hour	1.54	5	150[b]	30
	$PM_{2.5}$	24-hour	0.62	1.2[a]	35[c]	9[e]
		Annual	0.10	0.3[a]	15[d]	4[e]

[a] Option 1 from USEPA September 21, 2007 Rule Proposal.

[b] Not to be exceeded more than once per year on average over three years.

[c] To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 35 µg/m^3 (effective December 17, 2006).

[d] To attain this standard, the 3-year average of the weighted annual mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed 15.0 µg/m^3.

[e] Option 3 from USEPA September 21, 2007 Rule Proposal.

The NAAQS represent maximum allowable ambient concentrations. If modeled impacts from a new project exceed the SILs, then a multi-source compliance analysis is required to demonstrate that the potential impacts from the proposed project in conjunction with other background sources will not cause or significantly contribute to an exceedance or violation of a NAAQS.

The PSD increments represent a maximum increase in ambient concentration allowed in an area above a baseline concentration. PSD increments are consumed by both major PSD sources and new minor sources after the baseline date is set. In simplest terms, a new PSD project’s impact cannot be greater than the increment. It is important to note that the entire increment may not be available to a particular project. Determining the amount of increment available was beyond the scope of this evaluation.

The results of the dispersion modeling for the subset of facilities analyzed are shown in Table 4-22. A discussion of the dispersion modeling results as they apply to air permitting at each location is provided below.

BTCA1

- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are significantly greater than the SILs;
- Project is subject to NANSR; therefore, predicted impacts cannot exceed the SILs; and
- Permitting cooling towers at BTCA1 would be **very difficult** and might not be possible if impacts cannot be reduced to less than the SILs.

BTPA

- The Annual emissions of PM_{10} and $PM_{2.5}$ are greater than the Significant Emission Rates; therefore, this would be considered a major modification to an existing major source.
- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are greater than the SILs;
- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the PSD increments;
- A multi-source NAAQS and PSD increment compliance modeling analysis would be required to demonstrate that the combined potential impacts of all sources (i.e., the proposed project plus existing background sources within ~50 kilometers [km] of the project site) are less than the standards; and
- Permitting of cooling towers at BTPA is judged to be **moderate**. Permit approval would depend on the results of the multi-source compliance analysis.

BTPB

- Maximum predicted impacts of PM_{10} are less than the SILs;
- Maximum predicted impacts of $PM_{2.5}$ are slightly less than the 24-hour SIL and slightly above the annual SIL; and
- Project would be subject to state minor source permitting.
- Permitting of cooling towers at BTPB is judged to be a **minimal to moderate** effort, primarily because the plant is assumed not to be an existing major source. It is possible that the slight exceedance of the 24-hour SIL shown in Table 4-22 could be eliminated by a more detailed emission estimate and dispersion modeling that considers tower design and plant specific operating scenarios.

BTPC

- Maximum predicted impacts of PM_{10} are greater than the SILs and the PSD 24-hour Increments;
- 24-hour PM_{10} impacts would need to be reduced to less than the PSD Increment in order to obtain a PSD permit;
- A multi-source NAAQS and PSD increment compliance modeling analysis would be required for PM_{10} to demonstrate that the combined potential impacts of all sources (i.e., the proposed project plus existing background sources within ~50 km of the project site) are less than the standards;
- Maximum predicted impacts of $PM_{2.5}$ are greater than the SILs;

- The area is designated as nonattainment for $PM_{2.5}$; therefore, impacts must be reduced to less than the SILs in order to obtain NANSR approval; and
- Permitting cooling towers at BTPC would be **very difficult** and may not be possible if PM_{10} impacts cannot be reduced to less than the PSD increments and $PM_{2.5}$ impacts cannot be reduced to less than the SILs.

BTPD

- Maximum predicted impacts of PM_{10} are greater than the 24-hour SIL;
- A multi-source NAAQS and PSD increment compliance modeling analysis may be required for PM_{10} to demonstrate that the combined potential impacts of all sources (i.e., the proposed project plus existing background sources within ~50 km of the project site) are less than the standards.
- Maximum predicted impacts of $PM_{2.5}$ are less than the SILs; and
- Project would be subject to state minor source permitting.
- Permitting of cooling towers at BTPB is judged to be a fairly **standard** state minor source permitting effort which could include multi-source NAAQS and PSD increment compliance modeling. The risk of not being able to obtain a permit is considered low primarily because the estimated annual emission rates of PM_{10} and $PM_{2.5}$ are relatively low.

BTPE

- This will be a major modification to an existing major source because all Significant Emission Rates are exceeded;
- Maximum predicted impacts $PM_{2.5}$ are greater than the SILs for both averaging periods;
- Obtaining a state minor source air permit for BTPE should **not be difficult** unless the state specifically requires $PM_{2.5}$ dispersion modeling. Since $PM_{2.5}$ emissions are less than 15 tpy, the probability that modeling would be required is low.

BTCA2

- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are greater than the SILs;
- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the PSD Increments;
- A multi-source NAAQS and PSD increment compliance modeling analysis would be required for PM_{10} and $PM_{2.5}$ to demonstrate that the combined potential impacts of all sources (i.e., the proposed project plus existing background sources within ~50 km of the project site) are less than the standards; and
- Permitting of cooling towers at BTCA2 is judged to be **moderate**. Permit approval would depend on the results of the multi-source compliance analysis.

RFF

- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the SILs;
- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the PSD Increments; and

- Project would be subject to state minor source permitting. Permitting of cooling towers at this site should **not be difficult** due to the attainment status and relatively low emissions.

RFG

- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the SILs;
- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the PSD Increments; and
- Project would be subject to PSD review and require the application of best available control technology. Permitting at this site is judged to be **moderate** due to PSD review.

RFH

- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are greater than the SILs;
- Maximum predicted short-term (e.g., 24-hour) impacts of PM_{10} and $PM_{2.5}$ are greater than the PSD Increments;
- Maximum predicted long-term (e.g., annual) impacts of $PM_{2.5}$ is approximately 50 percent of the PSD Increment; and
- Permitting cooling towers at RFH would be **very difficult** and may not be possible if PM_{10} and $PM_{2.5}$ impacts cannot be reduced to less than the PSD increments.

RFI

- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the SILs;
- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the PSD Increments; and
- Project would be subject to state minor source permitting. Permitting of cooling towers at this site should **not be difficult** due to the attainment status and relatively low emissions.

RFJ

- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the SILs;
- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the PSD Increments; and
- Project would be subject to state minor source permitting. Permitting of cooling towers at this site should **not be difficult** due to the attainment status and relatively low emissions.

RFK

- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are greater than the SILs;
- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the PSD Increments;
- A multi-source NAAQS and PSD increment compliance modeling analysis would be required for PM_{10} and $PM_{2.5}$ to demonstrate that the combined potential impacts of all sources (i.e., the proposed project plus existing background sources within ~50 km of the project site) are less than the standards; and

- Permitting of cooling towers at this facility is judged to be **difficult** due to its location relative to a large city. Permit approval would depend on the results of the multi-source compliance analysis.

RFL

- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the SILs;
- Maximum predicted impacts of PM_{10} and $PM_{2.5}$ are less than the PSD Increments; and
- Project would be subject to state minor source permitting. Permitting of cooling towers at this site should **not be difficult** due to the attainment status and relatively low emissions.

4.6.2 Environmental Justice

The USEPA Environmental Justice program was created during the early 1990s in an effort to ensure that all people, without regard to “race, color, national origin, and income” are treated fairly in considering the “development, implementation, and enforcement of environmental laws, regulations, and policies” [45].

A discussion about the USEPA’s Environmental Justice program and the methodology used to make a determination on potential environmental justice areas are included in Appendix B. Table 4-23 details the ethnic makeup and income level determination at each of the seven BTPs.

Table 4-23
Environmental justice review

Site	Ethnic Makeup	Population Below Poverty Line	Assessment
BTCA1	White 80.7% Ethnic 19.3%	4.4%	Low Likelihood of Issue
BTPA	White 79.5% Ethnic 20.5%	18.3%	Low Likelihood of Issue
BTPB	White 94.7% Ethnic 5.3%	8.0%	Low Likelihood of Issue
BTPC	White 37.3% Ethnic 62.7%	16.8%	Potential Issue
BTPD	White 95.2% Ethnic 4.8%	6.4%	Low Likelihood of Issue
BTPE[a]	See Footnote	See Footnote	No Issue
BTCA2[b]	White 52.2% Ethnic 47.8%	8.5%	Low Likelihood of Issue

[a] The State has already completed an analysis for environmental justice areas within the state. This data layer was used to determine the potential impact at BTPE.

[b] This analysis did not include a nearby military base. No specific income level and ethnic makeup data for this military base are available.

Based on this assessment, a potential environmental justice issue is likely at one BTP. For the 17 RFs evaluated, a screening-level assessment was performed based on the PM_{10} modeling extent and a review of demographics to determine if a potential environmental justice issue exists (i.e., potentially impacted areas with a minority population greater than 20 percent). Based on that assessment, potential environmental justice issues are likely at RFI, RFM and RFV. Thus, this review indicates 4 of the 24 facilities studied, or 17 percent, have potential environmental justice issues.

4.6.3 Other Permitting and Environmental Issues

The minimization of potential environmental impacts, including avoidance where possible, was considered in the conceptual placement of the cooling towers at each plant. It is assumed that unavoidable environmental impacts would be minimized, as necessary, by incorporating BTA into the actual design and implementing best management practices during construction (e.g., wetlands or National Pollutant Discharge Elimination System water quality limits). Thus, for each plant, unless there is a specific regulatory prohibition of a site-specific impact, a restriction that cannot be met, or a controversial issue likely to receive public opposition, it is assumed that cooling towers can be permitted and/or approved with typical levels of effort by the appropriate agencies and groups. However, this may not always be the case. Site-specific circumstances for each plant may make cooling towers difficult to approve and/or permit. Potential issues for each BTP and RF are presented below.

4.6.3.1 BTCA1

BTCA1 is partially located within the California Coastal Zone and will need to demonstrate compliance with the California Coastal Act with approval by the California Coastal Commission. The following issues will need to be resolved [46, 47, 48, 49, 50, 51, 52, 53, 54]:

- Threatened and Endangered Species – Protected birds may be present at the facility by virtue of flyovers due to nearby critical habitat. Protected plants may also occur in the area. Species potentially present include:
  - Salt marsh bird’s-beak (*Cordylanthus maritimus* ssp. *maritimus*)–State and federally listed endangered;
  - California orcutt grass (*Orcuttia californica*)–State and federally listed endangered;
  - California brown pelican (*Pelecanus occidentalis californicus*)–State and federally listed endangered;
  - California least tern (*Sterna antillarum browni*)–State and federally listed endangered;
  - American peregrine falcon (*Falco peregrinus anatum*)–State listed endangered; and
  - Belding’s savannah sparrow (*Passerculus sandwichensis beldingi*)–State listed endangered;
- Burrowing owl (*Athene cunicularia*)–State listed species of special concern
  - This species has been observed on the plant facility site;

- Nearby Sensitive Areas – The California Department of Fish and Game recently cited a California Environmental Quality Act Environmental Impact Report for the construction of a Home Depot at a former fuel oil tank farm on the BTCA1 site as inadequate because night lighting and noise impacts to the Los Cerritos wetlands were not studied. Areas include:
  - Los Cerritos wetlands, and
  - Seal Beach Wildlife Refuge;
- Public Health/Water Quality
  - Bacteria content of waters at Alamitos Bay beaches is elevated above standards. Circulation modeling indicates a minimum sustained pumping rate of 600 cfs at BTCA1 is needed to maintain flushing sufficient to prevent violations of fecal coliform water quality standards. The estimated makeup water intake rate for cooling towers at BTCA1 (Units 3-6) would not be sufficient to maintain the recommended flow, and
  - Los Cerritos wetlands are part of the Alamitos Bay system that may be impacted by the reduced intake flow rate;
- Visible Plume – Potentially sensitive receptors include:
  - Seal Beach Wildlife Refuge;
  - Los Alamitos Armed Forces Reserve Center (airport);
  - Seal Beach Navel Weapons Station;
  - N. Studebaker Road;
  - Recreation Park and Golf Course;
  - El Dorado Park Municipal Golf Course;
  - College Park Drive (Route 22);
  - East Pacific Coast Highway (Route 1); and
  - Nearby housing communities; and
- City of Long Beach Municipal Code and Southeast Area Development and Improvement Plan
  - Building height limit of 65 ft above-grade, and
  - Noise limits for protection of nearby residential areas exceeded.

4.6.3.2 BTPA

The facility’s site is marginally within the respective coastal area defined as the land below the continuous 10-foot contour in counties.

- Threatened and Endangered Species potentially present–About eight acres of forested upland and wetland habitat will be impacted. Federally listed species known to occur in the county and identified as potentially affected by activities in forested areas could be present at BTPA in forest habitat. These are:

  - Wood stork (*Mycteria americana*)–State and federally listed endangered;
  - Eastern indigo snake (*Drymarchon corais couperi*)–State and federally listed threatened; and
  - Gopher tortoise (*Gopherus polyphemus*)–State and federally listed threatened; and
- Visible Plume – Potentially sensitive receptors include:
  - U.S. Route;
  - Southern Railroad; and
  - Burlington Northern, Inc. Railroad.

4.6.3.3 BTPB

The entire facility lies within the Coastal Zone Management Area under the jurisdiction of the State Coastal Management Program which is primarily implemented through the Natural Resources and Environmental Protection Act 1994 (PA 451). Sections of PA 451 designate natural areas to be protected by local zoning and/or state regulation. These include critical dune areas, high-risk erosion areas, wetlands, and submerged lands of the Great Lakes. Public access is also an important issue under this program.

- Critical Dune Area–Cooling tower site lies within boundaries of designated Critical Dune Areas;
- High Risk Erosion Area–Cooling tower site is across the road from a High Risk Erosion Area;
- State park to the north;
- Salt deposition on adjacent vineyards;
- Wetland Disturbances–Construction access may disturb emergent and scrub-shrub wetlands associated with a creek providing hydrology to wetland system;
- Rare, Threatened, and Endangered Species identified at the facility in 2002:
  - Caspian tern (*Sterna caspia*)–State listed threatened;
  - Straw sedge (*Carex straminea*)–State listed endangered;
  - Scirpus-like rush (*Juncus scirpoides*)–State listed threatened;
  - Red mulberry (*Morus rubra*)–State listed threatened;
  - Water-meal (*Wolffia papulifera*)–State listed threatened;
  - Carey’s smartweed (*Polygonum careyi*)–State listed threatened;
  - Purple coneflower (*Echinacea purpurea*)–State listed extirpated; and
  - Rose pink (*Sabatia angularis*)–State listed threatened;
- Rare, Threatened, and Endangered Species observed nearby and/or with potential habitat on-site:

  - Bald eagle (*Haliaeetus leucocephalus*)–recently delisted federal threatened; State listed threatened;
  - Osprey (*Pandion haliaetus*)–State listed threatened;
  - Common tern (*Sterna hirundo*)–State listed threatened; and
  - Indiana bat (*Myotis sodalis*) –Federally and state listed endangered;
- Consumptive Water Use-As a new and increased consumptive use of water to the multi-jurisdictional Great Lakes system, it may trigger cooperative consultations and reviews that, although not mandatory or regulatory in nature, may delay or constrain the use of cooling towers;
- Visible Plume - Potentially sensitive receptors include:
  - Nuclear plant security at fence line and other areas;
  - Close proximity to power lines from plant to substation and switchyard;
  - New housing development proposed just south of the property line;
  - State park;
  - U.S. Highway; and
  - CSX Railroad;
- Public Access – Potential interference with existing public access to the lakeshore; and
- NRC requirements.

4.6.3.4 BTPC

- State Coastal Zone Act–Offset requirements for environmental impacts;
- Visible Plume – Potentially sensitive receptors include:
  - Interstate Highway, and
  - Railroad; and
- New consumptive water use of cooling tower could affect water quality by influencing the location of the 250-parts per million isochlor (i.e., “salt line”) during droughts.

4.6.3.5 BTPD

This facility is located on a river impoundment created by a hydroelectric dam, one of a number of hydropower facilities and reservoirs operated by the utility with a Federal Energy Regulatory Commission (FERC) license. Water supply is a serious issue for the relicensing of this project, particularly as the relicensing process coincides with severe drought conditions for this watershed.

- Visible Plume – Potentially sensitive receptors include:
  - State park located about 2.5 miles from BTPD across the lake from the facility, and

  - U.S. Route is very close–tower distance as close as 400 ft from highway range;
- Local Ordinances and Zoning
  - General Industrial–height limitation of 50 ft;
  - Critical Watershed Protection District–impervious surface area limits; and
  - River Corridor District–river basin riparian buffer rules apply;
- Consumptive Water Use
  - Lake is a water supply reservoir and management of water availability within the context of droughts will be debated;
  - Hydroelectric Relicensing Project-Comprehensive Relicensing Agreement addresses lake management in terms of maintaining seasonal lake level ranges and restricting water use during droughts through a low inflow protocol. New consumptive water use of cooling towers is not a projected water demand considered in the Comprehensive Relicensing Agreement; and
  - New consumptive water use of cooling towers is a demand placed on the reservoir that could affect hydropower generation and water releases from the dam;
- Slopes and shoreline is a Significant Natural Heritage Area. Comprehensive Parks Master Plan states that forests adjacent to the shoreline should be protected from development, when possible;
- Great blue heron (*Ardea herodias*) rookery at ash basin; and
- Loss of fishing “hot holes”
  - The discharge from BTPD south of the U.S. Route bridge is a popular fishing spot for bass.

4.6.3.6 BTPE

BTPE is located on an impoundment on a large Northeast river created by a hydroelectric project operating under a FERC license. FERC requires specific pond elevations for varying natural flow conditions and time of year. Water use of the river, and the pond, is regulated by a basin commission under a management plan released in 2006.

- Consumptive Water Use
  - New consumptive water use of cooling towers is not a projected water demand considered in the pond management plan;
  - New consumptive water use of cooling towers is a demand placed on the pond reservoir that could affect hydropower generation by the dam and the pumped storage facility, and water release needs from the U.S. Army Corps of Engineers (USACE) flow augmentation reservoirs; and

  - New consumptive water use of cooling towers could affect FERC license -required reservoir recreational levels. The consumptive water use mitigation during low flow conditions required by the basin commission would also be increased and the amount of alternate storage required would be increased;
- Visible Plume – Potentially sensitive receptors include:
  - Pond recreational use;
  - Picnic area adjacent to facility; and
  - Nuclear plant security;
- Noise may potentially affect:
  - Pond recreational use, and
  - Picnic area adjacent to facility; and
- NRC requirements.

4.6.3.7 BTCA2

BTCA2 is within the California Coastal Zone and will need to show compliance with the California Coastal Act with approval by the California Coastal Commission. The following issues will need to be resolved [46, 54, 55, 56, 57, 58, 59, 60, 61, and 62].

- Threatened and Endangered Species (Potentially Impacted)
  - Coastal California gnatcatcher (*Polioptila californica californica*)–Federally listed threatened;
  - Western snowy plover (*Charadrius alexandrinus nivosus*)–Federally listed threatened and state Species of Concern;
  - Least Bell’s vireo (*Vireo bellii pusillus*)–Federally and state listed endangered;
  - Southwestern willow flycatcher (*Empidonax traillii extimus*)–Federally and state listed endangered;
  - Arroyo toad (*Bufo californicus*)–Federally listed endangered and state Species of Concern;
  - Coastal sage scrub species;
  - Riverside fairy shrimp (*Streptocephalus woottoni*)–Federally listed endangered;
  - San Diego fairy shrimp (*Branchinecta sandiegoensis*)–Federally listed endangered;
- Environmentally Sensitive Habitat Areas under the Coastal Act
  - Coastal California gnatcatcher habitat
    - Proposed USFWS designated critical habitat located to the north and south of BTCA2 on San Onofre State Beach;
    - Known gnatcatcher nest sites nearby in suitable habitat within a nearby military base;

    - Cooling tower locations at north and south ends of BTCA2 site near high quality gnatcatcher habitat;
    - NRC regulations may not allow artificial lighting to be shielded or angled away from gnatcatcher habitat as USFWS may require; gnatcatcher habitats may be adversely affected; and
    - 60-dbA noise threshold established by USFWS to protect gnatcatcher and other songbirds.
  - Western snowy plover habitat-USFWS critical habitat north of BTCA2 along north end of San Onofre State Beach;
  - Southwestern willow flycatcher – nesting habitat;
  - Riverside fairy shrimp-potential vernal pool habitat identified in undeveloped state park land between San Onofre Creek and Parking Lot 4 near northern location of hypothetical cooling tower;
  - Southern coastal bluff scrub habitat
    - Identified by California Department of Fish and Game as rare habitat type, and
    - Present along fence line at southern location of hypothetical cooling tower;
- Site Stability
  - While the bedrock underlying BTCA2 and outcropping at the San Onofre Bluffs fronting BTCA2 (i.e., San Mateo Formation) is not subject to the large, collapsing landslides found in the exposed bedrock immediately to the southeast of BTCA2 (i.e., Monterey Formation), some proposed towers are located very close to the bluff edge and may be affected by bluff erosion/retreat by other processes. Setback requirements are likely to be required and may affect space availability. May need to take precautions similar to placement of Units 1, 2, and 3; that is, slope armoring and construction of a seawall;
- Visible Plume, potentially sensitive receptors include:
  - Nuclear plant security;
  - Military base security;
  - Proximity of Interstate 5 and Santa Fe Railroad; and
  - San Onofre State Beach;
- NRC requirements; and
- San Diego County Ordinances
  - Noise limits, but no nearby receptors were identified;
  - Biological mitigation;
  - Natural resource protection; and
  - Coastal sage scrub habitat loss permit.

4.6.3.8 RFF

RFF is located on a bay which drains to a Great Lake.

- Threatened and Endangered Species potentially present –
  - Peregrine falcon (Falco peregrinus)–State listed endangered; Active nest on-site in 2008;
- Wetland Disturbances–Construction may disturb on-site open water and emergent/ scrub-shrub wetlands;
- Consumptive Water Use is regulated by:
  - State Department of Natural Resources;
- Visible Plume – Potentially sensitive receptors include:
  - State Highway within 50 meters;
  - Railroad;
  - Yacht Club;
  - Campground;
  - State Park within 1 km;
  - Recreational Park; and
  - Golf Club;
- Noise may potentially affect:
  - Bay and Lake recreational use, and
  - Campground and golf club adjacent to facility;
- Nearby Sensitive Areas–Areas include:
  - Wildlife Management Area located to the east of the facility along the bay area; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.9 RFG

RFG is located on a Northern river.

- Wetland Disturbances–Construction may disturb on-site open water, forest and emergent/ scrub-shrub wetlands associated with the river;
- Visible Plume – Potentially sensitive receptors include:
  - Recreational Parks;
  - Nature Preserve; and
  - Airport; and

- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.10 RFH

RFH is located on an estuary which drains into the Atlantic Ocean. Coastal Zone Management Regulations would likely be required for the construction of cooling towers adjacent to tidal waters.

- Threatened and Endangered Species potentially present–as indicated in the questionnaire for RFH.
  - Red-cockaded woodpecker (*Picoides borealis*)–Federally and State listed endangered. On-site mature longleaf pine habitat has been identified and may potentially be impacted by the cooling tower footprint and construction. Any proposed construction or facility expansion involving the removal of longleaf pine would require consultation with State and Federal agencies.
  - Wood stork (*Mycteria americana*)–Federally and State listed endangered. On-site habitat has been identified.
  - Piping plover (*Charadrius melodus*)–Federally and State-listed threatened. Previously identified on-site by plant personnel. On-site habitat has been identified;
- Wetland Disturbances–Construction may disturb freshwater emergent/scrub-shrub wetlands;
- Visible Plume – Potentially sensitive receptors include:
  - Nuclear plant security;
  - U.S. Route;
  - Recreational Park;
  - Ferry Route;
  - County Airport; and
  - Military Facility to the east of the facility;
- Noise is regulated by the local municipality and may potentially affect:
  - Bay recreational use, and
  - Military Facility;
- Nearby Sensitive Areas–Areas include:
  - Sensitive habitat for the threatened and endangered species potentially impacted by the construction of the cooling towers. There are no known USFWS designated critical habitats identified on-site, however, coordination with State and Federal agencies may be required;
- Local Ordinances and Zoning

  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower; and
- NRC requirements.

4.6.3.11 RFI

RFI is located on a Northern river.

- Visible Plume – Potentially sensitive receptors include:
  - Railroad;
  - Interstate Highway within 50 meters;
  - Recreational Park;
  - Navigable River; and
  - Residential Areas;
- Noise is regulated by the local municipality and may potentially affect:
  - River recreational use,
  - Park adjacent to facility;
  - School nearby; and
  - Residential areas; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.12 RFJ

RFJ is located on a Southwest lake.

- Wetland Disturbances–USFWS NWI wetlands mapping was unavailable for RFJ, therefore potential wetlands disturbances as a result of cooling tower construction could not be evaluated;
- Visible Plume – Potentially sensitive receptors include:
  - Residential Areas within 50-100 meters;
  - State Highway;
  - Golf Association;
  - Lake recreation; and
  - Railroad;
- Noise may potentially affect:

  - Residential Areas within 50-100 meters;
  - Golf Association; and
  - Lake recreation; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.13 RFK

RFK is located on a bay which drains into the Long Island Sound. Coastal Zone Management Regulations would apply to construction of a cooling tower adjacent to tidal waters. Proposed cooling tower locations were identified on an existing conservation easement.

- Visible Plume – Potentially sensitive receptors include:
  - Residential Areas;
  - Country Club;
  - County Park/Recreational Area;
  - Marina; and
  - Ferry Route;
- Noise may potentially affect:
  - Bay recreational use, and
  - Park and country club adjacent to facility; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.14 RFL

RFL is located on a Northern river.

- Wetland Disturbances – Construction may disturb freshwater emergent/scrub-shrub wetlands;
- Visible Plume – Potentially sensitive receptors include:
  - Navigation on river;
  - Railroad;
  - State highway; and
  - Recreation Area;
- Noise may potentially affect:

  - Recreation Area; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.15 RFM

RFM is located on a Southern river. A potential floodplain issue was identified in the location of the proposed cooling towers and would likely require a permit for construction.

- Visible Plume – Potentially sensitive receptors include:
  - State Park;
  - Golf Course; and
  - Recreation Area; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.16 RFN

RFN is located on a Northern lake along a large river.

- Threatened and Endangered Species potentially present –
  - Gray wolf (*Canis lupus*)–Federally and State-listed threatened, habitat identified on-site by plant personnel.
  - Bald eagle (*Haliaeetus leucocephalus*)–State-listed species of special concern, foraging habitat identified on-site by plant personnel;
- Wetland Disturbances–Construction may disturb on-site open water and emergent/scrub-shrub wetlands associated with the lake;
- Consumptive Water Use is regulated by:
  - The State Department of Natural Resources Water Appropriations;
- Visible Plume – Potentially sensitive receptors include:
  - State Highway within 50 meters; and
  - Railroad;
- Noise is regulated by the municipality and may potentially affect:
  - Residential areas;
- Nearby Sensitive Areas–Areas include:
  - Sensitive Environmental Areas of Impaired Waters–Large River adjacent to facility; and

- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.17 RFO

RFO is located along a Northern river.

- Threatened and Endangered Species potentially present –
  - Peregrine falcon (*Falco peregrinus*)–State-listed threatened; nest box being utilized on-site;
- Consumptive Water Use is regulated by:
  - State Department of Natural Resources;
- Visible Plume – Potentially sensitive receptors include:
  - Navigation on river;
  - State Highway within 50 meters;
  - Recreation Area;
  - Campground–largest in Upper Mississippi River Watershed;
- Nearby Sensitive Areas–Areas include:
  - Sensitive wetlands located across river from facility;
  - National Fish and Wildlife Refuge;
  - American Heritage River;
  - State Wildlife Management Area;
  - USACE Wetlands & Islands Restoration Areas; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.18 RFP

RFP is located on a Northern reservoir.

- Visible Plume – Potentially sensitive receptors include:
  - Residential Areas within 50 meters;
- Noise may potentially affect:
  - School nearby;
- Nearby Sensitive Areas–Areas include:

  - Agricultural/Croplands adjacent to facility;
- Public Health/Water Quality:
  - Facility located on a reservoir.
  - TDS concentrations may not meet water quality requirements; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.19 RFQ

RFQ located on a river in the Northeast.

- Threatened and Endangered Species potentially present–Bald eagle (*Haliaeetus leucocephalus*), State-listed endangered, foraging habitat at facility;
- Wetland Disturbances–Construction may disturb freshwater emergent/scrub-shrub wetlands;
- Consumptive Water Use is regulated by:
  - State Department of Environmental Protection; and
  - State Department of Public Health;
- Visible Plume – Potentially sensitive receptors include:
  - School located across river from facility;
- Noise is regulated by the local municipality, but no nearby receptors were identified;
- Nearby Sensitive Areas–Areas include:
  - Agricultural/Croplands adjacent to facility;
- Public Health/Water Quality
  - School located across river from plant; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.20 RFR

RFR is located along a Southern river.

- Consumptive Water Use-water withdrawal is regulated by a state/regional commission;
- Visible Plume – Potentially sensitive receptors include:
  - State Highway within 50 meters;
- Nearby Sensitive Areas–Areas include:

  - Agricultural/Croplands adjacent to facility; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.21 RFS

RFS is located along a Northern river.

- Visible Plume – Potentially sensitive receptors include:
  - Nuclear Plant Security;
  - Navigable River; and
  - State Highway;
- Nearby Sensitive Areas–Areas include:
  - Wetland areas located across the river from the facility;
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower; and
- NRC requirements.

4.6.3.22 RFT

RFT is located on a Northern river.

- Visible Plume – Potentially sensitive receptors include:
  - County Road; and
  - Residential Areas within 50 meters;
- Noise is regulated by the local municipality and may potentially affect:
  - Residential Areas within 50 meters; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.23 RFU

RFU is located on the western shore of a large river in the North central part of the United States.

- Threatened and Endangered Species potentially present–Piping plover (*Charadrius melodus*)–State and Federally listed as endangered; was identified on the questionnaire by plant personnel as present at the facility;
- Consumptive Water Use is regulated by:
  - State Water Commission;
- Visible Plume – Potentially sensitive receptors include:
  - County Road;
  - Scenic Waterway; and
  - Navigable Waterway/Boat Landing;
- Noise:
  - There were no noise receptors identified adjacent to the facility, however, it is regulated by the municipality; and
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower.

4.6.3.24 RFV

RFV is located on a Southeast reservoir.

- Consumptive Water Use is regulated by:
  - State Department of Natural Resources;
- Visible Plume – Potentially sensitive receptors include:
  - Nuclear Plant Security;
  - County Road; and
  - Residences within 50 meters;
- Noise is regulated by the local municipality and may potentially affect:
  - Residences within 50 meters;
- Public Health/Water Quality:
  - Facility is located on a reservoir;
- Local Ordinances and Zoning
  - Local ordinances, permits, and zoning requirements would likely be required for construction of the cooling tower; and
- NRC requirements.

The relative impact of major permitting issues, in addition to air, to the permitting effort at each facility is summarized below in Table 4-24. The issues identified in this table are likely to need resolution during the environmental approval and permitting process for each facility.

Table 4-24
Summary of permitting issues for BTPS and RFs

Facility	Permitting Issues
BTCA1	Protected Species and Critical Habitat Water Quality[a] Noise Limits Height Ordinances Visible Plume
BTPA	Protected Species Wetlands Visible Plume
BTPB	Critical Dune Area and Habitat Protected Species Great Lakes Consumptive Water Use NRC Requirements Noise Ordinances Salt Drift Visible Plume
BTPC	Environmental Justice State Coastal Zone Act Consumptive Water Use Visible Plume
BTPD	Height Restrictions Natural Heritage Area and Protected Species Consumptive Water Use Noise Ordinances Visible Plume
BTPE	Consumptive Water Use Noise Ordinances NRC Requirements Salt Drift Visible Plume
BTCA2	Protected Species and Critical Habitats Bluff Stability NRC Requirements Visible Plume
RFF	Consumptive Water Use Wetlands Protected Species Visible Plume

Table 4-24
Summary of permitting issues for BTPS and RFs (continued)

Facility	Permitting Issues
RFG	Wetlands Noise Ordinances Visible Plume
RFH	Protected Species and Critical Habitats Coastal Zone Management Regulations Wetlands Ecologically Sensitive Areas Noise Ordinances NRC Requirements Salt Drift Visible Plume
RFI	Environmental Justice Salt Drift Visible Plume
RFJ	Limited Data Available Noise Ordinances Salt Drift Visible Plume
RFK	Coastal Zone Management Regulations Salt Drift Visible Plume
RFL	Wetlands Noise Ordinances Visible Plume
RFM	Environmental Justice Floodplain Construction Noise Ordinances
RFN	Protected Species Wetlands Ecologically Sensitive Areas Noise Ordinances Consumptive Water Use Visible Plume
RFO	Consumptive Water Use Protected Species Ecologically Sensitive Areas Salt Drift Visible Plume
RFP	Ecologically Sensitive Areas Noise Ordinances Visible Plume

Table 4-24
Summary of permitting issues for BTPS and RFs (continued)

Facility	Permitting Issues
RFQ	Consumptive Water Use Protected Species Wetlands Ecologically Sensitive Areas Visible Plume
RFR	Consumptive Water Use Ecologically Sensitive Areas Visible Plume
RFS	Ecologically Sensitive Areas NRC Requirements Visible Plume
RFT	Noise Ordinance
RFU	Consumptive Water Use Protected Species Visible Plume
RFV	Consumptive Water Use Noise Ordinance NRC Requirements Environmental Justice Visible Plume

[a] The decrease in flow through the Los Cerritos Channel has been identified as a potential water quality issue.

4.6.4 Uncertainty

A source of uncertainty with the permitting analysis lies in limited site-specific knowledge of issues requiring atypical levels of regulatory scrutiny, which could adversely affect project feasibility, cost, permitting schedule, and permitting ability.

It is expected that some potential environmental impacts requiring permits (e.g., wetland loss, water quality of discharge) will be avoided and minimized such that permits will be issued without prohibitive delays or costs through the negotiation of permit conditions, such as mitigation and monitoring. However, the identification of site-specific issues for which there could be extensive regulatory concern and public opposition relied on information with limited substantiation (e.g., questionnaires and potential regulatory/approvals information available through the Internet) without the benefit of contacting regulatory and public stakeholders to assess the site-specific “regulatory climate” at each site. Federal, state, local, or regional permitting issues could prolong and/or preclude necessary permits and approvals.

In addition, many assumptions were applied in the development of the conceptual designs of the cooling towers at each facility. The variability in the number of units, footprint, location, and physical dimensions of the cooling towers that would actually be feasible and appropriate to install at each facility adds uncertainty when identifying permitting issues likely to be encountered and the degree of difficulty in successfully obtaining all required permits and approvals for the retrofit.

4.7 Greenhouse Gases

4.7.1 Quantification

'Greenhouse gases' such as water vapor, carbon dioxide (CO_2), methane, nitrous oxide and chlorofluorocarbons absorb and re-emit some of the Earth's outgoing thermal radiation, and elevate the Earth's temperature over what it would be without these gases. The appropriate amount of greenhouse gases is essential to Earth's habitability. Excessive amounts of greenhouse gases in the atmosphere may increase the global temperature, and with it, the amount of water vapor in the atmosphere via evaporation from the oceans. Increases in anthropogenic emissions of greenhouse gases have been implicated as promoters of 'climate change.'

The relative importance of a greenhouse gas depends on its abundance and radiating capacity. Therefore, the most important of the greenhouse gases is water vapor; the greenhouse effect of water vapor accounts for approximately 96 percent of the total greenhouse effect of all greenhouse gases, but its abundance in the atmosphere has not changed significantly [64]. However, increased atmospheric temperature may, according to some hypotheses, increase the vapor-holding capacity of the atmosphere and enhance the greenhouse effect of water vapor in the atmosphere [65]. Because there are no restrictions on water vapor emissions to the atmosphere and the greenhouse effect of water vapor emitted from cooling towers has not been studied, water vapor will not be discussed further.

CO_2 as a greenhouse gas has received a lot of attention because the anthropogenic emissions rate of CO_2 has increased over the past 100 or so years. In the United States, over 40 percent of anthropogenic CO_2 emissions are due to the combustion of fossil fuels for electricity generation [66]. The emission of CO_2 by fuel source and electricity generation by fuel source data are provided in the following table [4, 66].

If electricity generating facilities currently utilizing once-through cooling systems were to be retrofitted with closed-cycle cooling and optimize their condensers, those facilities that remain online during the retrofit would be required to makeup for the loss in electricity generation. While most fossil-fueled facilities are not anticipated to optimize their condensers because of cost and expected remaining facility lifetime, nuclear plants, will likely optimize to avoid the energy penalty and/or will require extended outages for other reasons. When nuclear plants go offline, their power is expected to be replaced primarily by a mix of fossil fuel plants, because the nuclear fleet is baseloaded (i.e., operate at near full capacity throughout the year). Thus, CO_2 emissions are expected to increase as fossil-fueled facilities makeup for lost generation at nuclear plants.

Table 4-25
Percent CO_2 emission and electricity generation in the United States by fuel source

	Electricity Generation (percent)	CO_2 Emissions Due to Electricity Generation (percent)
Coal	59%	80%
Natural Gas	11%	15%
Petroleum	2%	5%
Nuclear	17%	0%
Hydroelectric	11%	0%
Other (renewable energy sources, solid waste, etc.)	Negligible[a]	0%

[a] This percentage may increase based on the national effort to increase electric generation from biomass-based renewables.

Data on the duration of extended outages for retrofits are limited. EPRI's Closed-Cycle Retrofit Study estimated an average extended outage of six months for nuclear units. To account for uncertainty, estimates of extended outages for eight months are also considered in this study. The same 'mix' of fuels and facilities that currently generate electricity are also expected to be available to provide electricity during the retrofit. As detailed in Appendix B, approximately 1.341 pounds of CO_2 per kilowatt-hour of net generation (lbs/kWh) are emitted from the current 'mix' of fuels and facilities [66].

Table 4-26 projects potential additional CO_2 emissions if the current 'mix' of facilities were to compensate for the loss of electricity generation at representative nuclear facilities during the potential closed-cycle cooling retrofits. Calculation methodology and assumptions are provided in Appendix B.

The total CO_2 emission from all electricity-generating facilities in the United States in 1999 was approximately 2.47 billion tons [66]. The total CO_2 emission due to a 6-month outage at the six modeled nuclear facilities alone is calculated herein as approximately 29 million tons. This represents 1.2 percent of all CO_2 emissions from power plants in 1999. If an 8-month outage is assumed, the total CO_2 emissions are approximately 39 million tons, or 1.6 percent of all CO_2 emissions from power plants in 1999.

Table 4-26
CO_2 Emissions due to potential closed-cycle cooling retrofits at nuclear BTPs and RFs

Nuclear Facility	Estimate of CO_2 Emissions Due to an 6-Month Outage Period (million tons)	Estimate of CO_2 Emissions Due to an 8-Month Outage Period (million tons)
BTPB Unit 1	2.60	3.47
BTPB Unit 2	2.77	3.69
BTPE Unit 2	3.06	4.08
BTPE Unit 3	3.12	4.16
BTCA2 Unit 2	2.79	3.72
BTCA2 Unit 3	2.69	3.59
RFH Unit 1	2.62	3.49
RFH Unit 2	2.53	3.37
RFS Unit 1	2.15	2.87
RFS Unit 2	2.04	2.72
RFV Unit 1	2.68	3.58

In addition to the increase in electricity generation required of the remaining facilities, the bulk of which would be at fossil-fueled facilities, during the nuclear retrofit downtime, facilities would also be required to provide the additional electricity required to operate (a) the pumps and fans associated with the cooling towers (i.e., makeup for parasitic losses), and (b) potentially makeup for the lowered condenser efficiency due to the potentially higher temperature of the closed-cycle cooling water (i.e., makeup for the energy penalty). While the additional CO_2 emissions associated with parasitic losses and the energy penalty at retrofitted fossil fuel-fired power plants currently employing once-through cooling are presently not accounted for in this report, the incremental emission of CO_2 is thought to be in excess of that associated with the calculation above for nuclear plant retrofits. The U.S. Department of Energy has estimated that energy penalty associated with retrofit to wet cooling towers as:

- 2.4 to 4.0 percent for the hottest months of the year
- 0.8 to 1.5 percent for the annual average temperature conditions.

The replacement of this lost power with the current mix of generation may result in millions of tons of additional CO_2 emission.

4.7.2 Monetization

The existence of the carbon sequestration market reveals a societal WTP to avoid increased CO_2 emissions. In the voluntary offset market, approximately 24 million tons of sequestration was purchased at an average price of $3.80 per ton in 2007$ [67, 68], with smaller scale projects averaging around $5 per ton and larger scale projects averaging around $2 per ton. This WTP can be interpreted as a lower bound estimate of society's current WTP to avoid greenhouse gas emissions.

WTP to avoid any net marginal change in the volume of CO_2 emitted in the near term can be estimated as

$$TotalWTP = \sum_{t=2007}^{T} \Delta C_t \times \$3.80 \div (1+r)^{t-2007}$$

where T indexes year, ΔC_t is the change in tons of CO_2 emitted in year t, and r is the rate of discount. The average annual WTP is estimated by amortizing over the expected cooling tower lifespan.

To facilitate a direct comparison to other annual values reported herein, average annual WTP to avoid a one-time increase in CO_2 due to a retrofit-related shutdown at any individual nuclear facility is estimated as

$$AnnualAverageWTP = rWP \div \left((1+r)^n - 1\right),$$

where r is the discount rate, W is tons of CO_2 not released, P is the WTP per ton ($3.80), and n is the year of the CO_2 release.

These estimates are reported in Table 4-27. As discussed in the uncertainty section, the estimates reported are highly uncertain and must be interpreted with caution.

Table 4-27
Annual monetized impacts associated with a one-time increase in CO_2 at nuclear BTPs and RFs

Nuclear Facility and Unit	Million Tons of CO_2 (6-Month Outage Period)	Annual WTP to Avoid CO_2 Emitted in the Year 2037 (6-Month Outage Period) (2007$)	Million Tons of CO_2 (8-Month Outage Period)	Annual WTP to Avoid CO_2 Emitted in the Year 2037 (8-Month Outage Period) (2007$)
BTPB Unit 1	2.60	$207,900	3.47	$277,200
BTPB Unit 2	2.77	$220,900	3.69	$294,600
BTPE Unit 1	3.06	$244,600	4.08	$326,100
BTPE Unit 2	3.12	$249,200	4.16	$332,200
BTCA2 Unit 2	2.79	$223,100	3.72	$297,400
BTCA2 Unit 3	2.69	$215,300	3.59	$287,000
RFH Unit 1	2.62	$209,200	3.49	$278,900
RFH Unit 2	2.53	$202,000	3.37	$269,300
RFS Unit 1	2.15	$171,700	2.87	$229,000
RFS Unit 2	2.04	$163,100	2.72	$217,500
RFV Unit 1	2.68	$214,300	3.58	$285,700

Note WTP values rounded to the nearest $100.

4.7.3 Uncertainty

4.7.3.1 Quantification

The sources of uncertainty associated with the quantification of greenhouse gas emissions include:

- The composition of available capacity in the U.S. power plant fleet influences the quantification. If all makeup generation were to be with coal, the amount of additional CO_2 emitted may be as much as 49 percent greater than estimated. If makeup generation included a greater percentage of hydroelectric, nuclear, and other renewable energy-fueled facilities, the amount of additional CO_2 emitted would decrease;
- Required downtime at nuclear facilities is expected to vary. EPRI acquired five site specific closed-cycle cooling retrofit studies for nuclear facilities that indicated outages ranging from a few months to 22 months;
- A phased policy implementation similar to the Draft California policy would allow nuclear facilities an extended period of time to retrofit. Under that scenario, they may time the retrofit to coincide with a scheduled outage and so there would be a smaller net change in CO_2 emissions;
- The actual carbon and heat content of fuels differ by region, and these variations are not captured in this report; and
- The amount of CO_2 generated from concrete production necessary for cooling towers and basins was not quantified. Concrete production may be a considerable source of CO_2 and therefore, the absence of this value in the estimate of impacts likely biases the estimates low.

4.7.3.2 Monetization

There are five significant uncertainties associated with this estimate of WTP:

1. Instead of estimating the change in CO_2 by year associated with the identification of cooling towers as BTA (which would include changes in the composition of the generating fleet), the CO_2 emissions associated with nuclear plant shutdown were estimated. Focusing on only this one component of the CO_2 change represents a partial analysis. For fossil plants, a retrofit requirement will result in increased generation as a result of inefficiencies for facilities that retrofit to closed-cycle cooling caused by the energy required to operate cooling tower fans and water pumps, as well as a reduced heat rate at most facilities. However, this would likely be offset to an unquantified degree by the premature retirement of other fossil units that would be unprofitable to retrofit.
2. Rational economic consumers would link WTP to avoid future CO_2 emissions to the economic and environmental costs associated with those emissions. Often referred to as the social cost of carbon, published estimates range from negative numbers to several hundred dollars per ton of CO_2 emitted. Uncertainty associated with social cost of carbon estimates increases uncertainty surrounding WTP to avoid future CO_2 emissions;

3. The WTP estimate of $3.80 per ton is based on an observed WTP for marginal changes in the voluntary CO_2 market. The changes being valued are non-marginal compared to the volume of CO_2 trades made on the voluntary market; therefore, the use of $3.80 per ton may not be appropriate;
4. Voluntary CO_2 trading is currently a relatively small market characterized by high price variability. For example, in 2010 offset prices approximately doubled to $8 per ton on news of the adoption of a large-scale cap-and-trade program in California. WTP would be greatly affected by a nationwide policy initiative that significantly reduced allowable CO_2 emissions in the future. Whether such a policy would tend to increase or decrease WTP is dependent upon the future level of allowable CO_2 relative to the perceived socially optimal CO_2 emission level; and
5. The cost of carbon sequestration may decrease as technological innovation permeates this emerging market. If so, the assumption of $3.80 per ton through time may overstate true WTP for future changes associated with this one component of potential overall change in CO_2.

It is unclear whether these uncertainties, when taken as a whole, bias the current estimate towards over or under-estimation.

4.8 Aquatic Biota

Potential beneficial effects to aquatic biota associated with power plant cooling systems conversion from once-through to closed-cycle cooling are associated with reduced water withdrawal for use as condenser cooling water. The conversion from once-through to closed-cycle cooling results in a significant decrease in the amount of cooling water withdrawn from the waterbody and an assumed subsequent decrease in IM&E per USEPA’s remanded Phase II rulemaking [5]. Quantification of the potential effects of the operation of mechanical-draft evaporative cooling towers was assessed in terms of the changes in IM&E of fish and shellfish, and does not address issues such as entrainment survival that can be significant at some facilities. These assumptions are consistent with USEPA’s approach in the now remanded Phase II rulemaking [5].

The current levels of impingement and entrainment (if available) were compared with IM&E reduction achievable with mechanical-draft evaporative cooling towers at each facility [5]. Note that EPRI’s research has shown no compelling relationship between volume of water withdrawal and the status of fish populations. Even when a high volume of water is withdrawn, fish abundance in source waterbodies is shown to remain high. A decrease in community health with increasing water withdrawal [69] is found when metrics of community health are applied. However, the slope of the relationship is so small as to make it of little practical value. In fact, when sport fish populations were analyzed in Tennessee Valley Authority reservoirs, it was found that their numbers significantly increased with increasing withdrawals [69]. Thus there is evidence that IM&E losses are not biologically significant. Nevertheless, this assessment uses USEPA’s Phase II rulemaking approach.

The benefit of reduced entrainment of planktonic organisms is not included in the USEPA's Phase II rulemaking and likewise, not addressed in this report. USEPA has determined that there is "low potential impact" for phytoplankton and zooplankton communities associated with once-through cooling primarily because of their high reproductive capacity and life cycles (i.e., days or weeks) [70].

The potential cumulative benefit to a waterbody associated with the reduction of IM&E impacts from multiple plants on the same waterbody is not considered in the individual plant analysis. This may underestimate the potential benefits of reduced water withdrawal to a specific waterbody with multiple plants.

The effects of reduced thermal discharge are not addressed in this report. In order for a facility with once-through cooling to operate, it must meet temperature water quality standards at the edge of an approved mixing zone or demonstrate maintenance of a balanced, indigenous population of fish and other aquatic organisms through a CWA §316(a) variance. The potential magnitude and sign (positive or negative) of thermal effects and the associated monetized value or WTP is beyond the scope of this research. More detail on the environmental benefits of closed-cycle cooling can be found in a separate study on that subject, which is part of the EPRI's overall Closed-cycle Cooling Retrofit Research Program.

4.8.1 Quantification

The quantification of the existing impingement mortality (IM) and entrainment (IM&E) is based on recent data from each facility (See Appendix A). No impingement survival data are available for most Phase II facilities, including most of the BTPs and RFs, because specific survival studies to document survival rates are not often performed or no fish return system exists at the plant. Therefore, measures of impingement are used as surrogates for IM with the assumption of 100 percent mortality (i.e., assuming all organisms impinged on the screens are lost). Impingement survival data were available for BTPC and RFO and were therefore used in this evaluation; impingement rates were used for the other BTPs and RFs. "Impingement" and "impingement mortality" or "IM" will be used interchangeably in this report to represent calculations and assessments made using the impingement or IM data, as available.

Note many facilities located on large rivers, lakes and reservoirs were not required to collect entrainment data. Whenever possible, annualized numbers of fish and shellfish (i.e., crabs, shrimp, and lobsters where applicable) are based on actual plant flow instead of design flow baseline numbers. If actual flow data were not available for a facility, estimates were made based on design flow and the five-year average annual hours of operation.

Annualized IM and annualized entrainment estimates were made separately for the facilities where entrainment data were available. These estimates were calculated for a subset of dominant representative species. Representative species are taxa comprising at least 90 percent of the total number of organisms susceptible to IM&E and any threatened and endangered species. Age 1 equivalents, forgone fishery yield and forgone production for each representative species and non-representative species group were calculated following the methods and life history information provided in Appendix H[7]. Annualized estimates are based on the technology that existed at the time of the data collection or based on technology to be installed at the facility (See Appendix A). Species were classified as commercial, recreational, or forage was based on USEPA determinations in the Phase II Rule [71]. The estimated losses are reduced by the percentage of flow reduction potentially achievable with mechanical-draft evaporative cooling towers at that location. This assumes a 1:1 relationship between flow reduction and IM&E consistent with the remanded Phase II rulemaking even though preliminary analysis of the Impingement and Entrainment Database by EPRI has determined there is no relationship (with a few exceptions) between flow and IM&E for most waterbody types and regions of the U.S.

A total of 26 facilities were modeled, representing a range of waterbody types and fisheries populations. The modeled facilities include seven plants from the Beta Test, 17 RFs and two additional facilities to augment the Ocean/Estuary/Tidal River category. That category was considered underrepresented because of the large number of facilities and diversity of aquatic populations. The results for each of these facilities are reported in Appendix H, Tables H-31 through H-38. The detailed methods and assumptions are also provided in Appendix H.

4.8.2 Monetization

Benefits transfer and the methods outlined by USEPA in its 316(b) Phase II and III regional benefits assessment were used to estimate WTP to avoid the assumed loss of foregone recreational harvest, foregone commercial harvest, and foregone production [71, 72][8]. These include:

- WTP for recreationally harvested species was based on per fish/shellfish consumer surplus;
- WTP for commercially harvested fish and shellfish species was based on a per pound producer surplus; and
- WTP for forage fish/shellfish was estimated by converting the foregone prey biomass into potential reductions in the harvest of commercial and recreationally important species.

USEPA has noted that non-use values may arise if individuals value environmental changes apart from any personal past, present, or anticipated future use of the resource in question. Non-use values can be associated with use of a resource by others, either now or in the future; there may also be non-use values that are not associated with any use of a resource, by anyone, ever. USEPA has also noted that the potential existence of non-use values, as they relate to IM&E of aquatic organisms, is limited to situations where IM&E is judged to alter the viability of a species or materially impair ecosystem functioning (71 FR 35006-35046). As such, if IM&E is judged to alter the viability of a federally listed species and/or if IM&E is judged to materially alter ecosystem functioning, site-specific WTP estimates may include non-zero non-use values. Under all other circumstances, the non-use value is set to zero.

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[7] Twelve plants provided both impingement and entrainment data and 14 provided only impingement data. For these plants, modeling to estimate Age 1 equivalents, forgone yield and forgone production was performed as described in Appendix G. Two plants (BTPC and BTPD), provided the data as Age 1 equivalents, therefore forgone yield and forgone production were calculated from those data using the established methods.

[8] Increased recreational and commercial harvest rates are considered to be favorable outcomes of closed-cycle cooling; therefore WTP to avoid these impacts is a negative number. For ease of reading, the negative sign is omitted until calculation of a net WTP in the summary section.

Results of the monetization of IM&E are provided below in Appendix H, Tables H-31 through H-38 and summarized in Table H-39.

4.8.3 Uncertainty

4.8.3.1 Quantification

Annualized IM&E forms the basis of the aquatic biota impact analysis. The magnitude of impingement and entrainment can be influenced by natural variation in fish populations due to interactions with other species, climate and weather variability, changes in harvest rates, changes in fish movements and migrations, recruitment strength, and other variables, which may change from year to year. An example of this takes place at BTCA2, which impinged over 3.5 million fish in 2003 and 1.4 million fish during 2004 with no operational changes between years [73, 74]. This yearly variability is not captured in the current investigation as IM&E data from consecutive years were averaged. This variability in IM&E may be emphasized at facilities where a single species dominates impingement or entrainment samples. In many cases, forage species such as gizzard shad are the dominant species in freshwater and their populations are highly variable. Note that EPRI will publish a National Benefit Valuation Report that will analyze many more facilities and address other factors affecting quantification of impingement and entrainment reduction benefits.

Seven of the 26 facilities for which IM&E was quantified do not use standard 3/8-inch mesh screens in their intake structures. Six of those seven facilities use smaller mesh sizes and it is expected that the impact due to impingement at these facilities is greater than if standard mesh was used. The opposite is expected from BTCA1, the only facility using a larger mesh size. It is uncertain whether these changes in impingement impacts are offset when both entrainment and impingement are quantified.

Plant operations, including planned and unplanned shutdowns for maintenance purposes, may vary from year to year and affect IM&E losses, especially during times when IM&E are typically high. Cooling water pump shutdowns due to reduced capacity utilization may also lower approach velocities, thereby reducing IM even though water is still being passed though the intake structure.

The reduction in IM&E was calculated as the percent reduction of cooling water associated with closed-cycle cooling. However, the calculation does not include service water. Therefore, the percent reduction in cooling water and associated reduced IM&E is overestimated.

For quantification of IM&E, 100 percent mortality of all organisms impinged or entrained was assumed unless survival was quantified in the reports provided by the facility. This is a conservative assumption because mortality of impinged and entrained organisms has been shown to be less than 100 percent for facilities that have debris/fish return systems and low cross-condenser temperature rise [75].

The impacts are based solely on impingement and entrainment losses of fish and shellfish and do not account for losses of other tropic levels or aquatic organisms. They also do not consider non-use benefit that may be valued by some stakeholders.

Finally, recent entrainment data are not available for facilities on large rivers, lakes and reservoirs (BTPD, BTPE, RFG, RFJ, RFL, RFM, RFN, RFO, RFP, RFQ, RFR, RFS, RFU, and RFV), which prevents quantification of entrainment impacts at these sites. The lack of entrainment data will underestimate the benefit of closed-cycle cooling. Furthermore, entrainment data at BTPC, RFH, and RFN do not include eggs which may add to this underestimate.

4.8.3.2 Forgone Yield and Production Modeling

Certain species-specific parameters (i.e., life history data) can affect model output substantially. Mortality estimates for early life stages are of particular importance as they affect those stages during which impingement and entrainment losses are greatest. Stage weight also plays an integral role in both the calculation of forgone yield (commercial and recreational) and forgone production. An overestimation of weight at life stage results in inflated forgone estimates while the opposite is true if weight at life stage is underestimated. Further uncertainty arises due to the lack of life history data specific to each species and that life history parameters may change throughout the geographical range a species inhabits. Finally, the inability to identify to species at the very early life stages of some organisms adds uncertainty to the estimate.

4.8.3.3 Monetization

There are multiple uncertainties and omissions in this complex analysis. Key factors are briefly discussed here.

Timing of benefits delivery – USEPA’s methods suggests that annual WTP can be estimated as a linear function of the expected lifetime yield of a cohort of saved fish. This is a reasonable approximation if the fish in question mature quickly and are very short-lived (complete life cycle in one or two years). For long-lived fish that mature slowly, the USEPA methods result in an overestimate of annual WTP [71].

The magnitude of the bias increases as the lag time between saving a fish and the time when it can be harvested increases. For longer-lived species, the bias can be as high as 10 to 20 percent. Timing of benefits delivery was included for striped bass, a long-lived species with high value and a well-identified age class distribution in the harvest data. It was not incorporated for other species.

Shellfish harvest – It was generally assumed that all shellfish harvested were taken by commercial fishermen. To the extent that, for any given species, a non-trivial proportion of the individuals harvested are taken by recreational fishermen, and if recreational and commercial values are significantly different, WTP to avoid IM&E of shellfish may be over or under-estimated.

Addition of losses associated with forage and recreational fish – USEPA methods suggest that forage fish value is a function of the number of commercial/recreational fish that would have been produced had these forage fish not been removed from the ecosystem by IM&E because commercial and recreational fish are limited by food availability. USEPA methods simultaneously suggest that if IM&E of commercial/recreational fish are reduced, catch rates among commercial and recreational fishermen will increase (commercial and recreational fish are limited by the balance between the maximum intrinsic growth [in numbers] of the fish populations and the mortality associated with the harvest). Because both forage availability and the balance between population growth (in numbers) and harvest cannot simultaneously limit a system, deriving a benefit estimate as the sum of a forage fish component and a commercial/recreational component is theoretically inconsistent. This biases the WTP estimate toward overestimation.

Negative value of invasive/aquatic nuisance species is not incorporated – Reductions in IM&E necessarily reduce the number of invasive/nuisance species entrained or impinged. This in turn, may result in more invasive/nuisance species in the waterbody. The increase in these species could have two possible effects, each of which reduces the benefits of IM&E reduction. The two possible effects are:

- The invasive/nuisance species could directly compete with and displace native/desirable fish species; and
- The invasive/nuisance species may alter the probability of invasive/nuisance introductions to other waterbodies that lead to a cascading ecological failure.

Entrainment data for BTPD, BTPE, RFG, RFJ, RFL, RFM, RFN, RFO, RFP, RFQ, RFR, RFS, RFU, and RFV are not available – WTP to avoid a reduction in entrainment at these facilities has been omitted because of lack of recent data due to the exemption from the entrainment standard for these facilities in the remanded Phase II Rule. This biases the WTP estimates toward underestimation.

Use of values associated with groups of fish – WTP to avoid fish mortality is dependant upon the species of fish in question. This report places similar species into groups and assigns a ‘per fish’ value to all species in the group. The approach is appropriate for estimating national WTP. However, results at any one facility may be biased towards over or under estimation if IM&E at that facility is dominated by only one or two species in a group.

None of the facilities investigated reported IM&E that altered the viability of a species or impaired ecosystem function - Had IM&E been judged to alter the viability of a species or materially impair ecosystem functioning, non-use value may exist and some economists believe these non-use values could be large. Additionally, if IM&E impacts were judged to alter species viability or ecosystem functioning, existing statutes would likely require that facilities address the issue.

4.9 Uncertainty Summary for BTPs and RFs

The three environmental changes that have significantly higher WTP are also the three most uncertain. Uncertainties associated with the calculation of human health impacts, greenhouse gas changes, and aquatic biota benefits are summarized in this section, along with other general uncertainties associated with the BTP and RF evaluations.

Potential human health impacts are not reliably quantifiable due to a lack of human health impact studies focused on cooling tower fine particulates. Any impacts, if present, are likely to be highly variable depending on the nature of the fine particulates in the source waterbody. Therefore, quantification of potential risk of exposure to increases in PM and monetization of the WTP to avoid human health impacts were not included in this evaluation. However, conservative estimates made using USEPA methodology would indicate that the upper range of WTP values could be between $2,100 and $682,400 per facility (Appendix G). Due to lack of research on cooling tower PM, EPRI indicates the low end risk estimate could approach zero. The result is there is considerable uncertainty in these estimates. However, when the reported human health impacts are monetized, monetization omits potential WTP to avoid impacts to age classes not included in the assessment and WTP to avoid morbidity-related pain and suffering. This biases monetization of the reported impact in a downward direction.

The existence of a voluntary carbon sequestration market implies a WTP to avoid increases in CO_2 emissions. However, this market is still in its infancy and WTP estimates through time are therefore highly uncertain. The currently revealed WTP combined with the potential magnitude of CO_2 changes suggests that WTP to avoid CO_2 increases related to closed-cycle cooling alone equals or exceeds the benefits associated with reduced IM&E (Table 6-6) for nuclear facilities.

There are multiple omissions and uncertainties associated with the estimate of the WTP to avoid IM&E reductions. USEPA methods were used to capture all direct use and indirect use, and to determine that at the facilities evaluated, the potential for non-use values is *de minimus*. However, USEPA methodology embodies several assumptions that tend to bias WTP toward overestimation:

- WTP to avoid harvest level changes and WTP to avoid production foregone are additive when WTP is the greater of the two;
- Zero entrainment survival is assumed when many studies indicate entrainment survival;
- The benefit of entraining and impinging invasive species is not captured; and
- It is assumed that compensatory growth and survival among impacted fish populations is not occurring, when it likely occurs in all or most populations to some extent.

However, the above uncertainties are offset to an unknown extent as a result of not considering losses to organisms other than fish and shellfish or non-use value that may be important to some stakeholders (e.g., protected species).

In addition, there are uncertainties in the assessment not associated with monetization that impact the final WTP value. Among others, these include interannual variability in IM&E and lack of entrainment data at some facilities. The multiple uncertainties and the overall sign and magnitude of bias associated with the IM&E WTP estimates are discussed in detail in a separate study on that subject which is part of the EPRI's overall Closed-cycle Cooling Retrofit Research Program.

Lastly, it was beyond the scope of this study to consider cumulative impacts of different impact types for individual BTPs or RFs or cumulative impacts for multiple facilities located in close proximity (e.g., some of the California facilities). While these limitations contribute uncertainty to the results, the direction and magnitude of bias is unclear.

Table 4-28 provides a summary of the uncertainties associated with estimating environmental and social impacts associated with a national retrofit to closed-cycle cooling at Phase II facilities. The general direction and magnitude of bias is provided for each issue evaluated in this project.

Table 4-28
Summary of assumptions, effects not addressed, and potential bias of environmental and social impacts

Category	Quantified	Monetized	Comments/Assumptions	Potential Bias
Human Health				
Legionnaire's Disease	No	No	• Quantification not currently possible • Assumed controlled by halogenation	-
Population Exposed to Increased PM	Yes	No	• Reliable quantification of the risks associated with increased PM exposure (i.e., morbidity and mortality) is not currently possible	-/--
Long-term Loss of Non-unique, Non-rare Habitats	Yes	No	• No WTP data are available	SS -
Long-term Loss of Unique, Rare Habitat	Yes	Yes	• Off-site impacts are uncertain and not included	SS -
Salt/ Mineral Drift Impact to Native Vegetation	Yes	No	• No WTP data are available	SS -

Table 4-28
Summary of assumptions, effects not addressed, and potential bias of environmental and social impacts (continued)

Category	Quantified	Monetized	Comments/Assumptions	Potential Bias
Terrestrial Resources				
Salt/Mineral Drift Impact to Agricultural Soil	Yes	Yes	• Impact site-specific • Only one BTP is located near agricultural fields	SS -
Noise Impact to Terrestrial Wildlife	Yes	No	• Potential impact to threatened and endangered species difficult to quantify	SS -
Fogging/Icing Impacts on Terrestrial Vegetation	Yes	No	• No WTP data are available	SS -
Bird, Bat, and Insect Collisions/ Entrainment into Cooling Tower	No	No	• Survey suggest this is a minor issue for most facilities • May be of concern to threatened and endangered species	SS -
Salt Damage to Off-site Property	Yes	No	• No WTP data are available • Potential for impact to electrical equipment	SS --
Water Resources				
Evaporative Water Loss (Potable Water)	Yes	No	• No WTP data are available for loss of potable water	SS --
Biocides and Trace Metal Discharge	No	No	• Assumes that cooling tower blow down must meet water quality standards or have an approved mixing zone • Life cycle impacts associated with hazardous chemical are not addressed	SS -

Table 4-28
Summary of assumptions, effects not addressed, and potential bias of environmental and social impacts (continued)

Category	Quantified	Monetized	Comments/Assumptions	Potential Bias
Waste				
Debris Removal	Yes	Yes	• Site-specific • Data missing at numerous facilities • Reduction in cooling water usage does not include service water	SS – +
Solid Waste Generated by Cooling Tower	No	No	• Survey suggest this is a minor issue for most facilities • Site-specific treatment of sludge as toxic	SS -
Public Safety/Security				
Icing of Roadways	Yes	No	• No relevant accident data available • May be a significant site-specific impact in colder climates	SS --
Fogging of Roadways	Yes	Yes	• Impacts are expected to be site-specific • Increased travel time associated with increased accidents are not accounted for in this estimate • Impacts related to airport operation not monetized	SS -
Fogging/Icing at Airports	Yes	No	• Impacts are expected to be site-specific	SS -
Fogging at Nuclear Facilities	Yes	No	• No WTP data are available	SS -

Table 4-28
Summary of assumptions, effects not addressed, and potential bias of environmental and social impacts (continued)

Category	Quantified	Monetized	Comments/Assumptions	Potential Bias
Quality of Life				
Noise	Yes	Yes	• Assumes a WTP associated with a measurable two dB increase in noise level • Mitigation not considered	+
Viewshed	Yes	Yes	• WTP to avoid the plume was only evaluated for house and recreational sites when the plume was directly overhead	-
Greenhouse Gas				
6- or 8-Month Outage at Nuclear Facility	Yes	Yes	• Large uncertainty in future WTP to avoid additional greenhouse gas emissions • Large uncertainty in outage duration	+/-
Additional CO_2 Associated with Energy Penalty	No	No	• Regional analysis required, which is beyond the scope of this study	-
Change in Composition of Generating Fleet	No	No	• Closed-cycle cooling mandate could significantly alter composition of generating fleet • Addition of non-fossil generation could significantly alter composition of generating fleet	+
Water Vapor as Greenhouse Gas	Yes	No	• Additional water vapor from closed-cycle cooling mandate is an additional greenhouse gas emissions that is not estimated	-
Additional CO_2 Associated with Construction and Materials	No	No	• Additional CO_2 generation during construction • Additional CO_2 generation from material manufacturing i.e. concrete	-

Table 4-28
Summary of assumptions, effects not addressed, and potential bias of environmental and social impacts (continued)

Category	Quantified	Monetized	Comments/Assumptions	Potential Bias
Other				
Cumulative Impacts	No	No	• Additive impacts of several facilities in close proximity or on the same waterbody are not addressed	SS -
Aquatic Biota				
Impingement and Entrainment of Fish and Shellfish	Yes	Yes	• No compensation in population assumed • No entrainment survival • Reduction in cooling water usage does not include service water • WTP to avoid IM&E of commercially or recreationally pursued species and WTP to avoid impacts to forage fish are assumed to be additive • Potential losses were limited to fish and shellfish, and did not include higher trophic levels such as marine mammals or reptiles (e.g., turtles)	++
Entrainment of Planktonic Organisms	No	No	• No adverse impact because of high reproductive capacity and life cycle	-
Thermal Discharge Effects	No	No	• The potential magnitude and sign (positive and negative) of environmental effects not included	SS +/-

++	Significant overestimate
+	Overestimate
+/-	Bias may be in either direction
-	Underestimate
--	Significant underestimate
SS	Site-specific

5

RELATIVE IMPACTS ASSOCIATED WITH ALTERNATIVE COOLING TOWERS

In Section 3, a brief overview of alternative type cooling towers was provided. These types are:

- Wet mechanical-draft evaporative cooling towers;
- Wet natural-draft evaporative cooling tower;
- Dry cooling tower; and
- Hybrid (wet/dry combination) cooling tower.

Based on efficiency and economics, the mechanical-draft evaporative cooling towers normally would be the preferred alternative for retrofitting a once-through cooling Phase II facility to closed-cycle cooling. However, other site-specific factors may have to be considered that could necessitate the use of one of the other types of cooling towers. For example, if cooling water availability were severely limited, an alternative that does not result in a significant consumption of water through evaporation would have to be considered. There also may be site-specific factors that could preclude the use of an alternative type tower. An example of this would be if the available area at a station for locating a tower were severely limited, only a tower that has a smaller ‘footprint’ area might be viable.

This section discusses several aspects regarding the potential use of alternative type cooling towers:

- First, each type of tower was differentiated from the other types, including when one type generally would be used over another and how each type is different from the others in such attributes as size, efficiency, emissions, water use, and cost to install and operate;
- Secondly, the viability of using alternative types of cooling towers at each of the modeled facilities was preliminarily assessed, and factors that could limit the use of one or more types were identified; and
- Finally, the potential impacts from the use of alternative cooling tower types were compared to mechanical-draft evaporative cooling towers as the base case. The impacts could be relatively beneficial or adverse and are in relation to the types of environmental and social effects being considered in this study (see Section 4).

5.1 Alternative Cooling Towers

In general, a hybrid tower uses a conventional wet cooling system in combination with an indirect dry cooling system[1] mounted above the mechanical-draft evaporative cooling towers. Hybrid towers are used over fully wet towers only when a visible elevated plume or ground fogging/icing is unacceptable at any time, or when water conservation is paramount. A hybrid tower avoids visible fogging and plumes in two ways: (1) it decreases the temperature (i.e., heat load and required evaporation) of the circulating water that enters the wet portion of the tower, and (2) it increases the temperature of the exhaust air from the cooling tower. These factors result in altering the psychrometric conditions of the exhaust air such that visible fogging and plumes is diminished. Note that, depending on ambient air conditions, wet towers also, at times, will operate without a visible plume. The advantage of hybrid towers is that the water-cooled portion may be utilized during favorable ambient conditions; and the hybrid (air-cooled) portion may be utilized (at higher operating cost) during unfavorable ambient conditions.

Since there is no evaporation involved, dry cooling towers operate without a visible plume or fogging. Compared to wet or hybrid towers, dry tower operations may have fewer environmental impacts associated with cooling water intake (due to IM&E), salt deposition and PM emissions (due to drift), or water consumption (due to evaporation). However, construction period impacts could potentially be greater due to the larger footprint associated with dry towers.

There are tradeoffs in the use of a hybrid or dry cooling tower in comparison with the use of mechanical-draft evaporative cooling towers, including higher noise levels (due to fan noise), increased viewshed impacts (due to tower height, which also is an issue with natural-draft evaporative cooling towers), increased greenhouse gas emissions (due to higher energy penalty), more land disturbance/usage (due to larger footprint), less removal of trash from the waterbody (due to no intake flow), and higher capital and operating costs associated with the installation and operation of more complex, less efficient hybrid or dry towers.

Natural-draft evaporative cooling towers may not be a commercially viable option because they have not been built in the United States on a large scale in at least 20 years, although at least one new natural draft tower is under construction[2]. Capital costs to construct natural-draft towers would be relatively high due to their size, although operating costs would be lower since fans are not used to force or induce a draft. The height of these towers is such that they can be viewed from far away and are generally considered to degrade visual quality and be out of the scenic character of the surrounding areas. Table 5-1 compares the alternative cooling tower types relative to the mechanical-draft evaporative cooling towers (base case) on a number of key attributes.

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[1] See Section 3 for basic differences between direct and indirect dry cooling tower systems. The most likely type of dry cooling tower for use in a retrofitted system would be an indirect dry tower because a direct dry cooling tower requires significantly larger ductwork to move air, more finned-tube bundles to transfer heat, and longer runs of steam ducts. Most existing power plants would not have adequate space available for the larger components. Also, the existing steam condensers could continue to be used in an indirect system.

[2] Brayton Point is installing natural-draft evaporative cooling towers at least in part to prevent fogging.

Table 5-1
Comparison of cooling tower types

Attribute	**Cooling Tower Type**			
	Mechanical-draft Evaporative Cooling Towers (Base Case)	**Wet Natural Draft**	**Dry Air Cooled**	**Hybrid (Wet/Dry)**
Footprint Area	Arranged in one or more rows of single or back-to-back cells or in circles	Could be larger or smaller depending on separation of mechanical-draft evaporative cooling tower rows.	Largest (2-4 x mechanical-draft evaporative cooling towers) due to wider air-cooled section and arrangement limited to in-line	Larger (1-3 x mechanical-draft evaporative cooling towers) due to wider air-cooled section and arrangement limited to in-line
Height	Typically between 40 – 60 ft plus 9 ft for fan stack	Can approach 500 ft or more	Approx. 3 x mechanical-draft evaporative cooling towers	Approx 1.5 x mechanical-draft evaporative cooling towers
Visible Vapor Plume	Lower elevation plume; fogging/icing can occur	Higher visible plume; minimal, if any, fogging/icing	None	Minimal to no visible plume
PM Emission	Base case-depends on TDS, cycles of concentration, and drift eliminator efficiency	Similar to base case	None	Less than base case depending on need to use of dry portion of tower
Water Consumption	8 to 12 gpm/MWe	Equal to mechanical-draft evaporative cooling towers	None	1.5 to 12 gpm/MWe
Noise Emission	Base case-fan & cascading water noise	No fan noise and similar water noise	Greatest fan noise; no water noise	Greater fan noise than mechanical-draft evaporative cooling towers; less water noise
Solid Waste (Sediment)	Base case-depends on water/air quality, basin size, use of dispersing agents	Similar to base case	None	Similar to or less than base case

Table 5-1
Comparison of cooling tower types (continued)

Attribute	**Cooling Tower Type**			
	Mechanical-draft Evaporative Cooling Towers (Base Case)	**Wet Natural Draft**	**Dry Air Cooled**	**Hybrid (Wet/Dry)**
Cycle Efficiency	Base case	Equal to mechanical-draft evaporative cooling towers	Lowest; lowest summer output	Lower than mechanical-draft evaporative cooling towers; lower summer output
Energy Penalty[a]	Base case	Less than mechanical-draft evaporative cooling towers	Higher than mechanical-draft evaporative cooling towers (highest)	Higher than mechanical-draft evaporative cooling towers
Capital Cost	Base case	Higher than mechanical-draft evaporative cooling towers (approx. 3-5 x base case)	Highest (approx. 5-7.5 x base case)	Higher than mechanical-draft evaporative cooling towers (approx. 3-5 x base case)
Operating Cost	Base case	Lower than base case	Highest	Higher than base case

[a] Energy penalty includes both loss of generation capacity associated with decreased efficiency, and additional power loads associated with operating the modified cooling system (i.e., parasitic loads).
gpm/MWe = gallons per minute per megawatt-electric

The information in the above table is used in Section 5.3 to assess the potential impact of each alternative type of tower relative to mechanical-draft evaporative cooling towers (the base case) so that one can gain a sense of their relative environmental and social effects, which would be more or less pronounced than the base case.

5.2 Viable Cooling Tower Types for Facilities Investigated

The following table summarizes the preliminary assessment of the engineering viability of alternative cooling tower types that potentially could be used at the facilities investigated in conjunction with closed-cycle cooling retrofit. The mechanical-draft evaporative cooling towers were assessed in detail in Section 3. Facilities determined not to be feasible, or where it is extremely difficult to install mechanical-draft evaporative cooling towers, are classified as not viable in Table 5-2. Other alternative closed-cycle cooling options are considered viable if adequate space is available. However, in all cases, further study is needed to confirm viability. At some locations, alternative closed-cycle cooling systems are not considered practical based on the capacity, size, and/or age of the facility.

Table 5-2
Viability of cooling tower types at facilities investigated

Facility	Mechanical-draft Evaporative Cooling Towers	Wet Natural Draft Tower	Dry Cooling Tower **	Hybrid Cooling Tower	Viability Issues
BTCA1	viable	Not viable	Not viable	Not viable	Space & Height
BTPA	viable	*	Not practical	*	-
BTPB	viable	*	Not available	Not practical	Land Use
BTPC	Not viable	Not viable	Not viable	Not viable	Space
BTPD	viable	*	Not practical	*	-
BTPE	viable	Not practical	Not available	*	Land Use
BTCA2	viable	Not viable	Not available	Not viable	Space
RFF	viable	*	Not practical	*	-
RFG	viable	*	Not practical	*	-
RFH	viable	*	Not available	Not practical	-
RFI	viable	Not viable	Not viable	*	Space
RFJ	viable	Not viable	Not viable	Not viable	Space
RFK	Not viable	Not viable	Not viable	Not viable	Space
RFL	viable	*	Not practical	*	-
RFM	viable	Not viable	Not viable	Not viable	Space
RFN	viable	*	Not practical	*	-
RFO	Not viable	*	Not practical	*	-
RFP	viable	*	Not practical	*	-
RFQ	viable	Not viable	Not viable	Not viable	Space
RFR	viable	*	Not practical	*	-
RFS	viable	*	Not available	Not practical	-

Table 5-2
Viability of cooling tower types at facilities investigated (continued)

Facility	Mechanical-draft Evaporative Cooling Towers	Wet Natural Draft Tower	Dry Cooling Tower **	Hybrid Cooling Tower	Viability Issues
RFT	viable	*	Not practical	Not viable	-
RFU	viable	*	Not practical	*	-
RFV	viable	*	Not available	*	-

* = may be viable; further study needed

** “dry cooling is not considered available for nuclear facilities due to the backup cooling system and related safety requirements.

5.3 Relative Effects of Alternative Cooling Tower Types

Table 5-3 compares the relative environmental and social effects associated with the alternative cooling tower types.

Table 5-3
Relative environmental and social effects of alternative cooling tower types

Environmental and Social Effects	Alternative Cooling Tower Types			
	Wet Mechanical-draft Evaporative Cooling Towers (Base Case)	Wet Natural Draft	Dry Air Cooled	Hybrid (Wet/Dry)
Aquatic Biota (IM&E)	Base case	Similar to mechanical-draft evaporative cooling towers	No impact	Less than mechanical-draft evaporative cooling towers
Human Health (PM Emission)	Base case	Similar to mechanical-draft evaporative cooling towers	No impact	Similar to mechanical-draft evaporative cooling towers
Terres trial Resources (Habitat, Wetlands, Vegetation)	Base case	More than mechanical-draft evaporative cooling towers*	More than mechanical-draft evaporative cooling towers	Similar to mechanical-draft evaporative cooling towers

Table 5-3
Relative environmental and social effects of alternative cooling tower types (continued)

Environmental and Social Effects	Alternative Cooling Tower Types			
	Wet Mechanical-draft Evaporative Cooling Towers (Base Case)	**Wet Natural Draft**	**Dry Air Cooled**	**Hybrid (Wet/Dry)**
Water Resources (Consumption)	Base case	Similar to mechanical-draft evaporative cooling towers	No impact	Similar to mechanical-draft evaporative cooling towers
Solid Waste (Trash removal)	Base case	Similar to mechanical-draft evaporative cooling towers	More than mechanical-draft evaporative cooling towers	Similar to mechanical-draft evaporative cooling towers
Public Safety and Security (Fogging, Icing, Plume interference)	Base case	Less fogging/icing; more plume interference	No impact	Minimal impact**
Quality of Life (Noise and Visual)	Base case	Less noise/more visual impacts	More noise larger structure	More noise larger structure
Permitting (Environmental justice, Cultural Resources, Other)	Base case	Site-specific	Site-specific	Site-specific
Greenhouse Gas (Energy Penalty)	Base case	Less than mechanical-draft evaporative cooling towers	More than mechanical-draft evaporative cooling towers	More than mechanical-draft evaporative cooling towers

* = Refers to on-site impacts; off-site impacts may be less
** = May not be true for periods when only the ‘wet’ portion of the tower is operating.

An analysis to quantify the beneficial or adverse effects associated with the alternative cooling tower types is not included in this study.

6

MODELING SUMMARY AND NATIONAL SCALING RESULTS

This section provides the results of the final phases of the EPRI study to quantify the environmental effects of retrofitting once-through systems to closed-cycle cooling. This report investigated 24 representative plants on various waterbody types over a wide range of climatic and geographic conditions. This report also includes a summation of the results from the EPRI questionnaire and an updated list of Phase II facilities. Lastly, BTP and RF modeling results and EPRI questionnaire results were applied to estimate impacts on a national scale for all Phase II facilities for this final section.

Section 6 presents a summary of the BTP and RF modeling results detailed in Section 4 that were used in the national scaling process and the results of that national evaluation, as follows:

- Section 6.1 is a summary of the BTP and RF impact quantification modeling results;
- Section 6.2 contains a table of facility-specific WTP values monetized in Section 4 for the BTPs and RFs; and
- Section 6.3 provides the results of the national scaling quantification and monetization, where possible, for the eight primary topics evaluated, including uncertainties associated with the national scaling process.

Table 6-1, below, summarizes the type of evaluations (i.e., quantitative vs. qualitative) performed for each of the eight issues and provides the report section where the detailed analysis is provided for cross-reference in the report.

Table 6-1
Evaluations performed for potential environmental and social effects of retrofitting to closed-cycle cooling

Environmental and Social Effects	Assessment Performed		
	Quantification of Impacts	**Monetization of Impacts**	**National Scale-up**
Human Health			
Pathogens	Qualitative discussion (Section 4.1.1)	No (Section 4.1.1)	No (Section 6.3.1)
PM Emission	YES (Section 4.1.2.1)	No (Section 4.1.2.2)	Yes (Section 6.3.1)
Terrestrial Resources			
Habitat, Wetlands, Vegetation	YES (Section 4.2.1 – for BTPs, not RFs)	YES (Section 4.2.1 – for BTPs, not RFs)	YES (Section 6.3.2.1)
Drift Effects on Vegetation and Soils	YES (Section 4.2.2 for BTPs, not RFs)	YES (Section 4.2.2 for BTPs, not RFs)	No (Section 6.3.2.2)
Noise Impacts to Threatened and Endangered Species	YES (Section 4.2.3 for BTPs)	No (Section 4.2.3)	No (Section 6.3.2.3)
Fogging/Icing	YES (Section 4.2.4)	No (Section 4.2.4)	YES (Section 6.3.2.4)
Other: Corrosion	YES (Section 4.2.5)	No (Section 4.2.5)	No (Section 6.1.2.5)
Water Resource Quantity and Quality			
Consumption	YES (Section 4.3.1.1)	No (Section 4.3.1.2)	YES (Section 6.3.3.1)
Debris Removal	YES (Section 4.43.2.1)	YES (Section 4.3.2.2)	YES (Section 6.3.3.2)
Solid Waste (Tower Sludge)	Qualitative discussion (Section 4.3.3)	No	No (Section 6.3.3.3)

Table 6-1
Evaluations performed for potential environmental and social effects of retrofitting to closed-cycle cooling (continued)

Environmental and Social Effects	Assessment Performed		
	Quantification of Impacts	Monetization of Impacts	National Scale-up
Public Safety and Security			
Fogging/Icing on Roadways	YES (Section 4.4.1.1)	YES (Section 4.4.1.2)	YES (Section 6.3.4.1)
Plumes at Airports	Qualitative discussion (Section 4.4.1)	No (Section 4.4.1.2)	No (Section 6.4.3.2)
Fogging at Nuclear Facilities	YES (Section 4.4.3)	No (Section 4.4.3)	No (Section 6.4.3.3)
Quality of Life			
Noise	YES (Section 4.5.1.1)	YES (Section 4.5.1.2)	YES (Section 6.3.5.1)
Viewshed	YES (Section 4.5.2.1)	YES (Section 4.5.2.2)	YES (Section 6.3.5.2)
Permitting			
Air Permitting	YES (Section 4.6.1)	No	No (Section 6.3.6)
Environmental Justice	YES (Section 4.6.2)	No	No (Section 6.3.6)
Others: Cultural Resources, etc.	Qualitative discussion (Section 4.6.3)	No	No (Section 6.3.6)
Greenhouse Gas: Nuclear outage	YES (Section 4.7.1)	YES (Section 4.7.2)	YES (Section 6.3.7)
Greenhouse Gas: Energy Penalty	Qualitative discussion (Section 4.7.1)	No	No
Aquatic Biota: IM&E	YES (Section 4.8.1)	YES (Section 4.8.2)	No (see Section 6.3.8 for a discussion)

"YES" indicates the evaluation was performed. Report section numbers provided in parentheses.

The following sections summarize the results of the impact quantification and monetization process and the national scale-up.

6.1 Impact Quantification

6.1.1 Human Health

Although diseases associated with pathogens in cooling tower emissions, in general, have been identified as a health issue, no evidence of cases where such issues have resulted from power plant cooling towers were found. Therefore, the potential risks could not be quantified nor monetized. Additionally, best practices are often used to minimize risks. Therefore, this potential impact was not evaluated.

Facilities representing different waterbody types and located in three different wet-bulb regions were examined with respect to increased exposure to PM emitted from cooling towers. The maximum PM_{10} and $PM_{2.5}$ concentrations at the nearest offsite receptor, and the estimated Age 30+ and Age 65+ populations exposed to significant increases in PM for each facility evaluated are reported in Table 6-2. Facilities in urban areas (BTCA1, BTPC, RFF, RFH, RFI, RFK, and RFL) have the highest number of potential receptors.

Table 6-2
Summary of PM_{10} and $PM_{2.5}$ concentrations and estimated populations exposed to a significant increase in PM emissions

Facility Location	Max PM Concentration at Nearest Offsite Receptor ($PM_{10}/PM_{2.5}$)	Population 30+ Exposed to Cooling Tower Emissions	Population 65+ Exposed to Cooling Tower Emissions
BTCA1-Los Angeles Co., CA	1.70/0.51	19,377	9,576
BTPA-Southeast	0.22/0.08	183	41
BTPB-Midwest	0.15/0.06	6,746	1,523
BTPC-Northeast	1.03/0.28	39,290	8,823
BTPD-Southeast	0.13/0.07	535	99
BTPE-Northeast	0.22/0.09	7,554	1,282
BTCA2-Orange Co., CA	0.90/0.27	84	1
RFF	0.021/0.0089	15,139	3,498
RFG	0.036/0.015	1,809	288
RFH	2.0/0.45	23,407	5,397

Table 6-2
Summary of PM_{10} and $PM_{2.5}$ concentrations and estimated populations exposed to a significant increase in PM emissions (continued)

Facility Location	Max PM Concentration at Nearest Offsite Receptor (PM_{10}/$PM_{2.5}$)	Population 30+ Exposed to Cooling Tower Emissions	Population 65+ Exposed to Cooling Tower Emissions
RFI	0.10/0.042	223,756	38,495
RFJ	0.043/0.017	5,784	1,206
RFK	0.51/0.15	148,269	25,105
RFL	0.050/0.020	20,614	5,717
RFS	0.094/0.038	1,651	400

Because potential human health risks (e.g., morbidity or mortality) associated with increased exposure to PM from cooling towers cannot be reliably quantified, no estimates of human health impacts are provided in this evaluation. Appendix G provides an estimate of potential human health impacts at the high end of the upper bound based on conservative USEPA methodology for comparison.

6.1.2 Terrestrial Resources

6.1.2.1 Long-Term Loss of Wildlife Habitat, Wetlands, and Critical Habitat

Total land disturbance in the area proposed for cooling tower locations and a perimeter buffer varied among facilities. The greatest proposed disturbance of land is at BTPB (23 acres) while the lowest disturbance (1 acre) is at RFU. Average land disturbance for all 24 facilities is 6.5 acres. A variety of terrestrial habitats would be impacted, including: upland (forest and herbaceous/scrub-shrub), wetland (forest, emergent, scrub-shrub), and open water (Section 4.2.1.1).

Results for each of the BTPs predicted quantifiable losses of at least two types of habitat. The greatest cumulative impact from the seven BTPs was to upland forest. At two of the seven facilities, state-designated rare habitats would be lost (forested dunes at BTPB and coastal bluff scrub at BTCA2). The loss of 21 acres of critical forested dune habitat at BTPB represents the largest loss of a single habitat type at any of the facilities (Section 4.2.1.1).

The loss of non-unique/rare habitats could not be monetized because of a lack of studies on WTP. WTP to avoid the potential degradation of the 25-acre wetland site adjacent to BTCA1 as a result of the decreased flow was estimated at $5,200. However, there is considerable uncertainty as to the extent of degradation that may result and actual WTP is dependant upon the magnitude of the degradation. WTP to avoid impacts to forested dune habitat at BTPB is estimated to be $110,800. The loss of coastal scrub-shrub habitat at BTCA2 and longleaf pine habitat for State and Federally–listed red-cockaded woodpecker at RFH are adverse impacts; however, they could not be monetized due to a lack of information on which to base the WTP estimate (Section 4.2.1.2).

As a result of the Beta Test, which determined that non-unique/rare habitat impacts could not be monetized, it was determined that the evaluation of the 17 RFs for terrestrial resources would be qualitative (Section 4.2.1.3). A qualitative review of these 17 facilities suggested that cooling tower installation would result in habitat loss. However, only one facility, RFH, had the potential for the loss of critical habitat. Thus, of the 24 total facilities studied, critical habitat impacts may occur at three of the facilities or 12.5 percent of the total. Cooling tower construction at six RFs would potentially impact forest communities and at 15 plants, impacts to herbaceous/scrub-shrub communities may result from cooling tower installation. Cooling tower construction at six of the RFs would potentially impact wetlands and/or open waters. In all, wetland impacts may occur at eight of the 24 facilities representing 33 percent of the facilities studied.

6.1.2.2 Salt and Mineral Drift Effects on Vegetation and Soils

The Beta Test indicated that salt and mineral drift effects are a function of the TDS in the makeup water, tower drift rate and the location of the cooling tower relative to the property line. Confounding variables include local meteorology and topography. Salt drift impacts from cooling towers to native vegetation are difficult to quantify and the impacts cannot be monetized. Impacts of salt deposition to agricultural lands can be quantified and monetized; with minor impacts estimated at one site.

Salt damage to native vegetation is a potential adverse impact associated with retrofitting to closed-cycle cooling. However, site-specific information on the distribution of species exposed to the drift is not readily available to assess the potential extent of damage. Further, impacts cannot be monetized due to a lack of information on which to base the WTP estimate.

The order-of-magnitude analysis of drift effects shows that, with the exception of BTPD, each of the facilities have the potential to produce visible leaf damage to vegetation, and three of the facilities have the potential to damage vegetation to an extent that could warrant re-evaluation of tower basin TDS or tower design (Section 4.2.2.1; Table 4-5). Based on this screening, the high level of exposure predicted to occur at BTPA, BTPB, and BTCA2 facilities likely represents a realistic level of concern, although one that cannot be monetized.

Qualitative assessments of salt drift impacts for RFs using high TDS makeup water (RFH, RFI, RFJ, and RFK) were made (Section 4.2.2.3). This assessment found potential impacts to woody or herbaceous/scrub-shrub vegetation surrounding the facilities are likely.

BTPE was the only BTP with agricultural land nearby where salt deposition produces an adverse impact. In this case, approximately 26 hectares of agricultural land received salt deposition rates of between 0.5 to 2.5 kilogram per hectare per week (kg/ha/week) resulting in an approximately two percent reduction in production and an annual WTP to avoid this impact of approximately $80 (Section 4.2.2.2).

No agricultural lands were identified within or adjacent to the facility properties from RFs using high makeup water TDS (RFH, RFI, RFJ, and RFK). Based on the facilities studied, salt deposition to agricultural lands is not a significant issue and in the one case that it is predicted to occur, the annual WTP to avoid this impact is small.

The results of this study are consistent with those reported by other researchers. Observations at St. Johns River Power Park [76], based on the results of pre- and post-operation field monitoring of deposition and uptake at plots in the vicinity of the towers, concluded that although NaCl concentrations in deposition samples increased somewhat after Unit #2 began operating, there were no significant increases in concentration in the soil or vegetation samples. Furthermore, no injury was reported on the grasses or other vegetation near the Power Park, even at the location with the highest deposition rate.

Similar results were reported for the extensive study performed at the Chalk Point Cooling Tower Project in the late 1970s by the Maryland Power Plant Research Program [77]. The salt concentration in nearby tobacco field soils did not increase measurably and cooling tower operations did not result in losses of productivity for the nearby crops or damage to ornamental vegetation [76].

6.1.2.3 Noise Impacts on Terrestrial Wildlife

The impact of noise on wildlife is much less understood than the impact of noise on humans. Too few quantitative studies have been done to reliably apply the 60 dBA threshold to a national scaling of impacts. This, in combination with the lack of site-specific population data, results is a significant amount of uncertainty regarding the assessment of noise impacts to wildlife.

The Beta Test determined that between 100 and 200 acres of wildlife habitat will be exposed to noise levels at or beyond the 60 dBA threshold value at each BTP (Section 4.2.3.1). However, it cannot be concluded that wildlife other than the few avian species known to be affected by this noise level could actually be negatively impacted, if they occur in the area. Likewise, the impact to threatened and endangered species is difficult to quantify within impacted wildlife habitat without additional data. For example, the coastal California gnatcatcher, a federally listed threatened avian species, is known to be adversely impacted by 60 dBA noise levels [30]. However, actual impacts cannot be quantified without site-specific population data on the number and location of the species in the site area.

The Beta Test demonstrates that the size of the wildlife habitat area exposed to increased noise levels can be quantified and may be significant. However, limitations of species-specific noise sensitivity and site-specific population data limit the reliability of the impact assessment and monetization. As a result of the Beta Test, which indicated the limitations and reliability of this study, quantitative noise impacts to wildlife were not evaluated for the RFs and the impact could not be quantified on a national scale.

6.1.2.4 Impacts of Fogging and Icing on Terrestrial Vegetation

Although the NRC [28] has identified possible detrimental effects associated with increased fogging and icing on local vegetation from humidity-induced increases in fungal or other phytopathological infections or ice damage as a potential impact to the terrestrial environment from cooling towers, these impacts are not well studied. Using the results of SACTI modeling, fogging may occur at the rate of tens of hours/year at eight of the 18 evaluated facilities; icing may occur at this rate at two of the 18 facilities. Fogging and/or icing at this rate may cause detectable damage to nearby vegetation according to the NRC [28] (see Section 4.2.4). However, a WTP to avoid this damage was not calculated.

6.1.2.5 Other Terrestrial Impacts

Other social adverse effects associated with salt deposition from mechanical-draft evaporative cooling towers include damage to automobiles and other metal surfaces, corrosion and shorting of electrical equipment, and spotting of windows and other surfaces. Assuming a critical salt deposition rate for electric flashover of 0.03 mg/cm^2/week and deposition modeling of the BTPs, it was found that deposition at this rate may occur at a distance of up to 760 meters away from cooling towers for freshwater BTPs and from 300 meters to more than 1,100 meters at BTPs using saline or brackish water (Section 4.2.5). These potential impacts may be most severe within the property boundary because of the rapid deposition of salt drift. However, for facilities where the towers are located near the property boundary and those using high TDS makeup water and/or in urban areas, this analysis suggests the potential for significant offsite impacts, as described above. These impacts could not be monetized due to the lack of any studies to base a WTP.

Other on-site and offsite impacts, such as structural damage, were not evaluated in this study, but are possible based on a review of the operating results from seven facilities with seawater or brackish cooling towers. This review found accelerated corrosion on unprotected metal portions of buildings and equipment and deterioration of concrete basins and structures at nearly all the plants investigated [76].

6.1.3 Water Resource Quantity and Quality

Cooling tower blowdown may impact water quality by discharging biocides such as chlorine or other toxic chemicals. Additionally, cooling towers concentration contaminants already existing in the source waterbody (Section 4.3). Impacts to source and discharge waterbody quality were not investigated in detail during the BTP or RF evaluations.

6.1.3.1 Evaporative Water Loss

The study demonstrates that the net water consumption from retrofitting to closed-cycle cooling can be quantified. Net water consumption ranged from 0.5 to 26 MGD and could be a sensitive permitting issue, particularly in areas that experience severe droughts. This issue is limited to facilities located on fresh waterbodies. Consumptive water loss from proposed closed-cycle cooling towers at modeled facilities is between approximately 400-900 gallons per MW-hr electricity generation for fossil-fueled facilities and approximately 750-1,050 gallons per MW-hr for nuclear facilities; over double the water loss estimated for once-through cooling. Net consumption from a specific plant depends on its geographic location (wet-bulb region), meteorological conditions, condenser ΔT, cooling water flow rate, and type and design of the cooling tower.

Net water consumption from the installation of mechanical-draft evaporative cooling towers at the four completely freshwater BTPs totals 72.8 MGD (i.e., 18 MGD per facility, on average); one BTP is located on an estuary. This is the equivalent of the daily water use of approximately

560 - 970 thousand people (i.e. 135 – 235 thousand person-equivalents per facility)[1]. The four freshwater BTPs were located on large rivers, lakes, Great Lakes, or reservoirs, and the net consumption represents between 0.24 and 7.4 percent of low reference flows in the waterbody. This water loss is not expected to result in environmental changes because either the amount is minimal compared to water flow into the system, or existing institutional mechanisms mitigate adverse impacts (see Section 4.3). The increase in consumptive water use, however, is expected to increase the frequency of drought declarations in the watersheds of two of the source waterbodies by 0.2 to 1.3 percent. Although this impact was quantified, data are lacking to monetize these impacts.

Net water consumption from the installation of mechanical-draft evaporative cooling towers at the four RFs modeled totals approximately 5.2 MGD (i.e., approximately 1.3 MGD per facility). Note that the four RFs have a smaller capacity than the four BTPs on fresh waterbodies. This water consumption is equivalent to the daily water use of approximately 40-70 thousand people (i.e. 10–17 thousand person-equivalents per facility). For three of the four RFs modeled, the net water consumption represented a very small percent of the reference low flow.

Based on the site conditions (water management controls) and estimated excess water consumptions expressed as a percent of low flow at the four freshwater BTPs, one estuarine BTP, and four RFs evaluated, it was determined that no measurable change in water levels would be associated with the conversion from once-through cooling systems to closed-cycle cooling. Therefore, the WTP to avoid consumptive water loss at all BTPs and RFs is assumed to be zero. However, data on the water balance necessary to assess impact could not be obtained for the one facility located on a southwestern reservoir where the risk of impacts is potentially greatest.

The primary uncertainty associated with the monetization is that the WTP is based on potential changes in stream flows or water levels. Also, this assessment does not consider the private cost of acquiring water rights in arid regions. These costs for acquiring water rights, if available, can be as high as $7,500 per acre-foot. If rights are not available, this could be a potential obstacle to permitting a cooling tower retrofit.

6.1.3.2 Source Waterbody Debris Removal

Analysis of society’s WTP to avoid a reduction in the removal of trash from waterbodies due to retrofitting to closed-cycle cooling was performed. Changes in the amount of solid waste removed from waterbodies were site-specific (Section 4.3.2). Twelve of the 24 facilities report some trash removal. The amount ranged between negligible and 42 tons with an average of 6.6 tons of trash removed annually. For facilities located in urban environments, the amount of trash removed can be a up to 42 tons of man-made debris with an annual WTP for that service of approximately $47,000. The environmental benefit is much reduced or negligible for facilities in rural areas, or with offshore, submerged intakes. The average WTP to avoid a reduction in trash removal for the 18 facilities where data were available is $7,200.

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[1] Assuming typical annual average water requirement of between 75 and 130 gallons per capita day [11].

6.1.3.3 Solid Waste

The installation of cooling towers will also generate additional solid waste in the form of cooling tower sediment. Estimates of the amount of sediments potentially generated and other relevant information (e.g., potential toxicity) was investigated using an EPRI questionnaire submitted to the industry (Section 4.3.3). Results indicated that most facilities dispose of cooling tower sediment on-site and the material is typically non-hazardous.

6.1.4 Public Safety on Roadways and at Airports

The water vapor plume emitted directly from mechanical-draft evaporative cooling towers can produce adverse environmental impacts in the area around the tower such as fogging and icing from plume condensation and shadowing from visible water plumes. Some degree of fogging is predicted to occur at all facilities. Fogging on nearby roadways ranged from <0.1 to 196 hours of fogging. The monetization of this impact is based on a WTP to avoid roadway fogging. This analysis shows a range from $1 to $23,500 for the 24 evaluated facilities.

Icing is predicted to occur at eight of the 24 facilities (33 percent). This represents an adverse impact associated with retrofitting to closed-cycle cooling. While, WTP to avoid icing was not estimated because the appropriate accident data were not available, this could be a local permitting issue.

Visible plumes that could interfere with air traffic at nearby airports were determined based on predicted plume length (Section 4.4). The vapor plume from mechanical-draft evaporative cooling towers at one modeled facility crossed a nearby runway. Based on site-specific constraints at that BTP, a wet mechanical-draft evaporative cooling tower may not be viable.

Fogging from mechanical-draft evaporative cooling towers represents an adverse impact in terms of nuclear plant security. While this impact is not monetized because an estimate of the WTP associated with this issue is not available, this could be a permitting issue with the NRC.

6.1.5 Quality of Life

6.1.5.1 Noise

Increases in noise due to cooling towers are an adverse environmental impact. Noise impacts are driven by the background level and the juxtaposition of the source and the receptors (Section 4.5.1; Table 4-17). Thus, the population impacted by noise at BTPA, BTPC, BTCA2, RFF, RFI, RFK, RFO, RFR, RFS, and RFU is zero because the nearest receptors are remote from the mechanical-draft evaporative cooling towers and because of other existing nearby sound sources. Impacts of additional cooling towers at RFQ is zero because this facility already has much larger cooling towers and the increase in noise due to the new towers would be negligible in comparison. Impacts are intermediate in areas with low population densities and low background levels such as BTPB, BTPD, BTPE, RFG, RFH, RFP, RFT, and RFV. The greatest impacts were calculated for BTCA1, RFJ, RFL, RFM, and RFN because of the close proximity of a large population to these sites. Monetization of this impact ranges from $0 to nearly $246,000. Twelve of the 24 (50 percent) plants had a total annual WTP greater than $1,000 to avoid noise. Of the 12 facilities with an annual WTP less than $1,000, 11 of them have no WTP for noise impact. The average annual WTP for all 24 facilities is over $30,000.

Noise was also evaluated in terms of potential permitting issues related to local or state noise ordinances, which could be an important permitting concern for some facilities. Noise ordinances were assessed during the qualitative evaluation of permitting issues (Section 4.6.3) and are summarized in Section 6.1.6.

6.1.5.2 Viewshed

Viewshed deterioration is another quality of life issue associated with closed-cycle cooling retrofits. The Beta Test concluded that the impacts of viewshed deterioration from plume condensation associated with retrofitting to closed-cycle cooling can be quantified and monetized. Significant impacts to residential values occur at all of the BTPs except at BTCA2, which is remote from any household[2] (Section 4.5.2). Greatest impacts occur in densely populated areas. Viewshed deterioration at parks and recreational sites can be very significant and is dependent on site-specific conditions.

Visible plume and plume shadowing is a function of the drift rate, local meteorology, topography, and the number and location of the receptors. The number of households that would experience viewshed deterioration ranged from 0 at BTCA2, RFF, RFJ, RFL, RFM, RFN, RFQ, RFT, and RFU to 43,750 at BTCA1. Thus, this impact is highly dependent on the location and density of the population surrounding the facility, with highest impact occurring in more populated locations.

The impact of viewshed deterioration for local residents was monetized using housing values (Section 4.5.2). Seven of the 24 plants (29 percent), had a total annual WTP greater than $1,000 to avoid viewshed degradation. Of the 17 facilities with an annual WTP less than $1,000, nine of them have a no WTP for viewshed impacts. The greatest WTP to avoid viewshed degradation based on housing data is at BTCA1. The average annual WTP for all 24 facilities is nearly $10,000 based on housing data.

Viewshed deterioration at major parks and recreational sites was also monetized. This impact is site-specific and dependent on the proximity and number of visitors to the site. A State Beach near BTCA2, which has very high attendance, the plume visibility or shadowing, has a WTP to avoid viewshed degradation of over $150,000. Other parks are either smaller or experience a visible plume a much smaller percentage of the time. This results in monetized adverse impacts for these other parks of less than $3,000.

6.1.6 Permitting and Other Issues

All of the facilities have some site-specific issues that would need to be resolved during the permitting process. These include impacts that may preclude receiving necessary permits and/or

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[2] No census data is reported for a nearby army base.

approvals or as impacts that are not prohibited by regulation but which may be considered significant in a state environmental impact analysis and require mitigation. In addition, some facilities are likely to encounter large-scale and organized public opposition because of quality of life issues associated with cooling towers. Each of these situations can cause significant delays in approval or prevent approval completely.

The degree to which these issues are likely to become roadblocks to project approval was evaluated qualitatively at each site and summarized in Table 6-3. While some issues can be negotiated and resolved relatively easily (e.g., wetland mitigation, height variances), others may not.

An “X” in Table 6-3 is used to identify environmental issues that may have permitting problems associated with them using the following criteria:

- Air Quality: Using dispersion modeling results, the relative ease of obtaining permits were determined (Section 4.6.1). Moderate to difficult categories are identified in Table 6-3 as having permitting issues;
- Critical or Sensitive Habitat/Protected Species: If any critical habitat (including wetlands and agricultural lands) or rare, threatened, and endangered species were identified in the vicinity of the plant (Section 4.6.3), a permitting issue may exist;
- Noise: If potential receptors were identified during modeling as being impacted by the increase in noise due to the installation of cooling towers (Section 4.5.1), it was assumed that an ordinance is in place and some form of permit would be required;
- Salt Drift: BTPs with a positive WTP to avoid mineral drift impacts and RFs withdrawing water from high TDS waterbodies (Section 4.2.2) will likely have a permitting issue;
- Water Consumption: BTPs and RFs that withdraw water from potable water sources (i.e. fresh waterbodies) will likely have to obtain permits regarding this issue (Section 4.6.3);
- Visible Plume: If a public safety or security issue was identified due to fogging or icing caused by the installation of cooling towers (Section 4.4.1), or if an impact to the viewshed was determined by modeling the visible plume (Section 4.5.2), permitting issues will likely exist; and
- Environmental Justice: Evaluation of the census data near the plant identified potential environmental justice concerns (Section 4.6.2).

Table 6-3
Major permitting and environmental issues at BTPs and RFs[a]

Facility	Air Quality	Critical or Sensitive Habitat	Protected Species	Noise	Salt Drift	Water Consumption	Visible Plume	Environmental Justice	Other	Comments	Relative Permitting Difficulty[b]
BTCA1	X	X	X	X			X		X	Public opposition; public health concerns; water quality issues.	High
BTPA	X	X	X				X				Low
BTPB		X	X	X	X	X	X		X	Nuclear plant security; public access.	High
BTPC	X					X	X	X			Low
BTPD		X	X	X		X	X		X	Height, noise, impervious surface, riparian buffer limits by ordinance.	Moderate
BTPE				X	X	X	X		X	Nuclear plant security; permitting facilitated by replacing unused helper cooling towers.	Low
BTCA2	X	X	X				X		X	Nuclear plant security; site stability; public opposition.	High
RFF		X	X			X	X				Moderate

Table 6-3
Major permitting and environmental issues at BTPs and RFs[a] (continued)

Facility	Air Quality	Critical or Sensitive Habitat	Protected Species	Noise	Salt Drift	Water Consumption	Visible Plume	Environmental Justice	Other	Comments	Relative Permitting Difficulty[b]
RFG	X	X		X		X	X			Limited data available.	Low
RFH	X	X	X	X	X		X		X	Nuclear plant security; Coastal Zone Management regulations would apply.	High
RFI					X		X	X			Moderate
RFJ				X	X		X				Low
RFK	X				X		X		X	Coastal Zone Management regulations would apply.	High
RFL		X		X		X	X				Low
RFM	NE			X		X		X	X	Floodplain issue.	Moderate
RFN	NE	X	X	X		X	X				Moderate

Table 6-3
Major permitting and environmental issues at BTPs and RFs[a] (continued)

Facility	Air Quality	Critical or Sensitive Habitat	Protected Species	Noise	Salt Drift	Water Consumption	Visible Plume	Environmental Justice	Other	Comments	Relative Permitting Difficulty[b]
RFO	NE	X	X			X	X				Moderate
RFP	NE	X		X		X	X				Low
RFQ	NE	X	X			X	X				Moderate
RFR	NE	X					X				Low
RFS	NE	X				X	X		X	Nuclear plant security.	High
RFT	NE			X							Low
RFU	NE		X			X	X				Moderate
RFV	NE			X		X	X	X	X	Nuclear plant security.	High

[a] This table represents a summary of major permitting issue categories likely to need resolution during the environmental permitting process. Site-specific issues are discussed below under each facility.

[b] Subjective, relative indication of permitting difficulty based on site conditions and permit requirements.

NE = Not Evaluated

6.1.7 Greenhouse Gas

Retrofitting once-through Phase II facilities with closed-cycle cooling would very likely increase CO_2 emissions. The potential increases are due to (1) fossil-fueled facilities making up for generation lost at nuclear facilities during retrofit and optimization-related downtime; (2) parasitic losses; and (3) energy penalty. Only the first issue is addressed in this report because of the complexity of potential retirement of older facilities and the impacts on national net parasitic loss and energy penalty. The U.S. Department of Energy has estimated that energy penalty associated with retrofit to wet cooling towers as:

- 2.4 to 4.0 percent for the hottest months of the year
- 0.8 to 1.5 percent for the annual average temperature conditions.

The replacement of this energy penalty with the current mix of generation would result in the additional annual emission of millions of tons of $CO_{2.}$

The additional CO_2 emissions estimates during retrofit and optimization-related downtime at nuclear facilities are provided in this report and assume that the current composition of electricity generating facilities would continue to provide the added electricity required due to the closed-cycle cooling retrofit.

The total additional CO_2 emissions due to a 6- or 8-month downtime at the six representative nuclear facilities were calculated as approximately 29-39 million tons.

6.1.8 Aquatic Biota

Twenty-six (26) facilities representing five waterbody groups were examined with annual impingement losses for fish and shellfish ranging from nearly 900 to 4.6×10^7. Raw entrainment rates were calculated, but due to natural mortality, these values do not reflect the true magnitude of losses of adult fish. Losses of age-1 equivalents (calculated from entrainment rates only) ranged from 100 to 1.2×10^8.

Modeled plants represent a range of cooling water intake structure designs encompassing submerged offshore intake tunnels with velocity caps (two facilities), screening structures positioned parallel to the shoreline (13 facilities), and intakes drawing water from canals extending from source waters (10 facilities) (Table 6-4). All facilities, except BTPD, have at least one traveling screen cleaned with high-pressure sprayers. BTPD has fixed screens that are manually cleaned at regular intervals. Nineteen facilities use mesh screening with ⅜ inch square openings while BTPC and RFX use smaller mesh (½ x ⅛ inch rectangular openings), BTCA1 uses ½ x ¾ inch rectangular openings, RFH uses a combination of meshes with 1 mm square or ⅜ inch square openings, and RFP and RFV uses mesh with ¼ inch square openings. Differences in mesh size and cleaning schedule may influence the number and composition of impinged versus entrained organisms.

BTCA2, BTPE and RFH have modified cooling water intake structures designed to lower IM rates. BTCA2 has a fish diversion system (louvers) constructed immediately forward of the traveling screens that directs fish to a low turbulence area of the intake pool so that they can be periodically returned to the ocean using a fish return system during normal operations and during heat treatments to control biofouling. Additionally, BTCA2 utilizes a velocity cap, which, in conjunction with the fish return system, significantly reduces IM. BTPE has a secondary cooling water intake structure designed with increased screening surface area thereby greatly decreasing approach velocities. Lower approach velocities decrease IM by allowing more fish to escape impingement. RFH uses a combination of fine and standard mesh traveling screens with a fish return. The facility also has a fish diversion structure installed at the entrance to the intake canal. Constructed of fixed screens using standard mesh, it prevents many adult and juvenile fish from entering the canal and subsequently reduces impingement losses. BTPC is currently in the process of retrofitting its screens with a fish return system to increase survival.

There is considerable variability in IM&E between facilities, and both between and within waterbody categories. A portion of this variability may result from the type of IM&E mitigation procedures in use. The source waterbody composition and abundance of species vulnerable to IM&E play an important role in determining the magnitude of losses for a particular facility. For instance, the lowest annual impingement numbers adjusted for flow are found at facilities that draw water from small rivers or lakes and reservoirs. Highest annual impingement is found at facilities that draw water from the Great Lakes or oceans and estuaries, although impingement controls at BTPB, BTPC, BTCA2, and RFH, are effective in reducing this impact. For the BTPs and RFs, oceans and estuaries likewise have the highest entrainment rate per million gallons of cooling water (Table 6-5).

Total annual WTP to avoid losses due to IM&E (i.e., the WTP for the closed-cycle cooling retrofit) for the BTPs and RFs ranged from just over $100 to approximately $569,800. However, it is important to note that WTP did not include entrainment for more than half of the facilities because these stations were not subject to the entrainment standards. While the magnitude of IM&E forms the basis of the monetization process, the composition of the species lost and the value placed on each species also plays a determining role in the monetization process. The facility with this highest total monetized loss, RFF, impinged and entrained a substantial number of white bass, an important recreational fish in the Great Lakes region. Likewise, another facility with a monetized loss of over $400,000, BTCA2, impinged and entrained substantial numbers of two species important to recreational or commercial fisheries, queen fish and white croaker.

IM data were collected for all facilities and both fresh and saline waterbody types fell within a range of <1 to over 170 IM per million gallons of flow. The general trend, however, showed that facilities using freshwater sources had lower rates than those using marine or estuary waterbodies (Table 6-5). Consistently low IM rates occur at facilities on rivers or lakes/reservoirs. Entrainment data were collected for twelve of the facilities representing three waterbody types (marine/estuary, Great Lakes, and small rivers). Entrainment rates ranged from 0.2 to nearly 100,000 organisms per million gallons. Facilities located on marine or estuary waterbodies had the highest entrainment rates, with the exception of RFH, which utilizes fine mesh screening to limit entrainment. RFF, located on the Great Lakes, also had an elevated entrainment rate, but was the exception of the freshwater facilities.

Table 6-4
Cooling water intake characteristics for BTPs and RFs

Facility	Cooling Water Intake Structure Location	Fixed Screens	Traveling Screen	Fine Mesh	Mesh Size	Fish Return[a]	Velocity Cap	Systems Other Than Fish Return and Velocity Cap
BTCA1	Canal		X		½ x ¾ inch			
BTCA2	Offshore		X		⅜ inch square	X	X	Velocity cap, louver fish guidance, and fish collection and return system
BTPA	Canal		X		⅜ inch square			
BTPB	Offshore		X		⅜ inch square		X	
BTPC	Shoreline		X		⅛ x ½ inch	X		
BTPD	Canal	X			⅜ inch square			
BTPE	Shoreline		X		⅜ inch square			Cooling water intake structure with low approach velocities
RFF	Canal		X		⅜ inch square			
RFG	Shoreline		X		⅜ inch square			
RFH	Canal	X	X	X	⅜ inch square or 1 mm	X		Intake canal diversion structure
RFI	Canal		X		⅜ inch square			

Table 6-4
Cooling water intake characteristics for BTPs and RFs (continued)

Facility	Cooling Water Intake Structure Location	Fixed Screens	Traveling Screen	Fine Mesh	Mesh Size	Fish Return[a]	Velocity Cap	Systems Other Than Fish Return and Velocity Cap
RFJ	Canal		X		⅜ inch square			
RFK	Shoreline		X		⅜ inch square			
RFL	Shoreline		X		⅜ inch square			
RFM	Shoreline		X		⅜ inch square			
RFO	Shoreline		X		⅜ inch square			
RFP	Canal	X	X		¼ inch square			
RFQ	Shoreline		X		⅜ inch square			
RFR	Shoreline		X		⅜ inch square			
RFS	Canal		X		⅜ inch square			
RFT	Shoreline		X		⅜ inch square			
RFU	Shoreline		X		⅜ inch square			
RFV	Shoreline		X		¼ inch square			
RFW	Canal		X		⅜ inch square			
RFX	Shoreline		X		⅛ x ½ inch			

[a] Defined as installations made specifically to carry fish back to the source waterbody in good condition. Fish and debris return sluiceways do not qualify.

Table 6-5
Comparison of annualized IM&E per volume of cooling water used for BTPs and RFs by waterbody type

Facility	Cooling Water (MGY)[a]	Impingement per MG of Cooling Water[b]	Entrainment per MG of Cooling Water[b]	Total Loss (2007$)[e]	Loss per MG (2007$)
Great Lakes					
BTPB	877,580	1.6	121	$66,500	$0.08
RFF	270,300	170	7,276	$575,600	$2.13
RFT	346,900	0.5	46	$13,300	$0.04
Large Rivers					
RFG	263,000	0.7	NA	$6,400	$0.02
RFL	96,415	0.7	NA	$1,600	$0.02
RFM	159,277	1.4	NA	$5,200	$0.03
RFO	87,400	0.6	NA	$5,600	$0.06
RFQ	40,892	0.1	NA	$400	$0.01
RFS	531,382	1.7	NA	$41,400	$0.08
RFU	59,075	0.1	NA	$200	<$0.01
Small Rivers					
RFI	185,187	0.3	253	$8,300	$0.04
RFR	39,238	0.02	NA	$100	<$0.01
Lakes and Reservoirs					
BTPD	473,606	0.4	NA	$400	<$0.01
BTPE	696,311	0.3	NA	$6,400	$0.01
RFJ	105,500	0.1	NA	$1,100	$0.01
RFN	81,500	0.1	NA	$500	$0.01
RFP	160,555	1.7	NA	$1,900	$0.01
RFV	244,915	0.03	NA	$800	<$0.01

Table 6-5
Comparison of annualized IM&E per volume of cooling water used for BTPs and RFs by waterbody type (continued)

Facility	Cooling Water (MGY)[a]	Impingement per MG of Cooling Water [b]	Entrainment per MG of Cooling Water[b]	Total Loss (2007\$)[e]	Loss per MG (2007\$)
Ocean/Estuaries and Tidal Rivers					
BTCA1	132,844	3.3	17,296	\$141,500	\$1.07
BTPA	360,086	1.4	874	\$42,300	\$0.12
BTPC [c]	159,407	182	2,476	\$244,100	\$1.53
BTCA2	854,356	1.7	34,443	\$435,000	\$0.51
RFH	701,055	9.7	0.2 [d]	\$51,000	\$0.07
RFK	73,291	1.0	13,848	\$96,700	\$1.32
RFW	387,995	0.2	99,714	\$570,800	\$1.47
RFX	55,115	0.1	4,037	\$107,400	\$1.95

[a] MGY (million gallons of cooling water used per year) are from reported values in source data reports or calculated from five-year averages of reported actual cooling water usage [78].
[b] Results given in number of fish and shellfish impinged or entrained per million gallons (MG).
[c] Losses at BTPC are expected losses based on technology currently being installed at the facility. See Appendix A.
[d] This facility uses fine mesh screening thereby reducing entrainment.
[e] This is the total annual loss (rounded) due to IM&E without a cooling tower, not the benefit of a cooling tower. The benefit of the cooling tower is based upon the percent of IM&E that would no longer occur and is presented in Table 6-6.
NA = Not applicable because the facility is not subject to the entrainment standard.

IM&E reduction is the primary benefit associated with retrofitting to closed-cycle cooling. Based on this investigation the monetized losses varied widely and were principally determined by a combination of the scale of IM or IM&E losses, whether entrainment was considered, the composition of the species lost, the value of each species and whether a commercial fishery exists in the waterbody. Monetized losses per million gallons of cooling water used were generally low for facilities using freshwater and not located on the Great Lakes; they averaged \$0.02 per million gallons. Facilities on the Great Lakes or at ocean, estuary, and tidal river locations averaged much higher, \$0.75 and \$1.00 per million gallons, respectively (Table 6-5). Note that EPRI will publish a National Benefit Valuation Report that will analyze many more facilities and address other factors affecting quantification and monetization of impingement and entrainment.

6.2 Impact Monetization

Table 6-6 reports the facility specific WTP to avoid the identified environmental changes associated with the conversion of once-through cooling systems to closed-cycle cooling. Due to the high level of uncertainty, potential WTP to avoid changes in CO_2 emissions are reported separately.

Note that the correct interpretation of a negative net WTP is that society prefers the bundle of environmental goods associated with cooling towers relative to the bundle of environmental goods associated with the technologies that are currently being used on these once-through cooling facilities. This does not necessarily mean that cooling towers are the environmentally optimal solution at these facilities. At some facilities there may be alternative technologies that reduce IM&E and have significantly fewer adverse environmental impacts. In cases where such technologies exist, their utilization may maximize society's environmental well-being.

Excluding the impacts of greenhouse gas emissions, the net annual WTP to avoid the environmental changes associated with installation of a cooling tower was positive at 13 of the 24 facilities modeled. That is, the monetized impacts (WTP to avoid closed-cycle cooling impacts) are higher than the monetized benefits of reduced IM&E at 54 percent of the facilities. When WTP to avoid greenhouse gas emissions is included, there is a positive WTP to avoid the closed-cycle cooling related impacts at 17 of the 24 (71%) of the facilities (i.e. closed-cycle cooling environmental and social impacts are greater than once-through impacts on fish and shellfish).

Among the 17 facilities where WTP is positive, nine have net WTP greater than $100,000. At the seven facilities where net WTP is negative; the WTP is approximately $100 or less at two facilities, between $5,000 and $100,000 at three others, and exceeds $200,000 at two facilities. Thus, given the uncertainty of this study, the conversion to closed-cycle cooling has a significant net adverse environmental impact based on WTP at nine facilities and a significant net environmental benefit at only two of the facilities studied.

6.3 National Scale-Up

The approach to quantify the potential net environmental and social effects associated with a retrofit to closed-cycle cooling on a national scale included:

- Modeling net effects associated with mechanical-draft evaporative cooling towers at characteristic facilities within a facility subset;
- Normalizing the effects to the appropriate facility parameter (e.g., cooling water flow, population), if appropriate;
- Where possible, scaling the effects and monetized values to other facilities within each facility subset;
- Using information from the EPRI Questionnaire for site-specific issues that cannot be scaled; and
- Summing all effects and monetized values to a national scale.

Table 6-6
Summary of annual monetized impacts compared to the primarily benefit (reduced IM&E) associated with the retrofit to closed-cycle cooling at BTPs and RFs

A negative net WTP indicates society prefers the environmental effects associated with cooling towers relative to the environmental effects associated with the technologies that are currently being used on these once-through cooling facilities.

Facility	Average Annual WTP for Specified Environmental Change								Net Annual Average WTP to Avoid Change to Closed-cycle Cooling[c]	Increased Greenhouse Gases[f]	Total
	Increased Terrestrial Habitat Impacts	Increased Salt Deposition	Increased Consumptive Water Use	Increased Man-Made Debris[g]	Public Safety\ Increased Roadway Foggin[d]	Increased Nois[d]	Viewshed Degradatio[b,d]	Decreased IM and/or [e]			Net WTP to Avoid Change to Closed-cycle Cooling
BTPs											
BTCA1	$0[a]	$0	$0	$18,600	<$50	$53,800	$189,300	-$133,000	$128,700	--	$128,700
BTPA	$0	$0	$0	N/A	$0	$0	$300	-$40,600	-$40,300	--	-$40,300
BTPB	$110,800	$0	$0	$11,100	$100	$5,800	$8,600	-$65,200	$71,200	$428,800	$500,000
BTPC	$0	$0	$0	$2,200	<$50	$0	$4,400	-$241,700	-$235,100	--	-$235,100
BTPD	$0	$0	$0	$0	<$50	$16,200	$1,700	-$400	$17,500	--	$17,500
BTPE	$0	$80	$0	N/A	$0	$1,600	$100	-$6,300	-$4,500	$493,800	$489,300
BTCA2	$0	$0	$0	$0	$2,800	$0	$ 157,800	-$408,900	-$248,300	$438,400	$190,100
RFs											
RFF	NM	NM	$0	$200	<$50	$0	$0	-$569,800	-$569,600	--	-$569,600
RFG	NM	NM	$0	N/A	$200	$11,100	<$50	-$6,200	$5,100	--	$5,100
RFH	NM	NM	$0	$0	$0	$19,600	$4,900	-$47,400	-$22,900	$411,200	$388,300
RFI	NM	NM	$0	$46,600	$23,500	$0	$27,600	-$8,100	$89,600	--	$89,600
RFJ	NM	NM	$0	<$50	<$50	$63,000	$0	-$1,100	$61,900	--	$61,900
RFK	NM	NM	$0	$0	<$50	$0	$3,200	-$91,900	-$88,700	--	-$88,700
RFL	NM	NM	$0	N/A	$400	$245,900	$0	-$1,600	$244,700	--	$244,700
RFM	NM	NM	$0	$3,000	$0	$186,900	$0	-$5,100	$184,800	--	$184,800
RFN	NM	NM	$0	N/A	$100	$73,900	$0	-$500	$73,500	--	$73,500

Table 6-6
Summary of annual monetized impacts compared to the primarily benefit (reduced IM&E) associated with the retrofit to closed-cycle cooling at BTPs and RFs (continued)

Facility	Average Annual WTP for Specified Environmental Change								Net Annual Average WTP to Avoid Change to Closed-cycle Cooling[c]	Increased Greenhouse Gases[f]	Total
	Increased Terrestrial Habitat Impacts	Increased Salt Deposition	Increased Consumptive Water Use	Increased Man-Made Debris[g]	Public Safety\ Increased Roadway Foggin[d]	Increased Nois[d]	Viewshed Degradatio[b, d]	Decreased IM and/or [e]			Net WTP to Avoid Change to Closed-cycle Cooling
RFO	NM	NM	$0	$0	$100	$0	<$50	-$5,400	-$5,300	--	-$5,300
RFP	NM	NM	$0	N/A	$0	$14,700	<$50	-$1,800	$12,900	--	$12,900
RFQ	NM	NM	$0	$45,600	<$50	$0	$0	-$400	$45,200	--	$45,200
RFR	NM	NM	$0	$0	N/A	$0	<$50	-$100	-$100	--	-$100
RFS	NM	NM	$0	$1,500	$100	$0	$1,000	-$40,200	-$37,600	$334,800	$297,200
RFT	NM	NM	$0	$300	$0	$29,400	$0	-$13,000	$16,700	--	$16,700
RFU	NM	NM	$0	$200	<$50	$0	$0	-$200	<$50	--	<$50
RFV	NM	NM	$0	$400	<$50	$800	$100	-$800	$500	$214,300	$214,800

N/A = Data Not Available; NM = Not Monetized; "--" = Not Applicable

Note totals may not equal due to rounding.

[a] Does not include an estimated monetized loss of $5,200 to offsite wetlands.

[b] Visual impacts includes housing *and recreational* impacts.

[c] Net WTP without greenhouse gas.

[d] Impacts for these issues at RFM, RFN, RFO, RFP, RFQ, RFR, RFS, RFT, RFU, RFV were based on impacts for similar facilities; they were not modeled.

[e] These values indicate the WTP to avoid IM and/or E-related losses, not the total monetized losses due to IM and/or E. The total monetized losses are provided in Table 6-5 and include the IM and/or E that would continue to occur even with a cooling tower in place. 12 facilities had both IM&E impacts (BTCA1, BTPA, BTPB, BTPC, BTCA2, RFF, RFH, RFI, RFK, RFT, RFW, and RFX); entrainment impacts were not applicable at the remaining 14 facilities studied. [a] Does not include service water; therefore, the reduction is overestimated.

[f] Assumes a 6-month shutdown.

[g] Does not include service water; therefore, the increase is overestimated.

The complete list of Phase II facilities and their parameters and categories used for national scaling are provided in Appendix E and discussed in Section 2.2. For the purposes of this study, this list was finalized on November 9, 2010. For this scaling, facilities were grouped by salt or brackish waterbodies (termed Ocean/Estuaries/Tidal Rivers [O/E/TR] in this study), Great Lakes and small rivers (SR/GL) and larger rivers, reservoirs or lakes (LR/RL). However, this grouping may not be appropriate for scaling every impact. The methods used to scale to a national level, including which groupings were used, are summarized in each subsection below and detailed in Appendix B.

Table 6-7
Phase II facilities used for national scaling

	O/E/TR	SR/GL	LR/RL	Totals
Fuel[1]: Nuclear/Fossil	19/174	13/104	7/111	39/389[1]
Population[2]: High/Medium/Low	19/58/114	48/38/30	23/57/38	90/153/182
Geographic Region[3]: CA/NE/SE/West	0/55/43/93	21/45/42/7	0/72/29/17	21/172/114/117
Totals:	**191**	**116**	**118**	**425**[1]

[1] One facility in the O/E/TR and two in the LR/RL categories have both nuclear and fossil units. These three stations were each considered a single facility for calculations based on the total number of facilities.
[2] High >1,000 per sq mile, Medium 100-1,000 per sq mile, Low <100 per sq mile.
[3] CA = California, NE = Northeast, SE = Southeast (see Section 6.3.5.1). One facility, located in Guam, was not included in the evaluation.

6.3.1 Human Health

Pathogens e.g. *Legionella* sp. or other pathogens [17, 18], such as *Salmonella*, *Shigella*, *Pseudomonas aeruginosa*, thermophilic fungi, and free-living amoebae [17], are found in cooling system water and can be emitted from cooling towers. However, potential health risks associated with increased emissions due to retrofitting to closed-cycle cooling could not be quantified or monetized due to lack of available information. Therefore, this risk was not evaluated for the national scale-up phase of the project.

Sections 3.7 and 4.1.2.1 describe the process of estimating potential fine particulate impacts to human health, measured as the estimated population (Age 30+ and Age 65+) that is potentially exposed to significant increases in PM_{10} and $PM_{2.5}$ due to a closed-cycle cooling retrofit at the BTPs and RFs. Potential human health impacts from the increased exposure to PM from cooling towers were not quantified as there are currently no data available on impacts of cooling tower PM on human health on which to base an estimate.

For the national scale-up, two separate national estimates were made: 1) the total annual additional PM emissions (tons), and 2) the total population exposed to significant increases in PM_{10} and $PM_{2.5}$ emitted from cooling towers. Calculations of total annual additional PM emissions were performed based on the results for the BTPs and RFs shown in Section 3.7, Table 3-4. The national Age 30+ and Age 65+ populations estimated to be exposed to significant increases in

PM were estimated using the results of the quantification process for the BTPs and RFs shown in Section 4.1.2.1, Table 4-1.

The following two subsections provide the results of these separate national scaling calculations. A conservative estimate of the upper bound WTP to avoid additional human health effects associated with PM emissions (2007 $) (e.g., morbidity and mortality) was calculated using USEPA methods. Annual WTP to avoid mortality may be as high as $48 million, and an additional $6.5 million to avoid morbidity associated with additional PM using the USEPA methods that are not specific to cooling tower PM. These values represent the high end of the range of potential impacts. In the absence of cooling tower PM data, EPRI believes any risk is likely to be highly variable depending on particulates in the source cooling water and that the low end risk estimate could approach zero. Details of the results using the USEPA methods are provided in Appendix G for comparison purposes only.

6.3.1.1 PM_{10} and $PM_{2.5}$

The potential emissions of particulate material (PM, PM_{10} and $PM_{2.5}$) and water evaporation from closed-cycle cooling retrofit at selected facilities is estimated in Sections 3.7 and 3.8 of this report. This analysis shows that annual emissions can vary significantly. Emissions from facilities using brackish or salt water for tower makeup can have high emissions, while facilities using freshwater have relatively low emissions. Therefore, the national list of power plants was divided into two categories based on salinity of the makeup water, 1) plants withdrawing from oceans, estuaries, and tidal rivers and 2) plants using lakes, rivers, and the Great Lakes for cooling water.

The relationship of design cooling water flow to PM emissions was found to be linear and significant ($R^2 = 0.8733$ for freshwater plants; $R^2 = 0.83$ for saline plants). This relationship was used to estimate the total annual amount of PM that would be emitted from saline and freshwater plants if all Phase II facilities converted to closed-cycle cooling. Table 6-8 presents these results.

Table 6-8
Estimated total annual emissions of PM

Subgroup	Σ Design Cooling Water Flow (MGD)	Estimated Annual Emissions of PM (tons)	Estimated Annual Emissions of PM_{10} (tons)	Estimated Annual Emissions of $PM_{2.5}$ (tons)
O/E/TR	86,600	27,100	11,500	3,400
SR/GL	50,700	800	600	200
LR/RL	125,200	2,000	1,400	600
Total	262,500	29,800	13,500	4,200

Tons of PM rounded to the nearest 100 tons; totals may not equal due to rounding.

To put this in perspective, a typical existing coal-fired power plant emits 0.24 lbs of PM per MW-hr [79]. Therefore, the annual PM emission of a 500 MW coal-fired power plant operating at 70 percent capacity is estimated to be 368 tons. Thus, the national retrofit to closed-cycle cooling will result in cooling tower PM emissions nearly equivalent to that of 81 existing 500 MW coal-fired power plants in terms of the amount of fine particulates generated. However, while data are available on human health impacts from fossil fuel combustion, that is not the case for cooling tower PM and therefore human health implications are unknown.

6.3.1.2 Exposed Populations

The potential populations exposed to cooling tower PM was calculated by grouping modeled BTPs and RFs into the nine salinity/population categories. The BTP/RF with the maximum exposed population was chosen to represent the other facilities in that subgroup (see Table B-5, Appendix B). Note that because there were no BTPs/RFs in the SR/GL-Low Population subgroup, the results for RFS, the only freshwater BTP/RF in a Low Population area, were used for estimating the other facilities in that subgroup. Table 6-9 presents these results.

Table 6-9
Estimated total population exposed to a significant increase in PM_{10} and $PM_{2.5}$

Subgroup	Exposed Population (Age 30+)	Exposed Population (Age 65+)
O/E/TR	8,977,900	1,641,700
SR/GL	6,063,700	1,098,000
LR/RL	1,003,500	226,300
Total	16,045,000	2,966,000

The upper estimate of exposure is more than 16 million people. This estimate is roughly equivalent to double the 2010 population of the state of Virginia [80].

6.3.1.3 Uncertainty

Site-specific variations in wind, topography, building heights, and placement of the towers are all variables that cannot be accounted for in the scaling process and will add uncertainty to the exposed population estimates. In addition, uncertainty is generated by the absence of cooling tower PM health effects studies.

6.3.2 Terrestrial Resources

6.3.2.1 Long-term Loss of Wildlife Habitat, Wetlands, and Critical Habitat

This study found that the retrofit to closed-cycle cooling at all 24 evaluated facilities would result in the long-term losses of terrestrial resources, primarily upland herbaceous/shrub-scrub, followed by upland forest, open water areas, wetlands and some critical habitat. Potential wetland losses occur at 30 percent of the sites studied and critical habitat loss at 17 percent. These impacts are site-specific, and varied widely depending on the type and acreage of vegetation at the tower location, land availability, and size of the tower. Based on the BTPs, the long-term losses of terrestrial resources average approximately 6.6 acres. Assuming this is a representative sub-set of all Phase II facilities, a national retrofit may result in the loss of over 2,800 acres of terrestrial resources. However, this estimate is highly uncertain given the sample size.

Based on the information collected and analyses performed, the loss of critical habitat associated with a national closed-cycle cooling retrofit may be summarized as:

- Four of the 24 plants studied, or 17 percent, estimated potential loss of critical habitat during the closed-cycle cooling retrofit;
- Based on the EPRI Questionnaire, 29 of the 209 facilities responding indicated terrestrial or wetland resources would be impacted by closed-cycle cooling retrofit. Wetlands were cited in seven responses, with the remaining facilities reporting potential critical habitats such as protected dunes, lakes, threatened and endangered species habitat, and refuges. Thus, unique, rare, or threatened habitats may be lost at up to 22 (11 percent) of the facilities surveyed; and
- Based on these two subsamples, between 47 and 72 of the Phase II facilities may experience potential loss of critical habitat as a result a closed-cycle cooling retrofit.

A WTP to preserve non-unique, non-rare habitats could not be developed because of the lack of information in the literature. Therefore, the loss of over 2,800 acres of mostly herbaceous/shrub-scrub, upland forest and open water habitat cannot be monetized. Potential wetland impacts that may occur nationally are not monetized because federal and some state regulations require that these losses be mitigated by creation of new wetlands or restoration of existing wetlands. As such, there is no net loss of wetland services associated with cooling tower construction in wetlands.

WTP estimates exist for the preservation of critical habitats, thus allowing monetization of potential loss. Based on the seven facilities studied, the total WTP associated with critical habitat loss is $116,000. However, the quantity, type, and value of the critical habitat loss are site-specific. Only three of the seven BTPs were estimated to impact any critical habitat and the WTP to avoid one could not be calculated due to a lack of information (Section 4.2.1.2). Using this small subset of facilities, the arithmetic average WTP is $16,563. This is likely an underestimate because the WTP to avoid loss of coastal scrub-shrub habitat at BTCA2 is expected to be positive, but is not quantifiable, and therefore was assumed to be $0. However, this statistic is more appropriate for scaling than the median WTP value, which is $0; because the median would underestimate the national impacts more.

Based on the results of the EPRI Questionnaire and the BTP/RF evaluation (i.e., 47-72 Phase II facilities may experience potential loss of critical habitat as a result a closed-cycle cooling retrofit) and the average WTP ($16,563), the national annual WTP to avoid this loss may range from approximately $778,000 to over $1.19 million. However, this estimate is highly uncertain due to the site-specific nature of the impacts. Additionally, it is not possible to estimate potential impacts based on waterbody type due to the small subsample evaluated (e.g., only one BTP was located on a SR/GL).

6.3.2.2 Salt and Mineral Drift Effects on Vegetation and Soils

This study found that based on a screening analysis utilizing order-of-magnitude thresholds of impact derived from the NRC [28], salt and mineral drift from the retrofit to closed-cycle cooling have the potential to adversely affect on-site native woody and herbaceous vegetation (Section 4.2.2). This screening suggests that potential impacts such as visible leaf damage were likely at most of the facilities investigated in this study, representing both saline and fresh water sites. However, screening analysis assumes the most sensitive species are present and these impacts may not occur depending on site-specific species sensitivity. Thus, these impacts will vary widely depending on the type of vegetation, location of the vegetation relative to the tower location, and tower emissions. Given the uncertainties associated with salt and mineral drift impacts and that lack of information to develop a WTP, salt and mineral drift effects are not scaled.

Impacts of salt deposition to agricultural lands were quantified and monetized for the seven BTPs. For all BTPs, except one, modeling suggested no impacts to agricultural lands, either because there were no croplands nearby and/or salt drift deposition rates were low. The impact at BTPE, a large fresh water facility that had agricultural land nearby, was greater than zero, but the WTP associated with this impact was only $80 (Section 4.2.2). Additionally, no agricultural lands were identified within or adjacent to the two freshwater RFs that use high TDS makeup water. This suggests that the national WTP to avoid these impacts at the 118 facilities on SR/GL and the 191 facilities on LR/RL is minimal.

Few data (i.e., only two studies) were identified with information on salt drift effects on agriculture, one of which was focused on tobacco. Agricultural crops vary in terms of their sensitivity to salt drift, and due to the very small amount of data and information, it is not possible to estimate the agricultural impact from O/E/TR facilities that generate the majority of the salt drift from once-through cooled facilities.

6.3.2.3 Noise Impacts on Terrestrial Wildlife

Based on the facilities investigated, a significant area of habitat, up to over 200 acres per site, may exceed U.S. Fish & Wildlife Service’s threshold for noise level impacts to wildlife as a result of closed-cycle cooling retrofits. However, specific wildlife census data were lacking and therefore, it was not possible to quantify how much, and to what degree, the wildlife population may be impacted. Additionally, no data were available to monetize the impact.

Noise impacts to threatened, endangered, or otherwise protected species (such as terrestrial and semi-aquatic species like piping plover, Indiana bat, red legged frog) occupying affected habitat is possible. Results of the EPRI Questionnaire found that overall approximately 36 percent of the Phase II facility respondents identified at least one terrestrial or semi-aquatic protected species either on-site or nearby the station. If these facilities are assumed to be a representative subsample of all Phase II facilities, the results suggest that 157 Phase II facilities may experience cooling tower noise impacts to protected wildlife. These impacts appear to vary between source waterbody types, as shown in Table 6-10, below.

Table 6-10
Estimated number of Phase II facilities that may cause noise impacts to protected species with a closed-cycle cooling retrofit

Source Waterbody	Respondents Indicating Terrestrial/Semi-aquatic Protected Species in the Vicinity (%)	Estimated Number of Phase II Facilities with Noise Impacts to Protected Wildlife
O/E/TR	19 %	22
SR/GL	33 %	39
LR/RL	50 %	96

6.3.2.4 Impacts of Fogging and Icing on Terrestrial Vegetation

Fogging at the rate of tens of hours per year is predicted to occur at eight of the 18 facilities for which this impact was estimated (44.4 percent; six LR/RL and two SR/GL) and icing was predicted at this level at two of 18 facilities (11.1 percent; SR/GL) (Section 4.2.4). This rate of fogging and/or icing may cause detectable damage to vegetation [28] and in some cases may impact crops.

Fogging and icing associated with the four representative plants with a source waterbody classified as O/E/TR were predicted to be low (i.e., less than six hours/year). However, facilities withdrawing from freshwater sources were predicted to have fogging rates that could cause detectable damage to vegetation, if present, at 60 percent of the LR/RL plants and 50 percent at the SR/GL plants. Assuming the facilities evaluated are representative of all Phase II facilities, as many as 174 freshwater facilities (115 LR/RL and 59 SR/GL) may experience adverse level of fogging impact to vegetation associated with the closed-cycle cooling retrofit.

While these impacts have not been monetized, detrimental effects on local vegetation from humidity-associated increased fogging could impact as many as 174 freshwater facilities.

6.3.2.5 Other Terrestrial Impacts

Impacts such as salt deposition damage to automobiles and other metal surfaces and corrosion and shorting of electrical equipment were not quantified in this study other than an estimate of distance from the hypothetical cooling tower to a critical salt deposition rate that may cause electrical flashover at the BTPs (Section 4.2.5).

Cooling tower operation at all 116 facilities located on O/E/TR, along with any freshwater facilities with high TDS makeup water, may result in electrical equipment damage on- and off-site depending on the cooling tower location, distance and direction of the drift.

6.3.2.6 Uncertainty

The scaling methods cannot quantify the site-specific loss of rare or unique on-site habitats or the population of protected species impacted by increased noise created by the retrofit to closed-cycle cooling. It was assumed that the results from evaluating the BTPs/RFs and the responses to the EPRI Questionnaire were representative of all Phase II facilities. The overall direction of bias in the analysis is unknown.

6.3.3 Water Resource Quantity and Quality

Although impacts to source and discharge waterbody quality were not quantified nor monetized during this investigation, cooling tower blowdown may impact water quality at Phase II facilities that retrofit to closed-cycle cooling (Section 4.3). Because the consumption of active chlorine in wet cooling towers with fresh water makeup averages 200 kg/MW/yr compared to 85 kg/MW/yr for once-through cooling systems [32], the conversion to closed-cycle cooling has the potential to more than double chlorine use. Based on the total generating capacity of once-through Phase II facilities using the Great Lakes or small rivers as source waterbodies (61,062 MW), the conversion to closed-cycle cooling would result in the additional consumption of 7.0 million kg/yr (7,000 metric tons/yr) of chlorine at these facilities[3]. For facilities located on large rivers, reservoirs, and lakes (158,517 MW), this would result in the additional use of over 18 million kg/yr (18,000 metric tons/yr) of chlorine. This additional chlorine will need to be transported to and stored on-site.

6.3.3.1 Evaporative Water Loss

The national retrofit to closed-cycle cooling will increase the evaporation rate compared to once-through cooling water discharges. The evaporation rates due to closed-cycle cooling *in excess* of the current once-through evaporation rates were estimated for those facilities that utilize fresh water sources for condenser cooling water. Facilities withdrawing from saline waters (i.e., in the O/E/TR group) were not evaluated because the amount lost to evaporation is relatively small compared to the size of the waterbody and is assumed to be negligible.

The net evaporative water loss was calculated for seven (five fossil and two nuclear) BTPs/RFs located on fresh waterbodies (Section 4.3.1). These results were used for national scaling. The net evaporative freshwater loss for nuclear facilities on SR/GL and LR/RL was 415 gals/MW-hr and 479 gal/MW-hr, respectively. The average net evaporative freshwater loss for representative fossil plants evaluated on SR/GL was 291 gal/MW-hr and 315 gal/MW-hr for fossil plants on LR/RL.

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[3] The difference in active chlorine consumption between wet cooling towers and once-through cooling systems (200 kg/MW/yr – 85 kg/MW/yr = 115 kg/MW/yr) was multiplied by the design capacity of all the facilities within the waterbody category (in MW) to derive the chlorine consumption rate (kg/yr).

The Phase II facilities using freshwater sources were classified as to nuclear and fossil fuel type and to waterbody (SR/GL vs. LR/RL). The total MW-hr was summed for each of these four groups. The average calculated net potential evaporation rates estimated in this report were then used to estimate the total net evaporation for all 309 freshwater Phase II facilities (two facilities have both nuclear and fossil-fueled units). The results indicate that an additional 128 billion gallons of water per year may be lost to evaporation from the 118 plants located on SR/GL and 372 billion gallons of water per year may be lost to evaporation from the 191 plants located on LR/RL. Assuming a residential water use of 100 gallons per capita-day, this amount of additional fresh water evaporation is roughly equivalent to the yearly water use of 13.7 million people, or more than the 2009 population of Illinois (12.9 million) http://quickfacts.census.gov/qfd/index.html

Recent national estimates of water consumption by the thermoelectric industry using 1995 USGS data are 3,310 MGD for freshwater and 369 MGD for saline waters [81]. These values are of the same order of magnitude as the values calculated in this study (i.e., 1,370 MGD). The results suggest that water consumption by the thermoelectric industry could increase by nearly 40 percent if all freshwater Phase II facilities were to retrofit to closed-cycle cooling.

Water sustainability and water rights have become a significant, and contentious, issue among interested parties, including farmers and ranchers, cities and municipalities, wildlife and environmental conservationists, and many industries [82]. Groundwater levels have dropped significantly in many areas of the United States (e.g., groundwater levels are declining by 17 ft per year in the Chicago-Milwaukee area) and surface waterbodies have been notably impacted also (e.g., in 2007 Lake Powell was at its lowest level since 1973) [82]. Limerick Generating Station (LGS) is an example where a thermoelectric station with closed-cycle cooling that had numerous additional requirements placed on the owners in order to operate a closed-cycle cooling system. Due to restrictions imposed by the Delaware River Basin Commission (DRBC) on consumptive water use from the closed-cycle cooling system, a diversion system was created, including additional reservoirs and pumping stations, to supplement flow in the primary source waterbody, the Schuylkill River [83]. Under certain seasonal, river temperature, and flow conditions, LGS cannot withdraw its closed-cycle cooling makeup water solely from the Schuylkill River but must augment it with water withdrawn from the Delaware River. The supplemental water is pumped from the Delaware River and transported to LGS via the East Branch of Perkiomen Creek to the Main Stem of Perkiomen Creek, where it is again withdrawn and piped to LGS (a total transport distance of nearly 40 miles) [83].

Based on responses to the EPRI Questionnaire, consumptive water use is regulated or monitored by a state or regional agency at 48 percent (91 of 190 facilities) of the facilities responding to the question. Regional and state water boards (e.g., Los Angeles Regional Water Board, MNDNR Water Appropriations, Delaware River Basin Commission) and state environmental agencies (e.g., Texas Commission on Environmental Quality, Ohio Department of Natural Resources, Arkansas Natural Resources Commission) were cited as entities requiring permits, certificates, or monitoring reports for water withdrawal and/or consumption. Additionally, this concern was identified for 11 of the 24 BTPs/RFs (46 percent) (Section 4.6.3). These results suggest that nearly half of the Phase II facilities may have permitting issues associated with consumptive water use.

The BTP and RF study did not identify situations where *in-situ* water levels are likely to change in a meaningful manner, and therefore, WTP to avoid consumptive water loss was estimated to be zero for the BTPs and RFs. Therefore, no WTP was available to monetize the additional evaporative water loss for the 71 facilities located on small rivers or the 37 facilities on lakes/reservoirs in the Southwest that would be most at risk for consumptive water use issues.

However, if situations exist where in stream flows or water levels would be materially reduced, an assumed WTP equal to zero is underestimated. Similarly, if, in times of low supply increased consumptive water use reduces the availability of water for other uses such as drinking water or irrigation, WTP is underestimated. Nationally, these situations would be most likely to occur at the 71 facilities located on small rivers or the 37 facilities on lakes/reservoirs in the Southwest.


Lake Marion, 10-07

Figure 6-1
Marina on Lake Marion, SC during a severe drought in 2007
Courtesy of South Carolina state climatology office, south Carolina department of natural resources.

6.3.3.1.1 Uncertainty

The net evaporative water loss rates calculated from the one nuclear BTP/RF in each of the waterbody categories and the arithmetic average of the evaporation rate of the two fossil BTPs/RFs in the SR/GL category and three fossil plants on LR/RL were used to estimate the total net evaporation for all 309 freshwater Phase II facilities. These averages (415 gals/MW-hr for nuclear facilities on SR/GL; 479 gal/MW-hr for nuclear facilities on LR/RL; 291 gal/MW-hr for fossil facilities on SR/GL; 315 gal/MW-hr for fossil facilities on LR/RL) are based on calculations of in-stream evaporation and cooling tower evaporation. Calculated in-stream evaporative water losses at these facilities compare well with typical water consumption estimates [34, 35], including those calculated by EPRI (300 gals/MW-hr fossil; 400 gals/MW-hr nuclear) [33]. The cooling tower evaporation was estimated using well-accepted relationships between cooling water flow and temperature range and therefore, relatively little uncertainty is associated with those calculations. However, the cooling tower evaporation rates reported by

EPRI [33] (480 gal/MWh for fossil; 720 gal/MWh for nuclear plants) were slightly lower than the rates calculated for this study (approximately 600 gal/MW-hr fossil; 800 gal/MW-hr nuclear) and therefore, the net evaporation (i.e., the cooling tower evaporation minus the in-stream evaporation) is lower than the estimates used in the national scaling.

Other estimates of water consumption from closed loop cooling systems at fossil plants in the literature vary from 340 gal/MW-hr (cited as 0.34 gal/kWh in [84]) to 510 gal/MW-hr (cited as 0.51 gal/kWh in [85]). Calculations made for the Texas Water Development Board used the "average" rate of 600 gals/MW-hr (0.60 gals/kWh) for wet-type cooling tower consumption [86]. However, the authors noted that for smaller, less efficient fossil-fueled plants and currently operating nuclear units water consumption (i.e. evaporation) is 980 gals/MW-hr (0.98 gallons/kWh) in plants with wet-type towers but larger, modern plants may have evaporation rates as low as 560 gals/MW-hr (0.56 gallons/kWh) [86].

Differences in the types of cooling towers evaluated may be the source of the variation in cooling tower evaporation rates. However, these estimates are all within the same order of magnitude.

As explained further in Section 6.3.9, a small percentage of Phase II facilities employ helper cooling towers, usually seasonally during hot summer months. Some societal and environmental impacts calculated in this study are slightly overestimated at these facilities because existing towers already have some negative effects when they are operational.

6.3.3.2 Source Waterbody Debris Removal

The reduction in the water volume withdrawn associated with closed-cycle cooling retrofits, and the associated reduction of man-made debris removed from the waterbody, was evaluated for characteristic facilities (Section 4.3.2). The amount of trash removed was found to range up to 42 tons/year at some plants. A national estimate of the amount of trash removed by the existing cooling water intake structure was calculated using responses to the EPRI Questionnaire and as well as direct correspondence with some facilities. The estimated amount of man-made trash currently removed annually from the EPRI Questionnaire respondents totaled 289 tons/yr with a mean of 2.3 tons/year/facility. The amount of trash removed was normalized for plant size (i.e., by design cooling water flow in MGD) and the ratio was used to estimate the amount of human trash currently being removed nationally for the stations for which data were not available. An estimated 886 tons of man-made debris is removed annually by all Phase II facilities.

A retrofit to closed-cycle cooling will reduce the amount of water being withdrawn by 97 percent, on average (a range of 93 - 99 percent reduction was calculated for the facilities studied; see Section 4.3.2). Concomitantly, the volume of trash that is currently being removed during once-through cooling water withdrawal will also be reduced by approximately 97 percent. The national-level WTP to avoid this consequence was estimated for facilities in each waterbody category, as shown on Table 6-11.

Table 6-11
Estimated volume of man-made debris not removed due to closed-cycle cooling retrofit and the WTP to avoid this additional debris

Source Waterbody	Volume of Man-Made Debris No Longer Removed from Source Waterbodies (tons)	Total Average Annual WTP to Avoid Additional Debris (2007$)
LR/RL	338	$382,900
O/E/TR	281	$317,900
SR/GL	241	$273,300
National Total	861	$974,100

WTP rounded to the nearest $100; totals may not equal due to rounding.

The WTP to avoid a reduction in the removal of 861 tons of trash (approximately 97 percent of 886 tons, with rounding) in the nation’s waterbodies is over $974,000 annually, based on an estimate of society’s WTP for this service (Section 4.3.2.2).

NOAA has identified marine debris as a significant pollution issue in oceans, lakes, and other waterways [37]. A pilot project targeting the Great Lakes is planned, with future monitoring in the United States and Caribbean. The intent of the studies is to gain an understanding of the abundance and trends in shoreline, submerged, and coastal floating debris and well as to identify priority areas for cleanup efforts [37].

Figure 6-2
Man-made debris collected from a cooling water intake

6.3.3.2.1 Uncertainty

To estimate the national estimated amount of trash removed by Phase II facilities, and therefore left in the nations waterways if closed-cycle cooling retrofitting were to occur, the total amount of trash removed (tons, as estimated by EPRI Questionnaire responses and discussions with a number of facilities) was divided by the total design cooling water flow (MGD). This factor (in tons per MGD) was applied to the total design cooling water flow (MGD) of all the other Phase II facilities for which no trash removal information was available. Most facilities’ capacity utilization is less than 100 percent. Therefore, using design flow rates is likely to overestimate the benefit of trash removal if and when facilities shut down their cooling water pumps during non-generating times (e.g., ‘off-season’ for peaking units).

It is uncertain if the relationship between cooling water flow and trash removal is truly linear. Trash removal may not increase linearly with flow, which adds uncertainty to the estimates. The direction of this bias is not known. Additionally, the percent reduction of cooling water usage did not include service water; therefore, the reduction in cooling water and the amount of trash remaining in the waterways is overestimated.

6.3.3.3 Solid Waste

Solid waste, in the form of cooling tower sediment, is generated during closed-cycle cooling using towers. A national-level retrofit to closed-cycle cooling would therefore generate additional sediment. Solid waste generated nationally was not quantified because it is highly variable depending on the facility. Based on results of a specific solid waste EPRI questionnaire submitted to the industry (Section 4.3.3), the type of tower (mechanical-draft evaporative cooling towers versus natural-draft evaporative cooling towers) does not appear to correlate with the amount of sediment accumulated. However, sediment generation at nuclear facilities is approximately 70 percent less than that at fossil plants (150 CY/basin/year compared to 500 CY/basin/year, respectively). Since fossil facilities comprise over 90 percent of all Phase II facilities, this issue would impact the majority of power stations if a national retrofit to closed-cycle cooling were mandated. Most facilities responding to the questionnaire that analyzed the sediment indicated that it was non-toxic, and that it was disposed of on-site or in public landfills with no additional permitting. Therefore, while the generation of cooling tower sediment will impact all facilities, it has not been a significant permitting, disposal, or hazardous waste issue.

6.3.4 Public Safety on Roadways and at Airports

6.3.4.1 Fogging and Icing Impacts to Roadways

Water vapor emitted from mechanical-draft evaporative cooling towers may produce adverse social impacts in surrounding areas, such as:

- Fogging and icing of roadways;
- Fogging interference with nuclear facility security systems; and
- Visible plume interference with air traffic at nearby airports.

Potential adverse impacts from vapor plumes on the fogging and icing of roadways were evaluated for BTPs and RFs in Section 4.4.1. This study found fogging was predicted to occur on roadways at most facilities. However, estimates of the annual WTP to avoid fogging are only significant at facilities in high population areas in close proximity (0 to 50 meters) to major roads or highways (e.g., interstates, state routes, primary roads using DOT classification) (Table 6-12).

Table 6-12
Median annual WTP to avoid fogging calculated from BTPs/RFs (2007$)

	High Population	Medium/Low Population
Major Roadway Located 0 – 50 meters	$420	$40
No Major Roadways 0 – 50 meters	$50	$10

WTP values are rounded.

During the California scale-up portion of the Beta Test, impacts to roadways was determined using the area function and facility maps to identify roadways impacted by fogging. A monetized value was then assigned using the results from BTCA1 and BTCA2, based on the type of roadway affected (e.g., interstate highway, local road, etc.). The results of the California evaluation are summarized in Table 6-13, below.

Table 6-13
Monetized impacts of fogging for California facilities

Facility Name[a]	Roadways Experiencing at Least 0.5 Hours of Fogging Annually	Total Average Annual WTP to Avoid Fogging (2007$)
BTCA1	Local Road	<$50
BTCA2	Interstate	$2,800
CA4	Interstate, State Road	$2,800
	State-wide Total	**$5,500**

[a] WTP to avoid fogging was estimated to be $0 at the following facilities because no major roadways experiencing at least 0.5 hours of fogging annually were impact: CA1, CA2, CA3, CA5, CA6, CA7, CA8, CA9, CA10, CA11, CA12, CA13, CA14, and CA15.
WTP rounded to the nearest $100; totals may not equal due to rounding.

The California scale-up demonstrated that although fogging may occur at all facilities, the WTP to avoid fogging impacts is only significant when major roadways are nearby.

For the national scale-up, the WTP to avoid fogging impacts was estimated for the Phase II facilities not already estimated during the BTP/RF or California evaluations by applying the median annual WTP to avoid fogging calculated from the BTPs/RFs for high and medium/low population with and without major nearby roads (Table 6-12) . The Phase II facilities were grouped by population based on U.S. census data and by proximity to roadways based on responses to the EPRI Questionnaire and best professional judgment using aerial photography of the Phase II facilities in High population areas to determine if state or interstate roadways were present. Using the median annual WTP to avoid fogging (Table 6-12), in addition to the estimates calculated for the BTPs/RFs and California facilities, the total estimated annual WTP to avoid impacts caused by fogging nationally is over $54,700 (Table 6-14).

Table 6-14
Monetized impacts of fogging for all Phase II facilities

Waterbody Type	Population Group	Facilities	Annual WTP to Avoid Fogging (2007$)
O/E/TR	Low	CA[a]	$2,800
		BTPs/RFs	<$50
		Other Phase II	$100
	Medium	CA[a]	$0
		BTPs/RFs	$0
		Other Phase II	$400
	High	CA[a]	$2,800
		BTPs/RFs	<$50
		Other Phase II	$11,400
		O/E/TR subtotal	$17,600
LR/RL	Low	BTPs/RFs	$200
		Other Phase II	$1,200
	Medium	BTPs/RFs	$400
		Other Phase II	$500
	High	BTPs/RFs	$400
		Other Phase II	$4,600
		LR/RL subtotal	$7,300
SR/GL	Low	BTPs/RFs	$0
		Other Phase II	$500
	Medium	BTPs/RFs	$100
		Other Phase II	$500
	High	BTPs/RFs	$23,500
		Other Phase II	$5,200
	SR/GL subtotal		$29,800
		National Total	**$54,700**

WTP rounded to the nearest $100; totals may not equal due to rounding.

Roadway icing is expected to occur at seven of the 24 modeled facilities (29.2 percent); assuming this is a representative subsample of all Phase II facilities, up to 124 facilities may encounter some icing problems if cooling towers were operated. Based on the modeled impacts, icing may occur between 0.3 hour/year and 23.12 hours/year (Section 4.4.1) at these facilities. A WTP to avoid impacts from roadway icing could not be developed because appropriate accident data associated with these conditions are not available.

6.3.4.2 Fogging Impacts to Airports

Only one of the facilities evaluated for ground level fogging is predicted to have a vapor plume that may interfere with a nearby runway, indicating that this is likely not a significant national issue. Additionally, alternatives such as plume-abated (hybrid) towers or dry cooling towers may be available depending on site-specific characteristics (e.g., available land, salinity of the makeup water). Therefore, national scale impacts at airports of fogging associated with closed-cycle cooling were not calculated.

6.3.4.3 Uncertainty

Confounding variables related to the scaling of potential adverse impacts from fogging and vapor plumes on roadways include local meteorological conditions, topography, and placement of the towers. These variables are not accounted for in the scaling process and will add uncertainty. Scaling of monetized values assumes traffic patterns, travel speed, accident rates, and delays at the selected BTPs/RFs are representative of those found at other Phase II facilities. The overall direction of bias in the analysis is unknown.

The annual WTP to avoid impacts associated with roadway fogging for nearly 200 Phase II facilities in Low and Medium population areas were assigned the lowest median value (i.e., $6) although the proximity of roadways were unknown for these facilities. Because impacts to facilities in Low and Medium population areas were an order of magnitude less than that estimated in High population areas, regardless of proximity to roadways, it was assumed that the monetized impacts are relatively small and therefore roadway proximity was not determined for the facilities that did not respond to the EPRI Questionnaire or were not otherwise evaluated. The national annual WTP associated with fogging using this assumption is an underestimate because at least some of the facilities have roadways nearby although they were calculated as if they did not.

As explained further in Section 6.3.9, a small percentage of Phase II facilities employ helper cooling towers, usually seasonally during hot summer months. Some societal and environmental impacts calculated in this study are slightly overestimated at these facilities because existing towers already have some negative effects when they are operational.

6.3.4.4 Security at Nuclear Facilities

The potential impact to the line of sight at nuclear facilities due to fogging is an additional concern posed by on-site cooling towers. While it is likely that cooling towers would be located such that the predominant wind would carry the plume and fog away from the relatively small Protected Area that is under active visual surveillance, it is possible that a potential closed-cycle cooling retrofit with mechanical-draft evaporative cooling towers would likely cause some fogging within the Protected Area during certain weather conditions.

Based on the results of the characteristic facilities modeling, the additional hours of fogging per year within the Protected Area ranged from negligible to 10 hours; 0.1 hours – 6 hours of additional fogging per year was estimated within the Owner Controlled Area (see Section 4.4.3). The WTP to avoid these potential security issues at the nuclear facilities could not be monetized because there are insufficient data. However, there are 40 Phase II facilities with at least one nuclear unit which may experience some negative impacts on security from cooling tower plumes.

6.3.5 Quality of Life

6.3.5.1 Noise

The impact associated with increased noise levels[4] from retrofitting to closed-cycle cooling is a function of the size of the tower, noise emissions sources on-site, the relative position of the cooling tower to these noise sources, offsite ambient noise, distance to and number of receptors (population), and topography. In addition, WTP is related to home values.

During the Beta Test, state-wide impacts of closed-cycle cooling retrofitting in California were estimated for Phase II facilities based on the results of the two BTPs located in that state [16]. Quality of life impacts, including increased noise levels over ambient, were assessed using an area function that relates the distance to the three dB[5] above ambient noise level with cooling tower design expressed as a logarithm of the cooling water flow. The number of homes exposed at each California facility was estimated using an area function that adjusted the modeled noise level at the Beta Test facilities for differences in cooling tower design at each California facility. The number of homes exposed at each California facility was estimated by using the distance function and local housing data for each site. The resulting estimate of number of homes was then expressed as a fraction of the monetized values at the appropriate Beta Test site.

In order to model the other California facilities specific plant layouts obtained from aerial photography, and local population and housing data were obtained for the 15 additional plants evaluated. However, this site-specific methodology is not practical for the over 400 Phase II facilities in the national scaling. Therefore, an alternative approach was necessary.

The Beta Test and RF analyses found that because of the many confounding variables, no single variable was appropriate for scaling. Variables reviewed included generating capacity, number of homes in the area with an increase in noise, home value, and design CW flow. However, these parameters varied widely within each population group (see Section 4.5.1) and therefore scaling by population group was not appropriate.

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[4] A sound level of zero dB is the approximate threshold of human hearing and is the reference level against which the amplitude of other sound is compared. A two dB increase in ambient noise levels is assumed to represent a quantifiable change in the acoustic environment.

[5] Although a two dB noise level change is perceptible, a more conservative three dB change was used because of the uncertainty with the modeled results from one facility to another.

Table 6-15
Estimated monetized impacts of noise from cooling towers to local homes for California facilities

Facility	Sum of Homes Impacted	Ratio to BTCA1	Annual WTP to Avoid Cooling Tower Noise (2007$)
BTCA1	124	1	$53,800
BTCA2	0	0	$0
CA1	5	0.04	$2,200
CA2	0	0.00	$0
CA3	372	3.00	$161,500
CA4	113	0.91	$49,100
CA5	11	0.09	$4,800
CA6	578	4.66	$250,900
CA7	614	4.95	$266,500
CA8	0	0.00	$0
CA9	387	3.12	$168,000
CA10	51	0.41	$22,100
CA11	0	0.00	$0
CA12	213	1.72	$92,500
CA13 [a]	138	1.11	$59,900
CA14	2,277	18.36	$988,400
CA15	641	5.17	$278,300
State-wide Total			**$2,397,900**

[a] Facility evaluated in the Beta Test but removed from national scaling due to retirement.
WTP rounded to the nearest $100; totals may not equal due to rounding.

Since a significant factor to scale noise impacts was not apparent, the monetized national impacts were estimated based on three geographic regions in addition to California, where it is assumed that the variations in many of these variables (e.g. housing prices, population) would be represented by the facilities modeled:

- West, all plants west of the Mississippi River, except those in California;
- Northeast, plants in states east of the Mississippi River and north of the Mason-Dixon Line; and
- Southeast, facilities located east of the Mississippi River, but south of the Mason-Dixon Line.

Using the average annual WTP values calculated for BTPs/RFs in each geographic region, the annual WTP to avoid impacts associated with increased noise nationally at all Phase II facilities is over $16 million (Table 6-16). See Appendix B for details of the methodology and Appendix E for a list of all Phase II facilities and their U.S. region and source waterbody type.

Table 6-16
Estimated national impacts associated with noise from cooling towers to local homes

Source Waterbody Type	U.S. Region	Facilities	Annual WTP to Avoid Cooling Tower Noise (2007$)
O/E/TR	California[a]	CA (16)	$2,338,000
		Other Phase II (5)	$134,600
	West	BTPs/RFs (0)	$0
		Other Phase II (7)	$319,400
	Northeast	BTPs/RFs (2)	$0
		Other Phase II (43)	$1,020,800
	Southeast	BTPs/RFs (2)	$19,600
		Other Phase II (40)	$1,490,400
O/E/TR subtotal (115)[b]			$5,322,800
LR/RL	West	BTPs/RFs (3)	$0
		Other Phase II (90)	$136,900
	Northeast	BTPs/RFs (7)	$4,106,300
		Other Phase II (48)	$273,400
	Southeast	BTPs/RFs (3)	$1,139,500
		Other Phase II (40)	$203,900
LR/RL subtotal (191)			$7,350,400
SR/GL	West	BTPs/RFs (0)	$0
		Other Phase II (17)	$775,600
	Northeast	BTPs/RFs (4)	$35,200
		Other Phase II (68)	$1,614,300
	Southeast	BTPs/RFs (1)	$0
		Other Phase II (28)	$1,043,300
SR/GL subtotal (118)			$3,468,400
National Total (424)			**$16,141,600**

[a] Seventeen facilities located in California were evaluated in the Beta Test; one has been removed because it retired; two additional Californian facilities and three Hawaiian facilities were also grouped into US Region ‘California’ based on assumed similarities in housing values.

[b] One facility in Guam (withdrawing from an O/E/TR) was not evaluated for noise impacts because of its atypical location.
WTP rounded to the nearest $100; totals may not equal due to rounding.

6.3.5.1.1 Uncertainty

Confounding variables related to the scaling of potential adverse impacts from increased noise include variations in site-specific facility noise levels, community noise levels, topography, building heights, and placement of the towers. These variables are not accounted for in the scaling process and will add uncertainty. The overall direction of bias in the analysis is unknown. The primary uncertainty associated with this analysis relates to perceptibility. The studies relied upon generally assess the relationship between relatively large changes in ambient noise levels and housing prices; a WTP per dB was then calculated as total change in WTP divided by total change in noise level. The literature does not contain studies that actually assess WTP for a two dB change in noise levels. This uncertainty may bias WTP estimates in an upward direction. However, change in noise was estimated assuming average background noise levels. During the quieter periods of the day, the dB change in noise levels produced by the tower at a particular remote location would be higher than two dB.

Scaling of monetized values assumes similar WTP values based across all of the sites in the region (e.g., the “West”), which are based on property values. However, inter- and intra-state property values can vary significantly based on population centers, land use, and other environmental factors. The assumption was that variations in property values within the category evaluated would average out. The direction of this bias is unknown.

The California scale-up investigation resulted in an estimated annual WTP to avoid noise impacts of $2.4 million for 17 facilities. These results suggest that four percent of facilities contribute 14 percent of the national monetized impacts ($17 million). Although home values in California are higher than many other portions of the United States, the average WTP to avoid noise impacts calculated for the BTPs/RFs was not dramatically different among regions (CA: $27,000; West: $46,000; Northeast: $24,000; Southeast: $37,000). These arithmetic averages were used as the monetized impacts for the “other Phase II” facilities in each subgroup. However, the WTP values calculated during the Beta Test scale-up ranged from $0 to nearly $990,000, with an average WTP of $141,053. These estimates were used in the summation of national impacts and therefore, it appears that impacts from facilities in California are disproportionately high. Since the methodology used during the Beta Test scale-up accounted for more site-specific conditions and are generally considered more accurate, the results are likely more accurate. Using the average WTP values for the other regions appears to underestimate the national monetized impacts of increase noise from retrofitting to closed-cycle cooling.

An additional source of uncertainty associated with noise impacts lies with the fact that effects can be mitigated by modifying the source, enclosing the source, constructing a barrier at the source or receptor, or modifying the receptor. Mitigation methods were reviewed by EPRI [87] and found that due to the specific nature of cooling towers, sound barriers and enclosures are not effective or practical. However, low speed fans are available (albeit, expensive) options. Additionally, reducing the fan speed during cooler periods of the day can be effective in reducing noise levels [87]. Methods of receptor mitigation include property line sound barriers and upgrades to the structure, like multi-pane windows and in-wall sound insulation. However, these methods would not reduce noise levels on the surrounding property [87].

If noise impacts from cooling towers reach a certain threshold, permitting issues would require that these effects be abated. Therefore, the impacts of retrofitting to closed-cycle cooling pertinent to this study are only those that measurably increase the noise at a receptor above ambient levels, but are not so significant that they require mitigation. This range is undoubtedly site-specific and therefore, the uncertainty associated with noise impact estimates is great; the bias of the uncertainty is unknown.

As explained further in Section 6.3.9, a small percentage of Phase II facilities employ helper cooling towers, usually seasonally during hot summer months. Some societal and environmental impacts calculated in this study are slightly overestimated at these facilities because existing towers already have some negative effects when they are operational.

6.3.5.2 Viewshed

SACTI modeling was used to predict plume length and plume shadowing for the BTPs/RFs. The percent duration of vapor plumes of various lengths and plume shadow over the one-year model period was estimated for those facilities. The magnitude of impacts of plume shadowing on the viewshed is dependent on the number of receptors available to view the plume.

For the state-wide scale-up in California, potential viewshed impacts were assessed by estimating an area function that related the distance and frequency of vapor plume and vapor plume shadowing to cooling tower design as a function of flow and hours of operation [16]. Confounding variables included local meteorological conditions, topography, and other variables that were assumed to be similar across all California facilities. The predicted population that can view a significant visible plume was determined by superimposing percent duration of vapor plumes of various lengths over maps surrounding the facilities. The maps indicated the block groups impacted, the number of households in each block group, and the proportion of the time the plume/shadow are directly overhead. Impacts to parks and recreation areas were estimated for BTCA1 and BTCA2, however these potential impacts were too site-specific to scale. Thus, potential adverse impacts were most likely underestimated for California facilities with large parks and recreation areas nearby.

Results of the California scale-up are summarized in Table 6-17 below.

Table 6-17
Estimated monetized impacts of viewshed degradation from cooling towers to the local population near California facilities

Facility	Sum of Households Impacted	Ratio to BTCA1	Annual WTP to Avoid Viewshed Degradation (2007$)
BTCA1	125	1	\$189,100[a]
BTCA2	0	0	\$0
CA1	0	0.000	\$0
CA2	0	0.002	\$400
CA3	0	0.000	\$0
CA4	74	0.593	\$112,100
CA5	0	0.000	\$0
CA6	99	0.796	\$150,600
CA7	96	0.766	\$144,900
CA8	0	0.000	\$0
CA9	22	0.173	\$32,700
CA10	13	0.101	\$19,100
CA11	0	0.000	\$0
CA12	3	0.024	\$4,500
CA13 [b]	0	0.000	\$0
CA14	177	1.417	\$267,900
CA15	69	0.556	\$105,200
State-wide Total			**\$1,026,600**

[a] Does not include monetization of viewshed degradation to nearby parks of $871,216 at BTCA2 and $176 at BTCA1. These impacts are site-specific and not scalable.

[b] Facility removed from analysis during national scaling due to retirement
WTP rounded to the nearest $100; totals may not equal due to rounding.

A similar site-by-site evaluation of remaining 385 Phase II facilities not already modeled is not practical. However, the median WTP to avoid viewshed impacts is related to population surrounding the facilities with the highest WTP in High population areas and much lower WTP in Medium/Low population areas ($15,400 and $8, respectively) (Section 4.5.2). Therefore, WTP to avoid viewshed impacts nationally was evaluated using the median annual WTP calculated for the BTPs/RFs in these two population groups (High and Medium/Low). See

Appendix B for details of the methodology and Appendix E for a list of all Phase II facilities and their population category and source waterbody type. The results are summarized below in Table 6-18.

Table 6-18
Annual monetized impacts associated with viewshed degradation on a national scale

Source Waterbody Type	Population Category[a]	Facilities (#)	Annual WTP to Avoid Viewshed Degradation (2007$)
O/E/TR	High	CA[b]	$714,100
		Other BTPs/RFs	$3,200
		Other Phase II	$662,400
	Medium/Low	CA[b]	$312,500
		Other BTPs/RFs	$9,600
		Other Phase II	$400
O/E/TR subtotal			1,702,200
LR/RL	High	BTPs/RFs	$0
		Other Phase II	$277,300
	Medium/Low	BTPs/RFs	$2,600
		Other Phase II	$1,200
LR/RL subtotal			281,100
SR/GL	High	BTPs/RFs	$27,600
		Other Phase II	$338,900
	Medium/Low	BTPs/RFs	$6,400
		Other Phase II	$700
SR/GL subtotal			$373,600
National Total			**$2,356,900**

[a] Population categories as follows: Low (<100 people/mi^2); Medium (100-1,000 people/mi^2); High (>1,000 people/mi^2)
WTP rounded to the nearest $100; totals may not equal due to rounding.

The results indicate that the national annual WTP to avoid potential viewshed degradation caused by the retrofit of all Phase II facilities to closed-cycle cooling is $2.3 million, including the $1 million estimated WTP for California facilities. The 16 power plants in California account for nearly half the national estimate[6]. This may be due to the high property value and population impacted or to the more site-specific scaling methods used for California. This suggests that the national scaling method may underestimate viewshed degradation.

6.3.5.2.1 Uncertainty

Confounding variables related to the scaling of potential adverse impacts from the vapor plumes on viewshed include local meteorological conditions, topography, and placement of the towers. The estimated WTP values used for scaling were based on property values. The assumption was that variations in property values within the category evaluated would average out. This assumption adds uncertainty to the estimate. Viewshed degradation at nearby parks and recreation sites are not scaled. These potential impacts may be very large (e.g., approximately $158,000 for BTCA2), thus omission of these impacts represents an underestimate.

As explained further in Section 6.3.9, a small percentage of Phase II facilities employ helper cooling towers, usually seasonally during hot summer months. Some societal and environmental impacts calculated in this study are slightly overestimated at these facilities because existing towers already have some negative effects when they are operational.

6.3.5.3 Other Quality of Life Issues

Other potential adverse effects on quality of life associated with mechanical-draft evaporative cooling towers, including salt deposition damage to automobiles and other metal surfaces, corrosion and shorting of electrical equipment, and deposition on windows and other surfaces, could not be monetized because of lack of threshold of effects data. Thus, it is uncertain if these impacts are significant.

6.3.6 Permitting and Other Issues

Potential permitting issues associated with retrofitting to closed-cycle cooling, including concerns with air quality, environmental justice, threatened and endangered species, public heath/water quality, wetlands, consumptive water use, and other environmental issues, were evaluated qualitatively for the BTPs and RFs in Section 4.6. The results of this evaluation indicate that for many power plants, at least one or more of the following topics are likely to be a concern:

- Air quality;
- Rare, threatened, and endangered species;
- Sensitive areas (e.g., wildlife management areas, refuges, critical dunes, etc.);

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[6] Seventeen CA facilities were evaluated in the Beta Test. One facility, accounting for $0 in annual WTP to avoid viewshed degradation, has been removed due retirement.

- Public health/water quality;
- Local ordinances and zoning (e.g., noise, night lighting, building height, etc.);
- Wetland disturbances; and
- Consumptive water use.

Additionally, nuclear plants will need to adhere to NRC requirements.

Permitting issues associated with air quality for many parts of the United States would likely be significant, based on the results of the in-depth evaluation of the seven BTPs and seven RFs (Section 4.6.1) and the responses to the EPRI Questionnaire. The PSD program would apply to cooling towers at 50 percent of the BTPs/RFs assessed and 13 of the 14 BTPs/RFs would require Title V Operation Permits. Of the 209 responses to the EPRI Questionnaire, 40 percent of the facilities were located in a non-attainment area for air quality and 21 percent were located in or near a Class I area for air quality. Assuming these results are representative of all Phase II facilities, air quality permitting issues associated with a closed-cycle cooling retrofit may be summarized as:

- PSD program may apply at 213 facilities;
- Title V Operation Permits may be needed at 395 facilities;
- 170 facilities may be located in a non-attainment area for air quality; and
- 90 facilities may be located in or near a Class I area for air quality.

Note that these numbers are an estimate based on the BTPs/RFs and the 209 responses to the EPRI Questionnaire and not a site-specific analysis of each of the Phase II facilities.

Protected species and/or critical habitat were identified for potential permitting issues at 14 of the 24 (58 percent) BTPs/RFs, and wetlands were identified at two additional facilities. Over 50 percent of the EPRI Questionnaire responses indicated that threatened, endangered, or otherwise protected species are known to exist on or in the vicinity of the facility. Additionally, 66 percent of EPRI Questionnaire facilities indicated that a sensitive receptor is located within 1 km of the facility (e.g., landmarks, recreational areas, sensitive vegetation, protected species, new car lot, hospitals, and schools). This indicates that potentially 213-281 Phase II facilities may have permitting issues associated with protected species and/or critical habitat if they were to retrofit to closed-cycle cooling.

Thirteen BTPs/RFs would likely have noise permitting issues (54 percent) and two of those also were in areas with height ordinances. Over one-quarter of the responses to the EPRI Questionnaire indicated that local ordinances are in effect regarding height and 44 percent were located in areas with local noise ordinances. Coastal zone regulations may require special permitting for three of the BTPs/RFs and over one-third of the EPRI Questionnaire respondents. On a national scale, these results suggest that between 187 and 230 Phase II facilities may need noise permits, 35-106 facilities may need to meet permits for height, and 53-140 facilities may require coastal zone permits.

A potential Environmental Justice issue (defined as potentially impacted areas with a minority population greater than 20 percent) exists at four of the 24 facilities evaluated (16.7 percent). Site-specific PM_{10} modeling and census data would be needed to evaluate the impacts to all Phase II facilities. Although a site-by-site evaluation is not practical, the results of the Beta Test and RF evaluation predict Environmental Justice issues at approximately 17 percent of the facilities, or 71 Phase II facilities.

While the national impacts of permitting issues could not be quantified, it is likely that most facilities that retrofit to closed-cycle cooling will encounter some permitting issues. This may result in significant additional costs to mitigate the impacts or potentially prevent the construction of cooling towers altogether.

6.3.6.1 Uncertainty

The greatest source of uncertainty associated with the national scaling of permitting issues is the limited site-specific knowledge of the issues. Additionally, the use of dated reports prepared by others, reliance on data from the EPRI Questionnaire provided by the facilities, and the lack of proposed cooling tower footprint locations for each of the Phase II facilities adds to the overall uncertainty of the evaluation. These limitations reduce the ability to properly identify the potential permitting issues as well as possible public opposition for each site. The overall direction of bias in the analysis is unknown.

6.3.7 Greenhouse Gas

Carbon dioxide (CO_2) is a greenhouse gas that has received a lot of attention because the anthropogenic emissions rate of CO_2 is increasing rapidly. If electricity generating facilities currently utilizing once-through cooling systems were to be retrofitted with closed-cycle cooling and optimize their condensers, those facilities that remain online during the retrofit would be required to makeup for the loss in electricity generation. While most fossil-fueled facilities are not anticipated to optimize their condensers due to cost and expected remaining facility lifetime, nuclear plants will likely optimize and/or require an extended outage for other reasons and all are baseloaded. If nuclear plants were to go offline for optimization, their power would be replaced primarily by a mix of fossil fuel plants because the nuclear fleet is already near full capacity. Thus, CO_2 emissions are expected to increase as fossil-fueled facilities makeup for lost generation at nuclear plants.

The potential additional CO_2 emissions if the current ‘mix’ of facilities were to compensate for the loss of electricity generation at all Phase II nuclear facilities during the potential closed-cycle cooling retrofits were calculated using the assumptions described in Section 4.7 and Appendix B. Retrofitting the 39 Phase II nuclear plants (or nuclear units of mixed-fuel plants) would result in 163 million tons of CO_2 emitted by the fossil stations that remain online, if a 6-month outage is assumed (i.e., using EPRI’s best estimate). If an 8-month outage is necessary for all facilities, approximately 211.5 million additional tons of CO_2 would be emitted by the fossil stations that remain online.

Average annual WTP to avoid a one-time increase in CO_2 occurring in 2037 at the nuclear facilities is estimated to be $79,873 per million tons of CO_2 (see Section 4.7.2 for a discussion on monetization). Using this estimate, the annual WTP to avoid CO_2 emitted in the Year 2037 (2007$) from a national retrofit of all Phase II nuclear facilities is between $13 million and $16.9 million (depending on length of the outage). Tables 6-19 and 6-20 separate these estimates by waterbody type.

Table 6-19
Estimated impacts of additional CO_2 emissions due to retrofitting nuclear Phase II facilities (6-month outage)

Waterbody	Number of Facilities or Units	Required Makeup Generation (MW-hr)	CO_2 (Millions of Tons)	Annual WTP to avoid Additional CO_2
LR/RL	19	110,520,800	74	$5,918,900
SR/GL	7	32,506,100	22	$1,740,900
O/E/TR	13	100,066,000	67	$5,359,000
Totals	**39**	**243,092,900**	**163**	**$13,018,800**

WTP rounded to the nearest $100; totals may not equal due to rounding.

Table 6-20
Estimated impacts of additional CO_2 emissions due to retrofitting nuclear Phase II facilities (8-month outage)

Waterbody	Number of Facilities or Units	Required Makeup Generation (MW-hr)	CO_2 (Millions of Tons)	Annual WTP to avoid Additional CO_2
LR/RL	19	147,361,000	99	$7,891,900
SR/GL	7	43,341,400	29	$2,321,100
O/E/TR	13	124,795,200	84	$6,683,400
Totals	**39**	**315,497,600**	**212**	**$16,896,400**

WTP rounded to the nearest $100; totals may not equal due to rounding.

6.3.7.1 Uncertainty

The scaling of additional greenhouse gas emissions assumes that nuclear Phase II facilities could retrofit and optimize over a 6-month outage; an 8-month outage is also provided to account for uncertainty. The actual outage time may vary depending on site-specific conditions. The overall direction of bias in the analysis is unknown. Additionally, it was assumed that the replacement electricity would all be created using the same mix of fossil fuels currently in use. However, increasing reliance on ‘green’ energy such as wind, solar, and hydroelectric production may decrease the additional CO_2 emissions produced during outages at nuclear facilities. Using the current mix of fossil fuels overestimates the national calculations of CO_2 emissions and WTP to avoid those emissions.

As detailed in Section 4.7.3, there are also uncertainties associated with estimating WTP to avoid additional CO_2 emissions, including the significant variability in the published estimates of the social cost of carbon, ranging from negative values to several hundred dollars per ton of CO_2 emitted. Because voluntary CO_2 trading is currently a relatively small market characterized by high price variability, WTP may be greatly affected by future policies to reduce allowable CO_2 emissions or by technological innovation that reduces those emissions and $3.80 per ton may not be an appropriate value in the future.

6.3.8 Aquatic Biota

Potential adverse effects to aquatic biota associated with power plant cooling systems are associated with IM&E due to water withdrawal for use as condenser cooling water. Critical elements in the assessment of potential impacts to aquatic biota are discussed in Section 4.8 and Appendix H.

The conversion from once-through to closed-cycle cooling results in a significant decrease in the amount of cooling water withdrawn from the waterbody and an assumed subsequent decrease in IM&E per methods used by USEPA [5]. Section 4.8 of this report provided modeled quantification and monetization of current levels of IM&E compared with IM&E reduction achievable with mechanical-draft evaporative cooling towers to estimate a net benefit at 26 facilities. The estimated range in benefit from the 26 facilities studied, expressed in dollars per million gallons, is provided in the table below.

Table 6-21
Estimated benefit of IM&E reduction per million gallons of flow for 26 characteristic facilities

Waterbody	Minimum Value ($) per Million Gallons	Maximum Value ($) per Million Gallons	Number of Facilities Used in Calculation
RL	$0.001	$0.012	6
SR	$0.003	$0.045	2
LR	$0.004	$0.078	7
GL	$0.023	$2.130	3
O/E/TR	$0.073	$1.952	8

Based on the results of the EPRI Questionnaire, thirteen percent of facilities impinge or entrain threatened and endangered species, and 19 percent of facilities report impinging or entraining other species of concern to regulatory agencies. However, it is unlikely that these facilities would be permitted to alter the viability of a federally listed species or materially impair ecosystem functioning since this would have likely prevented permit renewal. EPRI’s detailed study on the national impingement and entrainment reduction benefits of reducing flow commensurate to closed-cycle cooling will have a much more complete analysis of threatened and endangered species based on more facilities. Those results will be reported under separate cover.

Nineteen percent of facilities responding to the EPRI Questionnaire reported concern from regulatory agencies regarding thermal discharge. Benefits of the thermal discharge were recognized at 48 percent of the plants. At facilities with 316(a) thermal variances, eight percent responded that the issue had been raised by regulatory agencies and/or other stakeholders with continuance of the variance. As discussed in Section 4.8, the positive or negative benefits of thermal discharge issues are not addressed in this report. Spatial or temporal, positive or negative potential effects to aquatic biota may occur at different facilities. However, in order for a facility with once-through cooling to operate, it must either demonstrate maintenance of a balanced indigenous population through a 316(a) variance or meet water quality standards at the edge of an approved mixing zone. The potential magnitude and sign (positive or negative) of environmental effects and the associated monetized value or WTP is considered beyond the scope of this study, given the complexities and site-specific nature of issues involved.

The national benefits of reduced IM&E were to be determined by scaling to cooling water flow. However, preliminary analysis of the IM&E Database by EPRI has determined there is no relationship (with a few exceptions) between flow and IM&E. As a result, this report does not estimate the national benefit of retrofits. EPRI has initiated an independent project to develop a national retrofit benefit estimate. The results of that investigation will be reported separately along with a summary of the EPRI Impingement and Entrainment Database and specific information regarding the impingement and entrainment of protected species.

6.3.9 General National Scaling Uncertainties

Uncertainties specific to each of the eight issues evaluated have been presented in the sections above. The following paragraphs discuss uncertainties associated with all portions of the national scaling.

6.3.9.1 Phase II Facility List

For the purposes of this study, the Phase II facility list was finalized on November 9, 2010. To be included on the list generated from the EPRI database, the facility must have an active NPDES permit, although the plant may not have operated in the last year or more. For example, two facilities have NPDES permits that allow once-through cooling that are still under construction. It was assumed that these facilities will be built with once-through cooling and would be required to retrofit to closed-cycle cooling in the future. Additionally, whole facilities or units of facilities retire in the normal course of operations. For example, Humboldt Bay Power Plant will retire by the end of 2010, but this facility (102 MW) was on the finalized list and was therefore included in the national scaling. Based on the available information on November 9, 2010, there are 428 facilities (total of 312,323 MW) in the United States which utilize (or will use) once-through cooling for at least one unit and therefore would be affected by any legislation requiring retrofit to closed-cycle cooling. Three of these facilities contain both nuclear and fossil-fueled units; they were evaluated in this study as two separate entities for impacts where fuel type was a criterion (for a total of 428 facilities) and as a single facility for other impacts (425 facilities). However, the actual number of facilities that will be impacted, if and when regulation is promulgated should EPA designate closed-cycle cooling as the basis for standards, may change due to economic pressures, lack of adequate space to build cooling towers, or the inability to obtain the necessary permits as well as any regulatory requirements for facilities associated with closed-cycle cooling standards as BTA.

A number of electricity generators have expressed that it would be economically advantageous to close certain facilities rather than to construct cooling towers. Another EPRI supplemental research program estimates that U.S. facilities generating 26,058 MW (approximately eight percent of the total generating capacity of the Phase II facilities evaluated) may be closed for economic reasons.

Retrofitting to close-cycle cooling will be impractical at some Phase II facilities due to a lack of adequate space for construction. The space needed for various types of cooling towers is described in Sections 3 and 5. For this report, it was assumed that no new land acquisitions would be made; all cooling towers would be located on existing site property[7]. However, another EPRI supplemental research program estimates that five percent of the total MW from all Phase II facilities will not be able to retrofit due to space issues. Therefore, over 15.5 gigawatts may not be produced if those facilities cannot comply with a Rule requiring closed-cycle cooling and must close.

Section 4.6 describes some of the potential permitting requirements that will be encountered during retrofit to closed-cycle cooling, including permits or regulatory compliance associated with air quality, environmental justice, protected species and habitats, water quality, noise limits, height ordinances, wetlands protection, coastal zone regulations, and the NRC. It is expected that some potential environmental impacts requiring permits will be avoided and minimized such that permits will be issued without prohibitive delays or costs through the negotiation of permit conditions, such as mitigation and monitoring. However, there are site-specific issues which could cause extensive regulatory concern and prolong and/or preclude obtaining the necessary permits and approvals. Without a site-by-site cooling tower feasibility study for each of the Phase II facilities, an estimate of the number of facilities that may have to close instead of retrofitting to closed-cycle cooling cannot be made.

In addition to the facilities currently included on the Phase II list that may eventually be eliminated, there are facilities in the EPRI database that may be exempt from the Rule. Some power plants were identified as having once-through cooling systems withdrawing cooling water from freshwater lakes and reservoirs. However, these facilities may, in fact, be withdrawing from cooling ponds that are considered part of a closed-cycle cooling system. Therefore, these facilities would likely be exempt from the Rule and should not be considered in the potential national impacts. No available estimate of how many facilities may fall into this category was found.

For all of these reasons, the actual number of Phase II facilities potentially impacted by a Rule requiring closed-cycle cooling is likely less than 428 and therefore, scaling using these facilities overestimates the national impacts of the closed-cycle cooling retrofit.

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[7] In conjunction with the New York State Pollutant Discharge Elimination System permit renewal for Dynegy's Danskammer Generating Station, based on a hearing report issued by Administrative Law Judge Daniel P. O'Connell, the New York Department of Environmental Conservation Deputy Commissioner Carl Johnson issued a Decision on May 24, 2006 that cooling towers would not fit on the site property. Petitioners in the adjudicatory hearing included Riverkeeper, Inc., Scenic Hudson, Inc., and National Resource Defense Council Inc. who proposed that the Plant be retrofitted with a closed-cycle cooling system. As a prerequisite to the Decision, an Interim Decision (May 13, 2005) based on an earlier hearing, deemed that the use of properties other than the site or the use of piers or barges in the Hudson River shall not be considered in determining whether a closed-cycle cooling system can be located on the site.

6.3.9.2 General Assumptions

The Phase II list contains a small percentage of facilities that employ helper cooling towers. These towers are usually operated only seasonally, during hot summer months. Some societal and environmental impacts calculated in this study are therefore slightly overestimated at these facilities because existing towers already have some negative effects when they are operational.

The generating capacities, expressed in MW, reported for each Phase II facility in Appendix E were either gross, net, or nameplate capacity, depending on the data available. It is uncertain which direction this biases the national estimates, if at all, because the type of capacity for each facility was not recorded in the database.

Some flow and capacity information in the EPRI database was provided by the facility owner/operator and only the once-through cooling unit-specific data were included. However, when those data were not available, USEPA (e.g., Appendices A and B of the suspended Phase II Rule), DOE databases, or other readily-available information were used, which may have included units that are not once-through cooled. By including these units in the scaling, the national impacts are overestimated because those units will not need to be retrofitted. The magnitude of this bias, however, is not known.

WTP values estimated for BTPs and RFs were used for national scaling. The application of these WTP values to all Phase II locations does not account for site-specific conditions. It is not clear how this uncertainty biases national estimates.

Lastly, it was beyond the scope of this study to consider cumulative impacts of different impact types for individual facilities or cumulative impacts for multiple Phase II facilities located in close proximity.

6.3.10 National Scaling Summary

Tables 6-22, 6-23, 6-24, and 6-25 summarize the results of the national scaling of the net environmental and social effects associated with a retrofit to closed-cycle cooling for all Phase II facilities, where quantification and monetization could be performed.

For some potential impacts identified during the study, monetization could not be achieved because no available WTP data or appropriate methodology was available, including:

- Human health effects from pathogens in cooling tower emissions and from PM emissions;
- Noise impacts to threatened and endangered species;
- Impacts to natural and man-made terrestrial resources from fogging/icing and corrosion;
- Water resource quantity and quality effects from water consumption and creations of tower sludge;
- Impacts to public safety and security from plumes at airports and fogging at nuclear facilities; and
- Permitting issues associated with air regulations, environmental justice, and others such as cultural resources.

Table 6-22
Summary of national scaling of quantified and monetized environmental and social impacts for LR/RL facilities should closed-cycle cooling be designated as best technology available

Impact Type	Impact Quantity	Annual WTP to Avoid Impacts (2007$)
Human Health		
PM (tons)	2,000	
PM_{10} (tons)	1,400	
$PM_{2.5}$ (tons)	600	
Exposed Population (Age 30+)	1,003,500	
Exposed Population (Age 65+)	226,300	
Terrestrial Resources		
Noise impacts on wildlife (# facilities)	96	
Fogging/icing impacts on vegetation (# facilities)	115	
Water Resource Quantity and Quality		
Active chlorine use (metric tons/year)	18,000	
Evaporative water loss (billion gallons/year)	372	
Debris removal (tons of trash not removed)	338	$382,900
Public Safety and Security		
Fogging/icing impacts to roadways		$7,300
Quality of Life		
Increased Noise		$7,350,400
Degraded Viewshed		$281,100
Greenhouse Gas		
CO_2 Emitted (6-month outage) (millions of tons)	74	$5,918,900
CO_2 Emitted (8-month outage) (millions of tons)	99	$7,891,900
Total[a]		**$13,940,600**

Totals may not equal due to rounding.
[a] Assumes a 6-month outage for greenhouse gas impacts.

Table 6-23
Summary of national scaling of quantified and monetized environmental and social impacts for SR/GL facilities should closed-cycle cooling be designated as best technology available

Impact Type	Impact Quantity	Annual WTP to Avoid Impacts (2007$)
Human Health		
PM (tons)	800	
PM_{10} (tons)	600	
$PM_{2.5}$ (tons)	200	
Exposed Population (Age 30+)	6,063,700	
Exposed Population (Age 65+)	1,098,000	
Terrestrial Resources		
Noise impacts on wildlife (# facilities)	39	
Fogging/icing impacts on vegetation (# facilities)	59	
Water Resource Quantity and Quality		
Active chlorine use (metric tons/year)	7,000	
Evaporative water loss (billion gallons/year)	128	
Debris removal (tons of trash not removed)	241	$273,300
Public Safety and Security		
Fogging/icing impacts to roadways		$29,800
Quality of Life		
Increased Noise		$3,468,400
Degraded Viewshed		$373,600
Greenhouse Gas		
CO_2 Emitted (6-month outage) (millions of tons)	22	$1,740,900
CO_2 Emitted (8-month outage) (millions of tons)	29	$2,321,100
Total[a]		**$5,886,000**

Totals may not equal due to rounding.
[a] Assumes a 6-month outage for greenhouse gas impacts.

Table 6-24
Summary of national scaling of quantified and monetized environmental and social impacts for O/E/TR facilities should closed-cycle cooling be designated as best technology available

Impact Type	Impact Quantity	Annual WTP to Avoid Impacts (2007$)
Human Health		
PM (tons)	27,100	
PM_{10} (tons)	11,500	
$PM_{2.5}$ (tons)	3,400	
Exposed Population (Age 30+)	8,977,900	
Exposed Population (Age 65+)	1,641,700	
Terrestrial Resources		
Noise impacts on wildlife (# facilities)	22	
Fogging/icing impacts on vegetation (# facilities)	0	
Water Resource Quantity and Quality		
Active chlorine use (metric tons/year)		
Evaporative water loss (billion gallons/year)		
Debris removal (tons of trash not removed)	281	$317,900
Public Safety and Security		
Fogging/icing impacts to roadways		$17,600
Quality of Life		
Increased Noise		$5,322,800
Degraded Viewshed		$1,702,200
Greenhouse Gas		
CO_2 Emitted (6-month outage) (millions of tons)	67	$5,359,000
CO_2 Emitted (8-month outage) (millions of tons)	84	$6,683,400
Total[a]		**$12,719,500**

Totals may not equal due to rounding.
[a] Assumes a 6-month outage for greenhouse gas impacts.

Table 6-25
Summary of national scaling of quantified and monetized environmental and social impacts for all Phase II facilities should closed-cycle cooling be designated as best technology available

Impact Type	Impact Quantity	Annual WTP to Avoid Impacts (2007$)
Human Health		
PM (tons)	29,800	
PM_{10} (tons)	13,500	
$PM_{2.5}$ (tons)	4,200	
Exposed Population (Age 30+)	16,045,000	
Exposed Population (Age 65+)	2,966,000	
Terrestrial Resources		
Loss of critical habitat (acres)	2,800	
Loss of critical habitat (# facilities)	47-72	$778,000 - $1,190,000
Salt deposition damage to vegetation	Not calculated	
Noise impacts on wildlife (# facilities)	157	
Fogging/icing impacts on vegetation (# facilities)	174	
Salt deposition damage to electric equipment	Not calculated	
Water Resource Quantity and Quality		
Active chlorine use (metric tons/year)	25,000	
Evaporative water loss (billion gallons/year)	500	
Debris removal (tons of trash not removed)	861	$974,100
Public Safety and Security		
Fogging/icing impacts to roadways		$54,700
Quality of Life		
Increased Noise		$16,141,600
Degraded Viewshed		$2,356,900
Permitting Issues		
Air Quality PSD Program (# facilities) Title V Operation Permits (# facilities) Non-attainment area (# facilities) Class I area (# facilities)	 213 395 170 90	

Table 6-25
Summary of national scaling of quantified and monetized environmental and social impacts for all Phase II facilities should closed-cycle cooling be designated as best technology available (continued)

Impact Type	Impact Quantity	Annual WTP to Avoid Impacts (2007$)
Protected Species/Critical Habitat (# facilities)	213-281	
Local Ordinances Noise (# facilities) Height (# facilities) Coastal zone (# facilities)	 187-230 35-106 53-140	
Environmental Justice (# facilities)	71	
Greenhouse Gas		
CO_2 Emitted (6-month outage) (millions of tons)	163	$13,018,800
CO_2 Emitted (8-month outage) (millions of tons)	212	$16,896,400
Total[a]		**$33,736,100**

Totals may not equal due to rounding.
[a] Assumes a 6-month outage for greenhouse gas impacts.

These results indicate that two categories of impacts were most significant: quality of life issues and greenhouse gas emissions. WTP to avoid negative impacts associated with cooling tower retrofitting, including 212 million tons of CO_2 emissions and decreased property values associated with increased noise, are significant (over $33 million annually combined).

For a number of issues, including evaporative water loss, impacts to terrestrial resources, solid waste created by cooling towers, fogging at airports, icing on roadways, security issues at nuclear facilities, permitting concerns and certain quality of life issues (e.g., salt deposition damage to automobiles and other metal surfaces, corrosion and shorting of electrical equipment, and deposition on windows and other surfaces), impacts were quantified and/or qualitatively discussed, but not monetized. Other potentially significant site-specific issues that were not addressed in the study include short term construction impacts, Legionnaire’s disease, bird and bat collisions and entrainment, entrainment of beneficial and/or protected insects (butterflies), and removal and disposal of excavated materials, if necessary, from construction. The overall result is that the nationally monetized impacts do not fully reflect the economic effects of a retrofit requirement.

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A
SITE SPECIFIC INFORMATION

A.1 Beta Test Plant California 1 (BTCA1)

Retrofitting BTCA1's once-through cooling system with closed-cycle cooling (CCC) is potentially feasible, but difficult. The main challenges include lack of space onsite and its highly regulated urbanized setting.

The retrofit will reduce cooling water intake to the plant. As discussed below, a corresponding decrease in impingement mortality and entrainment (IM&E) may also be expected from the CCC retrofit. However, this retrofit introduces several new environmental concerns like reductions in air quality, and potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are also discussed below.

The facility consists of six generating units (Units 1-6), all of which utilize once-through cooling systems [1]. Four cooling towers are proposed for this facility: one for Units 1 and 2, a second for Units 3 and 4, and two additional cooling towers for Units 5 and 6. The sizes, locations and impacts of these cooling towers are also discussed below.

A.1.1 Background

BTCA1 is a 1,982 megawatt (MW) natural gas fired steam electricity generating facility located in the highly urbanized City of Long Beach, CA, and is owned and operated by AES Southland Corporation. The facility is located on an industrial site along the west bank of a river, approximately two miles upstream of the entrance to the bay. The bay is hydraulically connected to the Pacific Ocean. The four BTCA1 cooling water intake structures (CWIS) withdraw cooling water from Los Cerritos Channel. Los Cerritos Channel in the vicinity of BTCA1 has recently been classified as an estuary. Due to the intake invert elevation, much of the water entering the BTCA1 CWIS is seawater. The design intake cooling water flow rate for the facility is 800,000 gallons per minute (gpm).

The facility's western edge is bordered by the Los Cerritos Channel and North Studebaker Avenue. State Highway 22 borders the northern edge of the property and Westminster Avenue/East 2nd Street borders the south. The San Gabriel River borders the facility to the east. Residential communities are located west of the Los Cerritos Channel, and the Los Cerritos Wetlands are located to the southwest. The facility consists mainly of industrial/developed land with some sparsely vegetated areas [2].

A location map of BTCA1 is provided as Figure A-1. Key information for each generating unit is provided in the following table.

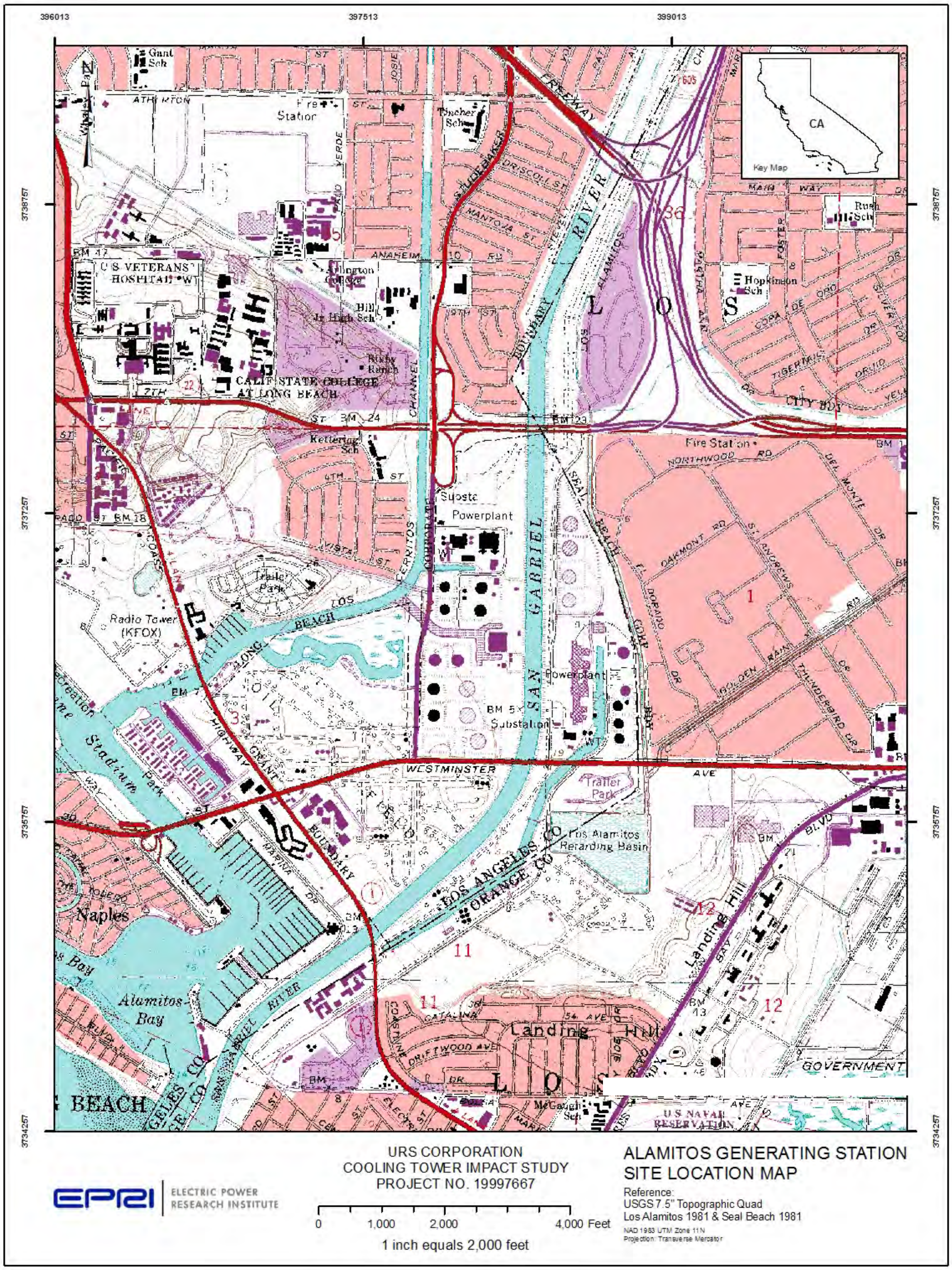


Figure A-1
BTCA1 site location map

Table A-1
BTCA1 engineering information [3]

Unit	Rated Capacity (MW)	Cooling Water Flow Rate (gpm)	Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006 (%)
Unit 1	163	68,500	24.6	1956	6.7%
Unit 2	163	68,500	24.6	1957	8.7%
Unit 3	333	129,500	21.7	1961	27.7%
Unit 4	333	129,500	21.7	1962	20.8%
Unit 5	495	202,000	18.2	1964	27.4%
Unit 6	495	202,000	18.2	1966	22.2%
Total	1,982	800,000	NA	NA	NA

A.1.2 Cooling Water Intake Structure

BTCA1 cooling water is withdrawn via one of four CWIS. Generating Units 1 and 2 share the first CWIS, and Generating Units 3 and 4 share a second; both these CWIS are located on one intake canal that is north of the Studebaker, LLC “Home Depot Design Center” property. Units 5 and 6 have separate CWIS that are mirror images of each other and use the third and fourth CWIS located at the end of the ‘southern’ intake canal, respectively [1]. All units discharge their heated cooling water into the San Gabriel River. The Los Angeles Department of Water and Power (LADWP) Haynes Generating Station, located directly across the San Gabriel River from BTCA1, also discharges its heated cooling water to the San Gabriel River [1].

The CWIS for Unit 1 and 2 has four intake bays (two for each Unit). This CWIS has a curtain wall and 9 ft wide traveling water screens with 1/2 in by 3/4 in mesh openings to prevent fish and debris from entering the cooling water system [1, 4]. The Unit 3 and 4 CWIS has a curtain wall and 8 ft wide traveling water screens angled at 34° [1]. The CWIS for Unit 5 and Unit 6 includes trash racks and 10 ft wide traveling water screens with 5/8 in square mesh openings [1]. High-pressure sprays are used to clean all traveling water screens.

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid getting impinged. At low approach velocities (e.g. less than 0.5 feet per second [fps]) an organism may be able to swim away; organisms are further challenged at higher approach velocities. The approach velocity therefore plays an important role in determining the ‘adverse impact’ of a cooling water intake structure.

Approach velocities at different locations along the intake bays in the BTCA1 CWIS are provided in Table A-2.

Table A-2
Approach velocities at various locations along the intake bays in BTCA1 CWIS [1]

Location Along Intake Bay	CWIS for Units 1 and 2 (fps)	CWIS for Units 3 and 4 (fps)	CWIS for Unit 5 (fps)	CWIS for Unit 6 (fps)
Under Curtain Wall	3.3	3.4	N/A	N/A
Approaching Trash Racks	N/A	N/A	1.0	1.0
Approaching Traveling Screens	2.2	2.7	1.1	1.1

The through-screen velocity is approximately twice the approach velocity-a typical rule of thumb. Given the above approach velocities, the through-screen velocities may be expected to be between 2-fps and 5-fps.

A.1.3 Proposed Cooling Towers at BTCA1

Limited availability of space on site poses a particular challenge to retrofitting BTCA1 with cooling towers. To optimize use of available space the proposed cooling towers for Units 1 and 2, and Units 3 and 4 have been combined. Conceptual cooling tower locations are shown in Figure A-2.

The preliminary design for this facility includes a 14-cell cooling tower for Units 1 and 2 located on the northwest corner of the property near the Los Cerritos Channel, a 22-cell cooling tower for Units 3 and 4, and one 14-cell cooling tower each for Units 5 and 6 located along the eastern boundary of the property adjacent to the San Gabriel River. All cooling towers are anticipated to be back-to-back. All cooling towers are oriented in a north-south direction to optimize use of space even though this is not the optimal tower orientation with respect to predominant summer wind.

The current employee parking lot, located between generating Units 1 and 4 and the switchyard, was dismissed as a potential location due to the overhead high-voltage power lines. Drift impacts of the proposed cooling tower on cables and switchgear need to be further evaluated.

Existing infrastructure and underground utilities need to be relocated or demolished, as appropriate, to accommodate potential cooling towers and associated piping. The multiple wastewater basins along the eastern boundary of the property will need to be demolished, and wastewater routed to one or more new wastewater tanks constructed elsewhere on the property. The maintenance building near Units 3 and 4 may need to be relocated to route makeup water piping to the Units 3 and 4 cooling tower.

The design wet-bulb temperature used for BTCA1 is 69°F [5]; the source water total dissolved solids (TDS) is approximately 33,500 parts per million (ppm). The basic characteristics of the towers for BTCA1 are given in the following table [6].

Figure A-2
BTCA1 conceptual cooling tower location map

Table A-3
Basic characteristics of cooling towers proposed for BTCA1

Unit Designation		**Unit 1**	**Unit 2**	**Unit 3**	**Unit 4**	**Unit 5**	**Unit 6**
Condenser Cooling water Flow	gpm	68,500	68,500	129,500	129,500	202,000	202,000
Cooling Tower Range/Condenser ΔT	°F	24.6	24.6	21.7	21.7	18.2	18.2
No. and Arrangement of Cooling Tower Cells		14 Back-to-back		22 Back-to-back		14 Back-to-back	14 Back-to-back
Cell Size (L x W x H)	ft	48 x 48 x 55		54 x 54 x 59		54 x 48 x 59	54 x 48 x 59
Cooling Tower Basin Size (L x W x H)	ft	344 x 104 x 6		602 x 116 x 6		386 x 116 x 6	386 x 116 x 6
Lift Pump Total	hp	658		1,309		1,940	1,940
Fan Total	hp	2,800		4,400		2,800	2,800
Fan Diameter	ft	30.0		32.8		32.8	32.8
Fan Housing Inside Diameter at Exit	ft	33.2		36		36	36
Air Flow Rate per Cell	acfm	1,153,479		1,358,601		1,196,520	1,196,520
Drift Elimination Efficiency	%	0.0005%		0.0005%		0.0005%	0.0005%
Cooling Tower Heat Dissipation Rate per Cell	gpm	1.20E+08		1.28E+08		1.31E+08	1.31E+08
Cycles of Concentration	BTU/ hr	1.5		1.5		1.5	1.5
Drift Rate per Unit	gpm	0.3	0.3	0.6	0.6	1.0	1.0
Cooling Tower Evaporation Rate	gpm	1,685	1,685	2,810	2,810	3,676	3,676
Blowdown Rate	gpm	3,370	3,370	5,620	5,620	7,353	7,353
Makeup Rate	gpm	5,055	5,055	8,430	8,430	11,029	11,029

A few of the engineering challenges associated with locating cooling towers at BTCA1 are listed below.

- The BTCA1 site itself is fully utilized-there is little available land on the property. Existing buildings and utilities would need to be moved or removed to make space for the proposed cooling towers.
- BTCA1 is adjacent to several highways. Operation of cooling towers could impact visibility. Barriers erected to shield cooling towers from view would hinder cooling tower performance.
- Los Angeles Regional Water Board regulates consumptive water use [3]. Closed-cycle cooling towers will increase consumptive water use.
- BTCA1's cooling towers would likely require exemptions from the City of Long Beach's height and noise ordinances [3].
- There are no more PM_{10} offsets available for BTCA1's cooling towers [3].
- The tower dimensions given in Table A-3 are for standard back-to-back mechanical-draft evaporative cooling towers (MECT) with no plume abatement. The need for plume abatement could be an issue due to the location of highways, residential properties, and a retirement facility, and the City of Long Beach viewshed. However, plume-abated towers are limited to in-line arrangements, and locating six in-line towers onsite is not practicable.
- The Haynes Generating Station is located across the San Gabriel River on the Los Angeles Department of Water and Power property. Should both Haynes and BTCA1 facilities retrofit the existing once-through systems with closed-cycle cooling towers, the synergistic effects of both towers may need to be considered (interference, noise, etc.).

A.1.4 Alternative Cooling Towers and Locations Considered

Alternate cooling tower locations considered include the Pacific Pipeline and Terminal Company property immediately to the south of BTCA1, and the main employee parking lot on the BTCA1 property. The Pacific Pipeline and Terminal Company property was eliminated because this location would require new land acquisition. The main employee parking lot was eliminated from consideration because the high voltage cables between the generating units and the switchyard run across the parking lot.

There is insufficient space for inline mechanical draft cooling towers, hyperbolic natural draft cooling towers, or hybrid towers. The layout of the BTCA1 property is not suitable for circular mechanical draft cooling towers.

A.1.5 Aquatic Biota

Biological information for BTCA1 is provided in Tables A-4 and A-5 [7]. The given annualized impingement and entrainment numbers are based on actual cooling water usage.

Table A-4
Annual impinged and entrained finfish- BTCA1

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Anchovies				
Deepbody Anchovy	*Anchoa compressa*	576		
Slough Anchovy	*Anchoa delicatissima*	1,300		
Anchovy, Unid.	*Anchoa* sp.	7		
Anchovies	Engraulidae unid.		25,101,765	21,410,242
Northern Anchovy	*Engraulis mordax*	1,462		
Northern Anchovy Larvae	*Engraulis mordax* larvae	6,582		
Blennies				
Blenny, unid.	Blennioidei unid.			12,470
Tube Blennies	Chaenopsidae unid.			295,060
Kelp Blennies	Clinidae unid.			175,556
Bay Blenny	*Hypsoblennius gentilis*	163		
Rockpool Blenny	*Hypsoblennius gilberti*	65		
Mussel Blenny	*Hypsoblennius jenkinsi*	7		
Combtooth Blennies	*Hypsoblennius* spp.			463,862,355
Labrisomid Blennies	Labrisomidae unid.			16,080,276

Table A-4
Annual impinged and entrained finfish- BTCA1 (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Drums/Croakers				
White Sea Bass	*Atractoscion nobilis*	23		
Black Croaker	*Cheilotrema saturnum*	14		138,814
White Croaker	*Genyonemus lineatus*	90	1,779,484	4,483,825
California Corbina	*Menticirrhus undulatus*	205		219,350
Spotfin Croaker	*Roncador stearnsi*			127,278
Croaker, unid.	Sciaenidae	7	1,154,697	1,389,708
Queenfish	*Seriphus politus*	2,167		591,844
Yellowfin Croaker	*Umbrina roncador*	189		
Flatfishes				
Sanddab Eggs	*Citharichthys* spp. (eggs)		969,234	
Sand Flounder Eggs	Paralichthyidae unid. (eggs)		8,019,392	
California Halibut	*Paralichthys californicus*	481	522,852	445,485
Flatfishes	Pleuronectiformes unid.			78,487
Diamond Turbot	*Pleuronichthys guttulatus*	1,600		1,078,502
Spotted Turbot	*Pleuronichthys ritteri*	47		
Righteyed Flounder, unid.	*Pleuronichthys* sp.	4		
Turbot Eggs	*Pleuronichthys* spp. (eggs)		470,141	
Hornyhead Turbot	*Pleuronichthys verticalis*	7		
Fantail Sole	*Xystreurys liolepis*	16		

Table A-4
Annual impinged and entrained finfish- BTCA1 (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Gobies				
Yellowfin Goby	*Acanthogobius flavimanus*	666		3,918,741
Longjaw Mudsucker	*Gillichthys mirabilis*	2,007		8,079,912
Gobies	Gobiidae unid.			1,065,638,741
Bay Goby	*Lepidogobius lepidus*	4		125,236
Chameleon Goby	*Tridentiger trigonocephalus*			463,027
Blind Goby	*Typhlogobius californiensis*			1,384,808
Herrings				
Pacific Sardine	*Sardinops sagax*	389		
Jacks/Pompanos				
Pacific Pompano	*Peprilus simillimus*	7		
Sculpins				
Sculpins	*Clinocottus* spp.			609,778
Sculpins	Cottidae unid.			438,063
Pacific Staghorn Sculpin	*Leptocottus armatus*	17,973		235,755
Roughcheek Sculpin	*Ruscarius creaseri*			130,770
Silversides				
Topsmelt	*Atherinops affinis*	221,960	4,780,532	
Silverside, unid.	Atherinopsidae	71,658	2,824,697	56,032,916
Jacksmelt	*Atherinopsis californiensis*	99		
California Grunion	*Leuresthes tenuis*	75		

Table A-4
Annual impinged and entrained finfish- BTCA1 (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Other Species				
Grey Smoothhound	*Mustelus californicus*	20		
Bat Ray	*Myliobatis californica*	146		
Senorita	*Oxyjulis californica*			387,570
Pacific Chub Mackerel	*Scomber japonicus*	17		
Pacific Barracuda	*Sphyraena argentea*	35		
Round Stingray	*Urobatis halleri*	245		
Jack Mackerel	*Trachurus symmetricus*	69		
Bullhead Catfish, unid.	*Ameiurus* sp.	16		
Sargo	*Anisotremus davidsonii*	13		
Tilapia, unid.	Cichlidae	19		
California Killifish	*Fundulus parvipinnis*	221		
Spotted Kelpfish	*Gibbonsia elegans*	20		
Clinid Kelpfishes	*Gibbonsia* spp.			2,439,568
Clingfishes	Gobiesocidae unid.			17,141,943
California Clingfish	*Gobiesox rhessodon*	11		
Giant Kelpfish	*Heterostichus rostratus*	149		179,172
Garibaldi	*Hypsypops rubicundus*			103,960

Table A-4
Annual impinged and entrained finfish- BTCA1 (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Reef Finspot	*Paraclinus integripinnis*	59		
Specklefin Midshipman	*Porichthys myriaster*	426		
Plainfin Midshipman	*Porichthys notatus*	21		
Midshipman, unid.	*Porichthys* sp.	16		
California Needlefish	*Strongylura exilis*	66		
California Tonguefish	*Symphurus atricaudus*	15		
Kelp Pipefish	*Syngnathus californiensis*	198		
Bay Pipefish	*Syngnathus leptorhynchus*	2,777		
Pipefish, unid.	*Syngnathus* sp	303		4,992,459
Mexican Lampfish	*Triphoturus mexicanus*			140,583
Salema	*Xenistius californiensis*	46		
Surfperches				
Shiner Perch	*Cymatogaster aggregata*	64,166		
Black Perch	*Embiotoca jacksoni*	152		
White Seaperch	*Phanerodon furcatus*	21		

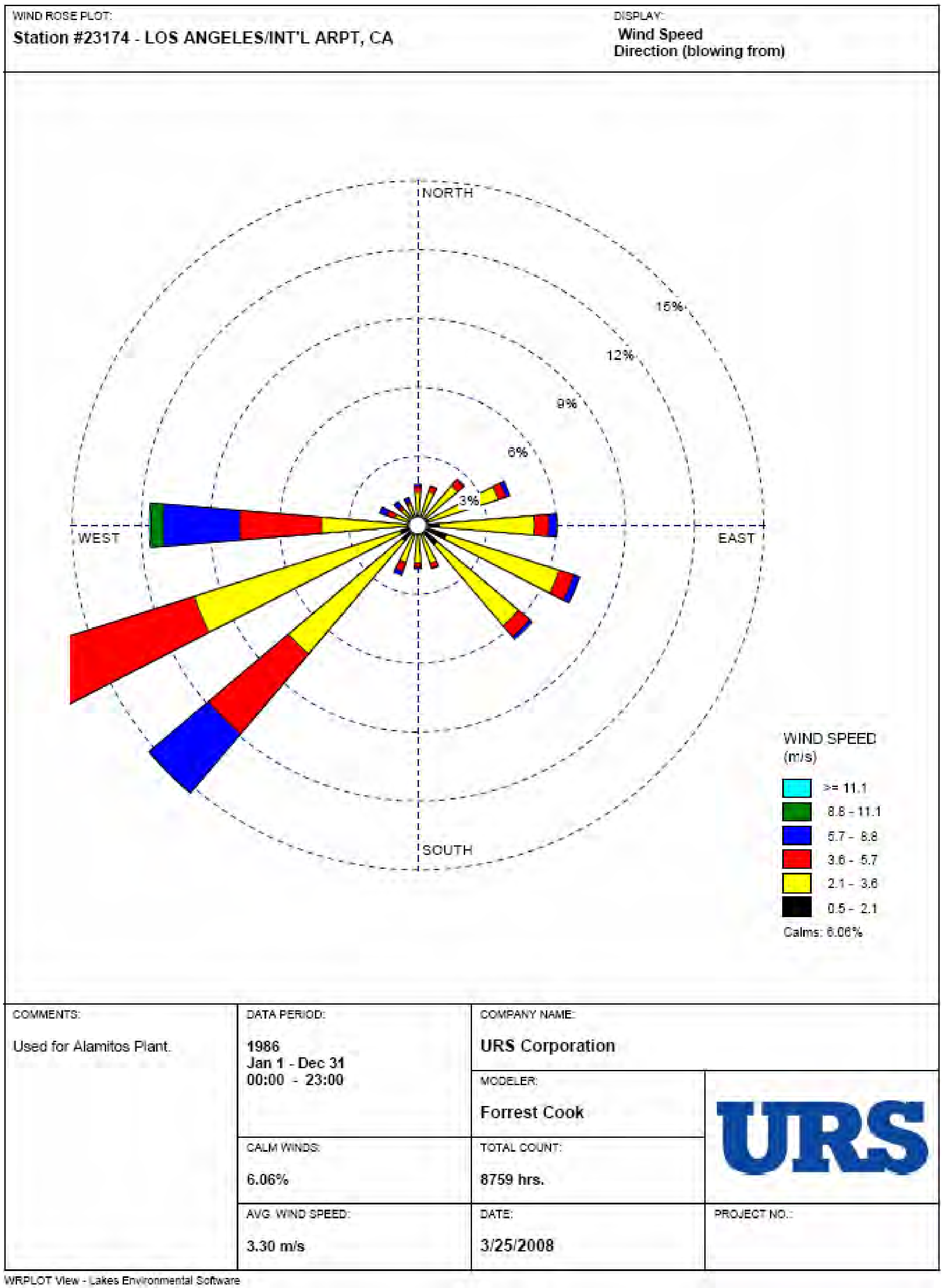
Table A-4
Annual impinged and entrained finfish- BTCA1 (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Groups/Unidentified				
Unidentified Fish Eggs	Fish eggs unid		552,563,055	
Unidentified Yolksac Larvae	larvae, unidentified yolksac			1,880,767
Unidentified Post larval Fish	Post-larvae, unidentified			2,660,353
Spl Fish Eggs	Sciaen./Paralich/Labr.		8,421,526	
Unidentified Damaged Fish	unidentified fish, damaged			9,373,776
	Total	**399,097**	**606,607,375**	**1,686,747,150**

Table A-5
Annual impinged and entrained shellfish - BTCA1

Common Name	Scientific Name	Annual Impingement (# of shellfish)	Annual Entrainment
Crabs			
Pacific Rock Crab	*Cancer antennarius*	5	
Yellow Crab	*Cancer anthonyi*	13	
Shore Crab Megalops	Grapsidae unid. (megalops)		1,558,390
Purple Shore Crab	*Hemigrapsus nudus*	7	
Yellow Shore Crab	*Hemigrapsus oregonensis*	40,793	369,313
Yellow Shore Crab Post-larval	*Hemigrapsus oregonensis* (post-larval)		77,773
Striped Shore Crab	*Pachygrapsus crassipes*	36	
Striped Shore Crab Megalops	*Pachygrapsus crassipes* (megalops)		179,096
Striped Shore Crab Post-larval	*Pachygrapsus crassipes* (post-larval)		141,127
Porcelain Crab Megalops	*Petrolisthes* spp. (megalops)		136,760
Pea Crabs Megalops	*Pinnixa* spp. (megalops)		727,447
Xantus Swimming Crab	*Portunus xantusii*	76	
Northern Kelp Crab	*Pugettia producta*	38	
Kelp Crabs Megalops	*Pugettia* spp. (megalops)		902,762
Unidentified Crab Megalops	unidentified crab (megalops)		237,284
	Totals	**40,968**	**4,329,952**
Shrimp			
Blackspotted Bay Shrimp	*Crangon nigromaculata*	14	
Yellowleg Shrimp	*Farfantepenaeus californiensis*	66	
Giant Ghost Shrimp	*Neotrypaea gigas*	18	
Intertidal Coastal Shrimp	*Heptacarpus palpator*	9	
Blue Mud Shrimp	*Upogebia pugettensis*	13	
	Totals	**120**	

A.1.6 Air Quality



WIND ROSE PLOT:
Station #23174 - LOS ANGELES/INT'L ARPT, CA

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:
Used for Alamitos Plant.

DATA PERIOD:
1986
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:
URS Corporation

MODELER:
Forrest Cook

CALM WINDS:
6.06%

TOTAL COUNT:
8759 hrs.

AVG. WIND SPEED:
3.30 m/s

DATE:
3/25/2008

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure A-3
Wind speed and direction for BTCA1

A.1.7 Population Information

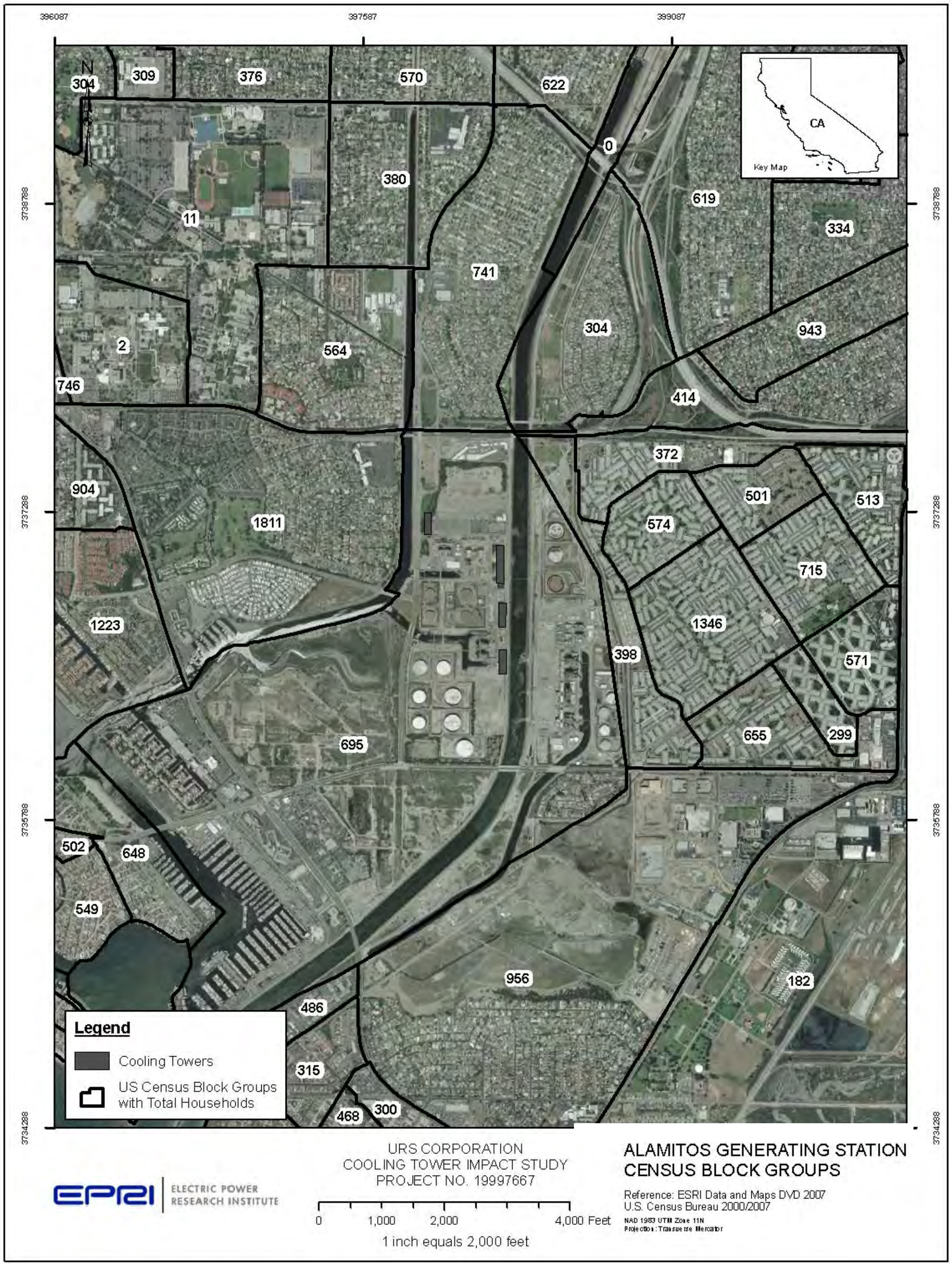


Figure A-4
Census blocks detailing local household numbers surrounding BTCA1

A.1.8 Terrestrial Resources

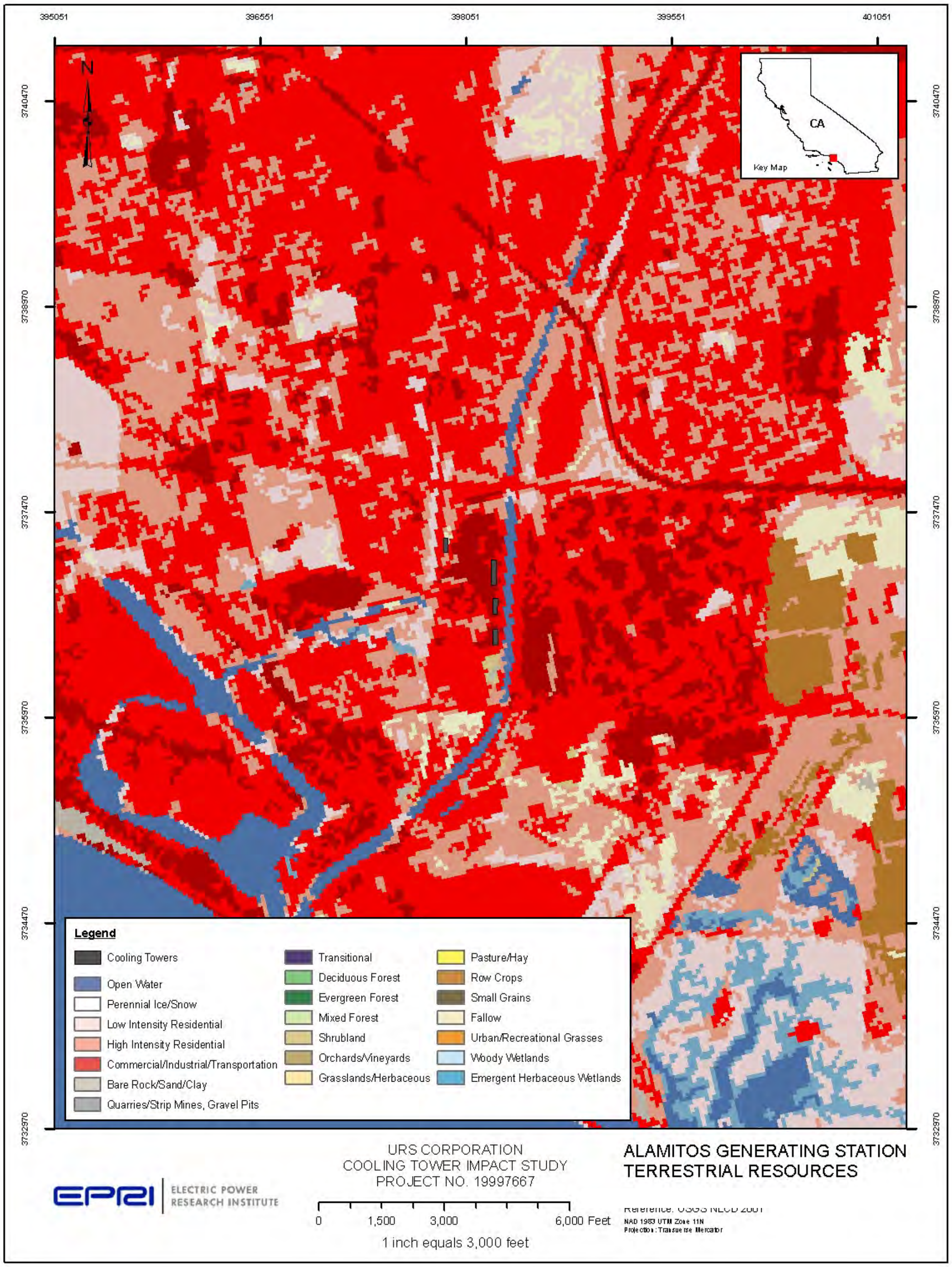


Figure A-5
Land cover classifications for areas surrounding BTCA1

A.1.9 Parks, Landmarks and Other Resources

Figure A-6
Local parks and landmarks near BTCA1

A.1.10 Summary of Potential Issues with Cooling Tower Implementation

Table A-6
Summary of impacts and issues at BTCA1 [3]

Resource	Issues
Engineering	Severe space limitation. Need to relocate existing infrastructure (waste water treatment, maintenance building) to accommodate cooling towers. Potential for interference with underground utilities. Need to construct around power lines and switchyard.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions. Large population of sensitive receptors (nation's largest retirement community is downwind of the facility).
Terrestrial Resources	The facility is in close proximity to ecologically sensitive areas, Los Cerritos wetlands and Seal Beach Wildlife Refuge, which provide habitat to several protected species. One state species of concern, burrowing owl, has been observed on-site.
Water Consumption	Source water is mostly saline.
Solid Waste	Large quantities of trash and debris are removed by existing intake.
Public Safety	Fogging of roadways and navigable waterways. Potentially lowered visibility at nearby Long Beach Airport.
Quality of Life	Noise, view shed, shadowing impacts.
Permitting	City of Long Beach's Height and Noise Ordinances; impacts to protected species. Air quality in the vicinity of BTCA1 is in non-attainment. There are no more PM_{10} offsets available. BTCA1 has no apparent allowance for any emissions. Active community groups (Cerritos Wetlands Land Trust and University Park Estates Neighborhood Association) opposed to development.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of CO_2.
Other	BTCA1's source waterbody is already classified as "impaired" [3]. Reducing the flow through the bay and channel, and then discharging a more concentrated effluent into the river may further impair water quality in both waterbodies. Circulation modeling indicates that a minimum sustained pumping rate of 600 cubic feet per second (cfs) at the plant is needed to maintain flushing sufficient to prevent violations of fecal coliform water quality standards. The estimated make-up water intake rate for cooling towers at BTCA1 is 110 cfs [8].

A.2 Beta Test Plant A (BTPA)

BTPA already utilizes CCC for Units 6 and 7. Units 1-5 currently use once-through cooling. Retrofitting BTPA's once-through cooling systems used by Units 1-5 with a closed-cycle re-circulating cooling system is deemed feasible at this time with an average level of difficulty.

The retrofit would reduce cooling water intake to the plant; IM&E may be expected to decrease correspondingly. Here too, the cooling tower retrofit is expected to introduce several new environmental concerns, such as loss of habitat. These issues are discussed below.

Five cooling towers (one for each once-through unit) are proposed for this facility. The sizes, locations and impacts of these cooling towers are also discussed in this section.

A.2.1 Background

BTPA is a 2,525 MW coal and natural gas fired electricity generating facility located in the U.S. Southeast. The facility is located on the freshwater tidal portion of a river. The facility consists of seven generating units-five steam units (1,525 MW) and two combined cycle units (1,000 MW) [9]. The steam-electric units (Units 1-5) are coal fired and utilize once-through cooling water from the tidal river. The combined cycle Units 6 and 7, installed in 2000, are natural gas fired and utilize CCC. The design intake cooling water flow rate for the facility is 777,000 gpm.

Table A-7
BTPA engineering information for steam-electric generating units that utilize once-through cooling

Generating Unit	Rated Capacity (MW)	Cooling Water Flow Rate (gpm)	Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006 (%)
Unit 1	125	89,000	17	1954	76%
Unit 2	125	89,000	19	1954	76%
Unit 3	225	160,000	18	1959	79%
Unit 4	350	172,000	19	1969	81%
Unit 5	700	267,000	24	1971	78%
Total	**1,525**	**777,000**	**NA**	**NA**	**NA**

** Units 6 and 7 are combined cycle units already utilizing closed-cycle cooling systems and are therefore not included here.

A location map of BTPA is provided as Figure A-7. Key information received from the plant for the generating units that use once-through cooling is provided in the following table.

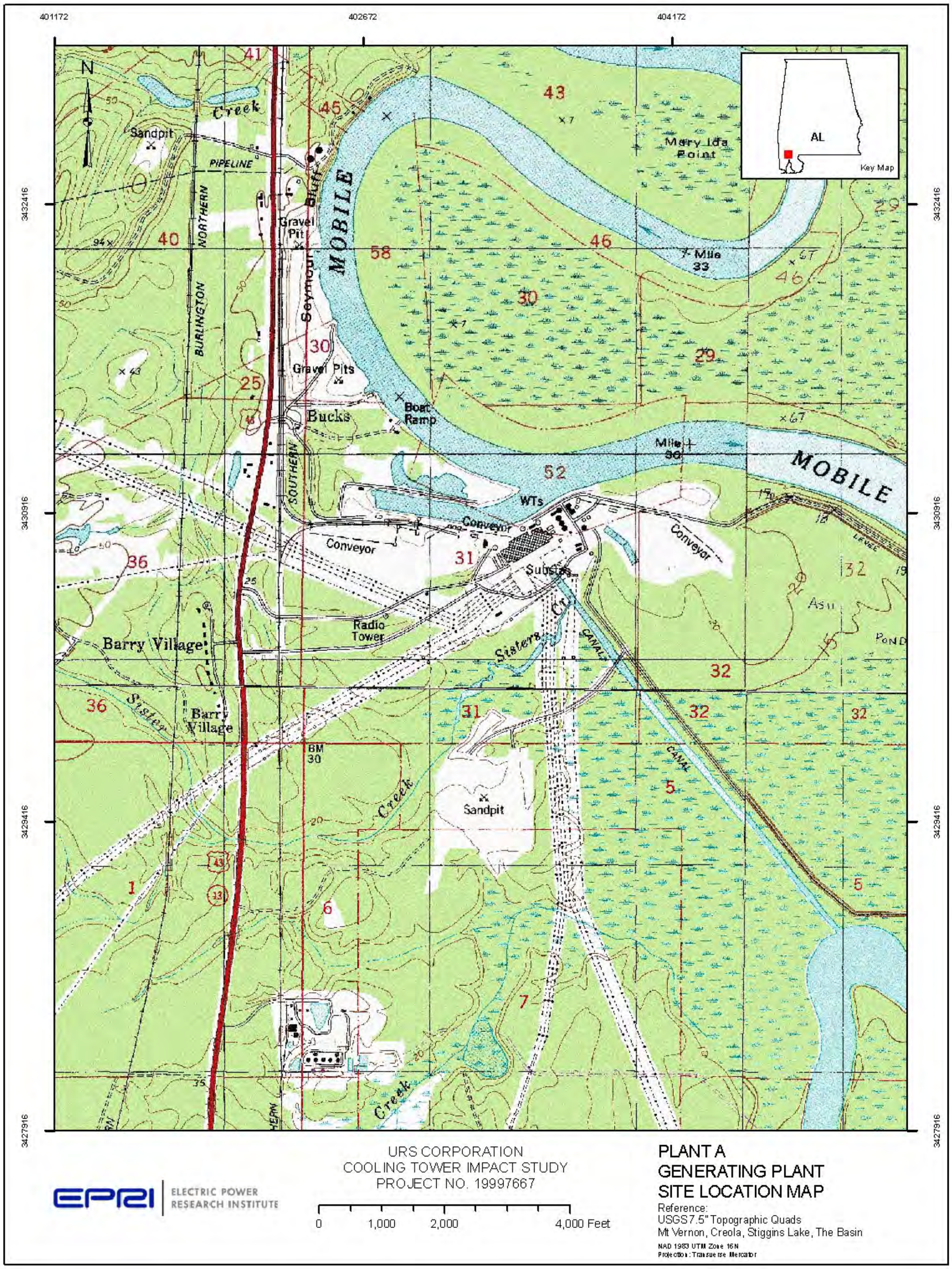


Figure A-7
BTPA site location map

A.2.2 Cooling Water Intake Structure

The two CWISs at BTPA withdraw cooling water from a short canal on the tidal river. The first CWIS provides cooling water to Units 1-3. The second CWIS provides cooling water to Units 4 and 5 [9]. Units 6 and 7 withdraw makeup water from the Units 1-3 condenser cooling discharge tunnel [9].

A.2.3 Proposed Cooling Towers at BTPA

Only five of BTPA's seven generating units need be considered for retrofitting with closed-cycle cooling towers. The combined cycle Units 6 and 7 already utilize closed-cycle cooling towers.

The preliminary conceptual design for this facility includes five cooling towers for Units 1-5 to be located to the southeast of the facility oriented in a NNE-SSW direction to optimize use of available space; the optimal direction with respect to predominant summer wind would be N-S. Conceptual cooling tower locations are shown in Figure A-8. The 10- and 18-cell back-to-back towers proposed for Units 4 and 5 would be located closer to the facility. The 10-cell back-to-back tower for Unit 3, and the 5- and 6-cell inline towers for Units 1 and 2, respectively, would be located further away.

The CWIS for BTPA are located in an intake canal hydraulically connected to the tidal river; these intake structures are located to the north and northwest of the facility. Since the proposed cooling towers are located diagonally across from the existing CWIS and facility, the circulating pumps may need to be relocated and a new piping system introduced to route the cooling water between the respective condensers and cooling towers. One intake structure may be sufficient to provide makeup water for all towers.

The design wet-bulb temperature used for BTPA is 79°F [5]. The tidal river in the vicinity of the BTPA CWIS is classified as tidal freshwater with TDS varying between 2,500-5,000 ppm [9]. The basic characteristics of the cooling towers for BTPA are given in Table A-8 [6].

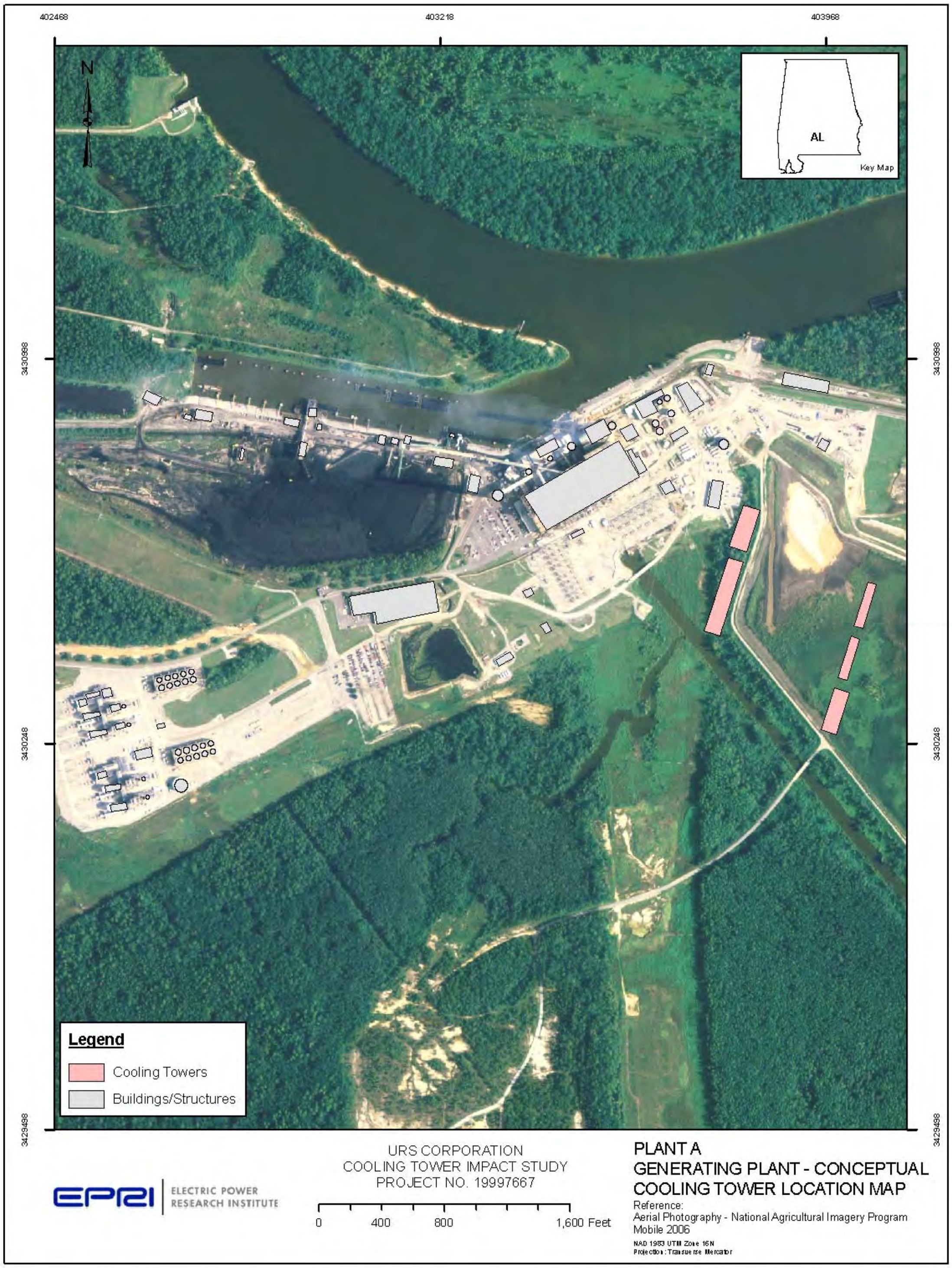


Figure A-8
BTPA conceptual cooling tower location map

Table A-8
Basic characteristics of cooling towers proposed for BTPA

Unit Designation		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Condenser Cooling Water Flow	gpm	89,000	89,000	160,000	172,000	267,000
Cooling Tower Range/Condenser ΔT	°F	17	19	18	19	24
No. and Arrangement of Cooling Tower Cells		5 Inline	6 Inline	10 Back-to-back	10 Back-to-back	18 Back-to-back
Cell Size (L x W x H)	ft	54 x 54 x 49	48 x 48 x 44	54 x 48 x 55	54 x 54 x 59	54 x 48 x 56
Cooling Tower Basin Size (L x W x H)	ft	278 x 62 x 6	296 x 56 x 6	278 x 104 x 6	278 x 116 x 6	494 x 104 x 6
Lift Pump Total	hp	630	607	1,537	1,739	2,632
Fan Total	hp	1,000	1,200	2,000	2,000	3,600
Fan Diameter	ft	32.8	30.0	32.8	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	33	36	36	36
Air Flow Rate per Cell	acfm	1,373,820	1,189,867	1,235,544	1,358,601	1,297,327
Drift Elimination Efficiency	%	0.0005%	0.0005%	0.0005%	0.0005%	0.0005%
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	1.51E+08	1.41E+08	1.44E+08	1.63E+08	1.78E+08
Cycles of Concentration		4	4	4	4	4
Drift Rate per Unit	gpm	0.4	0.4	0.8	0.9	1.3
Cooling Tower Evaporation Rate	gpm	1,513	1,691	2,880	3,268	6,408
Blowdown Rate	gpm	504	564	960	1,089	2,136
Makeup Rate	gpm	2,017	2,255	3,840	4,357	8,544

Increasing the spacing between towers would improve performance of towers by reducing interference.

A few of the engineering challenges associated with locating cooling towers at BTPA are listed below.

- Construction would need to accommodate BTPA's underground utilities [3].
- BTPA is located near a section of U.S. highway and state highway. Visibility may be affected during cooling tower operation.

A.2.4 Alternative Cooling Towers and Locations Considered

Alternate cooling tower locations considered include the parcel immediately to the south of the facility and west of the discharge canal; and the vegetated waterfront parcel approximately 1,500 ft east of the facility. The southern location was eliminated due to potential construction and permitting challenges associated with construction in and near a creek and surrounding wetlands; the eastern parcel was eliminated from further consideration because of the greater distance between potential cooling towers and the facility.

Further study would be needed to show whether other cooling tower options, such as natural draft, dry and hybrid, are viable at this site; however, there would have to be constraints imposed that would force BTPA to use such towers, which are more expensive and less efficient than the MECT's proposed here (See Section 6 for additional information on alternative towers).

A.2.5 Aquatic Biota

Biological data in Table A-9 are provided by the southeast power company as the biological collection results from 2008. The annual impingement and entrainment is based on design cooling water usage. These numbers were adjusted for analysis to account for actual cooling water usage based on a five-year average from 2002–2006 [10].

Table A-9
Annual impinged and entrained biota-BTPA

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of larvae)
Anchovies			
Bay Anchovy	*Anchoa mitchilli*	6,749	
Bowfin			
Bowfin	*Amia calva*	87	
Bullhead Catfish			
White Catfish	*Ameiurus catus*	137	161
Black Bullhead	*Ameiurus melas*	159	186
Blue Catfish	*Ictalurus furcatus*	76,168	89,334
Channel Catfish	*Ictalurus punctatus*	14,606	17,131
Flathead Catfish	*Pylodictis olivaris*	283	332

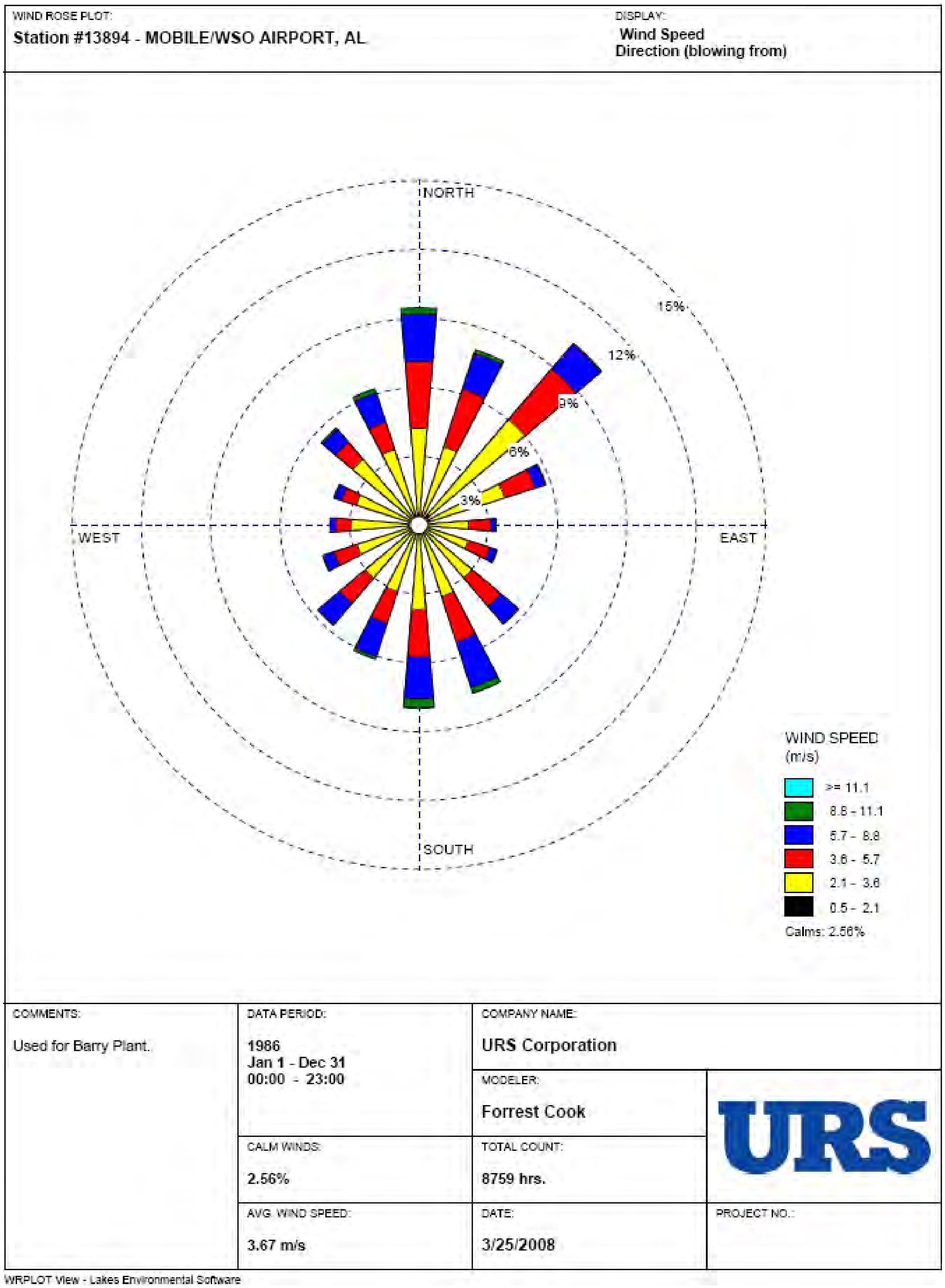
Table A-9
Annual impinged and entrained biota-BTPA (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of larvae)
Carps and Minnows			
Silver Chub	*Macrhybopsis storeriana*	158	756,256
Golden Shiner	*Notemigonus crysoleucas*	226	1,081,734
Emerald Shiner	*Notropis atherinoides*	1,474	7,055,200
Silverside Shiner	*Notropis candidus*	9,998	47,854,741
Longnose Shiner	*Notropis longirostris*	46	220,176
Drums			
Freshwater Drum	*Aplodinotus grunniens*	37,901	17,446,049
Sand Seatrout	*Cynoscion arenarius*	26	11,968
Eels			
American Eel	*Anguilla rostrata*	30	
Gars			
Spotted Gar	*Lepisosteus oculatus*	39	32,366
Longnose Gar	*Lepisosteus osseus*	54	44,815
Alligator Gar	*Lepisosteus spatula*	26	21,577
Herrings			
Skipjack Herring	*Alosa chrysochloris*	662	527,720
Menhaden	*Brevoortia patronus*	28	22,320
Gizzard Shad	*Dorosoma cepedianum*	11,131	8,873,182
Threadfin Shad	*Dorosoma petenense*	282,003	224,801,365
Lefteye Flounder			
Flounder	*Paralichthys lethostima*	181	
Needlefish			
Needlefish	*Strongylura marina*	59	68,127
Paddlefish			
Paddlefish	*Polyodon spathula*	900	31,178
Perches and Darters			
Mobile Logperch	*Percina kathae*	15	1,089,201
Gulf Logperch	*Percina suttkusi*	15	1,089,200
Pikes			
Chain Pickerel	*Esox niger*	133	10,778
Pirate Perch			
Pirate Perch	*Aphredoderus sayanus*	85	
Silversides			
Inland Silverside	*Menidia beryllina*	46	1,005,378

Table A-9
Annual impinged and entrained biota-BTPA (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of larvae)
Sleepers			
Spinycheek Sleeper	*Eleotris pisonis*	15	
Soles			
Hogchoker	*Trinectes maculatus*	12,571	
Striped Basses			
White Bass	*Morone chrysops*	1,324	150,448
Hybrid Striped Bass	*Morone chrysops x saxatilis*	61	6,932
Yellow Bass	*Morone mississippiensis*	138	15,681
Striped Bass	*Morone saxatilis*	108	12,272
Suckers			
Quillback	*Carpiodes cyprinus*	15	693,011
Highfin Carpsucker	*Carpiodes velifer*	15	693,011
Smallmouth Buffalo	*Ictiobus bubalus*	512	23,654,765
Blacktail Redhorse	*Moxostoma poecilurum*	52	2,402,437
Sunfishes			
Flier	*Centrarchus macropterus*	1,321	540,117
Green Sunfish	*Lepomis cyanellus*	174	71,143
Warmouth	*Lepomis gulosus*	124	50,700
Bluegill	*Lepomis macrochirus*	2,505	1,024,219
Longear Sunfish	*Lepomis megalotis*	15	6,133
Redear Sunfish	*Lepomis microlophus*	161	65,828
Redspotted Sunfish	*Lepomis miniatus*	78	31,892
Spotted Bass	*Micropterus punctulatus*	81	33,118
Largemouth Bass	*Micropterus salmoides*	982	401,510
White Crappie	*Pomoxis annularis*	295	120,617
Black Crappie	*Pomoxis nigromaculatus*	33,664	13,764,202
Topminnows			
Bayou Topminnow	*Fundulus notti*	15	
Significant Shellfish			
Blue Crab		5,990	
TOTAL		**503,641**	**355,888,511**

A.2.6 Air Quality



WIND ROSE PLOT:
Station #13894 - MOBILE/WSO AIRPORT, AL

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:
Used for Barry Plant.

DATA PERIOD:
1986
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:
URS Corporation

MODELER:
Forrest Cook

CALM WINDS:
2.56%

TOTAL COUNT:
8759 hrs.

AVG. WIND SPEED:
3.67 m/s

DATE:
3/25/2008

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure A-9
Wind speed and direction for BTPA

A.2.7 Population Information

Figure A-10
Census blocks detailing local household numbers surrounding BTPA

A.2.8 Terrestrial Resources

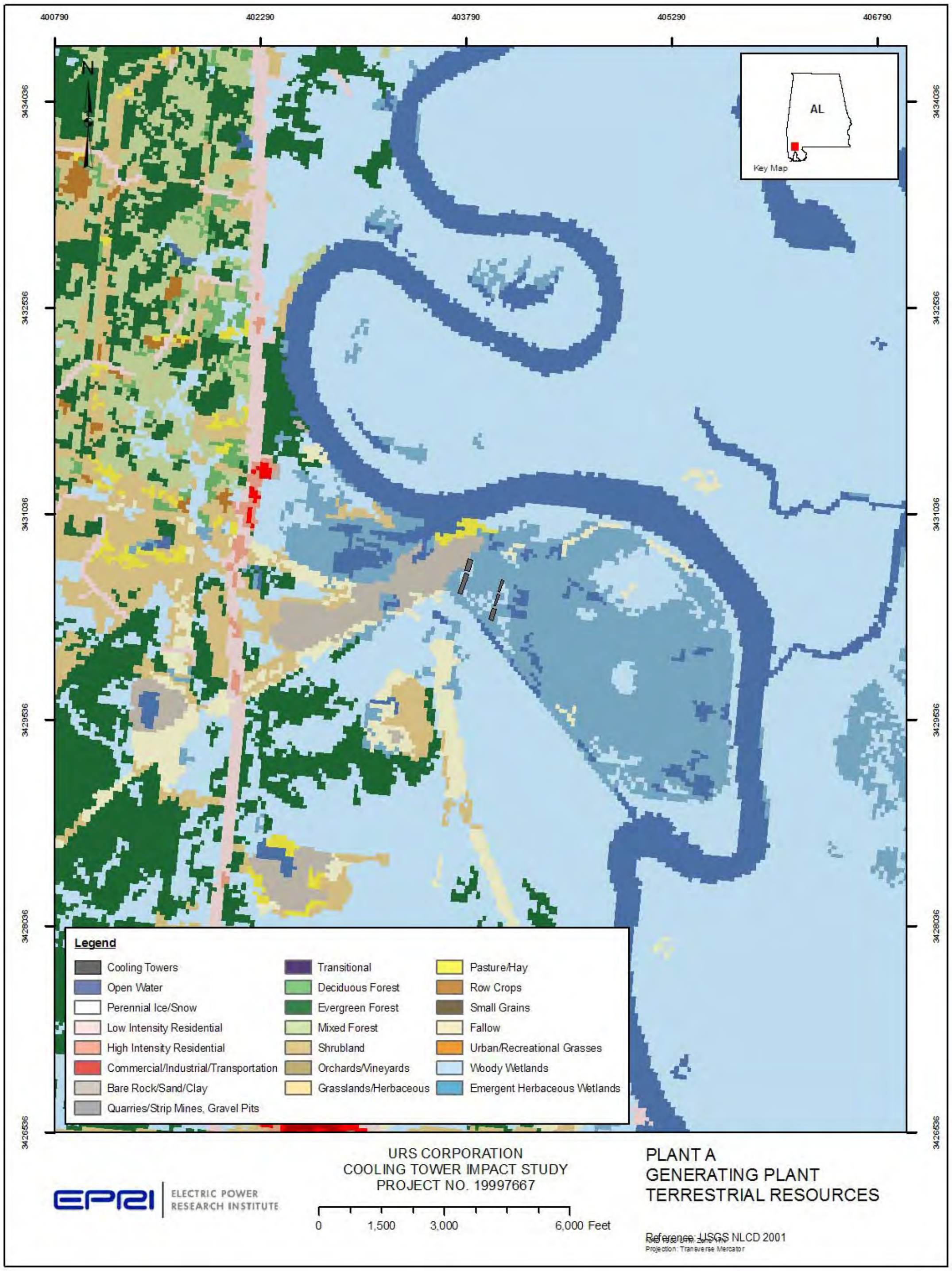


Figure A-11
Land cover classifications for areas surrounding BTPA

A.2.9 Parks, Landmarks and Other Resources

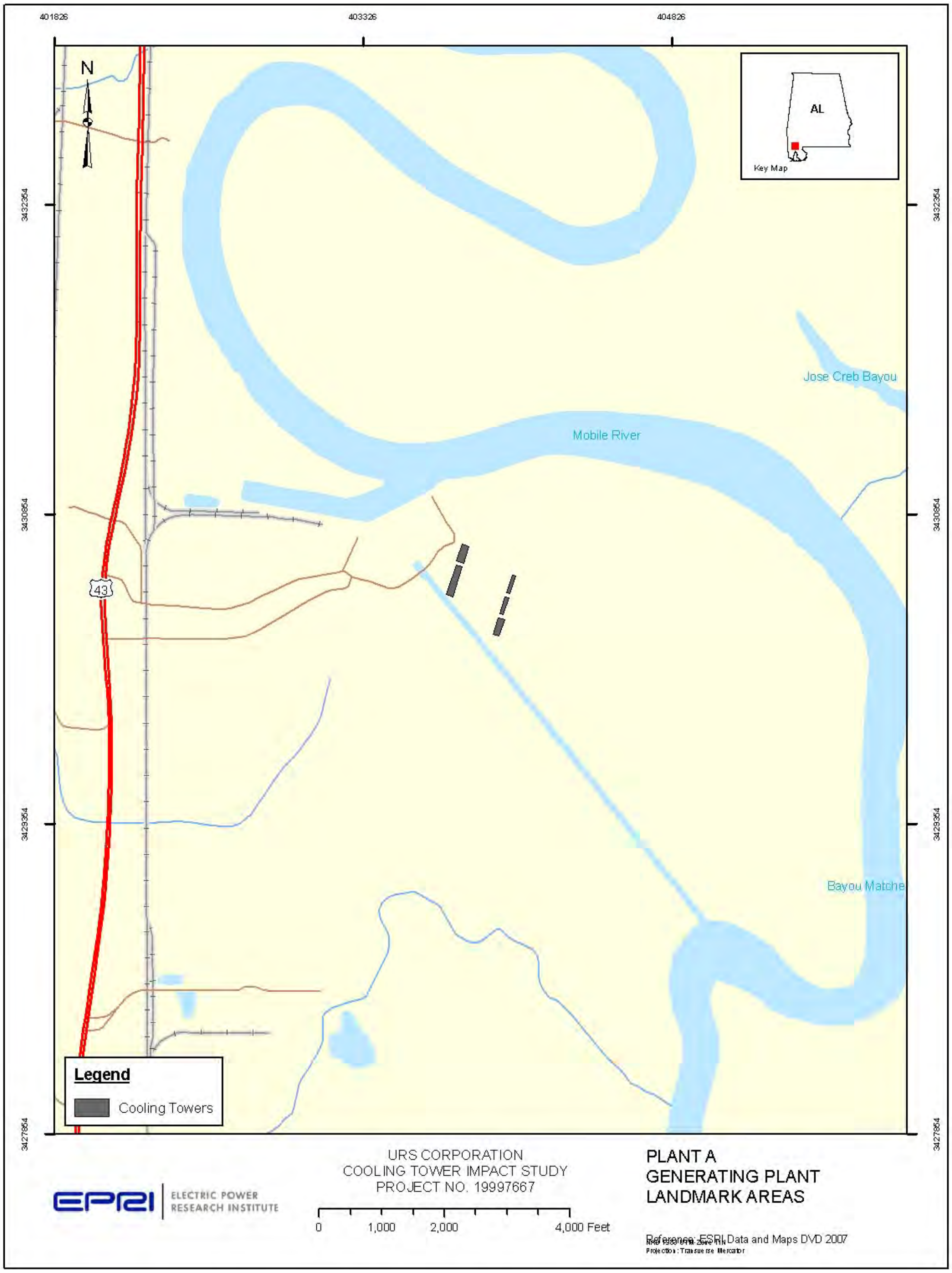


Figure A-12
Local parks and landmarks near BTPA

A.2.10 Summary of Potential Issues with Cooling Tower Implementation

Table A-10
Summary of impacts and issues at BTPA [3]

Resource	Issues
Engineering	Potential for interference with underground utilities. May need to re-route currently closed-cycle Units 6 and 7 makeup piping.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions.
Terrestrial Resources	Upland and wetland forested habitat will be impacted. Federally listed species could be affected (wood stork, Eastern indigo snake, gopher tortoise).
Water Consumption	Although consumptive water use is not currently regulated, the state office of water resources requires water withdrawal and discharge to be reported. Consumptive water use may be an issue in the future.
Solid Waste	Large quantities of trash and debris are removed by existing intake.
Public Safety	BTPA is located near a section of highway. Visibility may be affected during cooling tower operation. Barriers constructed to shield cooling towers and their emissions from view could hinder cooling tower performance. Fogging of roadways and navigable waterways.
Quality of Life	Noise, view shed, shadowing impacts.
Permitting	Loss of forested habitat and potential impacts to protected species.
Green House Gas	Parasitic losses and energy penalty will result in additional emissions of CO_2.
Other	

A.3.Beta Test Plant B (BTPB)

Given the large capacity of the facility, retrofitting BTPB’s once-through cooling system with a closed-cycle re-circulating cooling system would be a difficult but potentially feasible task. Its geologic heritage of sand dunes and location on one of the Great Lakes pose significant environmental concerns.

The retrofit will reduce cooling water intake to the plant; a corresponding reduction in IM&E may also be expected due to the closed-cycle cooling tower retrofit. As with other facilities, this retrofit introduces new environmental concerns, such as reductions in air quality, loss of important habitat, increase in net evaporative water loss, etc. These issues are discussed below.

Four cooling towers are proposed for this facility-two per unit. The sizes, locations and impacts of these cooling towers are also discussed below.

A.3.1 Background

BTPB is a base-load 2,130 MW nuclear facility with two pressurized water reactors located in the U.S. Midwest. BTPB uses once-through cooling systems to remove waste heat from the station’s main condensers [11]. The design intake cooling water flow rate for the facility is 1,490,300 gpm.

Table A-11
BTPB engineering information

Unit	Rated Capacity (MW)	Cooling water Flow Rate (gpm)	Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006 (%)
Unit 1	1,030	658,500	21.8	1975	87.2%
Unit 2	1,100	831,800	16.7	1978	86.8%
Total	**2,130**	**1,490,300**	**NA**	**NA**	**NA**

BTPB is located on the southeastern shoreline of a Great Lake, and its tract is part of the world’s largest formation of freshwater dunes (BTPB website). The BTPB property is comprised of approximately 650 acres including 4,350 ft of lakefront along a Great Lake and extends approximately 1.3 miles eastward to an interstate [11]. The CSX rail line runs in a north-south direction in the northeast corner of the property. A road forms the southern boundary of the property. The entire site is zoned for industrial use. BTPB surroundings are ‘rural,’ and characterized as agricultural and heavily wooded sand dunes. A state park is located approximately one mile northeast of BTPB [11].

A location map of BTPB is provided as Figure A-13. Key information for each generating unit is provided in the following table.

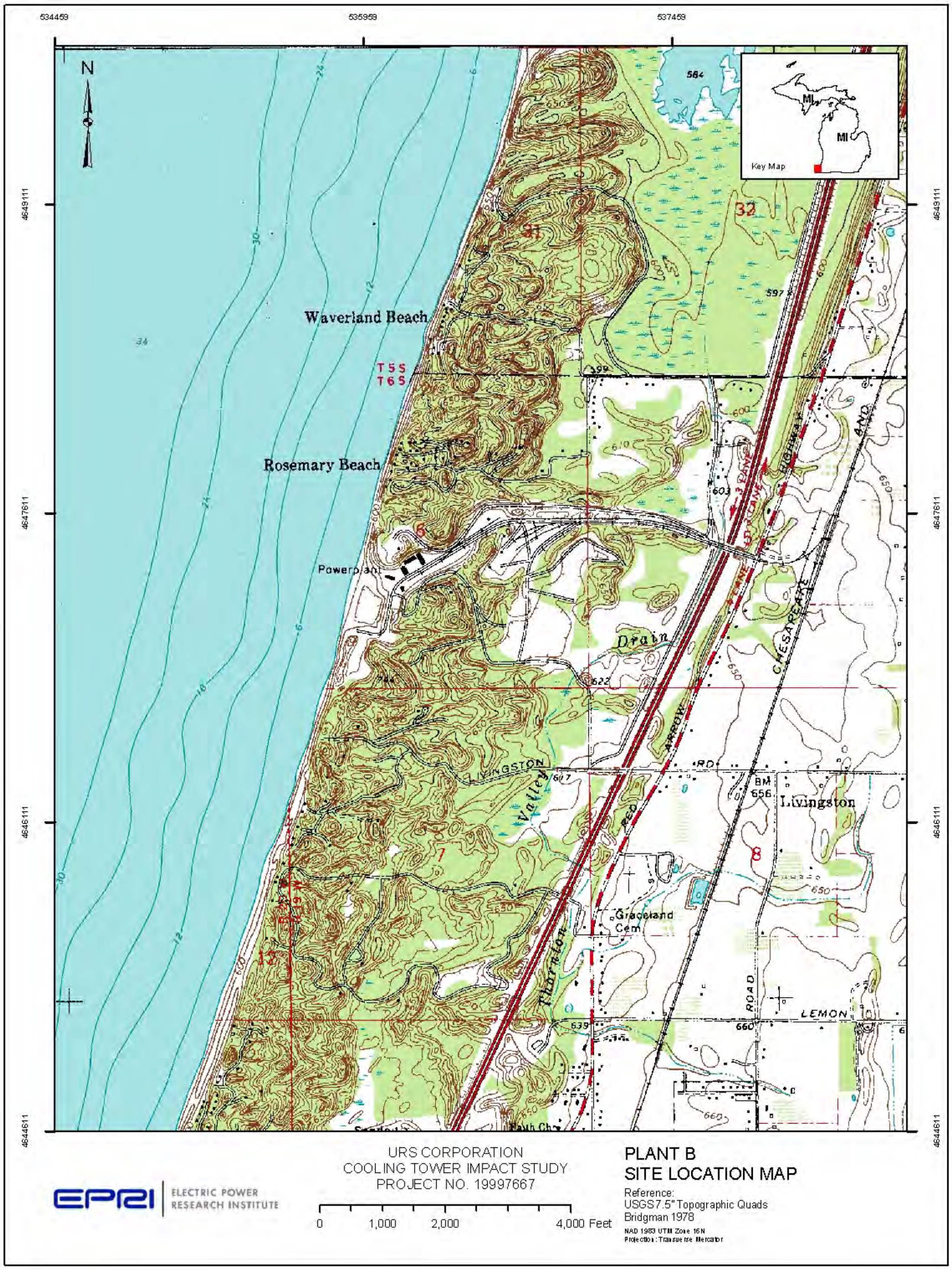


Figure A-13
BTPB site location map

A.3.2 Cooling Water Intake Structure

All cooling and service water is drawn from a Great Lake via three 16 ft diameter intake tunnels that extend about 2,250 ft offshore to a velocity cap crib. The intake tunnels convey the water from the offshore location to a common forebay located in the onshore screen house. Then the water passes through trash racks and traveling water screens [11].

The cooling water system is usually in continuous operation all year, except during maintenance shutdowns. The traveling water screens are rotated manually once per shift or automatically based on a pressure differential. The through-screen velocity at the traveling water screens has been calculated to be approximately 1.27 fps [11]. Since BTPB's primary intake is located offshore and water is conveyed to the onshore intake via tunnels, the approach and through screen velocities at the onshore intake is less important. Up to three circulating water pumps for Unit 1 and up to four pumps for Unit 2 take their suction from the intake afterbay. Additional service water pumps are also located in the afterbay. Water pumped by the seven circulating water pumps flows through the main steam condensers and is discharged back to a Great Lake through discharge nozzles. Some warm water is re-circulated for de-icing purposes during winter months [11].

A.3.3 Proposed Cooling Towers at BTPB

BTPB is a large (2,130 MW) facility that requires nearly 1.5 million gallons of cooling water per minute. The two generating units would therefore require 50 and 48 cooling tower cells, respectively, that for the purposes of this study, are grouped into two sets of cooling towers each. The specific characteristics of each tower are provided in the table below.

Several potential locations were considered before the towers were located to the south-southeast of the facility. Conceptual cooling tower locations are shown in Figure A-14. The four cooling towers have been preliminarily oriented in the northeast-southwest direction to coincide with the predominant summer wind direction. The currently proposed location is elevated and therefore, the site would have to be re-graded to allow for cooling tower construction [12]. The higher elevation of the tower basins would reduce pumping requirements from the cooling tower basins to condensers.

The cooling tower location proposed herein requires relocation of existing infrastructure; however, this location is expected to pose the least complications.

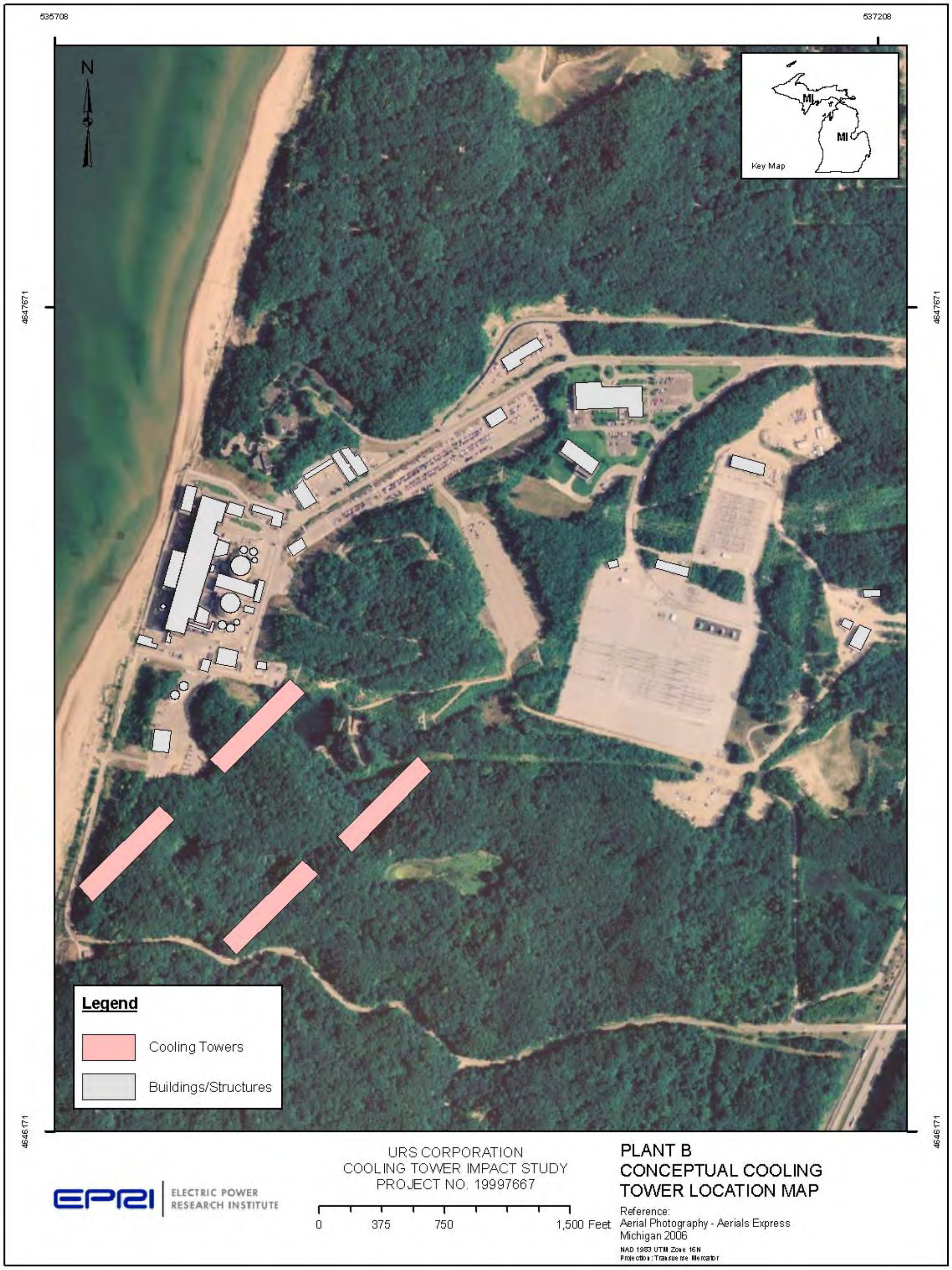


Figure A-14
BTPB conceptual cooling tower location

The design wet-bulb temperature used for BTPB is 75°F [5]; the Great Lake TDS is approximated to be 200 ppm. The basic characteristics of the cooling towers for BTPB are given in the following table [6].

Table A-12
Basic characteristics of cooling towers proposed for BTPB

Unit Designation		Unit 1	Unit 2
Condenser Cooling water Flow	gpm	658,500	831,801
Cooling Tower Range/Condenser ΔT	°F	21.8	16.7
No. and Arrangement of Cooling Tower Cells		One 24 cell tower; one 26 cell tower. Back-to-back	Two 24 cell towers; Back-to-back
Cell Size (L x W x H)	ft	54 x 48 x 55	54 x 48 x 55
Cooling Tower Basin Size (L x W x H)	ft	Two towers: 710 x 104 x 6; 656 x 104 x 6	Two towers, each 656 x 104 x 6
Lift Pump Total	hp	6,325	7,990
Fan Total	hp	10,000	9,600
Fan Diameter	ft	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36
Air Flow Rate per Cell	acfm	1,275,748	1,275,748
Drift Elimination Efficiency	%	0.0005%	0.0005%
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	1.44E+08	1.45E+08
Cycles of Concentration		8	8
Drift Rate per Unit	gpm	3.3	4.2
Cooling Tower Evaporation Rate	gpm	14,355	13,891
Blowdown Rate	gpm	2,051	1,984
Makeup Rate	gpm	16,406	15,876

A few of the engineering challenges associated with locating cooling towers at BTPB are listed below.

- A significant amount of wooded area would need to be cleared to install cooling towers.
- Large pipes would have to be installed above or below grade to convey cooling water between condensers and cooling towers.
- Some infrastructure would have to be relocated.

A.3.4 Alternative Cooling Towers and Locations Considered

Several alternate cooling tower locations were initially considered but later eliminated. The vegetated parcel between the reactors and the switchyard was eliminated due to the high voltage cables across it. Cooling towers set on piers (to the west of the facility) were eliminated due to construction and permitting difficulties. The vegetated parcel to the north of the reactors was eliminated because the piping to this location would need to be routed through the main entrance and visitor center.

Circular towers were also evaluated and eliminated because they provided no apparent additional advantage. If circular towers were used, Unit 2 would require four 12-cell towers, each 220 ft in diameters; and Unit 3 would require four 14-cell towers, each 250 ft in diameter. These towers would be approximately 50 ft high. More powerful fans (250 horsepower [hp]) would be needed for these towers.

Natural draft towers may be viable at this site. The capital cost associated with natural draft towers is greater than the MECTs proposed here; but this may be recouped over a period of time from the reduced operations and maintenance (O&M) costs. Dry and hybrid towers may also be feasible at this site but would have more intensive land use impacts. Unless their use is regulatory driven, less costly, more efficient MECTs would be specified.

A.3.5 Aquatic Biota

Biological data are provided in Table A-13 [13]. The annual impingement and entrainment is based on design cooling water usage.

Table A-13
Annual impinged and entrained fish–BTPB

Common Name	Scientific Name	Annual Impingement (#'s of fish)	Annual Entrainment (#'s)		
			Eggs	Larvae	Juveniles
Yellow Perch	*Perca flavescens*	1,116,300		301,547	1,580,000
Spottail Shiner	*Notropis hudsonius*	87,320	2,848,669	8,478,495	1,130,000
Alewife	*Alosa pseudoharengus*	82,705	9,126,055	12,443,837	740,000
Round Goby	*Neogobius melanostomus*	35,180		44,267,093	1,080,000
Gizzard Shad	*Dorosoma cepedianum*	34,375			
Lake Whitefish	*Coregonus clupeaformis*	9,416			
Rainbow Smelt	*Osmerus mordax*	8,990		9,307,749	510,000
Channel Catfish	*Ictalurus punctatus*	2,101			
Threespine Stickleback	*Gasterosteus aculeatus aculeatus*	1,621			
Bloater	*Coregonus hoyi*	1,015			
Slimy Sculpin	*Cottus cognatus*	1,010		271,392	
Bluegill	*Lepomis macrochirus*	1,008			
Longnose Sucker	*Catostomus catostomus catostomus*	958			
White Sucker	*Catostomus commersoni*	581		130,670	
Trout-perch	*Percopsis omiscomaycus*	536			
Sea Lamprey	*Petromyzon marinus*	523			

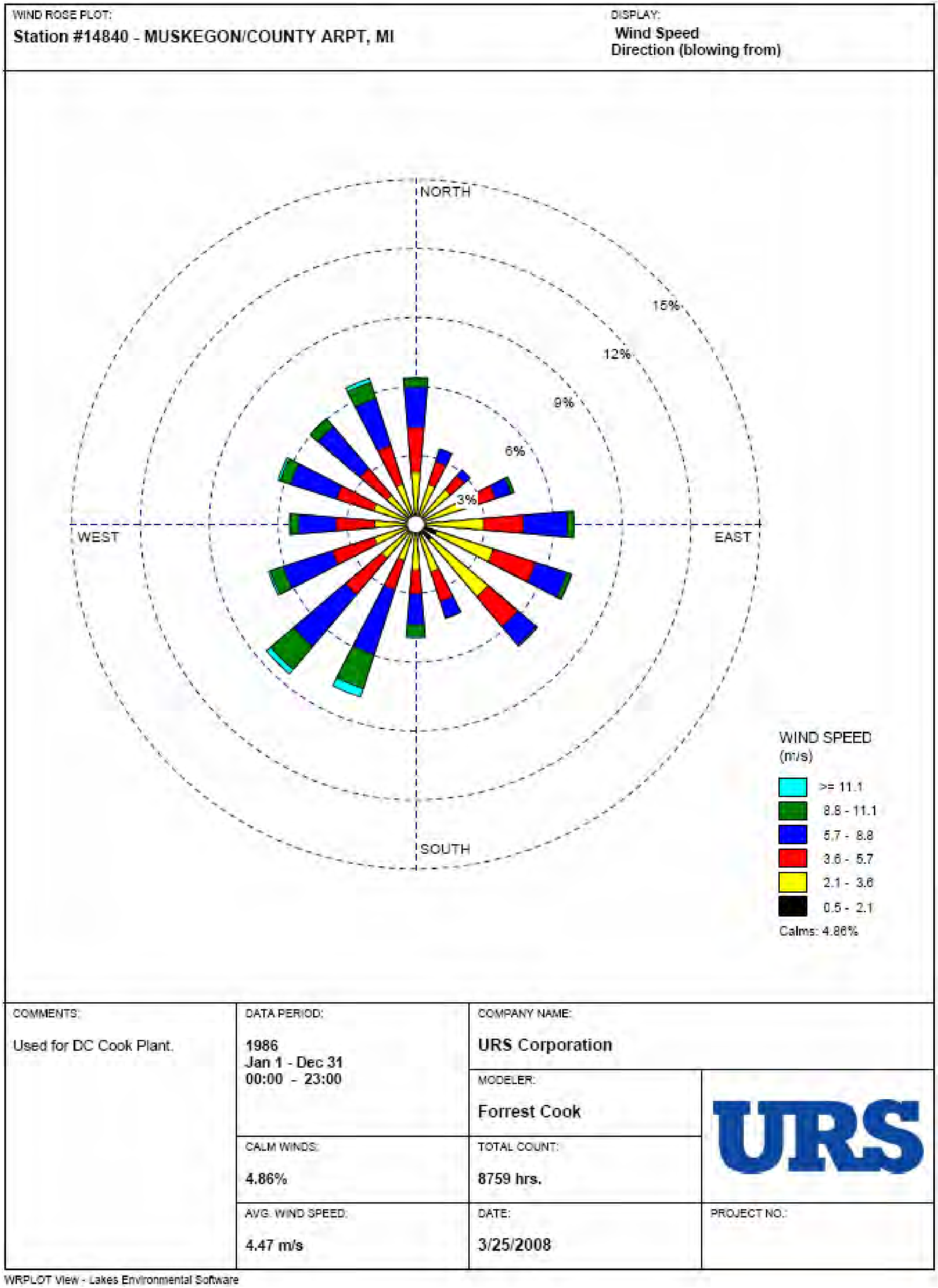
Table A-13
Annual impinged and entrained fish–BTPB (continued)

Common Name	Scientific Name	Annual Impingement (#'s of fish)	Annual Entrainment (#'s)		
			Eggs	Larvae	Juveniles
Burbot	*Lota lota*	475			
Ninespine Stickleback	*Pungitius pungitius pungitius*	329			
Brown Trout	*Salmo trutta*	230			
Chinook Salmon	*Oncorhynchus tshawytscha*	213			
White Perch	*Morone americana*	185			
Steelhead Trout	*Oncorhynchus mykiss*	120			
Lake Trout	*Salvelinus namaycush*	94			
Golden Redhorse	*Moxostoma erythrurum*	78			
Coho Salmon	*Oncorhynchus kisutch*	75			
Freshwater Drum	*Aplodinotus grunniens*	68			
Brown Bullhead	*Ameiurus nebulosus*	68			
Central Mudminnow	*Umbra limi*	52			
Deepwater Sculpin	*Triglopsis thompsonii*	45			
Rock Bass	*Ambloplites rupestris*	34			
Common Carp	*Cyprinus carpio carpio*	34	4,885,276	8,478,495	
Eastern Banded Killifish	*Fundulus diaphaneus diaphaneus*	34			
Unidentified		30	Distributed to identified species		

Table A-13
Annual impinged and entrained fish–BTPB (continued)

Common Name	Scientific Name	Annual Impingement (#'s of fish)	Annual Entrainment (#'s)		
			Eggs	Larvae	Juveniles
Mottled Sculpin	*Cottus bairdii*	25			
Pumpkinseed	*Lepomis gibbosus*	22			
Brook Silverside	*Labidesthes sicculus*	21			
Chestnut Lamprey	*Ichthyomyzon castaneus*	21			
Northern Pike	*Esox lucius*	20			
Flathead Catfish	*Pylodictis olivaris*	17			
Smallmouth Bass	*Micropterus dolomieui*	15			
Largemouth Bass	*Micropterus salmoides*	14			
Lake Sturgeon	*Acipenser fulvescens*	14			
Longnose Dace	*Rhinichthys cataractae*	13			
Shorthead Redhorse	*Moxostoma macrolepidotum*	11			
Lake Chub	*Couesius plumbeus*	7			
Greater Redhorse	*Moxostoma valenciennesi*	7			
Silver Redhorse	*Moxostoma anisurum*	7			
Bluntnose Minnow	*Pimephales notatus*	4			
Golden Shiner	*Notemigonus crysoleucas*	4			
Round Whitefish	*Prosopium cylindraceum*			140,722	
	Total	**1,386,025**	**16,860,000**	**83,820,000**	**5,040,000**

A.3.6 Air Quality



WIND ROSE PLOT:
Station #14840 - MUSKEGON/COUNTY ARPT, MI

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:
Used for DC Cook Plant.

DATA PERIOD:
1986
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:
URS Corporation

MODELER:
Forrest Cook

URS

CALM WINDS:
4.86%

TOTAL COUNT:
8759 hrs.

AVG. WIND SPEED:
4.47 m/s

DATE:
3/25/2008

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure A-15
Wind speed and direction for BTPB

A.3.7 Population Information

Figure A-16
Census blocks detailing local household numbers surrounding BTPB

A.3.8 Terrestrial Resources

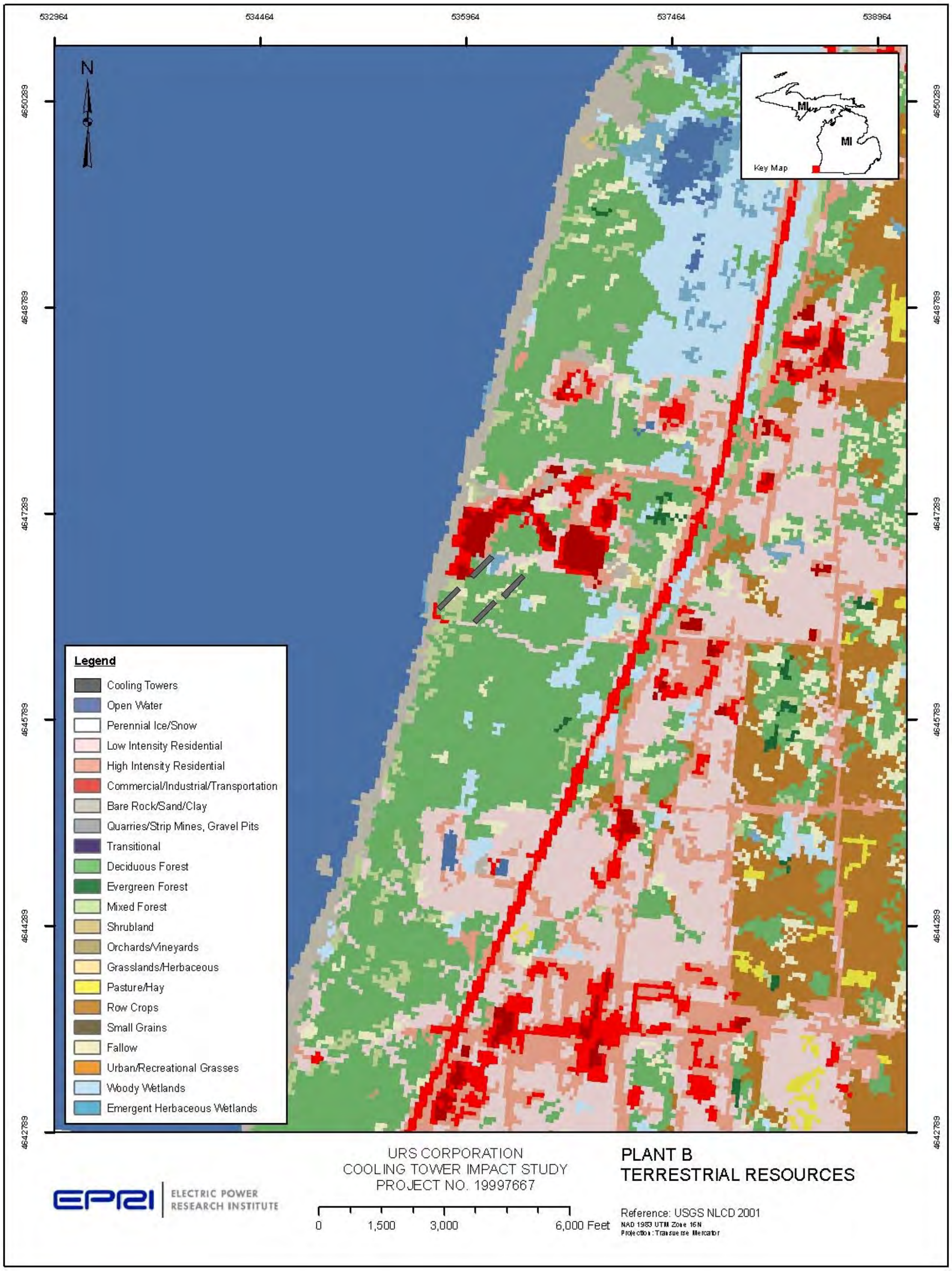


Figure A-17
Land cover classifications for areas surrounding BTPB

A.3.9 Parks, Landmarks and Other Resources

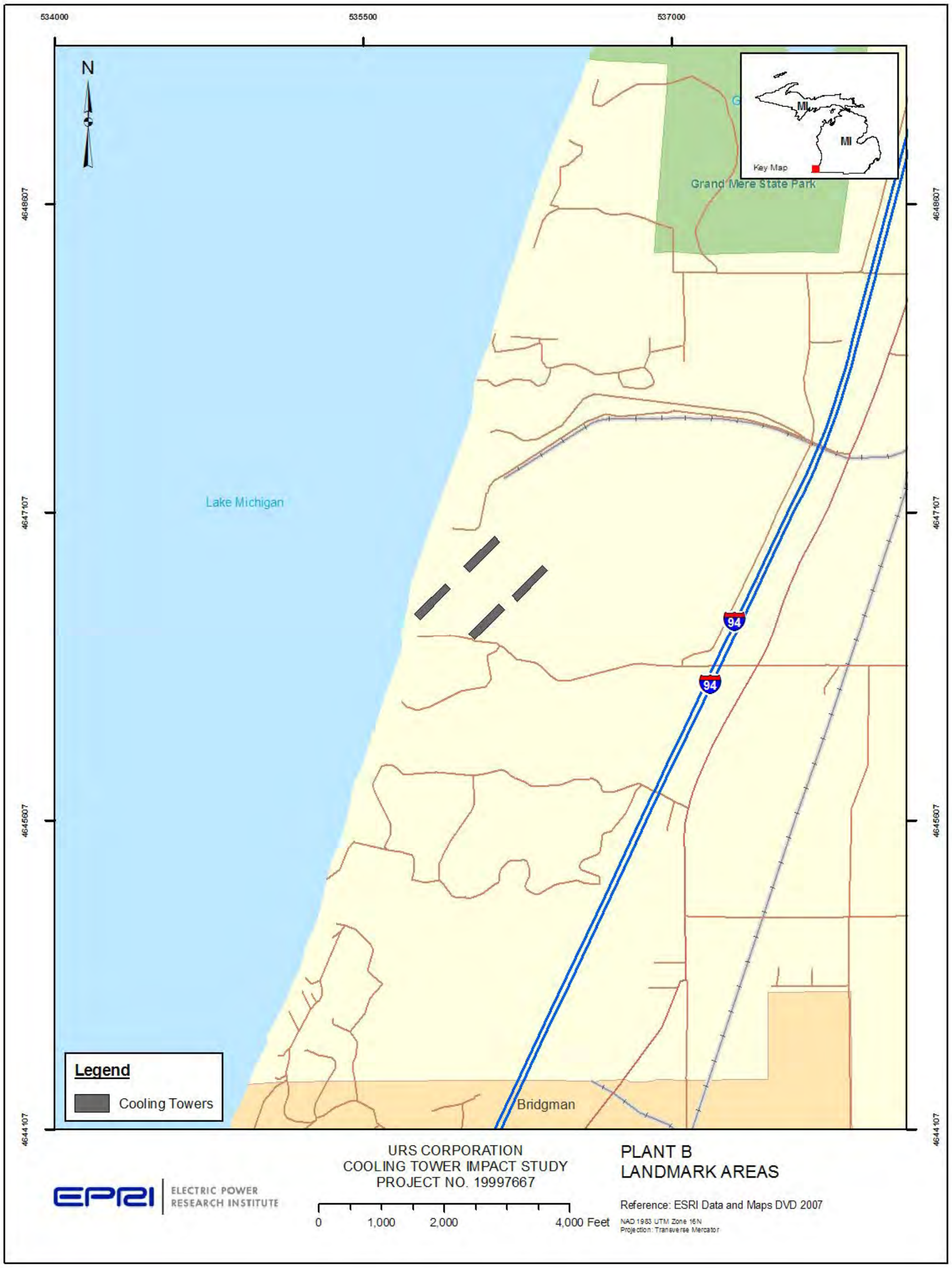


Figure A-18
Local parks and landmarks near BTPB

A.3.10 Summary of Potential Issues with Cooling Tower Implementation

Table A-14
Summary of impacts and issues at BTPB [3]

Resource	Issues
Engineering	Multiple cooling towers are required at BTPB. Need to arrange and orient them to minimize recirculation and interference.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions.
Terrestrial Resources	State threatened Caspian tern and seven state threatened plants found onsite in 2002. Over 21 acres of forested dunes, which provide potential habitat for Indiana bat (federal and state endangered) and bald eagle, would be lost. State threatened bald eagle, osprey, and common tern have been observed nearby.
Water Consumption	Consumptive water use is already a recognized problem on the Great Lake. New and increased consumptive uses of water from the Great Lakes Basin are regulated. The excess evaporation from cooling towers may trigger multi-jurisdictional review of all eight Great Lakes states and Canada.
Solid Waste	Submerged intake removes very little man-made solid waste.
Public Safety	Fogging impact to nuclear plant security and onsite power lines. Greater potential for ice formation on nearby roads.
Quality of Life	View shed of nearby housing development; restricted public access to beach. Shadowing and fogging of nearby neighborhood. Fogging and icing of nearby roads. Additional noise impacts.
Permitting	Construction within designated Critical Dune Area and adjacent to High Risk Erosion Area; potential impacts to protected species; Great Lakes consumptive water use; interference with public access; Nuclear Regulatory Commission (NRC) requirements.
Green House Gas	Prolonged shutdown for condenser re-optimization could result in additional burning of fossil fuels and greenhouse gas emissions.
Other	Potential impact to hydrology source to wetland system; salt deposition on nearby vineyards.

A.4 Beta Test Plant C (BTPC)

Retrofitting BTPC's once-through cooling system with a closed-cycle re-circulating cooling system is very difficult. There is insufficient space on the plant site to appropriately locate cooling towers for all its generating units.

The retrofit, if implementable, will reduce cooling water intake to the plant. As discussed below, given its current cooling water intake structure technologies, a corresponding decrease in IM&E reductions may also be expected from the closed-cycle cooling tower retrofit. However, this retrofit introduces several new environmental concerns like reductions in air quality, and potential reduction in quality of life in the vicinity of the facility due to alterations in view shed, increased noise, etc. These issues are also discussed below and in Section 4.

Two cooling towers are proposed for this facility: one for Units 1 and 2, and a second for Unit 3. The sizes, locations and impacts of these cooling towers are also discussed below.

A.4.1 Background

BTPC is located in the U.S. Northeast on an estuary. The three steam turbines associated with Units 1-3 with total generating capacity of 698 MW use once-through cooling. The two steam turbines associated with the six combustion turbines (nominal 2,200 MW) already use CCC, and are therefore not subject to the CCC retrofit. Units 1 and 2 are coal fired; Unit 3 uses fuel oil. An estuary provides cooling water for the once-through cooling systems utilized by all once-through generating units. The design intake cooling water flow rate for the facility is 581,318 gpm.

Table A-15
BTPC engineering information

Generating Unit	Rated Capacity (MW)	Cooling Water Flow Rate (gpm)	Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006 (%)
Unit 1	75	72,013	18	1954	58.8%
Unit 2	176.8	111,319	15.6	1966	64.8%
Unit 3	446	397,986	10	1973	14.4%
Total	**698**	**581,318**	**NA**	**NA**	**NA**

A location map of BTPC is provided as Figure A-19.

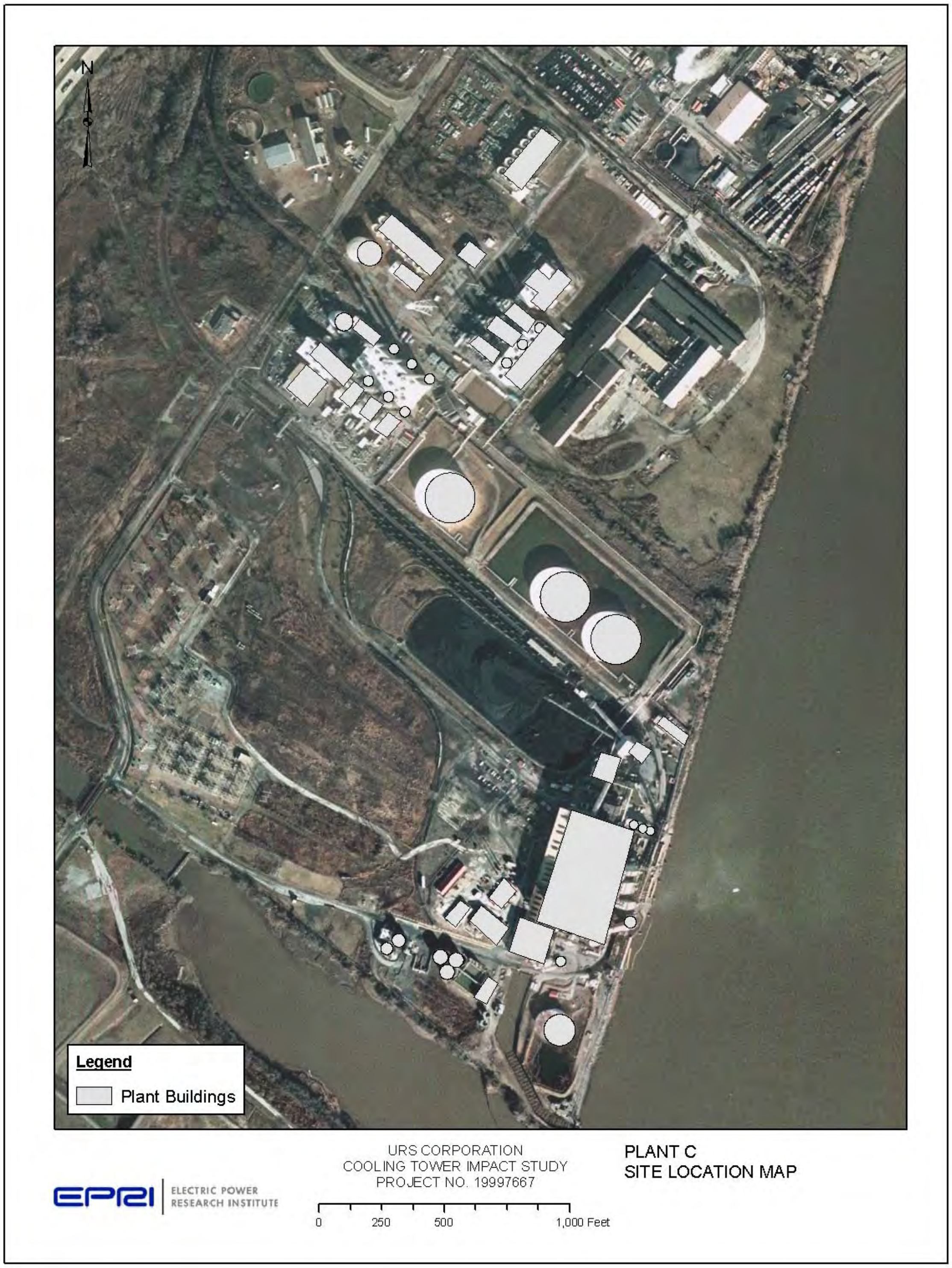


Figure A-19
BTPC site location map

A.4.2 Cooling Water Intake Structure

Two pump houses located on the estuary withdraw cooling water needed for the facility.

Two circulating pumps are associated with each generating unit. At the time the impingement and entrainment data were collected (2000–2001), all screens in both pumphouses were unmodified traveling screens. Pumphouse 2 had five 4 ft wide by 30 ft high dual-flow traveling water screens fitted with 3/16 in square mesh [14]. Pumphouse 3 had seven 5 ft wide conventional (through-flow) traveling screens fitted with 3/8 in square mesh; the eighth screen was a dual flow with dimensions equal to those screens found in Pumphouse 2 [14]. Screens were rotated and washed once every four hours to remove any impinged organisms and debris.

Since the IM&E studies were completed, the facility has incorporated operational changes and upgrades to its screens. Five years ago, the facility began continuous rotation of the screens. In 2004, the facility modified the fish returns (fiberglass returns which empty at mean low water) as a second interim measure. Recently, the facility replaced all eight traveling screens in Pumphouse 3 with new, modified 5 ft wide dual-flow traveling screens with 1/2 in x 1/8 in rectangular smooth mesh. The screens include fish buckets, high and low pressure spraywash, and separate fish and debris returns. A new fish return system is being installed and installation of similar screens in Pumphouse 2 is underway.

As described in Appendix A1 (BTCA1), the approach velocity of water to traveling screens often determines the level protection the CWIS affords swimmable aquatic organisms. The approach velocities at different locations along the intake bays in the Plant C CWIS are provided in Table A-16.

Table A-16
Through-screen and approach velocities at BTPC pump houses using current (pumphouse 3) and planned (pumphouse 2) screen dimensions

	Pump House 2 with 4 ft Dual Flow Screens (fps)	Pump House 3 with 5 ft Dual Flow Screens (fps)
Through-screen velocity	1.79	1.40
Approach velocity at face of screen	0.87	0.69
Approach velocity at curtain wall	0.81	0.61

A.4.3 Proposed Cooling Towers at BTPC

There is insufficient land on the BTPC property to locate cooling towers for the three generating units that currently use once-through cooling. Unit 3 would require a 20-cell back-to-back tower; Unit 1 and 2 would require 5- and 7-cell inline towers to remove the full heat load. Parameters associated with these full load CCC cooling towers are provided in Table A-17. The conceptual cooling tower locations shown in Figure A-20 are based on a previous study from over 15 years ago completed by a facility owner’s consultant and are helper cooling towers with significantly lower circulating flow rates.

Figure A-20
BTPC conceptual helper cooling tower location map

Note that the helper cooling towers depicted in figure A4-2 are smaller than the size stated in Table A-17. However, due to lack of space, the cooling towers currently proposed for BTPC's Units 1 and 2 have been combined and cooling tower arrangement modified to be a back-to-back. In addition, the cooling water flow has been reduced by one-third (with no change to the tower range). With this modified arrangement, the prior site of a fuel oil storage tank, which is between the discharge canal and the estuary, may have sufficient space for the cooling tower footprints, but not for the necessary spacing between the Unit 3 and Units 1 and 2 towers. There would be considerable recirculation and interference with such a densely situated cooling tower network. Increased recirculation and interference due to suboptimal cooling tower placement is often rectified by installing a few additional cooling tower cells; however, there is insufficient space to locate such additional cells at this site. The advantage of this location is that it provides relatively easy access to makeup water and direct access to the discharge canal for blowdown.

BTPC would likely require re-optimizing its condensers to operate with a lower cooling water flow rate. The feasibility of reducing the cooling water flow rate by as much as one-third from condenser re-optimization was not evaluated.

The design wet-bulb temperature used for BTPC is 76°F [5]. The estuary in the vicinity of BTPC is tidal and therefore its TDS concentration fluctuates between 20–7,400 ppm [3]. The basic characteristics of the cooling towers for BTPC are given in the following table [6].

Table A-17
Basic characteristics of cooling towers proposed for BTPC

Unit Designation		Unit 1	Unit 2	Unit 3
Condenser Cooling water Flow	gpm	72,013	111,319	397,986
Cooling Tower Range/Condenser ΔT	°F	18	15.6	10
No. and Arrangement of Cooling Tower Cells		5 Inline	7 Inline	20 Back-to-back
Cell Size (L x W x H)	ft	48 x 54 x 44	48 x 54 x 44	54 x 48 x 55
Cooling Tower Basin Size (L x W x H)	ft	248 x 62 x 6	344 x 62 x 6	548 x 104 x 6
Lift Pump Total	hp	510	779	3,823
Fan Total	hp	1000	1,400	4,000
Fan Diameter	ft	32.8	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36	36
Air Flow Rate per Cell	acfm	1,250,590	1,242,685	1,196,520
Drift Elimination Efficiency	%	0.0005%	0.0005%	0.0005%
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	129,676,235	122,643,529	99,558,529
Cycles of Concentration		5	5	5
Drift Rate per Unit	gpm	0.36	0.56	1.99
Cooling Tower Evaporation Rate	gpm	1,296	1,737	3,980
Blowdown Rate	gpm	324	434	995
Makeup Rate	gpm	1,620	2,171	4,977

The main engineering challenges associated with locating cooling towers at BTPC are:

- Lack of available land on the BTPC site.
- The need to relocate components and underground utilities.

A.4.4 Alternative Cooling Towers and Locations Considered

BTPC property is already fully utilized. Alternate cooling tower locations considered include the open parcel between the facility and the switchyard and an offsite landfill. The open parcel between the switchyard and the facility is a part of BTPC property; however, transmission lines currently occupy the space. In addition to overhead lines there is also a relatively new underground cable complex running through this open area and large portions of the area are currently planned to be utilized by a new required air pollution control project. The use of the landfill would require new property acquisition-assumed not required in Section 3.

In order to optimize use of limited available space on BTPC property, circular towers were also considered (and abandoned). If Unit 3 alone were retrofitted with circular towers, Unit 3 would require two 12-cell cooling towers each 200 ft in diameter, 50 ft high cells and 200 hp fans. If cooling water for all three units were combined, then two 14-cell 250 ft diameter circular cooling towers with 53 ft high cells and 250 hp fans would be needed. There is still insufficient available space at the demolished fuel oil storage tank site for all the necessary closed-cycle cooling towers.

Local height ordinance may prevent natural draft towers at this site, and available space limit their use. There is insufficient space onsite for the typically larger dry towers. The use of hybrid towers, if mandated, would require further study, but space limitations would likely prevail.

A.4.5 Aquatic Biota

The results of the 2000–2001 impingement and entrainment study, revised per location regulatory agency comments, are used in this report [15]. Because the facility is currently in the process of upgrading its screens, the most appropriate values to use for this analysis are the expected losses using the modified screens as this will be the existing technology in the near future.

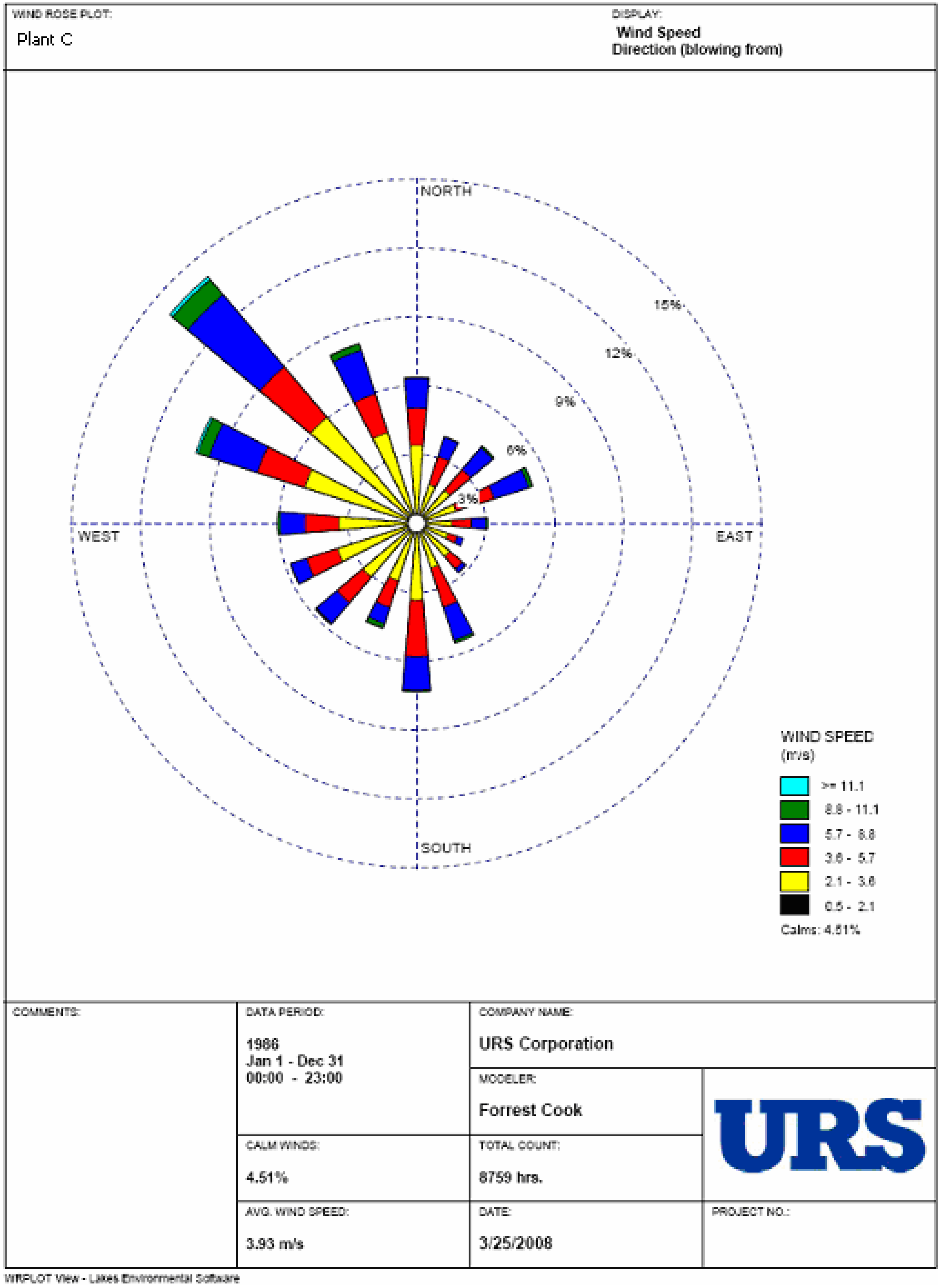
The expected losses presented in this report assume modified dual-flow screens with 1/2 in x 1/8 in mesh on both pumphouses. Organisms previously entrained with the larger mesh that will now be impinged on the smaller screens are included in the impingement numbers and impingement survival rates for juveniles and adults are applied. Survival of impinged and entrained larvae and eggs is assumed to be zero.

Survival rates for the identified Representative Species (RS) at the facility were estimated based upon available survival data for similar species on modified screens. The fish values were based on studies of modified dual-flow screens at three facilities: Roseton Station, Arthur Kill Generating Station, and Dunkirk Steam Station. No dual-flow studies were found for blue crab, and therefore average values from the modified through-flow screens at the Salem Nuclear Plant were applied. For the fish species, data for any species within the same taxonomic family were used. The values calculated for taxonomic families were averaged across the three sites. The final survival values used in the estimation of losses at BTPC on modified dual flow screens are:

- River herring–45%
- Bay anchovy–22%
- Striped bass, white perch–76%
- Atlantic croaker, weakfish–95%
- Blue crab–95%

These survival rates are generally consistent with the known “hardiness” of these species.

A.4.6 Air Quality



WIND ROSE PLOT:
Plant C

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:

DATA PERIOD:
1986
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:
URS Corporation

MODELER:
Forrest Cook

CALM WINDS:
4.51%

TOTAL COUNT:
8759 hrs.

AVG. WIND SPEED:
3.93 m/s

DATE:
3/25/2008

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure A-21
Wind speed and direction for BTPC

A.4.7 Population Information

Figure A-22
Census blocks detailing local household numbers surrounding BTPC

A.4.8 Terrestrial Resources

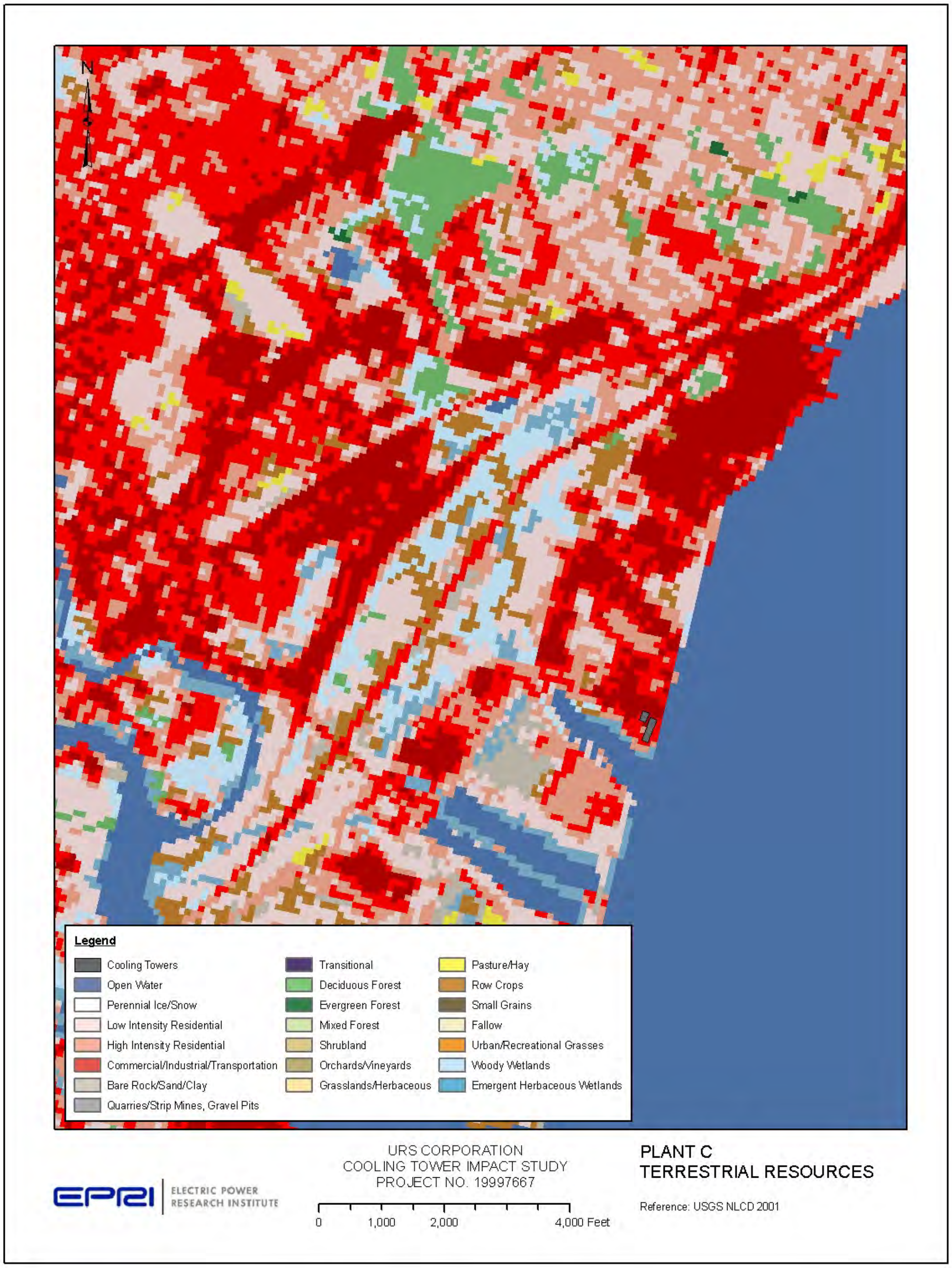


Figure A-23
Land cover classifications for areas surrounding BTPC

A.4.9 Parks, Landmarks and Other Resources

Figure A-24
Local parks and landmarks near BTPC

A.4.10 Summary of Potential Issues with Cooling Tower Implementation

Table A-18
Summary of impacts and issues at BTPC [3]

Resource	Issues
Engineering	There is insufficient land available on the BTPC site to install cooling towers for all its currently once-through units. Several underground utilities are located onsite.
Aquatic Biota	Net reduction in IM&E. The estuary in the vicinity of BTPC is considered 'impaired.' Discharging concentrated blowdown may worsen water quality in the vicinity of the facility.
Human Health	Increased particulate matter emissions. Local air quality is already classified as 'non-attaining,' therefore additional air permitting requirements may apply to BTPC.
Terrestrial Resources	A state park is located less than two miles from BTPC.
Water Consumption	Consumptive water use is regulated by a regional regulatory agency. New and increased consumptive use may affect position of salt line during droughts.
Solid Waste	Minor amounts of man-made solid waste.
Public Safety	Fogging and icing during winter may affect visibility in nearby highways and railways.
Quality of Life	BTPC is located in a heavily industrialized area, but near residential areas; impacts to local residents may occur.
Local Permitting	Potential cooling towers at BTPC will require an exemption from local height ordinance; BTPC is located within an environmental planning zone. State environmental planning program has strict environmental impact offset requirements; consumptive water use.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of CO_2.
Other	

A.5 Beta Test Plant D (BTPD)

Retrofitting BTPD's once-through cooling system with a closed-cycle re-circulating cooling system is deemed feasible and of easy-to-average difficulty.

The retrofit will reduce cooling water intake to the plant. As discussed below, given its current cooling water intake structure technologies, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit introduces several new environmental concerns like reductions in air quality, and potential reduction in quality of life in the vicinity of the facility. These issues are also discussed below.

Four cooling towers are proposed for this facility-one for each unit. The sizes, locations and impacts of these cooling towers are also discussed below.

A.5.1 Background

BTPD is a 2,090 MW coal-fired steam electric generating facility located in the U.S. Southeast. BTPD is located on a large lake that is a reservoir on a southeastern river [16]. The facility consists of four generating units, all of which utilize once-through cooling water from the reservoir. The single CWIS is located at the end of a 1.3 mile long, 200 acre cove, and has a design intake cooling water withdrawal capacity of 1,016,000 gpm [16].

The lake is an impounded reservoir created by the construction of a dam on the southeastern river in 1963. The water level in the lake is controlled by the power company and maintained high enough (745 ft mean sea level [MSL]) to support BTPD operations, but low enough (760 ft MSL) to minimize potential for flooding. The lake has a surface area of approximately 32,510 acres and storage volume of approximately 1,093,600 acre-ft at full pond water surface elevation of 760 ft MSL. Its retention time is approximately 206 days [16].

A location map of BTPD is provided as Figure A-25. Key information received from the plant for each generating unit is provided in the following table.

Table A-19
BTPD engineering information

Generating Unit	Rated Capacity (MW)	Cooling Water Flow Rate (gpm)	Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006 (%)
Unit 1	385	190,000	18	1965	77%
Unit 2	385	190,000	18	1966	81%
Unit 3	660	318,000	17	1969	77%
Unit 4	660	318,000	17	1970	81%
Total	**2,090**	**1,016,000**	**NA**	**NA**	**NA**

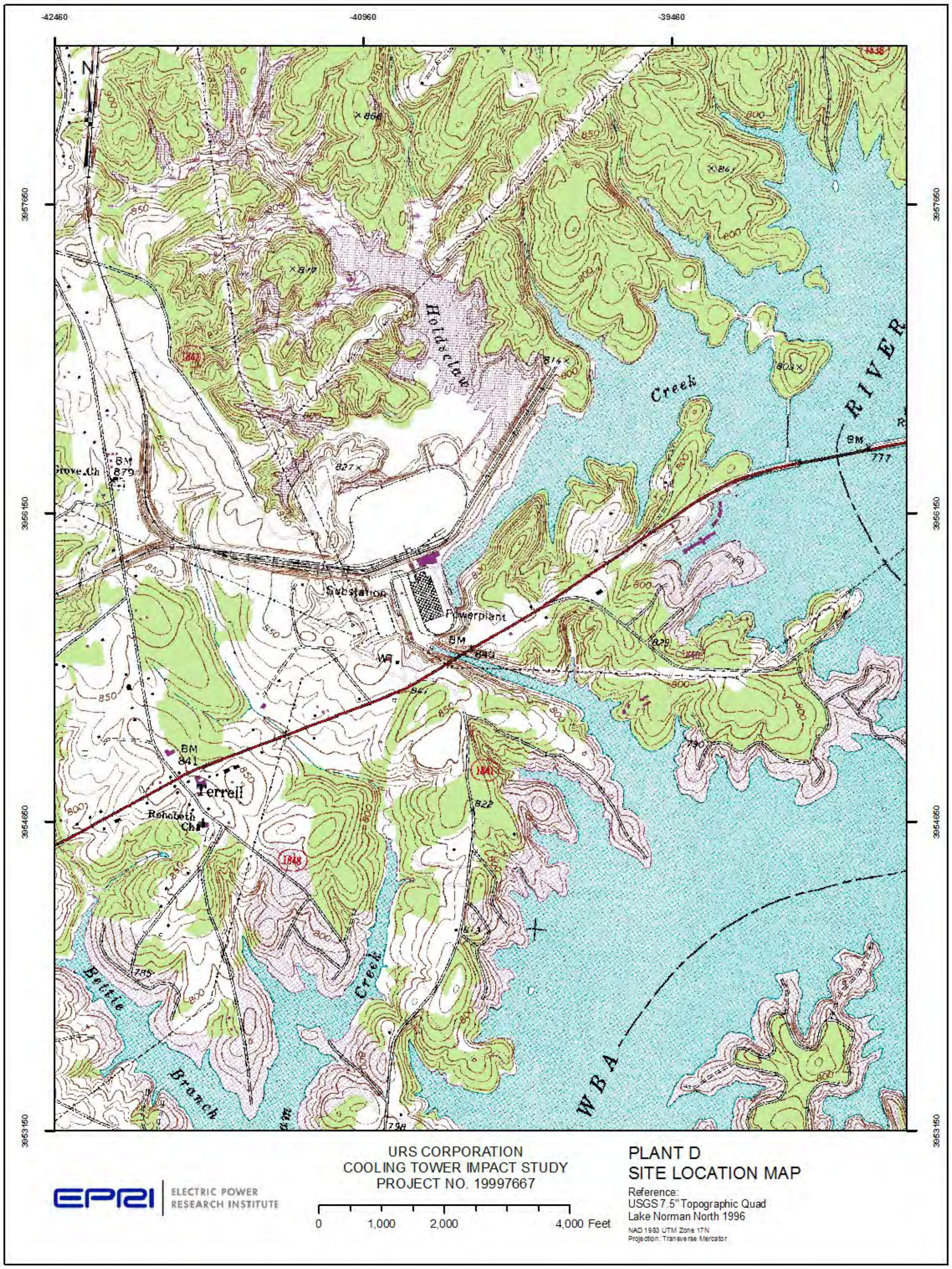


Figure A-25
BTPD site location map

A.5.2 Cooling Water Intake Structure

The BTPD CWIS is located on the western shore of the lake. A skimmer wall is located at the entrance of the intake canal to prevent floating debris from entering the cooling water system. Units 1 and 2 have three screen bays each; Units 3 and 4 have five screen bays each [16]. All screen bays are 11 ft and 2 in wide and are equipped with a trash rack and a fixed panel vertical screen. Trash racks are located at the face of the screenhouse to screen any debris from entering the intake bays. Fixed panel vertical screens located downstream of the trash racks are 10 ft and 8 in wide and 36 ft high with 3/8 in square stainless steel wire mesh.

Ten circulating water pumps provide cooling water to BTPD Units 1-4. BTPD utilizes fewer circulating water pumps during winter months [16]. The heated circulating water is routed back to the lake.

As described within the BTCA1 description, the approach velocity of water to traveling screens often determines the level of protection the CWIS affords swimmable aquatic organisms. At maximum lake drawdown (El. 745.0 ft MSL) and the plant withdrawing cooling water at the design rate, the approach velocity at the fixed panel vertical screens is approximately 0.7 fps [16]. At full pond level (El. 760.0 ft MSL) and with the plant withdrawing cooling water at the design rate, the approach velocity at the fixed panel vertical screens is approximately 0.4 fps [16].

A.5.3 Proposed Cooling Towers at BTPD

The preliminary design for BTPD includes four cooling towers (one per unit) located to the northeast of the facility near the flue gas desulfurization complex and wastewater treatment plant, and oriented in the predominant summer wind direction (southwest). One 12-cell back-to-back tower each is proposed for Units 1 and 2; one 20-cell back-to-back tower each is proposed for Units 3 and 4. Conceptual cooling tower locations are shown in Figure A-26.

This location was favored because (1) it allows for the circulating water to be routed from the cooling towers back to the intake and continue to utilize the existing circulating water pumps; (2) it is away from other underground utilities; and (3) it is relatively easy to access and has relatively low impact on other plant activities during construction.

Figure A-26
BTPD conceptual cooling tower location map

The design wet-bulb temperature used for BTPD is 76°F [5]; the lake TDS is approximated at 200 ppm. The basic characteristics of the towers for BTPD are given in Table A5-2 [6].

Table A-20
Basic characteristics of cooling towers proposed for BTPD

Unit Designation		Unit 1	Unit 2	Unit 3	Unit 4
Condenser Cooling Water Flow	gpm	190,000	190,000	318,000	318,000
Cooling Tower Range/Condenser ΔT	°F	18	18	17	17
No. and Arrangement of Cooling Tower Cells		12 Back-to-back	12 Back-to-back	20 Back-to-back	20 Back-to-back
Cell Size (L x W x H)	ft	48 x 48 x 55	48 x 48 x 55	54 x 48 x 55	54 x 48 x 55
Cooling Tower Basin Size (L x W x H)	ft	296 x 104 x 6	296 x 104 x 6	548 x 104 x 6	548 x 104 x 6
Lift Pump Total	hp	1,595	1,595	3,057	3,057
Fan Total	hp	2,400	2,400	4,000	4,000
Fan Diameter	ft	30.0	30.0	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	33	33	36	36
Air Flow Rate per Cell	acfm	1,153,479	1,153,479	1,271,523	1,271,523
Drift Elimination Efficiency	%	0.0005%	0.0005%	0.0005%	0.0005%
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	1.25E+08	1.25E+08	1.35E+08	1.35E+08
Cycles of Concentration		8	8	8	8
Drift Rate per Unit	gpm	0.8	0.8	1.6	1.6
Cooling Tower Evaporation Rate	gpm	2,989	2,989	5,410	5,410
Blowdown Rate	gpm	427	427	773	773
Makeup Rate	gpm	3,416	3,416	6,183	6,183

Onsite underground utilities are the main engineering challenge associated with constructing cooling towers at BTPD.

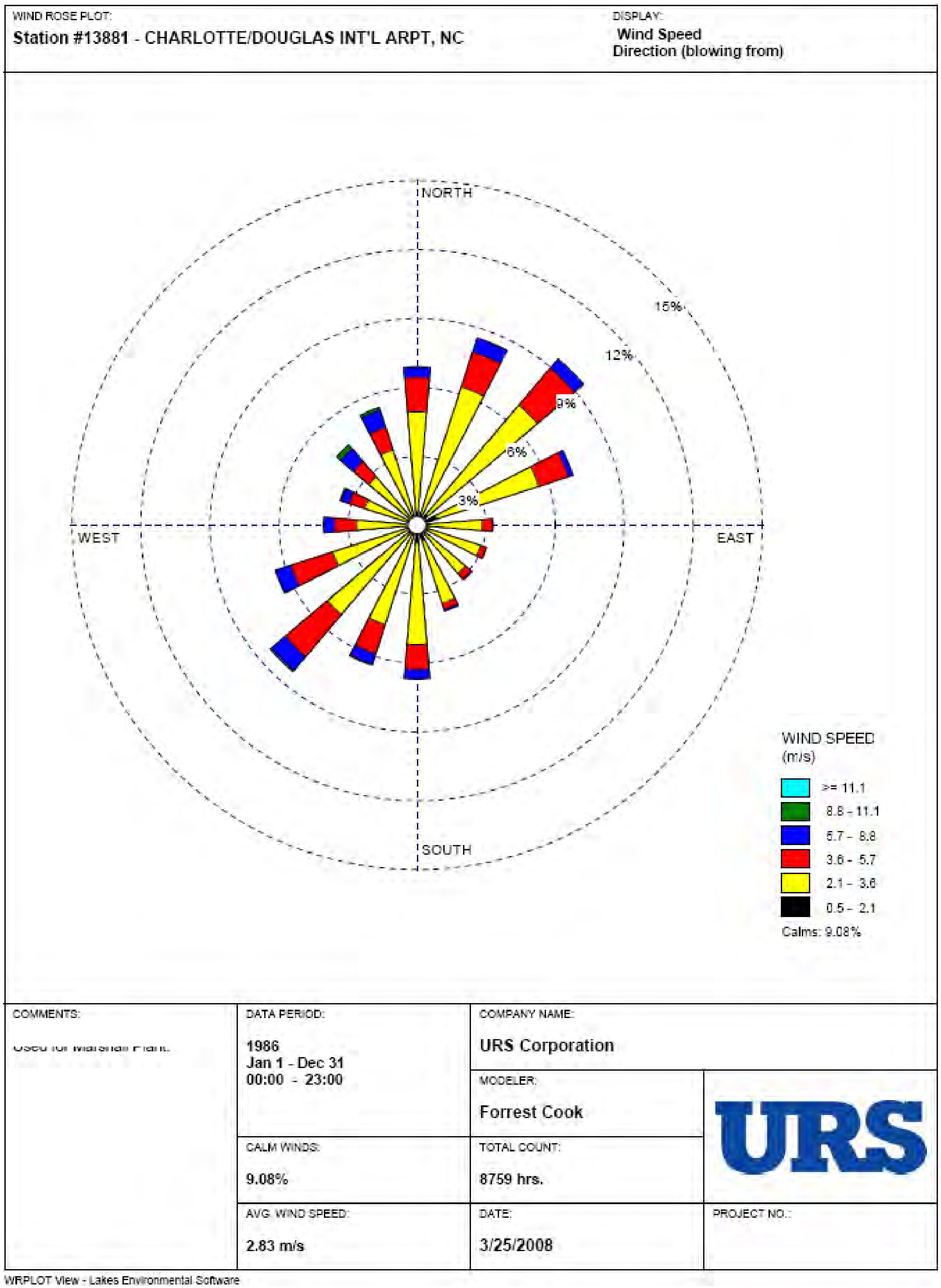
A.5.4 Alternative Cooling Towers and Locations Considered

Natural-draft, hybrid, or dry towers may be a viable alternative at this facility. However, unless their use is regulatory driven, the use of more economical and efficient MECTs would be specified. Since non-MECTs typically have larger footprints, an alternative cooling tower location also would be needed if a different type of cooling tower were considered for this facility.

A.5.5 Aquatic Biota

Data were provided by ASA Analysis & Communication, Inc.

A.5.6 Air Quality



WIND ROSE PLOT:

Station #13881 - CHARLOTTE/DOUGLAS INT'L ARPT, NC

DISPLAY:

Wind Speed
Direction (blowing from)

COMMENTS:

Used for Marshall Plant.

DATA PERIOD:

1986
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:

URS Corporation

MODELER:

Forrest Cook

CALM WINDS:

9.08%

TOTAL COUNT:

8759 hrs.

AVG. WIND SPEED:

2.83 m/s

DATE:

3/25/2008

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure A-27
Wind speed and direction for BTPD

A.5.7 Population Information

Figure A-28
Census blocks detailing local household numbers surrounding BTPD

A.5.8 Terrestrial Resources

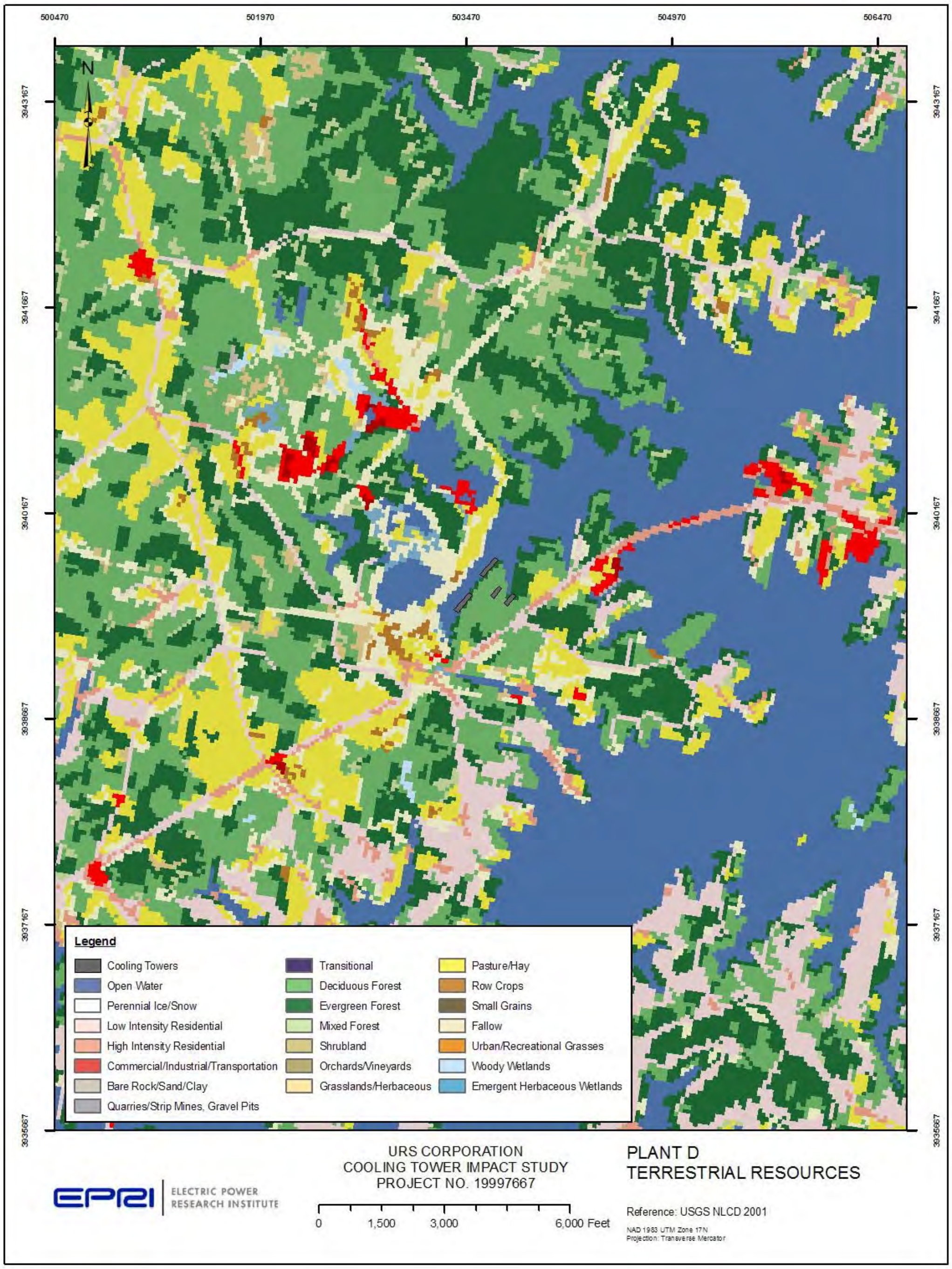


Figure A-29
Land cover classifications for areas surrounding BTPD

A.5.9 Parks, Landmarks and Other Resources

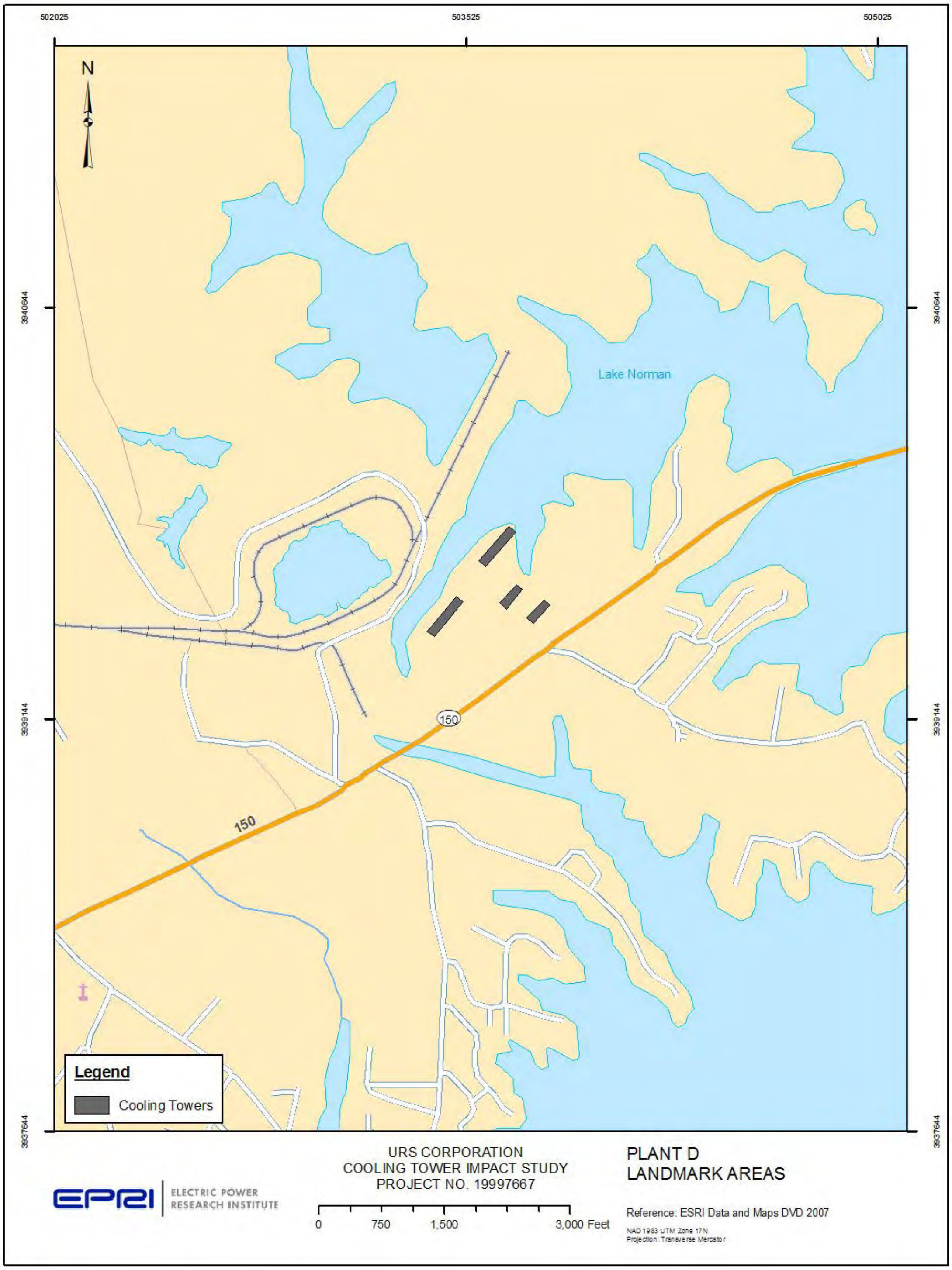


Figure A-30
Local parks and landmarks near BTPD

A.5.10 Summary of Potential Issues with Cooling Tower Implementation

Table A-21
Summary of impacts and issues at BTPD [3, 17]

Resource	Issues
Engineering	Onsite underground utilities may pose construction difficulties.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions. The current ‘non-attainment’ status of air quality around BTPD might pose an added challenge to permitting BTPD’s potential cooling towers.
Terrestrial Resources	A state park 2.5 miles from plant; lake slope/shoreline is a Significant Natural Heritage Area; great blue heron rookery at ash basin.
Water Consumption	Consumptive water use is already a recognized problem on the lake. New and increased consumptive water use could affect water supply, hydropower generation, water releases from downstream hydro dam, and frequency of drought declarations.
Solid Waste	Minor amounts of man-made solid waste.
Public Safety	The regional airport is located six miles from BTPD. Compromised visibility around the airport, on nearby highway (as close as 400 ft); and to recreational boaters on the lake may be a concern.
Quality of Life	BTPD’s proximity to facilities housing sensitive populations would challenge construction of cooling towers. BTPD is in a rural locale, but it is located within one-half mile of residences, six miles of a retirement facility, and four miles of the an elementary school. Noise, view shed, shadowing impacts.
Permitting	County height restrictions and impervious surface area limits; state river basin riparian buffer limits; consumptive water use.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of CO_2.
Other	

A.6 Beta Test Plant E (BTPE)

BTPE already has helper cooling towers, although not currently required to be used. Retrofitting BTPE’s once-through cooling system with a closed-cycle re-circulating cooling system is deemed feasible and of average difficulty.

The retrofit would reduce cooling water intake to the plant. As discussed below, given its current cooling water intake structure technologies, a corresponding decrease in impingement mortality (IM) may also be expected. However, this retrofit introduces several new environmental concerns like reductions in air quality, and potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are also discussed below.

Five cooling towers are proposed for this facility. The sizes, locations and impacts of these cooling towers are also discussed below.

A.6.1 Background

BTPE is a base-load 2,209 MW nuclear facility with two boiling water reactors. The facility is located in the U.S. Northeast, on the west shore of a reservoir.

The BTPE property is approximately 620 acres. The area around the site is predominantly rural, characterized by farmland and woods [18]. The area immediately behind the site is a rock cliff that rises to an elevation of approximately 300 ft MSL [19].

BTPE is designed to withdraw 1,500,000 gpm of once-through cooling water from the reservoir. Unit 2 began commercial operation in June 1974 and Unit 3 in December 1974. Unit 1 is currently licensed as Safe Storage (SAFSTOR). Several helper cooling towers were constructed onsite to help lower the discharge temperature of the cooling water. However, as a result of a four-year fishery study of the reservoir the operation of helper cooling towers ceased in 2001.

A location map of BTPE is provided as Figure A-31. Key information for each generating unit is provided in the Table A-22.

Table A-22
BTPE engineering information

Generating Unit	Rated Capacity (MW)	Cooling Water Flow Rate (gpm)	Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006 (%)
Unit 2	1,116	750,000	20.8	1974	94.7%
Unit 3	1,093	750,000	20.8	1974	98.5%
Total	**2,209**	**1,500,000**	**NA**	**NA**	**NA**

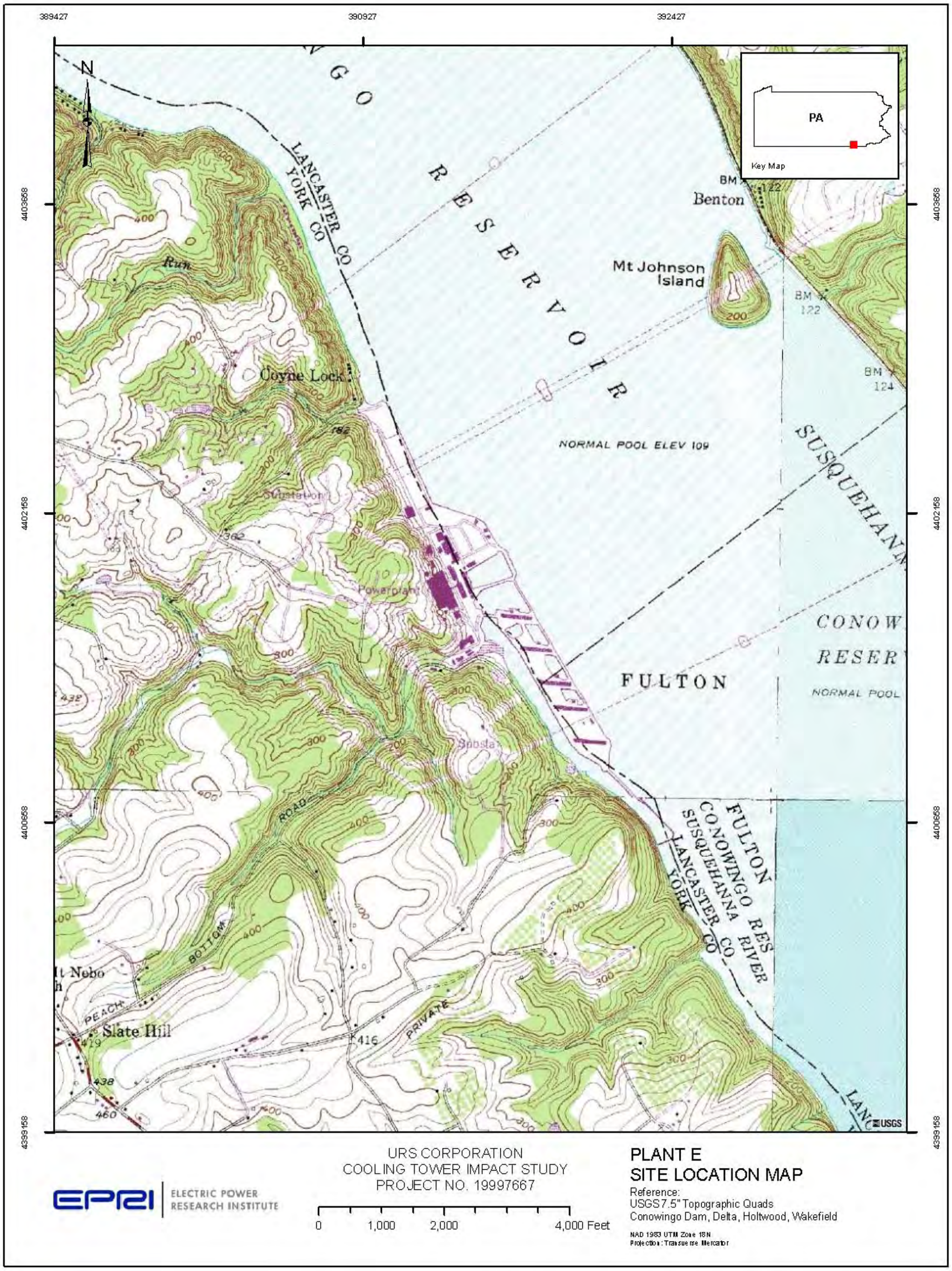


Figure A-31
BTPE site location map

A.6.2 Cooling Water Intake Structure

BTPE's cooling water is withdrawn through the screens of the outer intake structure, two 3 acre intake ponds (one for each unit), and then through an inner intake structure/pumphouse. The BTPE CWIS provides a continuous supply of water from the reservoir to Units 2 and 3 and includes the following major components [18]:

- An outer screenhouse structure consisting of 29 active trash racks and 24 through-flow traveling water screens
- Two intake basins
- An inner screenhouse structure consisting of six dual-flow cooling water traveling screens and four through-flow service water traveling water screens
- Six circulating water pumps, six service water pumps, eight high pressure service water pumps, and two emergency service water pumps

The outer screenhouse structure is approximately 480 ft long and 32 ft high, and is enclosed. The trash racks keep large debris out. Divers manually clean the trash racks as needed. The traveling water screens prevent smaller aquatic organisms from entering the cooling water system. Screen baskets are 10 ft wide and have 3/8 in square mesh openings. Debris and fish are removed from the screens by a high-pressure spray-wash system on the ascending side of the screens to sluiceways (one per unit). The debris from the screens is collected in dumpsters and disposed of off-site [18].

Water flows from the outer screen house structure into two intake basins (one per unit) before reaching the inner screen house structure. The inner screenhouse structure consists of eight bays (four per unit). Six of these bays, each with its own traveling screen, direct the water to six circulating water pumps (three per unit). These screens are dual-flow traveling screens with 1/4 in by 1/2 in mesh openings. The remaining two bays (one bay per unit) have four through flow traveling water screens (two per bay). The water pumped from these two bays provides service water to the units. During normal operation, approximately 96 percent of the design intake flow is used for condenser cooling with the remainder used for plant services [19].

The approach and through-screen velocities of water in intake bays often determine the level of protection the CWIS affords swimmable aquatic organisms. The maximum through screen flow at the design intake flow and pond elevation of 104 ft MSL for the BTPE Outer CWIS is 1.2-fps. Since the inner screenhouse has fewer traveling water screens, the through screen velocity through them is approximately 2.4 times the outer through screen velocity. The approach velocity at the outer screens is approximately 0.39-fps.

Non-contact cooling water is pumped from the CWIS through the main condensers, where it becomes heated, and then discharges into a discharge pond and canal that flows back to the reservoir downstream of the intake. Helper cooling towers are now bypassed. The discharge canal is oriented parallel to the shoreline [19].

A.6.3 Proposed Cooling Towers at BTPE

The closed-cycle cooling towers are proposed to be on the same sites as the existing helper towers, but with larger basin footprints. Conceptual cooling tower locations are shown in Figure A-32. Two 22-cell back-to-back towers, and one-half of a 20-cell back-to-back tower are anticipated for each generating unit.

If BTPE were retrofitted with closed-cycle cooling towers, several of the intake bays may be decommissioned. Water from cooling towers may be routed back to the intake basins; and the inner intake structure may continue to be used. The heated cooling water can continue to be routed to the discharge canal, which may be used to feed the cooling towers.

Figure A-32
BTPE conceptual cooling tower location map

The design wet-bulb temperature used is 74°F [5]; reservoir TDS from BTPE's discharge monitoring reports is 126 ppm. The basic characteristics of the towers for BTPE are given in the following table [6].

Table A-23
Basic characteristics of cooling towers proposed for BTPE

Unit Designation		Unit 2	Unit 3
Condenser Cooling Water Flow	gpm	750,000	750,000
Cooling Tower Range/Condenser ΔT	°F	20.8	20.8
No. and Arrangement of Cooling Tower Cells		Two 22-cell towers and one-half of a 20-cell tower; back-to-back	Two 22-cell towers and one-half of a 20-cell tower; back-to-back
Cell Size (L x W x H)	ft	54 x 48 x 55	54 x 48 x 55
Cooling Tower Basin Size (L x W x H)	ft	Two towers, each 602 x 104 x 6 dedicated to Unit 2. One tower sized at 548 x 104 x 6 to be shared with Unit 3.	Two towers, each 602 x 104 x 6 dedicated to Unit 2. One tower sized at 548 x 104 x 6 to be shared with Unit 2.
Lift Pump Total	hp	7,204	7,204
Fan Total	hp	10,800	10,800
Fan Diameter	ft	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36
Air Flow Rate per Cell	acfm	1,296,838	1,296,838
Drift Elimination Efficiency	%	0.0005%	0.0005%
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	1.45E+08	1.45E+08
Cycles of Concentration		8	8
Drift Rate per Unit	gpm	3.8	3.8
Cooling Tower Evaporation Rate	gpm	15,600	15,600
Blowdown Rate	gpm	2,229	2,229
Makeup Rate	gpm	17,829	17,829

A.6.4 Alternative Cooling Towers and Locations Considered

Since BTPE already has helper cooling towers, their current locations were an obvious choice for this facility. No other locations were evaluated. However, the site of the existing helper cooling towers seems suitable only for MECT. An alternate location would be required for natural draft or dry cooling towers, which is deemed to be not practicable. Hybrid towers may also be feasible at this site; however, unless their use is mandated by regulatory requirements, the use of more economical and efficient MECTs would be specified.

A.6.5 Aquatic Biota

Biological data for impingement are presented in Table A-24 [20]. The annualized impingement is based on actual cooling water usage and is provide in Table A-24.

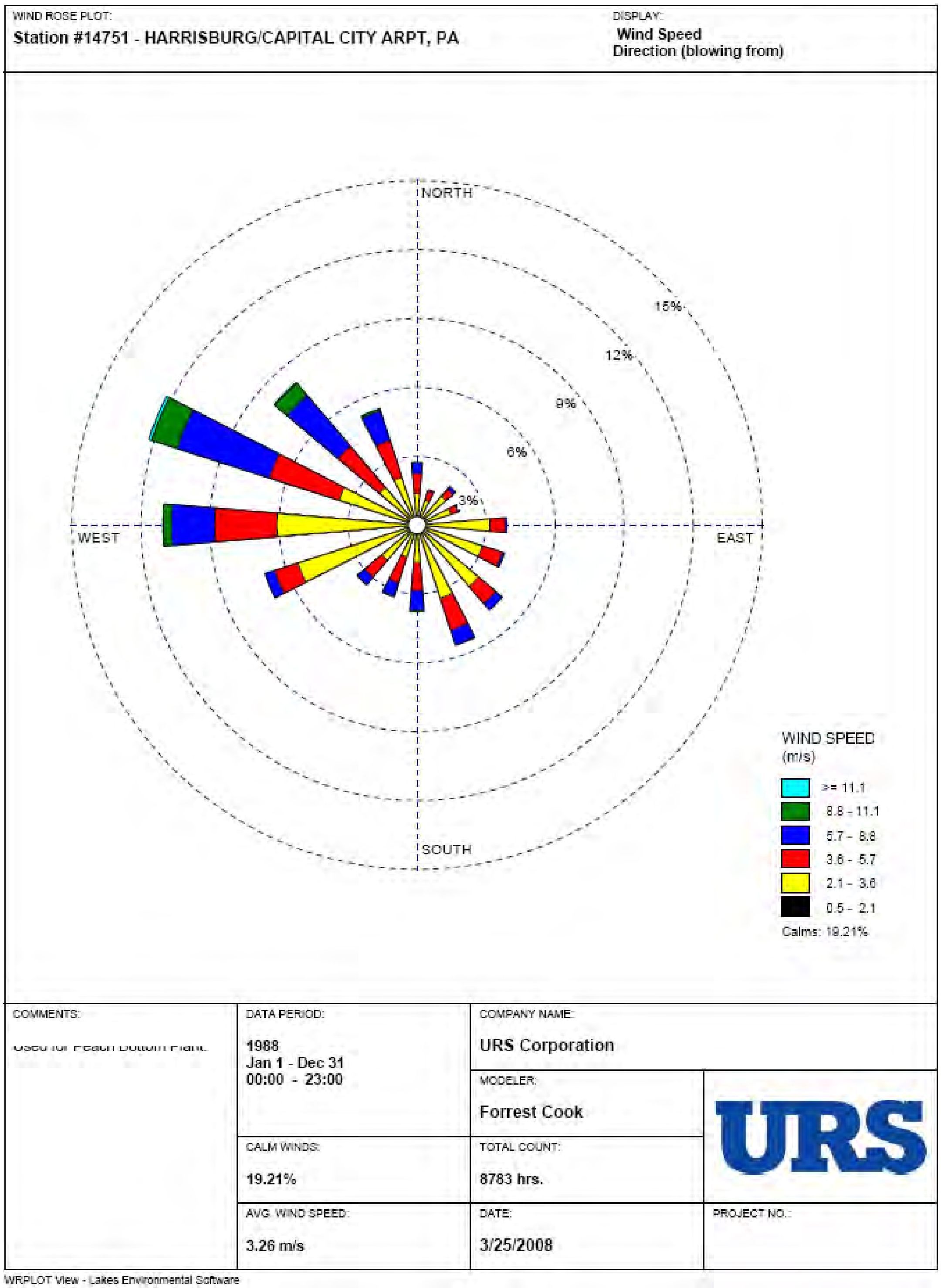
Table A-24
Annual impinged biota–BTPE

Common Name	Scientific Name	Annual Impingement (#'s of Fish)
Gizzard Shad	*Dorosoma cepedianum*	191,180
Channel Catfish	*Ictalurus punctatus*	14,096
Bluegill	*Lepomis macrochirus*	11,861
Walleye	*Stizostedion vitreum*	791
Yellow Perch	*Perca flavescens*	611
Comely Shiner	*Notropis amoenus*	335
Rock Bass	*Ambloplites rupestris*	311
American Shad	*Alosa sapidissima*	281
White Crappie	*Pomoxis annularis*	264
Green Sunfish	*Lepomis cyanellus*	245
Smallmouth Bass	*Micropterus dolomieu*	211
Tessellated Darter	*Etheostoma olmstedi*	178
Flathead Catfish	*Pylodictis olivaris*	163
Spotfin Shiner	*Cyprinella spiloptera*	138
Alewife	*Alosa pseudoharengus*	138
Carp	*Cyprinus carpio*	129
Largemouth Bass	*Micropterus salmoides*	95
Spottail Shiner	*Notropis hudsonius*	79
Northern Hogsucker	*Hypentelium nigricans*	76
Golden Shiner	*Notemigonus crysoleucas*	44
Quillback	*Carpiodes cyprinus*	44
Pumpkinseed	*Lepomis gibbosus*	30
White Perch	*Morone americana*	27
Striped Bass	*Morone saxatilis*	14
Redbreast Sunfish	*Lepomis auritus*	10
Shorthead Redhorse	*Moxostoma macrolepidotum*	10
Greenside Darter	*Etheostoma blennioides*	9
Logperch	*Percina caprodes*	9
Mummichog	*Fundulus heteroclitus heteroclitus*	9
Common Shiner	*Luxilus cornutus*	4
Swallowtail Shiner	*Notropis procne*	4
Banded Darter	*Etheostoma zonale*	4
Central Stoneroller	*Campostoma anomalum*	4

Table A-24
Annual impinged biota–BTPE (continued)

Common Name	*Scientific Name*	Annual Impingement (#'s of Fish)
White Sucker	*Catostomus commersoni*	4
Creek Chub	*Semotilus atromaculatus*	4
Black Crappie	*Pomoxis nigromaculatus*	3
White Catfish	*Ameiurus catus*	3
Yellow Bullhead	*Ameiurus natalis*	3
Shield Darter	*Percina peltata*	0
	Total	**221,421**

A.6.6 Air Quality



WIND ROSE PLOT:
Station #14751 - HARRISBURG/CAPITAL CITY ARPT, PA

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:
Used for Peach Bottom Plant.

DATA PERIOD:
1988
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:
URS Corporation

MODELER:
Forrest Cook

CALM WINDS:
19.21%

TOTAL COUNT:
8783 hrs.

AVG. WIND SPEED:
3.26 m/s

DATE:
3/25/2008

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure A-33
Wind speed and direction for BTPE

A.6.7 Population Information

Figure A-34
Census blocks detailing local household numbers surrounding BTPE

A.6.8 Terrestrial Resources

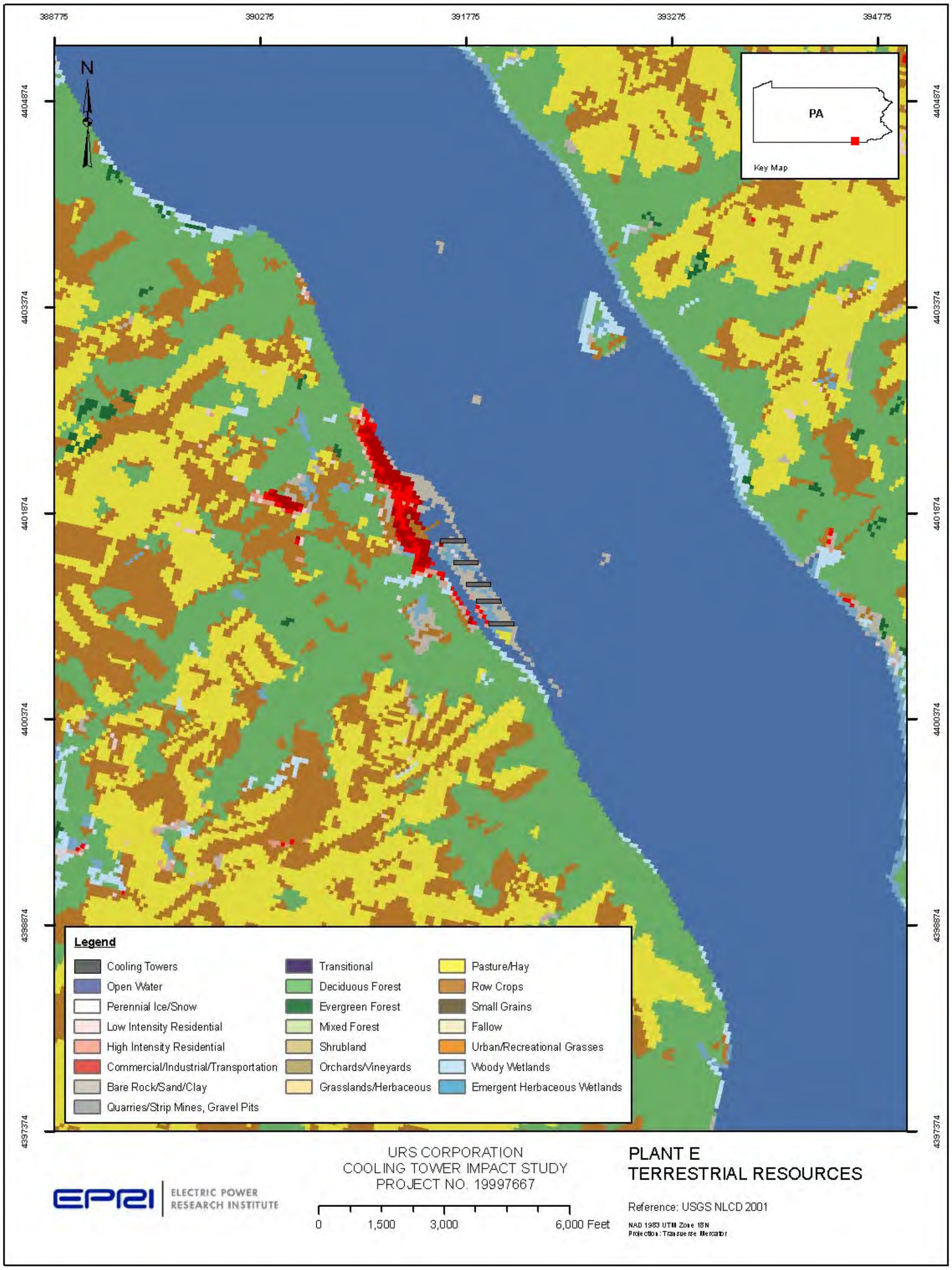


Figure A-35
Land cover classifications for areas surrounding BTPE

A.6.9 Parks, Landmarks and Other Resources

Figure A-36
Local parks and landmarks near BTPE

A.6.10 Summary of Potential Issues with Cooling Tower Implementation

Table A-25
Summary of impacts and issues at BTPE [3]

Resource	Issues
Engineering	Need to demolish existing helper cooling towers.
Aquatic Biota	Net reduction in IM.
Human Health	Increased particulate matter emissions.
Terrestrial Resources	
Water Consumption	Consumptive water use is already a recognized problem and is regulated by the river basin commission. New and increased consumptive water use could affect water supply, hydropower generation, water releases from downstream hydro dam, and frequency of drought declarations.
Solid Waste	Unknown amounts of man-made solid waste
Public Safety	Recreational boating traffic on the reservoir. Impact to nuclear facility security and line of sight control requirements
Quality of Life	Increased noise and fogging to the reservoir, a major regional recreation area, and to a park immediately adjacent to facility
Permitting	Already ‘non-attainment’ classification for air quality in the area; consumptive water use; NRC requirements.
Greenhouse Gas	Prolonged shutdown for condenser re-optimization could result in additional burning of fossil fuels and greenhouse gas emissions.
Other	

A.7 Beta Test Plant California 2 (BTCA2)

Retrofitting BTCA2’s once-through cooling system with a closed-cycle re-circulating cooling system is deemed potentially feasible, but difficult. The main challenges include lack of space onsite, proximity to major highways and a military base, and its regulatory setting.

Five cooling towers are proposed for this facility: two for Unit 2 and three for Unit 3. The sizes, locations and impacts of these cooling towers are also discussed below.

A.7.1 Background

BTCA2 is a base-load 2,150 MW nuclear facility with two pressurized reactors located in the City of San Clemente, in San Diego County, California. Southern California Edison (SCE) is BTCA2's operator. However, the ownership of these generating units is divided between SCE (75.05 percent), San Diego Gas and Electric (SDG&E, 20 percent), City of Anaheim (3.16 percent) and City of Riverside (1.79 percent) [21]. BTCA2 is located on the Pacific Ocean, adjacent to San Onofre State Beach, which includes a narrow beach area with steep dunes/cliffs along the facility boundary. The 84 acre BTCA2 site is almost entirely paved and developed, and located within the boundaries of the U.S. Marine Corps Base under an easement granted by the U.S. government [21]. Unit 2 and Unit 3 began commercial operation in 1983 and 1984, respectively. Unit 1 was retired from service in 1992. BTCA2's once-through cooling water is withdrawn via offshore velocity caps from the Pacific Ocean; the discharge is also routed offshore. The total design intake cooling water flow rate is 1,594,000 gpm.

A location map of BTCA2 is provided as Figure A-37. Key information for each generating unit per the NRC database is provided in the following table.

Table A-26
BTCA2 engineering information

Generating Unit	Rated Capacity (MW)	Cooling Water Flow Rate (gpm)	Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006 (%)
Unit 2	1,070	797,000	20	1982	90.1%
Unit 3	1,080	797,000	20	1983	86.1%
Total	**2,150**	**1,594,000**	**NA**	**NA**	**NA**

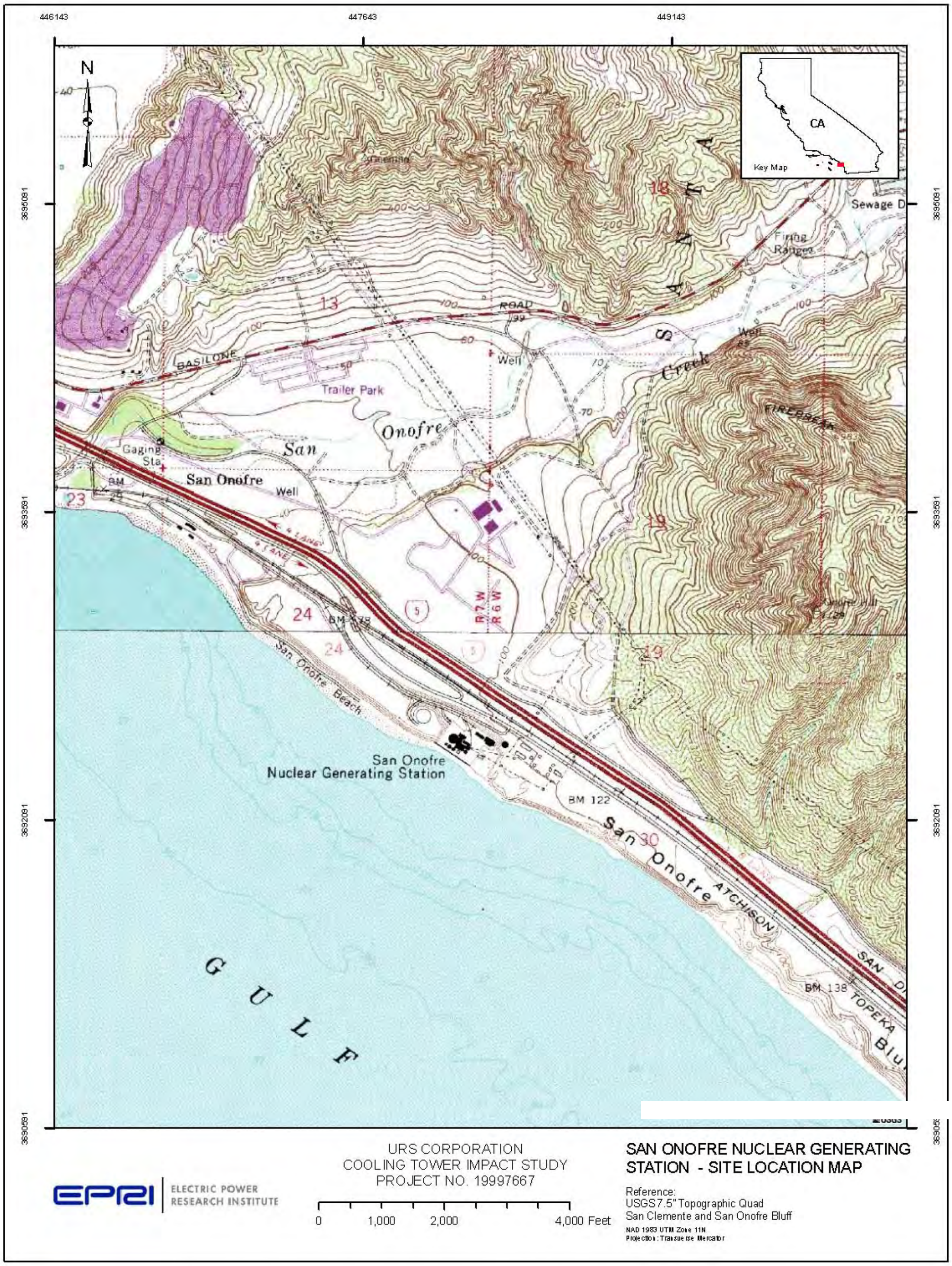


Figure A-37
BTCA2 site location map

A.7.2 Cooling Water Intake Structure

BTCA2's current cooling water intake system with offshore submerged velocity caps and onshore fish collection and return systems provides significant fish protection. Units 2 and 3 utilize two submerged intake structures located 3,183 ft offshore at a depth of 32 ft. Condenser cooling water for each unit flows through an 18 ft internal diameter submerged pipe to the CWIS located onshore within the facility [21]. Onshore, the cooling water passes through a series of vanes and louvers located in front of the traveling water screens. The louvers also function as bar racks designed to prevent large debris from entering the CWIS. The pressure differential across the louvers and vanes are expected to encourage fish to move to a quiet water area at the end of the intake structure where the fish return system is located. In addition to the louvers, a "fish chase" procedure using elevated temperatures is used to further encourage fish to move into the fish return system prior to heat treatments [21]. The cooling water for each of the two units, after passing through the bar racks, passes through six traveling screens located in parallel. The water is then pumped through any of the eight circulating water pumps (four per unit) to the condensers. The through-screen water velocity of the traveling screens is approximately 3.0 fps; therefore the approach velocity is expected to be approximately 1.5 fps. Given that the primary intake is located offshore, the approach and through screen velocities are less important at BTCA2. The heated discharge is also routed to a location over 3,000 ft offshore.

A.7.3 Proposed Cooling Towers at BTCA2

Five cooling towers are proposed for BTCA2 -two 32-cell back-to-back cooling towers for Unit 2 to be located to the northwest of reactor 2 on the main employee parking lot; and three 22-cell back-to-back cooling towers to the east of reactor 3 on the demolished sites of the wastewater treatment and low-level radiation waste facilities. The cooling towers are oriented as close as possible to the predominant summer wind from the northwest. Conceptual cooling tower locations are shown in Figure A-38.

Figure A-38
BTCA2 conceptual cooling tower location map

Constructing the Unit 3 cooling towers may be particularly difficult. The cooling tower sited closer to the bluffs may require additional foundation stabilization. In additional the wastewater treatment and low-level radiation facilities need to be relocated.

Routing the circulating water piping between the condensers and the Unit 2 cooling towers is also challenging. The decommissioned Unit 1 reactor is located between the Unit 2 reactor and the main employee parking lot. Ground in the vicinity of the Unit 1 reactor cannot be disturbed; therefore all piping, at least in the vicinity of Reactor 1, would have to be placed above ground or be routed around the Reactor 1 area.

The design wet-bulb temperature used is 68.5°F [5]; Pacific Ocean water TDS is approximately 33,500 ppm. The basic characteristics of the towers for BTCA2 are given in Table A-27 [6].

Table A-27
Basic characteristics of cooling towers proposed for BTCA2

Unit Designation		Unit 2	Unit 3
Condenser Cooling Water Flow	gpm	797,000	797,000
Cooling Tower Range/Condenser ΔT	°F	20	20
No. and Arrangement of Cooling Tower Cells		Two 32-cell towers; back-to-back	Three 22-cell towers; back-to-back
Cell Size (L x W x H)	ft	54 x 54 x 59	54 x 54 x 59
Cooling Tower Basin Size (L x W x H)	ft	Two towers, each 872 x 116 x 6	Three towers, each 602 x 116 x 6
Lift Pump Total	hp	8,059	8,059
Fan Total	hp	12,800	13,200
Fan Diameter	ft	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36
Air Flow Rate per Cell	acfm	1,382,409	1,382,409
Drift Elimination Efficiency	%	0.0005%	0.0005%
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	1.25E+08	1.21E+08
Cycles of Concentration		1.5	1.5
Drift Rate per Unit	gpm	4.0	4.0
Cooling Tower Evaporation Rate	gpm	15,940	15,940
Blowdown Rate	gpm	31,880	31,880
Makeup Rate	gpm	47,820	47,820

A few of the engineering challenges associated with locating cooling towers at BTCA2 are listed below.

- There is insufficient suitable space onsite for large cooling towers. BTCA2 is located on property leased from the military base. The military base itself is located across highways and a railroad.

- Additional ground stabilization and seawalls may be required for construction near the cliff.
- The tower dimensions given above are for standard back-to-back wet cooling towers with no plume abatement. The cooling tower cells would have to be arranged inline if plume abatement were required due to BTCA2's proximity to the highway, railroad, military base, and recreational parks. However, there is insufficient space to locate inline towers with appropriate spacing between towers.

A.7.4 Alternative Cooling Towers and Locations Considered

Circular towers were also evaluated for this facility. Each generating unit requires five 12-cell cooling towers, each approximately 220 ft in diameter. Each tower was expected to be approximately 53 ft tall. Each cell would require a 300 hp fan.

Available property on the military base across from U.S. Interstate 5, and the Pacific Ocean were also considered as potential sites for BTCA2's cooling towers. Available property on the military base cannot house all towers. The need to tunnel under U.S. Interstate 5, State highways and the railroad when installing the circulating water pipes were considered to be the primary impediments to siting the cooling towers on the military base. The need to stabilize for wave action and the added permitting burdens from constructing in the Pacific Ocean were the primary impediments for offshore cooling towers.

Given the security, regulatory, space and other myriad of constraints at this location, alternate types of cooling towers (hybrid tower would require further study) are deemed not viable for this site.

A.7.5 Aquatic Biota

The annual impingement and entrainment provided in Tables A-28 and A-29 are based on actual cooling water usage [22].

Table A-28
Annual impinged and entrained finfish – BTCA2

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Anchovies				
Anchovies	Engraulidae spp.		11,157,637,827	498,098,097
Anchovy	*Anchoa* spp.			184,053
Northern Anchovy	*Engraulis mordax*	396,074		913,349,918
Deepbody Anchovy	*Anchoa compressa*	23,504		
Slough Anchovy	*Anchoa delicatissima*	8,543		
Blennies				
Blenny eggs	Blenniidae spp.		2,398,747	
Combtooth Blennies	*Hypsoblennius* spp.			118,746,656
Kelp Blennies	Clinidae spp.			1,917,118
Tube Blennies	Chaenopsidae spp.			487,578
Labrisomid Blennies	Labrisomidae spp.			15,546,965
Rockpool Blenny	*Hypsoblennius gilberti*	2,747		
Mussel Blenny	*Hypsoblennius jenkinsi*	103		
Cabezon				
Cabezon	*Scorpaenichthys marmoratus*	382		146,596
Sea Basses				
Sand Bass	*Paralabrax* spp.		15,251,189	10,773,865
Kelp Bass	*Paralabrax clathratus*	177		159,512
Barred Sand Bass	*Paralabrax nebulifer*	177		
Spotted Sand Bass	*Paralabrax maculatofasciatus*	6		
Giant Sea Bass	*Stereolepis gigas*	1		

Table A-28
Annual impinged and entrained finfish– BTCA2 (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Deep-sea Smelts				
Blacksmelt eggs	Bathylagidae spp.		714,900	
Drums/Croakers				
Croakers	Sciaenidae spp.		346,845,518	29,170,126
Spotfin Croaker	*Roncador stearnsi*	130		12,134,563
Black Croaker	*Cheilotrema saturnum*	126		2,544,449
White Croaker	*Genyonemus lineatus*	9,557		94,021,894
Yellowfin Croaker	*Umbrina roncador*	9,258		175,012
White Seabass	*Atractoscion nobilis*	115	3,858,003	161,903
Queenfish	*Seriphus politus*	712,937		144,754,247
California Corbina	*Menticirrhus undulatus*	16		4,041,410
Flatfishes				
Flatfishes	Pleuronectiformes spp.			184,053
Righteye Flounder	Pleuronectidae spp.		9,081,872	176,303
Sand Flounder	Paralichthyidae spp.		558,289,256	833,081
Sanddab eggs	*Citharichthys* spp.		218,441,477	
Turbot eggs	*Pleuronichthys* spp.		201,444,895	
Bigmouth Sole eggs	*Hippoglossina stomata*		163,387	
Califormia Halibut	*Paralichthys californicus*	152		11,288,329
C-O Sole	*Pleuronichthys coenosus*	15		
Curlfin Turbot	*Pleuronichthys decurrens*	1		
Diamond turbot	*Pleuronichthys guttulatus*	42	1,942,563	2,965,969

Table A-28
Annual impinged and entrained finfish– BTCA2 (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
English Sole	*Parophrys vetulus*			395,229
Fantail Sole	*Xystreurys liolepis*	14		390,708
Hornyhead Turbot	*Pleuronichthys verticalis*	269		722,649
Pacific Sanddab	*Citharichthys sordidus*			375,855
Speckled Sanddab	*Citharichthys stigmaeus*	616		700,692
Spotted Turbot	*Pleuronichthys ritteri*	483		580,451
Gobies				
Gobies	Gobiidae spp.			117,115,619
Bay Goby	*Lepidogobius lepidus*	1		201,489
Blind Goby	*Typhlogobius californiensis*			70,552,251
Longjaw Mudsucker	*Gillichthys mirabilis*			1,461,263
Yellowfin Goby	*Acanthogobius flavimanus*			187,928
Herrings				
Pacific Sardine	*Sardinops sagax*	107,466	3,074,004	3,037,838
Jacks/Pompanos				
Jack eggs	Carangidae spp.		163,543	
Rockfish				
Rockfishes	*Sebastes* spp.	2		170,491
Brown Rockfish	*Sebastes auriculatus*	17		
Vermillion Rockfish	*Sebastes miniatus*	4		
Grass Rockfish	*Sebastes rastrelliger*	3		
Kelp Rockfish	*Sebastes atrovirens*	1		

Table A-28
Annual impinged and entrained finfish– BTCA2 (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Bocaccio	*Sebastes paucispinis*	98		
Treefish	*Sebastes serriceps*	2		
Sculpins				
Sculpin	Cottidae sp.	1		
Sculpin	*Oligocottus/Clinocottus* spp.			193,094
Roughcheek Sculpin	*Ruscarius creaseri*			920,909
Smoothhead Sculpin	*Artedius lateralis*			142,722
Pacific Staghorn Sculpin	*Leptocottus armatus*	99		
Coralline Sculpin	*Artedius corallinus*	15		
Snubnose Sculpin	*Orthonopias triacis*	15		
Silversides				
Silversides	Atherinopsidae spp.		1,181,768	9,548,265
California Grunion	*Leuresthes tenuis*	310	951,032	38,710,951
Jacksmelt	*Atherinopsis californiensis*	4,038	123,482,424	14,847,012
Topsmelt	*Atherinops affinis*	10,556	126,018	171,783
Other Species				
Cusk-Eels	Ophidiidae spp.	1		2,901,575
Basketweave Cusk-Eel	*Ophidion scrippsae*	137		
Yellow Snake Eel	*Ophichthus zophochir*	28		
Bat Ray	*Myliobatis californica*	289		
California Butterfly Ray	*Gymnura marmorata*	71		
Grey Smoothhound	*Mustelus californicus*	14		

Table A-28
Annual impinged and entrained finfish– BTCA2 (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Halfmoon	*Medialuna californiensis*	5		
Horn Shark	*Heterodontus francisci*	44		
Pacific Chub Mackerel	*Scomber japonicus*	1,747		
Pacific Electric Ray	*Torpedo californica*	184		
Pacific Pompano	*Peprilus simillimus*	5,067		
Painted Greenling	*Oxylebius pictus*			547,638
Round Stingray	*Urobatis halleri*	20		
Senorita	*Oxyjulis californica*	133		904,764
Swell Shark	*Cephaloscyllium* spp.	14		
Rock Wrasse	*Halichoeres semicinctus*	33		169,845
Wrasse eggs	Labridae spp.		38,899,703	
California Sheepshead	*Semicossyphus pulcher*	1		311,921
Jack Mackerel	*Trachurus symmetricus*	1,477		
Pacific Barracuda	*Sphyraena argentea*	1,874	20,562,886	7,618,490
Spiny Dogfish	*Squalus acanthias*	14		
Sargo	*Anisotremus davidsonii*	2,087		174,366
Blacksmith	*Chromis punctipinnis*	23		
California Headlight Fish	*Diaphus theta*			1,424,633
Spotted Kelpfish	*Gibbonsia elegans*	156		
Striped Kelpfish	*Gibbonsia metzi*	5		
Clinid Kelpfishes	*Gibbonsia* spp.			143,417,220
Clingfishes	Gobiesocidae spp.			3,401,424

Table A-28
Annual impinged and entrained finfish– BTCA2 (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Clingfishes	*Gobiesox* spp.			32,716,111
Grunts	Haemulidae spp.			2,297,108
Zebraperch	*Hermosilla azurea*	218		
Giant Kelpfish	*Heterostichus rostratus*	774		15,649,326
Garibaldi	*Hypsypops rubicundus*	1		199,552
Pacific Butterfish	*Peprilus simillimus*			1,548,284
Thornback	*Platyrhinoidis triseriata*	84		
Specklefin Midshipman	*Porichthys myriaster*	1,336		
Plainfin Midshipman	*Porichthys notatus*	2,683		
Stripefin Ronquil	*Rathbunella alleni*	1		
Shovelnose Guitarfish	*Rhinobatos productus*	18		
Slender Clingfish	*Rimicola eigenmanni*			150,471
Kelp Clingfishes	*Rimicola* spp.			7,716,652
Northern Lampfish	*Stenobrachius leucopsarus*			6,072,650
Pipefishes	*Sygnathus* spp.	375		860,137
California Tonguefish	*Symphurus atricaudus*	3		
Kelp Pipefish	*Syngnathus californiensis*	6,639		
Barcheek Pipefish	*Syngnathus exilis*	58		
Bay Pipefish	*Syngnathus leptorhynchus*	27		
California Lizardfish	*Synodus lucioceps*	1,652		
Mexican Lampfish	*Triphoturus mexicanus*			1,475,650
Salema	*Xenistius californiensis*	8,310		150,471

Table A-28
Annual impinged and entrained finfish– BTCA2 (continued)

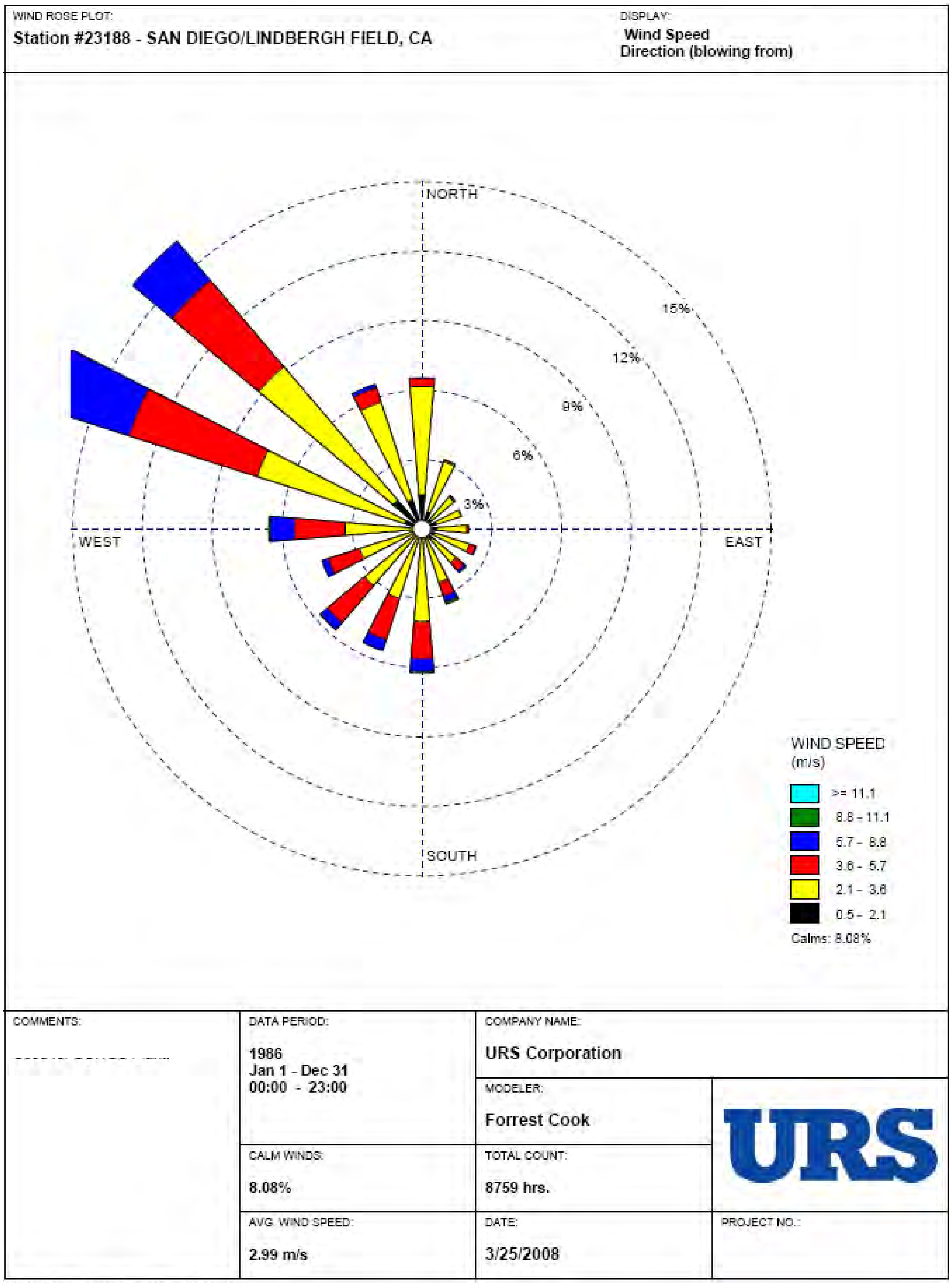
Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Surfperches				
White Seaperch	*Phanerodon furcatus*	18,724		
Walleye Surfperch	*Hyperprosopon argenteum*	675		
Spotfin Surfperch	*Hyperprosopon anale*	2		
Barred Surfperch	*Amphistichus argenteus*	1		
Shiner Perch	*Cymatogaster aggregata*	7,641		
Black Perch	*Embiotoca jacksoni*	1,149		
Rubberlip Seaperch	*Rhacochilus toxotes*	178		
Dwarf Perch	*Micrometrus minimus*	134		
Kelp Perch	*Brachyistius frenatus*	20		
Pile Perch	*Rhacochilus vacca*	2		
Scorpionfish				
California Scorpionfish	*Scorpaena guttata*	956		
Groups/Unidentified				
Unidentified Yolksac Larvae	Unidentified yolksac larvae			28,661,013
Unidentified Larvae	Unidentified larvae			14,037,177
Larval Fishes	larval/post-larval fish unid.			7,123,163
Perch-Like Fishes	Perciformes			4,866,096
Unidentified Larval Fishes	Unidentified larval fishes			3,191,971
Unidentified Fish Eggs	Unidentified fish eggs		10,360,708,897	
Fish Eggs	Sciaen./Paralichth./Labridae		3,931,077,351	
Wrasse/Grouper Eggs	Labridae/Serranidae		1,806,300	
Hake/Barracuda Eggs	Merlucciidae/Sphyraenidae		1,364,573	
	Total	**1,353,158**	**26,999,468,133**	**2,409,876,604**

Table A-29
Annual impinged and entrained shellfish– BTCA2

Common Name	Scientific Name	Impingement	Entrainment[a]
Crabs & Lobster			
Yellow Crab	*Cancer anthonyi*	22,781	7,740,546
Xantus Swimming Crab	*Portunus xantusii*	17,296	
Hairy Rock Crab	*Cancer jordani*	11,888	
Brown Rock Crab	*Cancer antennarius*	8,356	7,764,283
Cancer Crab, unid.	*Cancer* sp.	4,576	
California Spiny Lobster	*Panulirus interruptus*	2,151	19,763,570
Graceful Crab	*Cancer gracilis*	1,071	6,135,346
Red Rock Crab	*Cancer productus*	453	554,340
	Total	**68,572**	**41,958,085**
Shrimp			
Blackspotted Bay Shrimp	*Crangon nigromaculata*	15,259	
Yellowleg Shrimp	*Farfantepenaeus* sp.	2,467	
Bay Ghost Shrimp	*Neotrypaea californiensis*	515	
Giant Ghost Shrimp	*Neotrypaea gigas*	119	
Red Rock Shrimp	*Lysmata californica*	4,451	
Intertidal Coastal Shrimp	*Heptacarpus palpator*	3,020	
Coastal Shrimp, unid.	*Heptacarpus* sp.	504	
Twistclaw Pistol Shrimp	*Alpheus clamator*	34	
Mantis Shrimp	*Hemisquilla californiensis*	28	
Littoral Pistol Shrimp	*Synalpheus lockingtoni*	24	
Visored Shrimp	*Betaeus longidactylus*	22	
Longeye Shrimp unid. A	*Ogyrides* sp.	14	
Solenocerid Shrimp 1	*Solenocera mutator*	14	
Visored Shrimp, unid.	*Betaeus* sp.	1	
	Total	**26,472**	

[a] Only select species were enumerated in entrainment and were limited to megalops or phylosome stages.

A.7.6 Air Quality



WIND ROSE PLOT:
Station #23188 - SAN DIEGO/LINDBERGH FIELD, CA

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:

DATA PERIOD:
1986
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:
URS Corporation

MODELER:
Forrest Cook

CALM WINDS:
8.08%

TOTAL COUNT:
8759 hrs.

AVG. WIND SPEED:
2.99 m/s

DATE:
3/25/2008

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

Figure A-39
Wind speed and direction for BTCA2

A.7.7 Population Information

Figure A-40
Census blocks detailing local household numbers surrounding BTCA2

A.7.8 Terrestrial Resources

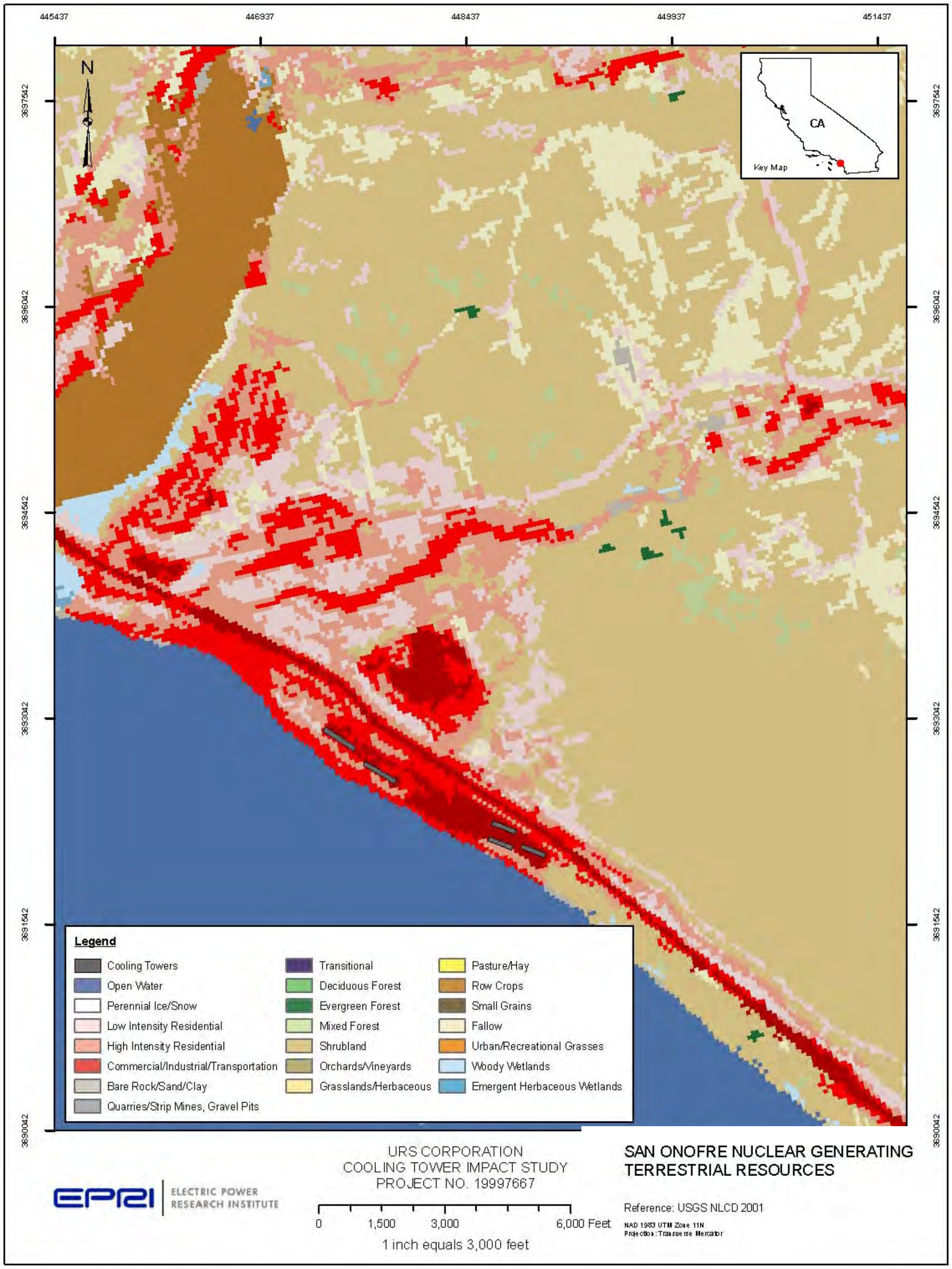


Figure A-41
Land cover classifications for areas surrounding BTCA2

A.7.9 Parks, Landmarks and Other Resources

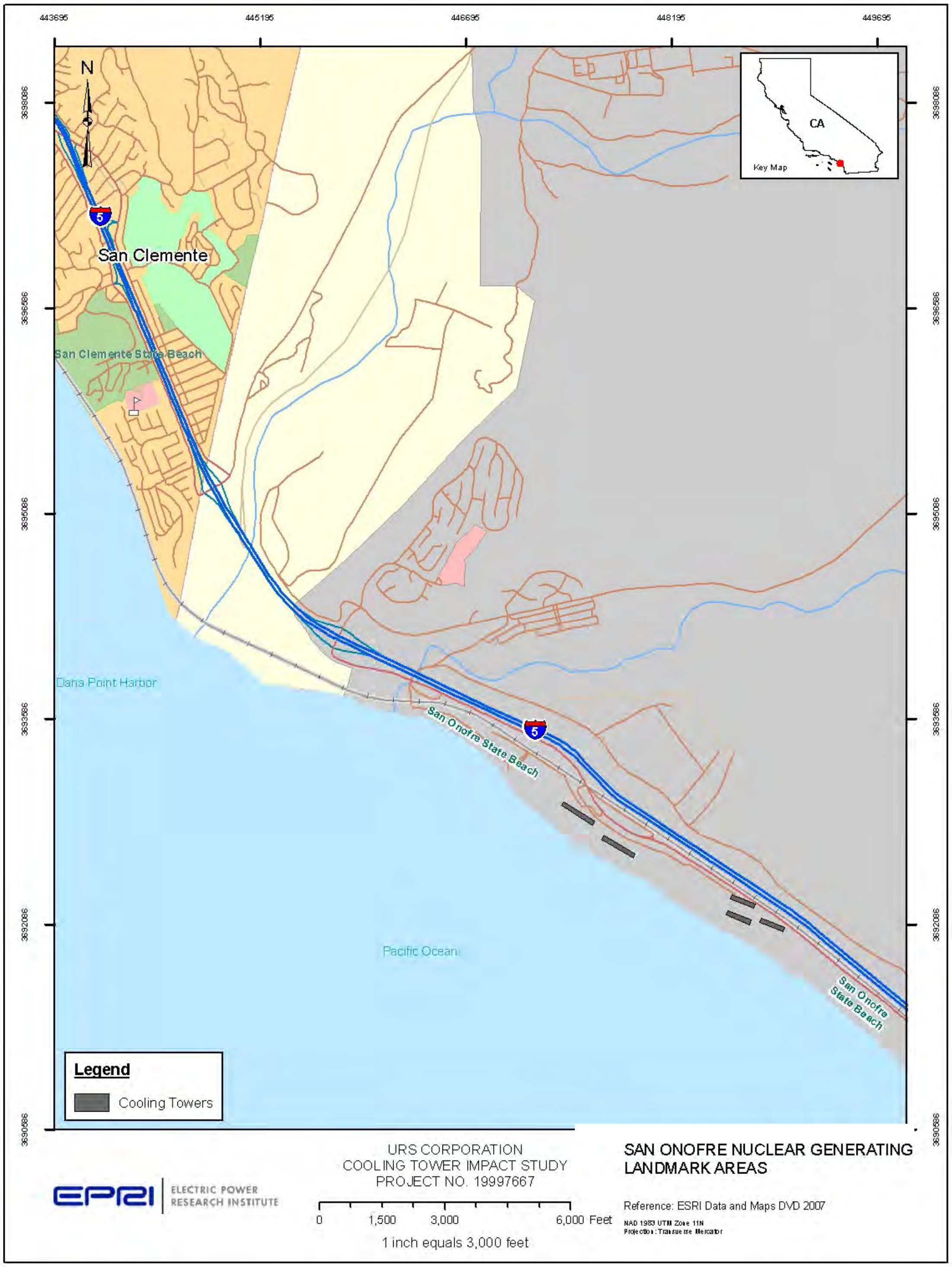


Figure A-42
Local parks and landmarks near BTCA2

A.7.10 Summary of Potential Issues with Cooling Tower Implementation

Table A-30
Summary of impacts and issues at BTCA2 [3]

Resource	Issues
Engineering	Due to space limitations cooling towers are proposed to be located adjacent to eroding/retreating bluff edge. Slope stability setback requirement may aggravate already limited space availability. Slope armoring and/or seawall may be needed.
Aquatic Biota	Net reduction in IM&E. Green sea turtles (endangered), California sea lions and harbor seals (Marine Mammal Protection Act) may also be impacted.
Human Health	BTCA2's air quality is already classified as a "non-attainment" area. BTCA2 currently has no PM_{10} emissions associated with generation. If cooling towers were constructed BTCA2 would need to obtain PM_{10} off-sets.
Terrestrial Resources	Numerous T&E species and Environmentally Sensitive Habitat Areas on-site and nearby, including U.S. Fish and Wildlife Service (USFWS) proposed or designated Critical Habitats for California gnatcatcher and Western snowy plover, respectively. CA recognized rare habitat type, Southern coastal bluff scrub, is present at south cooling tower location.
Water Consumption	Water source is saline
Solid Waste	Submerged intake removes very little man-made solid waste
Public Safety	Fogging impact to nuclear plant security, military base security, and nearby U.S. Interstate 5 and Santa Fe Railroad.
Quality of Life	View shed and noise impacts to adjacent San Onofre State Beach.
Permitting	Impacts to protected species and critical habitats; bluff stability safeguards; NRC requirements. U.S. military base is located across road from BTCA2. Potential environmental justice issues from placing cooling towers close to marine base families who are obligated to live on the base. San Diego County ordinances on noise limits, biological mitigation, natural resource protection, and coastal sage scrub habitat loss permit.
Greenhouse Gas	Prolonged shutdown for condenser re-optimization could result in additional burning of fossil fuels and greenhouse gas emissions.
Other	Potential lighting and noise impacts to Federally-threatened California gnatcatcher.

A.8 Representative Facility F (RFF)

Retrofitting RFF’s once-through cooling systems used by Units 1-4 with CCC appears to be potentially feasible at this time with an average level of difficulty.

The retrofit would reduce cooling water intake to the plant; IM&E may be expected to decrease correspondingly. Here, too, the cooling tower retrofit is expected to introduce several new environmental concerns, such as compromised visibility on surroundings roads, potential impacts to wetlands, on-site open waters, and protected species, and potential human health risk concerns in the surrounding neighborhoods. These issues are discussed below.

Four cooling towers (one for each unit) are proposed for this facility. The sizes, locations and impacts of these hypothetical cooling towers are also discussed in this section

A.8.1 Background

RFF is a 637 MW facility located in the U.S. Midwest on a Great Lake at the mouth of a river. The facility consists of four generating units: Units 1 through 4. Units 2, 3 and 4 use coal; Unit 1 uses petroleum coke[1] (“petcoke”). All units utilize once-through cooling water from the Great Lake. The design intake cooling water flow rate for the facility is 562,400 gpm.

RFF’s surrounding land uses include commercial, retail, light and heavy manufacturing and residential properties. A location map of RFF is provided as Figure A-43. Key information for the generating units is provided in the following table.

Table A-31
RFF engineering information [23, 24]

Generating Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 1	140	123,600	10	1955	83%
Unit 2	140	123,600	10	1959	64%
Unit 3	140	123,600	10	1963	65%
Unit 4	217	191,600	13	1968	65%
Total	**637**	**562,400**	**NA**	**NA**	**NA**

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[1] Petroleum coke is a carbonaceous solid derived from oil refinery coker units or other cracking processes. Other coke may be derived from coal.

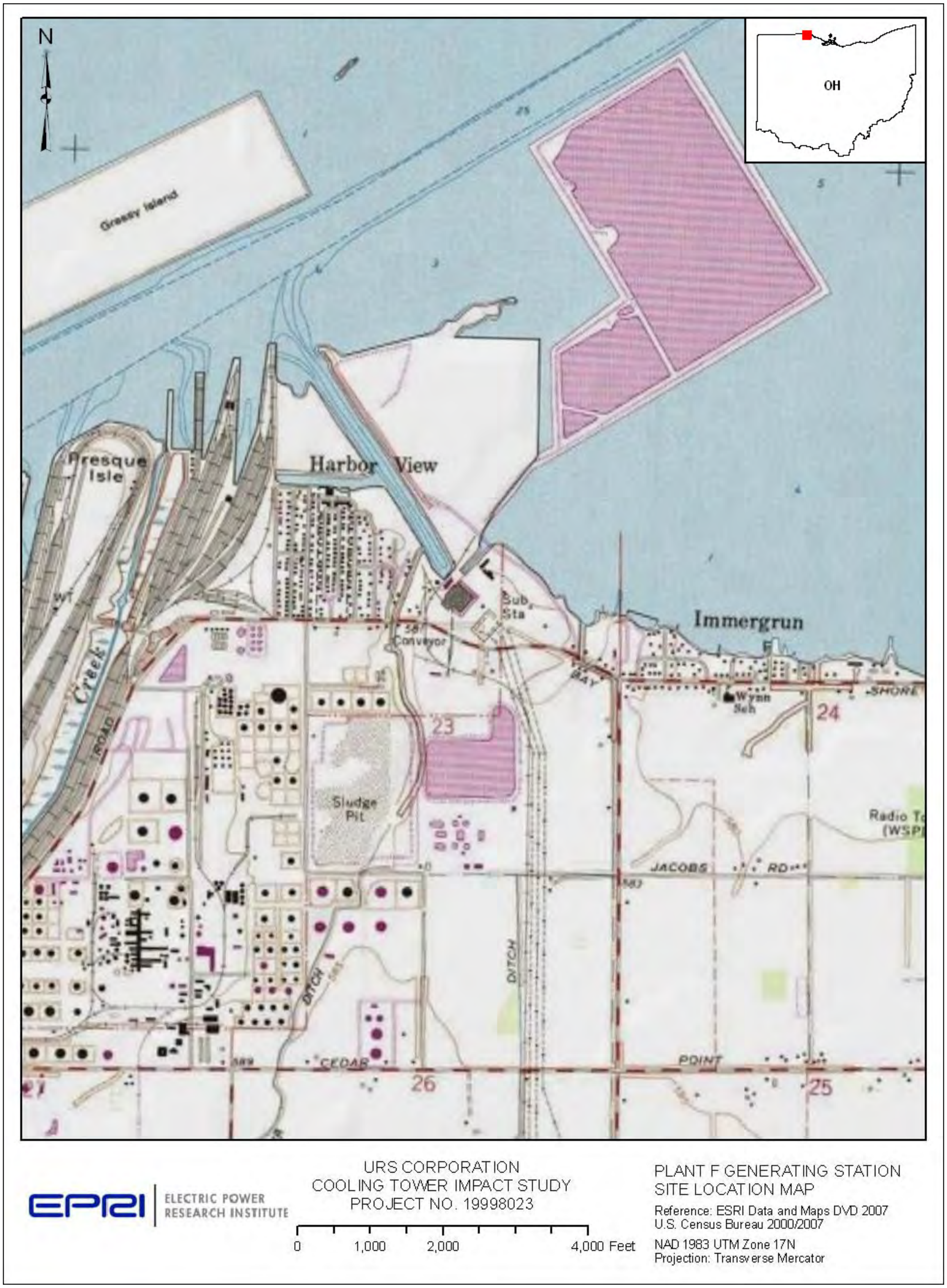


Figure A-43
RFF site location map

A.8.2 Cooling Water Intake Structure

All four generating units at RFF utilize once-through cooling water withdrawn via nine intake bays installed within a single CWIS [23]. RFF is located on the western shore of a Great Lake and withdraws cooling water via the river. An open intake channel approximately 3,700 ft in length and located along the western boundary of a local island conveys the water from the source waterbody to the CWIS [23]. A shorter discharge canal located along the southeastern boundary of the island conveys heated water back to the bay.

Each of the nine intake bays is equipped with a bar rack and a vertical traveling screen with 3/8 inch square mesh openings. A common fish return system serves all intake bays. Fish and debris collected from the traveling screens are returned to the bay [23].

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity. The design through-screen velocity at RFF has been estimated at 2.58 fps [23]; therefore the design approach velocity at the traveling water screens may be approximated to be 1.29 fps.

A.8.3 Proposed Cooling Towers at RFF

For study purposes, four conceptual cooling towers are proposed for this facility-one for each generating unit. The conceptual design assumes that the Units 1, 2 and 3 towers would be located on the southwestern tip of the island; and that the Unit 4 tower would be located immediately to the northeast of the turbine building. All cooling towers would be oriented northeast to southwest to take advantage of the predominant summer wind direction [25]. The hypothetical cooling tower locations are shown in FigureA-44.

This conceptual design includes a 14-cell tower for each of Units 1-3; and a 20-cell tower for Unit 4. All towers are assumed to be counterflow type and arranged back-to-back.

Units 1 and 2 towers are proposed to be located along the intake canal and therefore re-routing makeup and cooling water would be less difficult. A part of the Unit 3 cooling tower is located on the ash pond; the ash pond would need to be reconfigured. Therefore, construction of the Unit 3 cooling tower and routing its cooling water pipes would be more difficult and costly. The Unit 4 cooling tower is located in the main plant area and is relatively close to the intake structure; therefore only short lengths of pipe would need to be installed to re-route makeup and cooling water. But, constructing the tower would be both difficult and risky-difficult because of the underground and overhead utilities that would need to be relocated; risky because this location is adjacent to existing buildings and there might not be sufficient space for foundation excavation.

The design wet-bulb temperature used for RFF is 77°F [26]. The TDS concentration in the source waterbody is between 300-400 ppm [27]. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells has been determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The basic characteristics of the cooling towers are given in Table A-32.

Figure A-44
RFF conceptual cooling tower location map

Table A-32
Basic characteristics of cooling towers proposed for RFF

Unit Designation		Unit 1	Unit 2	Unit 3	Unit 4
Condenser Cooling Water Flow	gpm	123,600	123,600	123,600	191,600
Cooling Tower Range/Condenser ΔT	°F	10	10	10	13
No. and Arrangement of Cooling Tower Cells		14/ Back-to-back	14/ Back-to-back	14/ Back-to-back	20/ Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	358 x 108 x 6	358 x 108 x 6	358 x 108 x 6	508 x 108 x 6
Lift Pump Total	hp	1,375	1,375	1,375	2,131
Fan Total	hp	2,800	2,800	2,800	4,000
Fan Diameter	ft	32.8	32.8	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36	36	36
Drift Elimination Efficiency	%	0.0005	0.0005	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	4.42E+07	4.42E+07	4.42E+07	6.23E+07
Cycles of Concentration		8	8	8	8
Drift Rate	gpm	0.6	0.6	0.6	1.0
Cooling Tower Evaporation Rate	gpm	1,236	1,236	1,236	2,491
Blowdown Rate	gpm	177	177	177	356
Makeup Rate	gpm	1,413	1,413	1,413	2,848

A few of the engineering challenges associated with locating cooling towers at RFF are listed below.

- A section of the ash pond would need to be relocated to make space for the Unit 3 cooling tower. The Unit 3 cooling tower may need to be constructed on pilings.
- The Unit 4 cooling tower is in the main plant. Underground and overhead utilities would need to be removed or relocated to accommodate this tower. In addition, construction of the basin would be challenging and risky due to the tower’s close proximity to the turbine building. There might not be sufficient space for foundation excavation.

A.8.4 Alternative Cooling Towers and Locations Considered

This site is severely space-constrained. The only alternate available space appears to be to the south and southwest of the coal pile. Due to the significant distance between the condensers and the intake structures, and its close proximity to the coal pile (which would cause entrainment of coal dust), these locations were deemed unsuitable for cooling towers.

Further study would be needed to show whether other cooling tower options, such as natural draft, dry or hybrid, would be viable at this site; however, there would have to be constraints imposed that would require RFF to use such alternative types of towers, which tend to be more costly and less efficient than the MECTs proposed herein (See Section 6 for additional information on alternative towers).

A.8.5 Aquatic Biota

Biological information for RFF was provided by the power plant [28] and is summarized in Table A-33. The given annualized impingement and entrainment numbers are based on actual cooling water usage.

Table A-33
Annual finfish impingement and entrainment–RFF

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)	Annual Entrainment (# of juveniles)
Basses					
White Bass	*Morone chrysops*	1,593,199	40,876	155,755,228	1,097,805
White Perch	*Morone americana*	4,769,163	2,151	4,678,031	58,452
Carps/Minnows					
Central Stoneroller	*Campostoma anomalum*	815			
Goldfish	*Carassius auratus*	4,571			
Spotfin Shiner	*Cyprinella spiloptera*	741			
Carp/Minnows	Cyprinidae			4,246,141	
Common Carp/Goldfish	*Cyprinus carpio/Carassius auratus*			1,420,887	
Common Carp	*Cyprinus carpio*	8,673			
Northern Redfin Shiner	*Lythrurus umbratilis*	130			
Silver Chub	*Macrhybopsis storeriana*	10,703			
Golden Shiner	*Notemigonus crysoleucas*	416			
Emerald Shiner	*Notropis atherinoides*	24,080,877		10,979,303	3,636,594
Spottail Shiner	*Notropis hudsonius*	313,326		69,835	
Shiners	*Notropis* spp.			1,464,121	17,405
Sand Shiner	*Notropis stramineus*	32,112			
Bluntnose Minnow	*Pimephales notatus*	2,357			23,228
Fathead Minnow	*Pimephales promelas*	995			
Creek Chub	*Semotilus atromaculatus*	130			
Drums/Croakers					
Freshwater Drum	*Aplodinotus grunniens*	225,706	208,300,983	1,052,032,715	155,542

Table A-33
Annual finfish impingement and entrainment–RFF (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)	Annual Entrainment (# of juveniles)
Freshwater Catfishes					
Black Bullhead	*Ameiurus melas*	458			
Yellow Bullhead	*Ameiurus natalis*	1,249			
Brown Bullhead	*Ameiurus nebulosus*	7,448			
Channel Catfish	*Ictalurus punctatus*	77,469		78,791	
Tadpole Madtom	*Noturus gyrinus*	1,272			
Flathead Catfish	*Pylodictis olivaris*	158			
Gobies					
Round Goby	*Neogobius melanostomus*	93,918			2,035,154
Herrings/Shad					
Alewife	*Alosa pseudoharengus*	270			
Gizzard Shad	*Dorosoma cepedianum*	14,313,113			
Killifishes					
Western Banded Killifish	*Fundulus diaphanus menona*	171			
Lampreys					
Silver Lamprey	*Ichthyomyzon unicuspis*	152			
Pikes/Pickerels					
Grass Pickerel	*Esox americanus vermiculatus*			50,738	
Northern Pike	*Esox lucius*	421			
Perches					
Black Darter	*Etheostoma duryi*	372			
Yellow Perch	*Perca flavescens*	123,405		3,451,161	

Table A-33
Annual finfish impingement and entrainment–RFF (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)	Annual Entrainment (# of juveniles)
Perches	*Percidae*			2,478,703	
Logperch	*Percina caprodes*	51,547		34,059,381	1,328,768
Channel Darter	*Percina copelandi*	342			
Walleye/Yellow Perch	*Sander vitreus/Perca flavescens*			690,126	
Sauger	*Stizostedion canadense*	128			
Walleye	*Stizostedion vitreum*	77,812		7,877,247	499,799
Salmons/Trouts					
Lake Whitefish	*Coregonus clupeaformis*			23,298	
Steelhead Trout	*Oncorhynchus mykiss*	93			
Rainbow Trout	*Oncorhynchus mykiss*	93			
Sculpins					
Mottled Sculpin	*Cottus bairdii*				23,228
Silversides					
Brook Silverside	*Labidesthes sicculus*	20,538			
Smelts					
Rainbow Smelt	*Osmerus mordax*	11,472		431,115,154	4,016,961
Suckers					
Quillback	*Carpiodes cyprinus*	1,430			
Suckers	Catostomidae		221,479	714,976	
White Sucker	*Catostomus commersoni*	1,172		32,681,112	
Bigmouth Buffalo	*Ictiobus cyprinellus*	281			
Black Redhorse	*Moxostoma duquesnei*	826			
Shorthead Redhorse	*Moxostoma macrolepidotum*	1,555			
Redhorse	*Moxostoma* spp.	1,315			

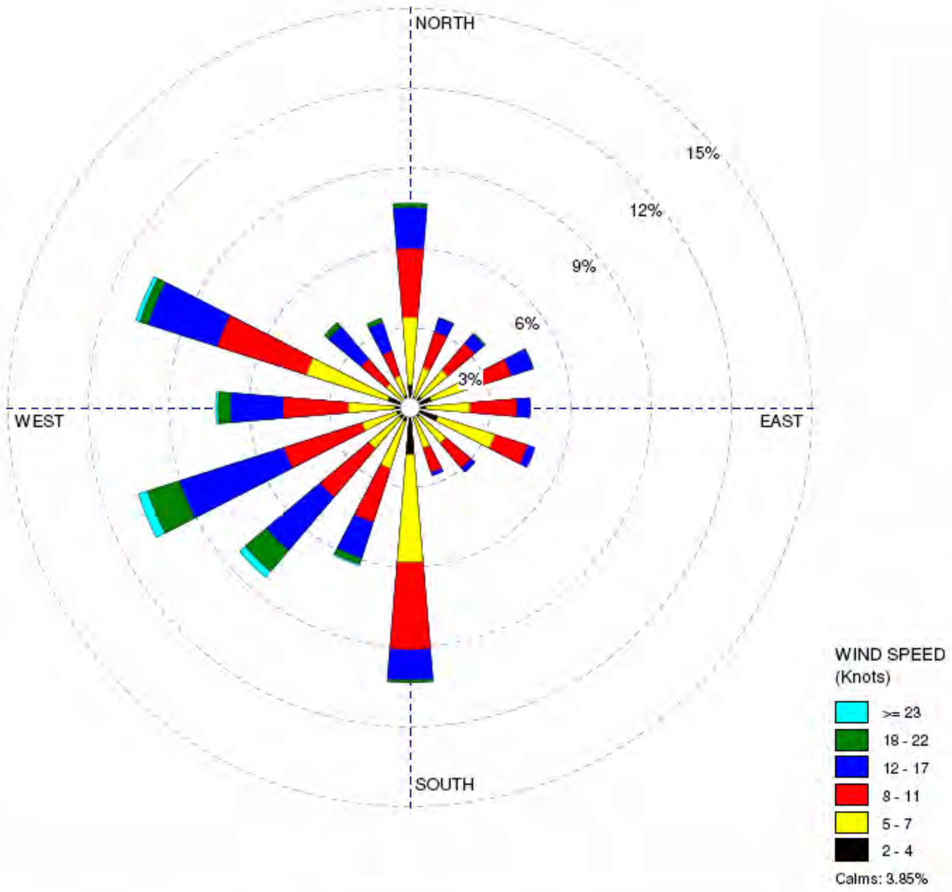
Table A-33
Annual finfish impingement and entrainment–RFF (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)	Annual Entrainment (# of juveniles)
Sunfishes					
Sunfish/Black Basses	Centrarchidae			23,578	
Green Sunfish	*Lepomis cyanellus*	384			
Pumpkinseed	*Lepomis gibbosus*	3,333			
Orangespotted Sunfish	*Lepomis humilis*	1,621			
Bluegill	*Lepomis macrochirus*	23,103			
Sunfish	*Lepomis* spp.	171		300,079	
Smallmouth Bass	*Micropterus dolomieu*	4,445			
Largemouth Bass	*Micropterus salmoides*	3,031			
Stonecat Madtom	*Noturus flavus*	296			
White Crappie	*Pomoxis annularis*	1,306			
Black Crappie	*Pomoxis nigromaculatus*	545			
Crappies	*Pomoxis* spp.			201,499	
Trout-perches					
Trout-Perch	*Percopsis omiscomaycus*	159,379		733,918	
	Total	**46,030,008**	**208,565,489**	**1,745,126,022**	**12,892,936**

A.8.6 Air Quality

WIND ROSE PLOT:
Station #94847 - DETROIT/METROPOLITAN ARPT, MI

DISPLAY:
Wind Speed
Direction (blowing from)



COMMENTS:

DATA PERIOD:
1986
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:

MODELER:

CALM WINDS:
3.85%

TOTAL COUNT:
8760 hrs.

AVG. WIND SPEED:
8.98 Knots

DATE:
9/10/2008

PROJECT NO.:

Figure A-45
Wind speed and direction for RFF

A.8.7 Population Information

Figure A-46
Census blocks detailing local household numbers surrounding RFF

A.8.8 Summary of Potential Issues with Cooling Tower Implementation

Table A-34
Summary of impacts and issues at RFF [3]

Resource	Issues
Engineering	Severe space constraints. The Unit 3 cooling tower may need to be constructed on pilings. There is insufficient space for foundation excavation for the Unit 4 cooling tower.
Aquatic Biota	Net reduction in IM&E.
Human Health	The river is the receiving waterbody of the local city's combined sewer overflows (CSOs). Running such water through cooling towers and creating aerosols may cause health risk concerns for the surrounding neighborhoods.
Terrestrial Resources	Potential impacts to wetlands and on-site open waters. Protected species, peregrine falcon (State endangered), was identified on-site. State park within 1 km of facility. Wildlife Management Area located to the east of facility.
Water Consumption	Consumptive water use will increase if the plant were converted to CCC. Consumptive water use is currently regulated by the state department of natural resources.
Solid Waste	The RFF CWIS removes several tons of leaves, wood and plastic per year from its source water [3]; reducing intake water flow rate would reduce solid waste removal correspondingly.
Public Safety	Fogging and icing, impact to switchyard.
Quality of Life	Noise and visible plume.
Permitting	Loss of wetlands and Waters of the U.S. would be regulated by State and/or Federal agencies. Potential impacts to protected species/habitats would require coordination with State and/or Federal agencies. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of $CO_{2.}$
Other	

A.9 Representative Facility G (RFG)

Retrofitting RFG's once-through cooling systems used by Units 1-6 with closed-cycle re-circulating cooling systems appears to be potentially feasible with a medium to high level of difficulty. The complexity of the layout of existing infrastructure, the multiple switchyards, the proximity to the floodplain, and currently planned environmental projects constrain availability of potential cooling tower sites.

The retrofit would reduce cooling water intake to the plant; IM&E may be expected to decrease correspondingly. However, the cooling tower retrofit is expected to introduce several new environmental concerns, such impacts to the township's drinking water source, fogging of local roadways and navigable waterways, and potential loss of wetlands. These issues are discussed below.

For study purposes, four conceptual cooling towers are proposed for this facility. The sizes, locations and impacts of these hypothetical cooling towers are also discussed in this section.

A.9.1 Background

RFG produces 1,222 MW from its coal-fired steam turbine generators and another 188 MW from its combustion turbine generators [27]. This facility, located in the U.S. Midwest, is co-owned by three electric producers [24]. The facility is located on a pool in a larger river approximately 17 miles downstream of a lock and dam.

The facility consists of 10 generating units-six steam turbine units (Units 1-6) and four combustion turbine units. All steam units utilize once-through cooling water from the large river. The design intake cooling water flow rate for the facility is 488,520 gpm [27].

RFG is located on a large tract of land with a U.S. Route running through its property [27]. Much of the major infrastructure has been built adjacent to the large river, immediately to the east of the state boundary; therefore, the riverfront section of the property is within the floodplain [27]. The boilers are located immediately to the east of the intake structures and the steam turbine buildings are located further east of the boilers [27]. The combustion turbines are located to the southeast of the steam turbines. Two switchyards and the switchyard control station are located in the vicinity of the main plant area. Another larger switchyard is located to the east of the U.S. Route [27]. High voltage transmission lines run between the generators and the switchyards.

The coal pile is located to the north of the main plant area such that the coal barges can unload directly from the large river to this coal pile. Oil barges unload at a dock immediately south of the main plant area. Currently there are two active ash ponds: Ash Pont B to the east of the coal pile and Ash Pont C to the south of the main plant area [27]. Ash Pond C has been earmarked for a flue gas desulfurization (FGD) facility [27].

The section of property located to the north of the coal pile, an abandoned ash pond, has been preliminarily identified as the site of potential cooling towers for the purposes of this study. The township's drinking water wells are located on its northern section on an easement from RFG [27]. However, this property may be utilized for a future power generating unit [27]. A location map of RFG is provided as Figure A-47. Key information for each steam generating units is provided in the following table.

Table A-35
RFG engineering information [27]

Generating Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2007
Unit 1	115	46,730	22	1952	56.5%
Unit 2	113	53,460	22	1953	58.9%
Unit 3	125	63,460	21	1954	67.6%
Unit 4	163	73,070	22	1958	70.7%
Unit 5	245	107,600	25	1962	61.4%
Unit 6	461	144,200	36	1969	65.9%
Total	**1,222**	**488,520**	**NA**	**NA**	**64.40%**

Figure A-47
RFG site location map

A.9.2 Cooling Water Intake Structure

RFG withdraws its cooling water via three shoreline intake structures on the large river. Each of the intake structures consists of two intake bays-one bay for each steam generating unit [29].

Each intake bay is equipped with a trash rack and a traveling water screen with 3/8-inch square mesh openings. Fish and debris removed from the trash racks and traveling water screens are combined into a single trough [29].

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity.

The design approach velocity at the traveling water screens at normal pool elevation has been calculated to range from 0.6 fps for Unit 1 to 1.7 fps for Unit 6 [29].

A.9.3 Proposed Cooling Towers at RFG

The conceptual cooling tower design used for the study of this facility includes four cooling towers for the six steam generating units. To optimize use of available space the proposed cooling towers for Units 1 and 2, and Units 3 and 4 have been combined. The hypothetical cooling tower locations used for this study are shown in Figure A-48.

The conceptual design for this facility includes a 14-cell cooling tower for Units 1 and 2; a 16-cell tower for Units 3 and 4; a 12-cell tower for Unit 5; and an 18-cell tower for Unit 6. For the purposes of this study all towers have been preliminarily located to the north of the coal pile, on an abandoned ash pond, and are assumed to be counter flow type with back-to-back arrangement. All cooling towers would be oriented southwest-northeast corresponding to the predominant summer wind direction for this region [25].

The section of property proposed to be utilized for the cooling towers is outside the floodplain. Its western boundary drops sharply down into the floodplain and the large river. The disadvantage of this location is the need to run approximately 2,500 ft of large diameter pipe or tunnel each way to convey cooling water between cooling towers and condensers. In addition, the cooling tower air inlets may entrain significant coal dust due to their proximity to the coal pile. The impact of the coal pile (and dust) on cooling tower performance and cycles of concentration needs to be further evaluated. The township’s drinking water wells are currently located on the northern section of this parcel on an easement from RFG; the potential impact on the drinking water wells due to extensive construction on this property would also need to be evaluated. In addition, the current site of potential cooling towers is being considered for other plant expansion projects [27].

The design wet-bulb temperature used for RFG is 78°F [26]. The TDS concentration in the source waterbody is expected to be less than 200 ppm [24]. For study purposes, all cooling tower cells have been sized at 50 ft wide by 50 ft long by 55 ft high. The basic characteristics of the towers for RFG are given in the following table [24].

Figure A-48
RFG conceptual cooling tower location map

Table A-36
Basic characteristics of cooling towers proposed for RFG

Unit Designation		Units 1-2	Units 3-4	Unit 5	Unit 6
Condenser Cooling Water Flow	gpm	100,190	136,530	107,600	144,200
Cooling Tower Range/Condenser ΔT	°F	22	21.5	25	36
No. and Arrangement of Cooling Tower Cells		14/ Back-to-back	16/ Back-to-back	12/ Back-to-back	18/ Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	358 x 108 x 6	408 x 108 x 6	308 x 108 x 6	458 x 108 x 6
Lift Pump Total	hp	1,114	1,519	1,197	1,604
Fan Total	hp	2,800	3,200	2,400	3,600
Fan Diameter	ft	32.8	32.8	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36	36	36
Drift Elimination Efficiency	%	0.0005	0.0005	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU /hr	7.88E+07	9.19E+07	1.12E+08	1.44E+08
Cycles of Concentration		8	8	8	8
Drift Rate	gpm	0.5	0.7	0.5	0.7
Cooling Tower Evaporation Rate	gpm	2,204	2,940	2,690	5,191
Blowdown Rate	gpm	315	420	384	742
Makeup Rate	gpm	2,520	3,361	3,075	5,934

A few of the engineering challenges associated with locating cooling towers at RFG are listed below.

- The significant distance between the proposed cooling tower locations and main plant area would require long runs of pipe to be installed within the floodplain, in the coal pile or in the ash pond.
- The U.S. Route runs through RFG. Visibility on the highway in the vicinity of the proposed cooling towers may be affected during cooling tower operation.
- The proposed cooling towers are to be located adjacent to the coal pile. A significant quantity of dust may be entrained in the cooling air and potentially diminish cooling water quality.

A.9.4 Alternative Cooling Towers and Locations Considered

Several other cooling tower locations were considered and then dismissed due to site-specific considerations. One such location includes the riverfront strip of land immediately to the south of the intake structure. All riverfront sections of the RFG property are within the floodplain [27]. In addition, an oil pipeline runs between the oil unloading dock and the main plant [27]. Therefore this location was dismissed.

The section of the RFG property between the main plant area and the U.S. Route was dismissed from further consideration due to its close proximity to switchyards, high voltage transmission lines and the U.S. Route.

The section of property to the east of the U.S. Route, although available, was dismissed due to its significant distance from the intake structures, outfall and condensers. Installing pipes and pumping water across the U.S. Route would also be cumbersome.

Ash Pond C (immediately to the south of the main plant area) is currently earmarked for a FGD facility [27] and is, therefore, unavailable for potential cooling towers.

Further study would be needed to show whether other cooling tower options, such as natural draft, dry and hybrid, are viable at this site; however, there would have to be additional constraints imposed that would require RFG to use alternate types of towers, which are more costly and less efficient than the MECTs proposed herein (See Section 6 for additional information on alternative towers).

A.9.5 Aquatic Biota

Biological information for RFG was provided by the power plant [30] and is summarized in Table A-37. The given annualized impingement numbers are based on actual cooling water usage and are an average of the most recent two years of data (June 2005 – June 2007).

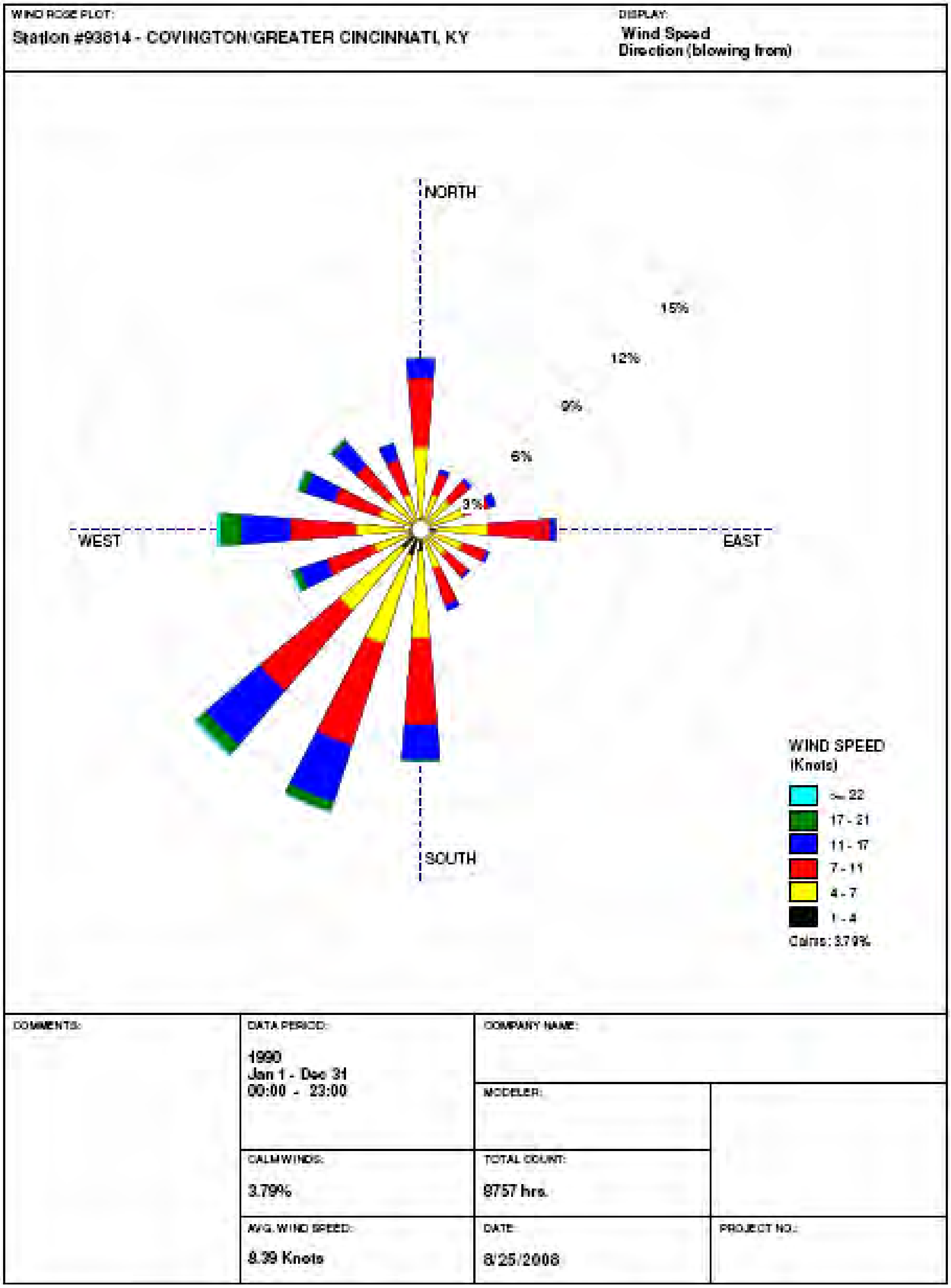
Table A-37
Annual finfish impingement–RFG

Common Name	Scientific Name	Annual Impingement (# of fish)
Basses		
White Bass	*Morone chrysops*	1,316
White Perch	*Morone americana*	46
Hybrid *Morone*	*Morone* sp. x *Morone* sp.	18
White Bass/Perch	*Morone* sp.	10
Carp/Minnow		
Silver Chub	*Macrhybopsis storeriana*	838
Emerald Shiner	*Notropis atherinoides*	586
Channel Shiner	*Notropis wickliffi*	89
Common Carp	*Cyprinus carpio*	48
River Shiner	*Notropis blennius*	10
Carpsuckers		
Carpsuckers, unid.	*Carpiodes* sp.	6
Drum/Croaker		
Freshwater Drum	*Aplodinotus grunniens*	81,556

Table A-37
Annual finfish impingement–RFG (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)
Freshwater Catfishes		
Channel Catfish	*Ictalurus punctatus*	2,192
Flathead Catfish	*Pylodictis olivaris*	132
Yellow Bullhead	*Ameiurus natalis*	10
Gars		
Longnose Gar	*Lepisosteus osseus*	488
Herring/Shad		
Gizzard Shad	*Dorosoma cepedianum*	96,067
Skipjack Herring	*Alosa chrysochloris*	3,314
Mooneyes		
Mooneye	*Hiodon tergisus*	24
Paddlefishes		
Paddlefish	*Polyodon spathula*	12
Perches		
Sauger	*Stizostedion canadense*	6,228
Saugeye	*Sander canadense* x *S. vitreus*	32
Logperch	*Percina caprodes*	26
River Darter	*Percina shumardi*	48
Suckers		
Smallmouth Buffalo	*Ictiobus bubalus*	97
Quillback	*Carpiodes cyprinus*	85
Golden Redhorse	*Moxostoma erythrurum*	58
Silver Redhorse	*Moxostoma anisurum*	32
Smallmouth Redhorse	*Moxostoma breviceps*	28
White Sucker	*Catostomus commersonii*	10
River Carpsucker	*Carpiodes carpio*	6
Spotted Sucker	*Minytrema melanops*	6
Blue Sucker	*Cycleptus elongatus*	6
Sunfishes		
Bluegill	*Lepomis macrochirus*	432
Spotted Bass	*Micropterus punctulatus*	183
White Crappie	*Pomoxis annularis*	114
Longear Sunfish	*Lepomis megalotis*	50
Rock Bass	*Ambloplites rupestris*	48
Green Sunfish	*Lepomis cyanellus*	30
Orangespotted Sunfish	*Lepomis humilis*	24
Warmouth	*Lepomis gulosus*	16
Black Crappie	*Pomoxis nigromaculatus*	12
Smallmouth Bass	*Micropterus dolomieu*	10
	Total	**194,343**

A.9.6 Air Quality



WIND ROSE PLOT:
Station #93814 - COVINGTON/GREATER CINCINNATI, KY

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:

DATA PERIOD:
1990
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:

MODELER:

CALM WINDS:
3.79%

TOTAL COUNT:
8757 hrs.

AVG. WIND SPEED:
8.39 Knots

DATE:
8/25/2008

PROJECT NO.:

Figure A-49
Wind speed and direction for RFG

A.9.7 Population Information

Figure A-50
Census blocks detailing local household numbers surrounding RFG

A.9.8 Summary of Potential Issues with Cooling Tower Implementation

Table A-38
Summary of impacts and issues at RFG [3]

Resource	Issues
Engineering	Significant distance between the proposed cooling towers and main plant area requires long runs of pipe to be installed to convey cooling water. Potential impact on the township's drinking water source.
Aquatic Biota	Net reduction in IM&E.
Terrestrial Resources	Potential impacts to wetlands and on-site open waters.
Water Consumption	Consumptive water is not currently regulated by state department or regional basin commission, but would increase if a CCC retrofit were implemented.
Public Safety	RFG is located near a U.S. Route. Visibility may be affected during cooling tower operation. Barriers constructed to shield cooling towers and their emissions from view could hinder cooling tower performance. Fogging of roadways and navigable waterways.
Quality of Life	Noise impacts and visible plume.
Permitting	Loss of wetlands and Waters of the U.S. would be regulated by State and/or Federal agencies. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of CO_2.
Other	

A.10 Representative Facility H (RFH)

Given the large capacity of the facility, retrofitting RFH's once-through cooling system with a closed-cycle re-circulating cooling system appears to be feasible but with a medium to high level of difficulty.

The retrofit would likely reduce cooling water intake to the plant; a corresponding reduction in IM&E may also be expected due to the closed-cycle cooling tower retrofit. As with other facilities, this retrofit would introduce new environmental concerns, such as reductions in air quality, potential impacts to protected species, loss of wetlands and Waters of the U.S., increase in net evaporative water loss, etc. These issues are discussed below.

For study purposes, six cooling towers are proposed for this facility-three per unit. The sizes, locations and impacts of these hypothetical cooling towers are also discussed below.

A.10.1 Background

RFH is a base-load 1,875 MW two-unit nuclear facility that utilizes steam turbines as its prime movers. It is located in the U.S. Southeast. RFH uses once-through cooling systems, with a total design intake rate of 1,333,734 gpm [24], to remove waste heat from the station's main condensers [31].

RFH is located adjacent to an Atlantic coast estuary near the mouth of a larger river, and the facility's cooling system withdraws cooling water predominantly from the surface layer of the river through an approximately three-mile long intake canal and channel that bisects a marsh [32].

RFH is located within a large tract of land and is surrounded by other rural wooded and vegetated parcels. A location map of RFH is provided as Figure A-51. Key information for each generating unit is provided in the following table.

Table A-39
RFH engineering information [24, 32]

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 1	949	666,867	22	1977	95%
Unit 2	926	666,867	22	1975	94%
Total	**1,875**	**1,333,734**	**NA**	**NA**	**NA**

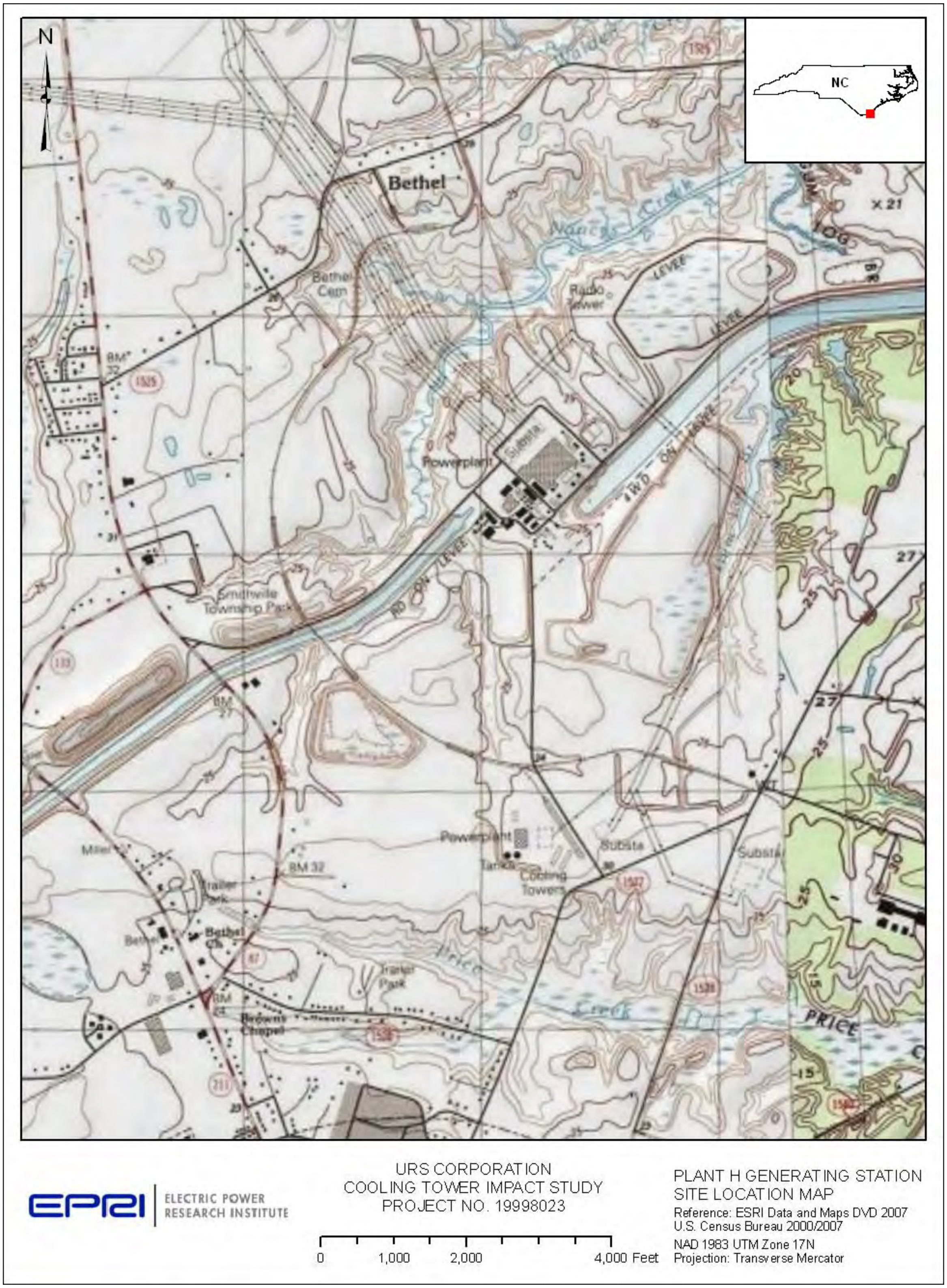


Figure A-51
RFH site location map

A.10.2 Cooling Water Intake Structure

RFH's once-through cooling system is designed to continuously remove waste heat from the two main condensers. The cooling water system includes the intake canal from the estuary to the plant, the intake structure, the intake pumps, condensers, a pump station, and the discharge canal that transports the heated cooling water back to the estuary [31, 32].

The cooling water is withdrawn from the estuary via a 3-mile long intake canal system consisting of an open cut channel from the ship channel through a marsh and on through the upland area between the estuary and the plant site. The canal is influenced by tidal fluctuations [32]. Dredging helps maintain the canal bottom at approximately -18 MSL; and the deeper water column helps reduce the through-screen velocity. A fish diversion structure consisting of plastic bar racks with 3 in spacing has been installed across the mouth of the canal at an angle to the primary direction of water flow. The angle of the diversion structure is expected to cause the fish that come into contact with the diversion structure to swim away from the mouth of the canal or be moved by the current along the screen face, and out of the influence of the plant intake [31].

The CWIS, located at the other end of the canal, consists of eight intake bays (four per unit) and is approximately 175 ft wide, 44 ft high and 105 ft deep [32]. Each bay includes a bar rack, a vertical traveling screen, provisions for stop logs, and a vertical intake pump. The bar racks are located near the front of the intake structure and prevent large debris from entering the cooling system. Debris that accumulates on trash racks is removed manually either from the operating deck, a boat in the intake canal, or temporary staging suspended from the operating deck [32].

The traveling screens are equipped with stainless steel wire mesh. Two of the four traveling screens associated with each unit use fine mesh in all panel; 50 percent of panels on the other two screens also use fine mesh [27]. The screens rotation is actuated by a preset pressure differential across the screen face. Fish and debris washed off the screens are washed into a collection trough leading to the fish return system. The fish return system consists of a gravity flume system approximately 4,000 ft in length that transports the organisms to a return basin, for eventual return to the estuary.

The vertical circulating water pumps convey water from the intake canal to the condensers serving each unit via eight 6 ft diameter pipes.

The discharge canal, shaped like an inverted trapezoid, drops its bottom elevation from -12 ft MSL near the weir to approximately -19.2 ft MSL on a nearby island [32]. The discharge canal width at MSL is approximately 170 ft.

A.10.3 Proposed Cooling Towers at RFH

RFH is a large (1,875 MW) facility that requires over 1.3 million gallons of cooling water per minute. Each of the two generating units would therefore require 68 cooling tower cells that, for the purposes of this study, are grouped into three sets of cooling towers. The specific characteristics of each tower are provided in the table below.

The conceptual design for the study of this facility includes two 22-cell towers and one 24-cell tower for each generating unit. All towers have been preliminarily oriented northeast-southwest to coincide with the predominant summer wind direction, and are assumed to be counter-flow and back-to-back. While the towers would include drift eliminators, they do not include plume abatement.

For the purposes of the study, the cooling towers associated with Unit 1 have been preliminarily located on the site of previously planned (but abandoned) natural draft cooling tower foundations. Cooling towers associated with Unit 2 have been located between the proposed Unit 1 towers and the discharge canal on currently wooded property.

Given the large cooling water flow rate required by the two generating units, large pipes or tunnels would have to be installed to convey water between cooling tower basins and condensers, and between cooling tower basins and the discharge canal. Existing infrastructure may need to be moved or removed to accommodate the new piping. The intake structure would need to be modified.

The design wet-bulb temperature used for RFH is 81°F [26]. The TDS concentration in the source waterbody is expected to be less than 200 ppm [31]. For study purposes, all cooling tower cells have been sized at 50 ft wide by 50 ft long by 55 ft high; and the number of cells was determined to allow for cooling water throughput of approximately 10,000 gpm per cell.
The basic characteristics of the towers for RFH are given in the following table [32].

Figure A-52
RFH conceptual cooling tower location map

Table A-40
Basic characteristics of cooling towers proposed for RFH

Unit Designation		Unit 1			Unit 2		
Condenser Cooling water Flow	gpm	215,751	215,751	235,365	215,751	215,751	235,365
Cooling Tower Range/Condenser ΔT	°F	22	22	22	22	22	22
No. and Arrangement of Cooling Tower Cells		22/back-to-back	22/back-to-back	24/back-to-back	22/back-to-back	22/back-to-back	24/back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	558 x 108 x 6	558 x 108 x 6	608 x 108 x 6	558 x 108 x 6	558 x 108 x 6	608 x 108 x 6
Lift Pump Total	hp	2,400	2,400	2,618	2,400	2,400	2,618
Fan Total	hp	4,400	4,400	4,800	4,400	4,400	4,800
Fan Diameter	ft	32.8	32.8	32.8	32.8	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36	36	36	36	36
Drift Elimination Efficiency		0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/r	1.08E+08	1.08E+08	1.08E+08	1.08E+08	1.08E+08	1.08E+08
Cycles of Concentration		1.5	1.5	1.5	1.5	1.5	1.5
Drift Rate	gpm	1.1	1.1	1.2	1.1	1.1	1.2
Cooling Tower Evaporation Rate	gpm	4,747	4,747	5,178	4,747	4,747	5,178
Blowdown Rate	gpm	9,493	9,493	10,356	9,493	9,493	10,356
Makeup Rate	gpm	14,241	14,241	15,535	14,241	14,241	15,535

Several engineering challenges associated with locating cooling towers at RFH are listed below.

- A 1985 study of the facility which briefly evaluated natural draft cooling towers determined that due to the complexity of the condenser cooling system at RFH, converting the facility's cooling system from once-through to closed-cycle would be more complex than the physical erection of two natural draft cooling towers [32].
- A significant amount of wooded area would need to be cleared to install cooling towers.

- Several large diameter pipes would have to be installed above or below grade to convey cooling water between condensers and cooling towers.
- Sizes and orientation of cooling towers need to be optimized to reduce recirculation and interference that would result from locating six large cooling towers in relative close proximity.
- Existing infrastructure would have to be relocated.
- Construction would need to be performed without compromising site security at this nuclear power plant.

A.10.4 Alternative Cooling Towers and Locations Considered

The cooling tower location proposed herein is the site of previously abandoned natural draft cooling tower foundations. During a 1980s study, this location was identified as more appropriate than any other With respect to proximity to the intake structures, discharge canal and condensers, this location requires less utility and infrastructure relocation and less site disturbance than other potential locations. However the cost and environmental impact of erecting cooling towers was found to outweigh the benefit and cooling tower project cancelled.

Natural draft towers may be viable at this site; however, the capital cost associated with natural draft towers is greater than the MECTs proposed here but may be recouped over a period of time from the reduced O&M costs. Dry and hybrid towers may also be feasible at this site but would have more extensive land use impacts. There would have to be additional constraints imposed that would require RFH to use non-MECTs, which are more expensive and less efficient than the MECTs proposed herein (See Section 6 for additional information on alternative towers).

A.10.5 Aquatic Biota

Biological information for RFH was provided by the power plant [33] and is summarized in Table A-41. The given annualized impingement and entrainment numbers are based on design cooling water usage assuming all pumps are continuously operating (nuclear facility).

Table A-41
Annual finfish and shellfish impingement and entrainment–RFH

Common Name	Scientific Name	Annual Impingement (# of Larvae)	Annual Impingement (# of Juveniles and Adults)	Annual Entrainment (# of Larvae)
Anchovies				
Bay Anchovy	*Anchoa mitchilli*	1,309,194	1,189,870	73,304
Striped Anchovy	*Anchoa hepsetus*		25,215	
Blennies				
Combtooth Blennies, unid.	Blenniidae	5,870		1,369
Feather Blenny	*Hypsoblennius hentz*		304	
Freckled Blenny	*Hypsoblennius ionthas*		395	
Blowfishes				
Northern Puffer	*Spheroids maculatus*	91		61
Bluefishes				
Bluefish	*Pomatomus saltatrix*		243	
Butterfishes				
Harvestfish	*Peprilus alepidotus*		7,543	
Butterfish	*Peprilus triacanthus*		61	30
Butterfly-Rays				
Smooth Butterfly Ray	*Gymnura micrura*		395	
Burrfishes				
Striped Burrfish	*Chilomycterus schoepfii*	335	700	61
Clingfishes				
Skilletfish	*Gobiesox strumosus*	2,068	122	1,217
Cods				
Southern Hake	*Urophycis floridana*		91	
Spotted Hake	*Urophycis regia*		1,551	
Hake, unid.	*Urophycis* spp.		30	

Table A-41
Annual finfish and shellfish impingement and entrainment–RFH (continued)

Common Name	Scientific Name	Annual Impingement (# of Larvae)	Annual Impingement (# of Juveniles and Adults)	Annual Entrainment (# of Larvae)
Cornetfishes				
Bluespotted Cornetfish	*Fistularia tabacaria*		30	
Cusk-eels				
Speckled Worm Eel	*Myrophis punctatus*	28,258	517	791
Shrimp Eel	*Ophichthus gomesii*	274	1,004	30
Crested Cusk-Eel	*Ophidion josephi*		517	
Cutlassfishes				
Atlantic Cutlassfish	*Trichiurus lepturus*		3,620	
Drums/Croakers				
Silver Perch	*Bairdiella chrysoura*	102,322	15,056	5,566
Spotted Seatrout	*Cynoscion nebulosus*	22,022	943	760
Weakfish	*Cynoscion regalis*	15,360	7,726	821
Banded Drum	*Larimus fasciatus*		183	
Spot	*Leiostomus xanthurus*	785,723	40,606	15,391
Atlantic Croaker	*Micropogonias undulatus*	394,078	11,802	6,570
Black Drum	*Pogonias cromis*	3,194		152
Drums, unid.	Sciaenidae			122
Red Drum	*Sciaenops ocellatus*	578	243	
Star Drum	*Stellifer lanceolatus*	3,163	19,467	61
Eels				
American Eel	*Anguilla rostrata*	669		
Filefishes				
Planehead Filefish	*Monacanthus hispidus*	122	487	61

Table A-41
Annual finfish and shellfish impingement and entrainment–RFH (continued)

Common Name	Scientific Name	Annual Impingement (# of Larvae)	Annual Impingement (# of Juveniles and Adults)	Annual Entrainment (# of Larvae)
Gobies				
Gobies, unid.	Gobiidae	355,054	517	18,463
Groupers				
Gag	*Mycteroperca microlepis*		122	
Grunts				
Pigfish	*Orthopristis chrysoptera*	24,151	517	852
Halfbeaks				
Silverstripe Halfbeak	*Hyporhamphus unifasciatus*	487		
Herrings/Shad				
Blueback Herring	*Alosa aestivalis*		2,555	
Alewife	*Alosa pseudoharengus*	243		
American Shad	*Alosa sapidissima*		183	
Atlantic Menhaden	*Brevoortia tyrannus*	9,368	46,629	274
Gizzard Shad	*Dorosoma cepedianum*		1,034	
Threadfin Shad	*Dorosoma petenense*	0	79,722	0
Atlantic Thread Herring	*Opisthonema oglinum*		1,247	
Horseshoe Crabs				
Horseshoe Crab	*Limulus polyphemus*		61	
Jacks				
Jacks, unid.	Carangidae	122		
Atlantic Bumper	*Chloroscombrus chrysurus*		1,125	
Leatherjack	*Oligoplites saurus*		61	
Lookdown	*Selene vomer*		1,004	
Florida Pompano	*Trachinotus carolinus*	30		

Table A-41
Annual finfish and shellfish impingement and entrainment–RFH (continued)

Common Name	Scientific Name	Annual Impingement (# of Larvae)	Annual Impingement (# of Juveniles and Adults)	Annual Entrainment (# of Larvae)
Killifishes				
Mummichog	*Fundulus heteroclitus*	365		
Kingfishes				
Southern Kingfish	*Menticirrhus americanus*		1,643	
Kingfish spp.	*Menticirrhus* spp.	3,893		61
Left-eye Flounders				
Ocellated Flounder	*Ancylopsetta quadrocellata*		456	
Whiff Larvae	*Citharichthys* spp.	6,114	2,707	122
Fringed Flounder	*Etropus crossotus*		9,399	
Summer Flounder	*Paralichthys dentatus*		2,525	
Southern Flounder	*Paralichthys lethostigma*		730	
Flounder Larvae	*Paralichthys* spp. larvae	4,289		61
Ladyfishes				
Ladyfish	*Elops saurus*	1,186		
Mojarras				
Mojarras	Gerreidae	1,460		91
Irish Pompano	*Diapterus auratus*		304	
Spotfin Mojarra	*Eucinostomus argenteus*		578	
Mullets				
Striped Mullet	*Mugil cephalus*	3,194	760	274
White Mullet	*Mugil curema*	122	365	
Needlefishes				
Atlantic Needlefish	*Strongylura marina*	213	30	

Table A-41
Annual finfish and shellfish impingement and entrainment–RFH (continued)

Common Name	Scientific Name	Annual Impingement (# of Larvae)	Annual Impingement (# of Juveniles and Adults)	Annual Entrainment (# of Larvae)
Pipefishes				
Lined Seahorse	*Hippocampus erectus*	122		
Northern Pipefish	*Syngnathus fuscus*	456	8,760	61
Chain Pipefish	*Syngnathus louisianae*	1,916	2,251	
Inshore Lizardfish	*Synodus foetens*	639	487	122
Porgies				
Sheepshead	*Archosargus probatocephalus*	1,156	61	91
Pinfish	*Lagodon rhomboides*	26,706	16,668	1,125
Requiem Sharks				
Atlantic Sharpnose Shark	*Rhizoprionodon terraenovae*		183	
Rock Shrimps				
Rock Shrimp	*Sicyonia* sp.		152	
Sea Robins				
Leopard Searobin	*Prionotus scitulus*		669	
Searobin	*Prionotus* sp.	2,373		30
Bighead Searobin	*Prionotus tribulus*	365	10,038	30
Silversides				
Silversides, unid.	Atherinidae	2,738		23,299
Rough Silverside	*Membras martinica*		791	
Atlantic Silverside	*Menidia menidia*	335	6,114	30
Snappers				
Gray Snapper	*Lutjanus griseus*		1,795	
Snapping Shrimps				
Snapping Shrimp	*Alpheus* sp.		183	

Table A-41
Annual finfish and shellfish impingement and entrainment–RFH (continued)

Common Name	Scientific Name	Annual Impingement (# of Larvae)	Annual Impingement (# of Juveniles and Adults)	Annual Entrainment (# of Larvae)
Soles				
Hogchoker	*Trinectes maculatus*	5,962	5,049	61
Squilled Mantis Shrimp				
Mantis Shrimp	*Squilla empusa*		1,551	
Stargazers				
Northern Stargazer	*Astroscopus guttatus*	30		
Southern Stargazer	*Astroscopus y-graecum*		30	
Stingrays				
Atlantic Stingray	*Dasyatis sabina*		91	
Southern Stingray	*Dasyatis americana*		30	
Swimming Crabs				
Blue Crab	*Callinectes sapidus*	642,734	103,478	2,616
Lesser Blue Crab	*Callinectes similis*		98,307	
Unid. Swimming Crab	*Callinectes* unid.	1,947		30
Tarpons				
Tarpon (Leptocephalus)	*Megalops atlantica* (leptocephalus)	122		0
Toadfishes				
Oyster Toadfish	*Opsanus tau*	122	1,369	
Tonguefishes				
Blackcheek Tonguefish	*Symphurus plagiusa*		26,432	
Tonguefish Larvae	*Symphurus* spp.	2,068		61

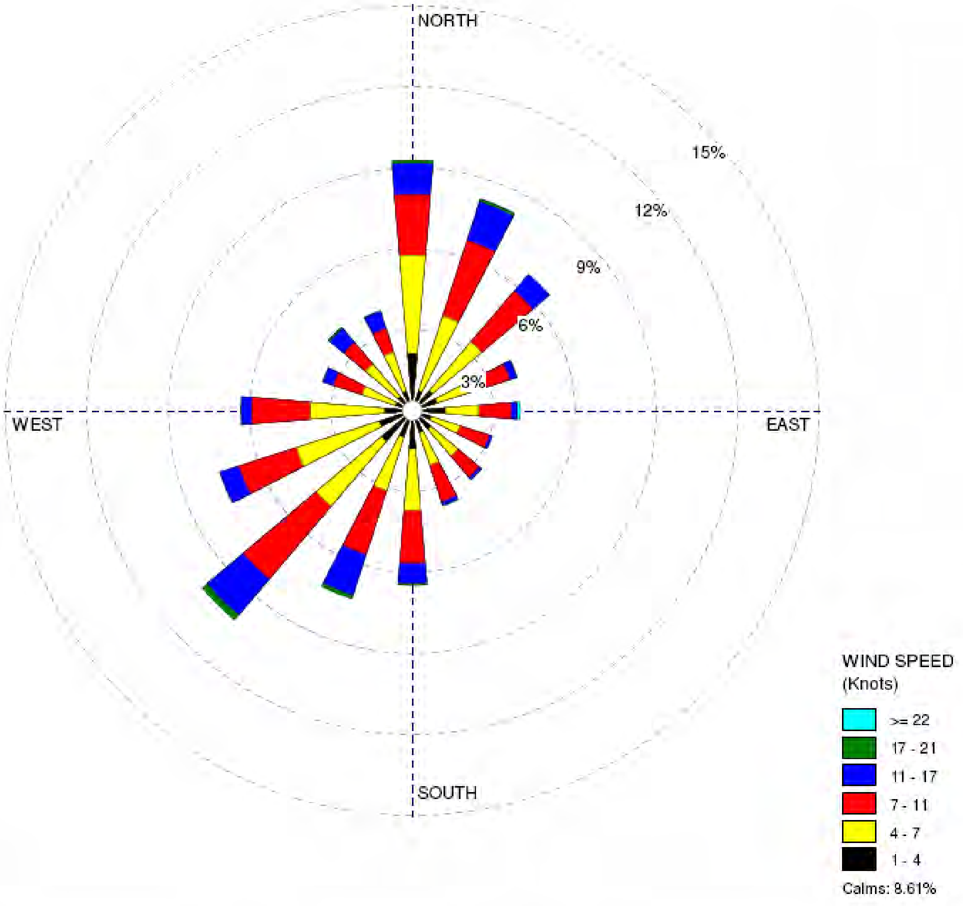
Table A-41
Annual finfish and shellfish impingement and entrainment–RFH (continued)

Common Name	Scientific Name	Annual Impingement (# of Larvae)	Annual Impingement (# of Juveniles and Adults)	Annual Entrainment (# of Larvae)
Tripletails				
Tripletail	*Lobotes surinamensis*		30	
Others				
Commercial Shrimp		595,923	637,229	5,566
	Total	**4,367,379**	**2,306,436**	**159,687**

A.10.6 Air Quality

WIND ROSE PLOT:
Station #13748 - WILMINGTON/NEW HANOVER COUNTY, NC

DISPLAY:
Wind Speed
Direction (blowing from)



COMMENTS:

DATA PERIOD:
1989
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:

MODELER:

CALM WINDS:
8.61%

TOTAL COUNT:
8758 hrs.

AVG. WIND SPEED:
6.97 Knots

DATE:
9/2/2008

PROJECT NO.:

Figure A-53
Wind speed and direction for RFH

A.10.7 Population Information

Figure A-54
Census blocks detailing local household numbers surrounding RFH

A.10.8 Summary of Potential Issues with Cooling Tower Implementation

Table A-42
Summary of impacts and issues at RFH [3]

Resource	Issues
Engineering	Six large cooling towers are required at RFH. Need to arrange and orient them to minimize recirculation and interference. Need long runs of large diameter pipes between cooling towers and condensers.
Aquatic Biota	Net reduction in IM&E.
Terrestrial Resources	Potential impacts to wetlands and on-site open waters. Potential impacts to upland forest communities. Protected species, red-cockaded woodpecker (State and Federally-listed endangered) habitat may potential impacted by the cooling tower construction. Other protected species or habitats identified on-site, which may potential be impacted, include; Kemp's ridley sea turtle, wood stork, American alligator, green sea turtle, loggerhead sea turtle, and piping plover. Estuary designated as primary nursery habitat by the state division of marine fisheries.
Water Consumption	Consumptive water use is not currently regulated by state department or regional basin commission, but would increase if the once-through cooling system were replaced with a closed-cycle system.
Public Safety	Fogging issues
Quality of Life	Noise impacts and visible plume.
Permitting	Loss of wetlands and Waters of the U.S. would be regulated by State and/or Federal agencies. Potential impacts to protected species/habitats would require coordination with State and/or Federal agencies. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Prolonged shutdown for cooling system tie-ins and condenser re-optimization could result in additional burning of fossil fuels and greenhouse gas emissions. It is estimated that approximately 7 million tons of CO_2 would be emitted due to retrofit-related downtime, if the retrofit were to be performed within 8 months.
Other	

A.11 Representative Facility I (RFI)

Retrofitting RFI's once-through cooling system with CCC appears to be feasible, but very difficult. The main challenge is the lack of space onsite.

The retrofit would reduce cooling water intake to the plant; however, the impact of the reduction may be slightly smaller than in comparison to a facility that utilizes higher quality freshwater. Nevertheless, as discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit would introduce several new environmental concerns such as reductions in air quality, loss of open water habitats on-site, potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are also discussed below.

The facility consists of two active generating units (Units 7 and 8), both of which currently utilize once-through cooling systems [34]. For the purposes of this study, two cooling towers are proposed for this facility; these towers are based on the results of a former site-specific cooling tower study and on space availability, and are not dedicated to each generating unit. The sizes, locations and impacts of these hypothetical cooling towers are also discussed below.

A.11.1 Background

RFI is a 542 MW coal-fired steam electricity generating facility located in a highly urbanized Midwest city. The facility is located within close proximity to commercial and residential properties on the northern bank of a sanitary and ship canal, which flows in an east-northeast to west-southwest direction. The two generating units share a single cooling water intake structure, and withdraw cooling water from the canal at a total design intake rate of 382,000 gpm [24].

A location map of RFI is provided as Figure A-55. Key information for each generating unit is provided in the following table.

Table A-43
RFI engineering information

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 7	220	138,000	16	1958	58%
Unit 8	322	244,000	15	1961	69%
Total	**542**	**382,000**	**NA**	**NA**	**NA**

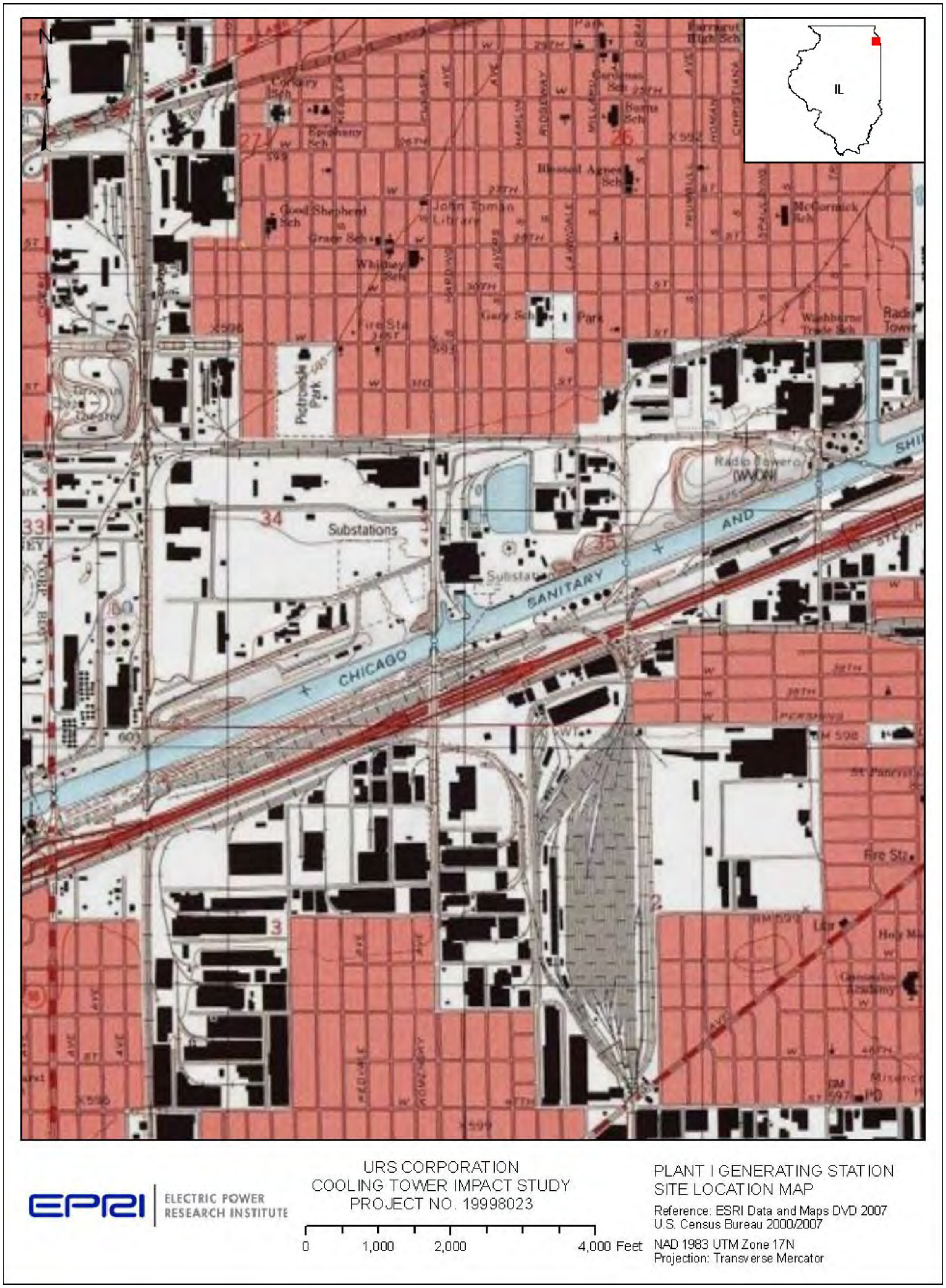


Figure A-55
RFI site location map

A.11.2 Cooling Water Intake Structure

Units 7 and 8 share the CWIS, which withdraws cooling water from a dedicated intake channel off of the sanitary and ship canal. The discharge canal, located approximately 450 ft west and downstream of the intake canal, discharges heated wastewater back to the sanitary and ship canal.

The intake screenhouse is equipped with trash racks, 11 through-flow traveling water screens, and a high-pressure wash-water system. All traveling screens utilize mesh with 3/8 in square openings [34]. Seven of the traveling screens are in 7 ft wide bays and the other four are in 9 ft wide bays. A single 12 ft by 12 ft intake tunnel conveys the cooling water from the intake screenhouse into the facility. Before the cooling water reaches the respective condensers, the tunnel divides the cooling water into two pipes, and one pipe each conveys cooling water to Units 7 and 8 condensers [34].

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity.

The design maximum through-screen velocity has been calculated to be 2.26 fps [34]; therefore the approach velocity at RFI may be estimated at approximately 1.13 fps.

A.11.3 Proposed Cooling Towers at RFI

A consultant to the facility performed a conceptual-level cooling tower study for RFI in April 2008, and proposed two in-line cooling towers for the facility: one 8-cell tower and one 22-cell tower. The current study uses the conceptual tower arrangement and locations provided by that consultant. However, this study deviates from the facility-consultant’s tower-type recommendation: the facility-consultant proposed hybrid towers (i.e. plume-abated towers). In order to maintain consistency of impacts among representative facilities, this study assumes the use of MECTs (i.e. *no plume-abatement*).

The 22-cell tower would be oriented north-south and located between the coal pile and the water treatment plant. The 8-cell tower would be oriented west-northwest to east-southeast and located immediately to the east of the intake canal on the nearby switchyard. Potential cooling tower locations identified by the RFI consultant and used for the purposes of this study are shown in Figure A-56.

The two proposed cooling tower locations may pose constructability issues [35]. The 8-cell tower requires relocation of the 138 kilovolt (kV) line and switchyard to prevent ice buildup during winter months [35]. In addition, the 345 kV line may need to be raised and supplemented with additional insulation [35]. The overall drift impacts of the proposed cooling towers on cables and switchgear needs to be further evaluated.

The northern tower may not be ideally oriented with predominant summer winds and may be subject to increased recirculation [35]. The incoming cooler air would likely entrain significant amounts of coal dust and potentially lower the cycles of concentration. In addition, this tower location may require routing of the 10-foot diameter circulating water lines across the site [35]. Furthermore, the northern tower has been located adjacent to other existing infrastructure. Cooling tower foundation excavation may therefore be extremely challenging and potentially dangerous. The northern tower may also require removal/relocation of other underground and above ground existing infrastructure.

Units 7 and 8 condenser temperature rises (ΔT) are conservatively assumed to be 16°F and 15°F, respectively. Because the two units utilize a common intake tunnel, cooling towers are not dedicated to each generating unit. The cooling tower range is prorated by condenser heat discharge rate. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells was determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The design wet-bulb temperature with 1 percent exceedance is 78°F [35]; the source water TDS is approximately 700 ppm [35]. The basic characteristics of the towers for RFI are given in the following table [24].

Figure A-56
RFI conceptual cooling tower location map

Table A-44
Basic characteristics of cooling towers proposed for RFI

		Southern Tower	**Northern Tower**
Cooling Tower Water Flow Rate	gpm	101,867	280,133
Cooling Tower Range	°F	15.4	15.4
No. and Arrangement of Cooling Tower Cells		8 In-line	22 In-line
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	408 x 58 x 6	1108 x 58 x 6
Lift Pump Total	hp	1,133	3,116
Fan Total	hp	1,600	4,400
Fan Diameter	ft	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36
Drift Elimination Efficiency	%	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	9.79E+07	9.79E+07
Cycles of Concentration		5	5
Drift Rate	gpm	0.5	1.4
Cooling Tower Evaporation Rate	gpm	1,565	4,303
Blowdown Rate	gpm	391	1,076
Makeup Rate	gpm	1,957	5,380

Several engineering challenges associated with locating cooling towers at RFI are listed below.

- There is very limited space onsite. For the purposes of this study, both towers have been located over existing infrastructure that would need to be removed or relocated.
- Foundation excavation adjacent to existing buildings and water treatment basins may be challenging and potentially dangerous.
- Several underground and overhead utilities within this limited space pose additional challenges to retrofitting RFI with closed-cycle cooling towers.
- RFI is adjacent to several highways. Operation of cooling towers could impact visibility. Barriers erected to shield cooling towers from view would hinder cooling tower performance.
- RFI's cooling towers would likely require exemptions from local height and noise ordinances [3].
- RFI currently uses the sanitary and ship canal water for its cooling purposes. This is the receiving waterbody for all of the city's major publicly-owned treatment works (POTWs) [24], whose discharges are currently not required to be disinfected. Depending on weather conditions, there are also additional untreated effluents contributing to the flow due to the predominance of combined sewer overflows (>200) which feed into the canal system [27].

Running such water through cooling towers and creating aerosols may cause health risk concerns for the surrounding dense residential neighborhood.

- This study assumed MECT (i.e. no plume-abatement). The need for plume abatement could be an issue due to the high voltage power lines [35], the location of highways, residential and commercial properties, and the local airport [24].

A.11.4 Alternative Cooling Towers and Locations Considered

Given the limited space, height ordinances and residential surroundings, dry or natural draft cooling towers at this site seem infeasible at this time.

This study also considered three back-to-back towers over filled-in intake and discharge canals. The alternate arrangement intended to take advantage of the lowered cooling water intake and discharge flow rate due to the closed-cycle conversion. Such alternate towers would also have required relocation of existing infrastructure, and they would likely have impacted visibility on a major thoroughfare in the city.

A.11.5 Aquatic Biota

Biological information for RFI was provided by the power plant [36] and is summarized in Table A-45. The given annualized impingement and entrainment numbers are based on actual cooling water usage.

Table A-45
Annual finfish impingement and entrainment–RFI

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of fish)
Basses			
White Perch	*Morone americana*	1,801	
White Bass	*Morone chrysops*	103	
Yellow Bass	*Morone mississippiensis*	462	
Carps/Minnows			
Goldfish	*Carassius auratus*	39	
Common Carp	*Cyprinus carpio*		817,594
Spotfin Shiner	*Cyprinella spiloptera*	1,986	
Golden Shiner	*Notemigonus crysoleucas*	465	
Emerald Shiner	*Notropis atherinoides*	920	
Spottail Shiner	*Notropis hudsonius*	429	
Unidentified Shiner	*Notropis* sp.	7	
Bluntnose Minnow	*Pimephales notatus*	3,736	76,348
Fathead Minnow	*Pimephales promelas*	14	
Carp/Sucker	*Cyprinid/Catostomid* sp.		25,794,597

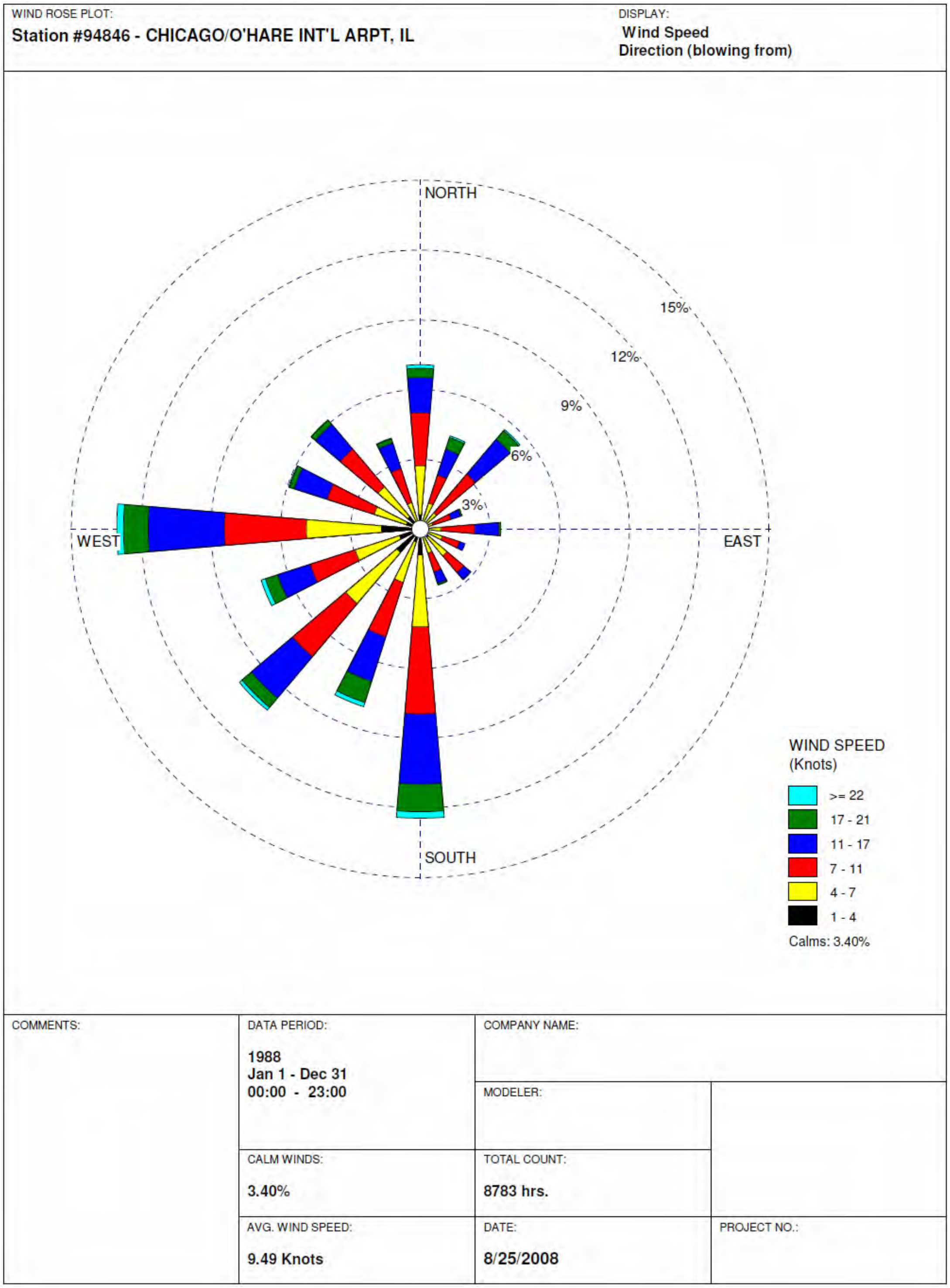
Table A-45
Annual finfish impingement and entrainment–RFI (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of fish)
Carp/Drum	*Sciaenidae/Cyprinid*		112,295
Unid. Cyprinid	Cyprinidae sp.		880,858
Cichlids			
Nile Tilapia	*Oreochromis niloticus*	378	
Drums/Croakers			
Freshwater Drum	*Aplodinotus grunniens*	253	95,082
Freshwater Catfishes			
Black Bullhead	*Ameiurus melas*	13	
Yellow Bullhead	*Ameiurus natalis*	295	
Channel Catfish	*Ictalurus punctatus*	489	16,659
Tadpole Madtom	*Noturus gyrinus*	7	
Herrings/Shad			
Skipjack Herring	*Alosa chrysochloris*	6	
Alewife	*Alosa pseudoharengus*	290	253,742
Gizzard Shad	*Dorosoma cepedianum*	37,168	1,963,576
Threadfin Shad	*Dorosoma petenense*	115	
Unid. Clupeidae	Clupeidae sp.		13.055,270
Unid. Alosa	*Alosa* sp.		133,607
Gobies			
Round Goby	*Neogobius melanostomus*	1,255	
Perches			
Yellow Perch	*Perca flavescens*	61	
Smelts			
Rainbow Smelt	*Osmerus mordax*	478	
Sticklebacks			
Threespine Stickleback	*Gasterosteus aculeatus*	3	
Ninespine Stickleback	*Pungitius pungitius*	7	
Suckers			
White Sucker	*Catostomus commersonii*	52	
Sunfishes			
Green Sunfish	*Lepomis cyanellus*	135	
Pumpkinseed	*Lepomis gibbosus*	284	
Orangespotted Sunfish	*Lepomis humilis*	19	

Table A-45
Annual finfish impingement and entrainment–RFI (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of fish)
Bluegill	*Lepomis macrochirus*	924	
Longear Sunfish	*Lepomis megalotis*	62	
Redear Sunfish	*Lepomis microlophus*	258	
Hybrid Sunfish	*Lepomis* sp. x *Lepomis* sp.	19	
Largemouth Bass	*Micropterus salmoides*	155	
White Crappie	*Pomoxis annularis*	52	
Black Crappie	*Pomoxis nigromaculatus*	13	
Unid. Centrarchidae	Centrarchidae sp.		153,438
Unid. *Lepomis*	*Lepomis* sp.		1.116,030
Unid. *Pomoxis*	*Pomoxis* sp.		97,583
Topminnows			
Western Mosquitofish	*Gambusia speciosa*	9	
Unidentified			2,249,619
	Total	**52,762**	**46,816,298**

A.11.6 Air Quality



WIND ROSE PLOT: **Station #94846 - CHICAGO/O'HARE INT'L ARPT, IL**	DISPLAY: **Wind Speed** **Direction (blowing from)**

COMMENTS:	DATA PERIOD: **1988** **Jan 1 - Dec 31** **00:00 - 23:00**	COMPANY NAME:	
		MODELER:	
	CALM WINDS: **3.40%**	TOTAL COUNT: **8783 hrs.**	
	AVG. WIND SPEED: **9.49 Knots**	DATE: **8/25/2008**	PROJECT NO.:

Figure A-57
Wind speed and direction for RFI

A.11.7 Population Information

Figure A-58
Census blocks detailing local household numbers surrounding RFI

A.11.8 Summary of Potential Issues with Cooling Tower Implementation

Table A-46
Summary of impacts and issues at RFI [3]

Resource	Issues
Engineering	Severe space limitations. Need to relocate existing infrastructure (high voltage power line owned by other entity, switchyard, sewer lines, other buried and overhead infrastructure) to accommodate cooling towers [3]. Foundation excavation challenges.
Aquatic Biota	Net reduction in IM&E.
Human Health	Creation of aerosols of untreated POTW and CSO effluents [27].
Terrestrial Resources	Potential impacts to on-site open water.
Water Consumption	Increased evaporation with cooling tower use; concentration of untreated POTW/CSO effluent constituents [27]. However, consumptive water use is not currently regulated by a state department or regional basin commission.
Solid Waste	Approximately 60 tons per year of trash and debris are removed by the existing intake [3]. Converting from once-through to closed-cycle would reduce the extent of solid waste removed by the facility [27].
Public Safety	Increased fogging/limited visibility for nearby highways, roads and airport [27].
Quality of Life	Degraded view shed, due to additional site equipment, fogging, aerosol creation [27].
Permitting	Cooling towers may not be permitted due to site-specific issues; the plant is within city limits and subject to local jurisdiction [27]. Local ordinances would likely require plume abatement due to proximity to residential areas, electrical lines, highways, airport, etc. [27]. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of $CO_{2.}$
Other	

A.12 Representative Facility J (RFJ)

Retrofitting RFJ’s once-through cooling systems used by its currently active Units 2-5 with CCC appears to be potentially feasible at this time with an average level of difficulty. The main challenges are related to the lack of space onsite, the potential need to run long lengths of piping between the cooling towers and condensers, and the potential need to perform construction adjacent to the existing 200,000-barrel fuel oil tanks.

The retrofit would reduce cooling water intake to the plant; IM&E may be expected to decrease correspondingly. Here too, the cooling tower retrofit is expected to introduce several new environmental concerns, such as compromised visibility on the adjacent highway. These issues are also discussed below.

For the purposes of this study, two cooling towers are proposed for this facility. The sizes, locations and impacts of these hypothetical cooling towers are also discussed in this section.

A.12.1 Background

RFJ is a 486 MW natural gas- and fuel-oil-fired power generating facility located in the U.S. Southwest on a lake [37]. The dam for the lake is located on a local river, and was constructed in part for cooling water use for the RFJ [37]. The dam is owned and operated by the local water company for municipal and industrial uses [37]. The facility currently consists of four generating units: Units 2 through 5 [37]. Unit 1 is now retired. Units 2-4 are gas-fired and Unit 5 uses gas and oil. All active units utilize once-through cooling water from the lake; the design intake cooling water flow rate for the facility is 443,900 gpm [37].

A location map of RFJ is provided as Figure A12-1. Key information for each generating unit is provided in the following table.

Table A-47
RFJ engineering information

Generating Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 2	31	59,400	10.5	1951	1%
Unit 3	32	58,800	10.5	1953	2%
Unit 4	79	73,700	15.8	1956	2%
Unit 5	344	252,000	12	1974	18%
Total	**486**	**443,900**	**NA**	**NA**	**NA**

Figure A-59
RFJ site location map

A.12.2 Cooling Water Intake Structure

RFJ is designed with two CWISs, located on the northern shore of the lake [37]. The CWIS for Units 2-4 is approximately 45.5 ft wide and 34 ft deep [37]. The three bays associated with Units 2-4 are hydraulically connected; and each bay is 11 ft and 2 in wide [37]. Unit 5 has a separate CWIS consisting of three 11 ft and 2 in wide bays; this CWIS is 46.5 ft wide and 35 ft deep [37].

Each intake bay consists of a bar rack, a traveling water screen, and provision for stop logs. All screens are 10 ft wide and use mesh with 3/8-inch square openings. The screens are rotated for two 30 minute periods each day [37]. However, screens are rotated continuously during heavy debris loading events. The Unit 5 screens may actuate automatically based on the pressure differential across the screen face. When the units are offline for extended periods, the screens are typically operated once per week. The low pressure service water pumps for Units 1-4 and the high pressure service water pump for Unit 5 are used to wash debris from the screens to a trough with a wire basket at the end to catch debris [37], and disposed according to characterization of waste [3].

The circulating water pumps operate continuously when the units are on-line. The circulating water pumps associated with Units 2-4 take suction from a common intake tunnel which runs underneath the turbine room basement floor; the heated water is discharged into a common discharge tunnel located immediately above the intake tunnel. Although Unit 1 has been retired, its circulating water pumps are operated several times each year [37].

The nearly 1.5 mile long circulating water discharge flume runs in a west to east direction south of the main plant area, and discharges heated water back into the lake [27].

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity.

The design through screen velocity at Units 2-4 screens have been calculated at 2.76 fps; and the through screen velocity at the Unit 5 screens have been calculated at 2.3 fps [37]. Therefore, the approach velocity at RFJ’s Units 2-4 screens and Unit 5 screens may be estimated to be approximately 1.38 fps and 1.15 fps, respectively.

A.12.3 Proposed Cooling Towers at RFJ

The preliminary conceptual design used for the study of this facility includes two cooling towers. One 26-cell counter flow back-to-back cooling tower for Unit 5 located to the east of the two 200,000 barrel fuel oil tanks, and one 20-cell counter flow back-to-back cooling tower for Units 2-4 located further east of the hypothetical Unit 5 tower. Both towers are oriented northwest to southeast to optimize use of available space; however, the north to south predominant summer wind direction would be the preferred orientation. The hypothetical cooling tower locations are shown in Figure A-58.

Given the proposed cooling tower locations, approximately 3/4 mi long piping would be required each way to convey the heated water from the condensers to the cooling towers, and to convey cooled water from the cooling tower basins back to the condensers. In addition, RFJ would require infrastructure modifications to convey makeup water to the cooling towers. The circulating water discharge flume may continue to be used to return the cooling tower blowdown back to the lake.

Units 2,3 and 4 condenser temperature rises (ΔT) are 10.5°F, 10.5°F, and 15.8°F, respectively [37]. The Units 2-4 cooling tower range was estimated to allow for the design heat discharge rate of these three units and their total cooling water flow rate. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells was determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The wet-bulb temperature with 1 percent exceedance for this area is 80°F [26]; the source water TDS is approximately 500 ppm [38]. The basic characteristics of the towers for RFJ are given in Table A-48 [24].

Figure A-60
RFJ conceptual cooling tower location map

Table A-48
Basic characteristics of cooling towers proposed for RFJ

Unit Designation		Units 2-4	Unit 5
Cooling Tower Flow Rate	gpm	191,900	252,000
Cooling Tower Range	°F	12.5	12
No. and Arrangement of Cooling Tower Cells		20 Back-to-back	26 Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	508 x 108 x 6	658 x 108 x 6
Lift Pump Total	hp	2,134	2,803
Fan Total	hp	4,000	5,200
Fan Diameter	ft	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36
Drift Elimination Efficiency	%	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	6.02E+07	5.82E+07
Cycles of Concentration		5	5
Drift Rate	gpm	1.0	1.3
Cooling Tower Evaporation Rate	gpm	2,406	3,024
Blowdown Rate	gpm	601	756
Makeup Rate	gpm	3,008	3,781

Several potential engineering challenges associated with locating cooling towers at RFJ are listed below.

- Performing construction adjacent to RFJ’s two 200,000 barrel fuel oil tanks would be risky and challenging. Depending on depth of excavation for foundation, the tower may need to be moved further away from the containment berm.
- A state highway is immediately to the north of RFJ. Visibility may be affected during cooling tower operation. Use of plume abated towers (at higher cost and larger footprint) would help lower fogging impacts; however, in order to maintain consistency of assumptions and impacts between studies performed on different representative facilities, no plume abatement is assumed at RFJ.
- Long runs of pipe may be required between the cooling towers and condensers.
- The intake structures may need to be relocated closer to the cooling towers, or additional piping would be needed between the existing intake structures and the proposed cooling towers.

- One or more of the several high voltage transmission lines may need to be permanently or temporarily relocated to accommodate the cooling towers and their construction.
- The gas lines may also need to be relocated.

A.12.4 Alternative Cooling Towers and Locations Considered

No other space appears to be available onsite where cooling towers may be located, therefore no alternate onsite locations were considered.

Given the limited space availability, locating natural draft towers, hybrid towers or dry cooling towers at this facility may be even more difficult. (See Section 6 for additional information on alternative towers).

A.12.5 Aquatic Biota

Biological information for RPJ was provided by the power plant [39] and is summarized in Table A-49. The given annualized impingement numbers are based on estimated actual cooling water usage based on design flow and hours of operation reported for each unit.

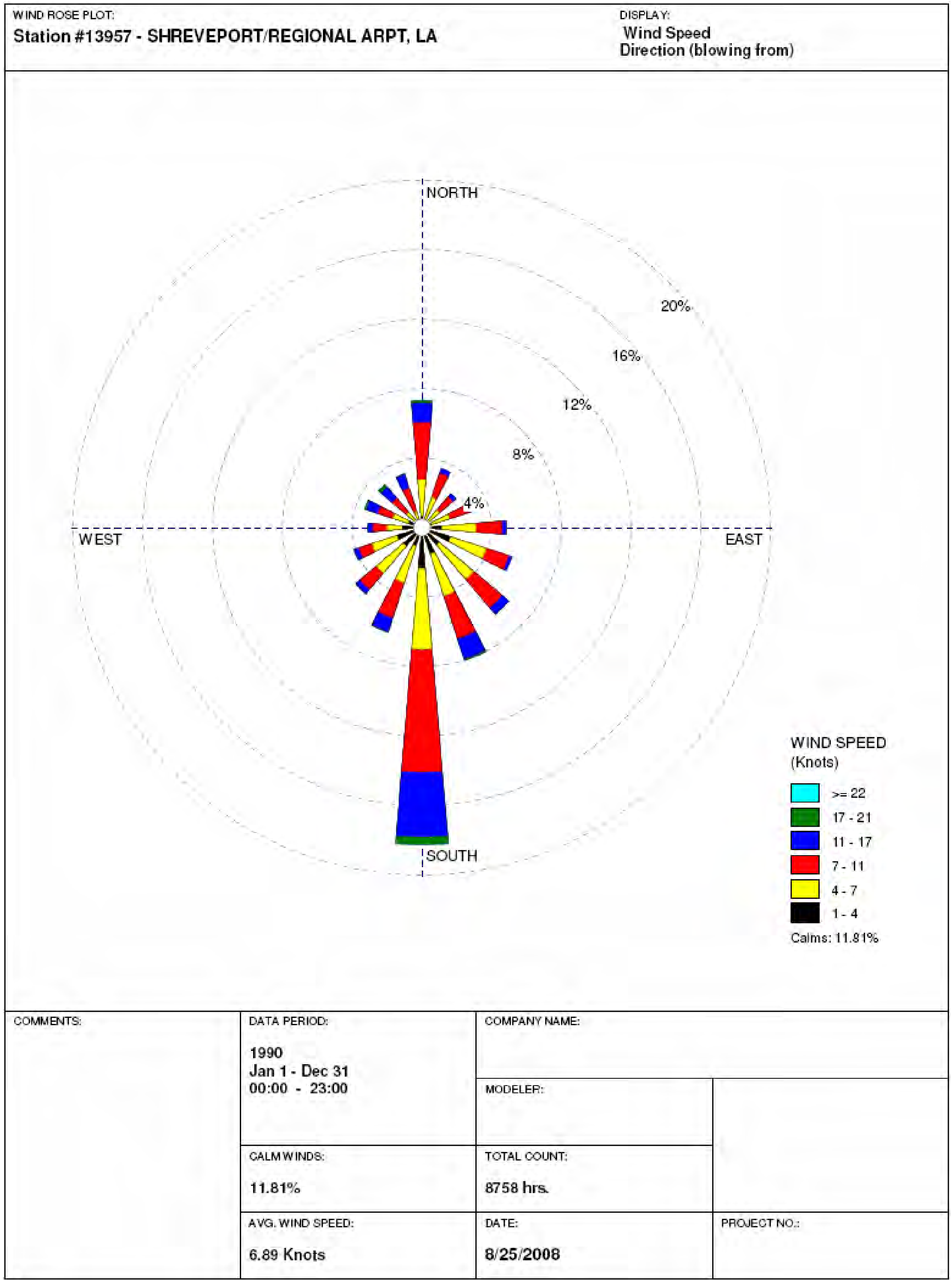
Table A-49
Annual finfish impingement–RFJ

Common Name	Scientific Name	Annual Impingement (# of fish)
Carps/Minnows		
Pugnose Minnow	*Opsopoeodus emiliae*	26
Herrings/Shad		
Gizzard Shad	*Dorosoma cepedianum*	40
Threadfin Shad	*Dorosoma petenense*	2,413
Pikes/Pickerels		
Chain Pickerel	*Esox niger*	46
Perches		
Logperch	*Percina caprodes*	11
Silversides		
Inland Silverside	*Menidia beryllina*	213
Sunfishes		
Warmouth	*Lepomis gulosus*	11
Orangespotted Sunfish	*Lepomis humilis*	60

Table A-49
Annual finfish impingement–RFJ (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)
Bluegill	*Lepomis macrochirus*	2,018
Longear Sunfish	*Lepomis megalotis*	11
Redear Sunfish	*Lepomis microlophus*	129
Spotted Sunfish	*Lepomis punctatus*	11
Largemouth Bass	*Micropterus salmoides*	952
White Crappie	*Pomoxis annularis*	748
	Total	**6,689**

A.12.6 Air Quality



WIND ROSE PLOT:
Station #13957 - SHREVEPORT/REGIONAL ARPT, LA

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:

DATA PERIOD:
1990
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:

MODELER:

CALM WINDS:
11.81%

TOTAL COUNT:
8758 hrs.

AVG. WIND SPEED:
6.89 Knots

DATE:
8/25/2008

PROJECT NO.:

Figure A-61
Wind speed and direction for RFJ

A.12.7 Population Information

Figure A-62
Census blocks detailing local household numbers surrounding RFJ

A.12.8 Summary of Potential Issues with Cooling Tower Implementation

Table A-50
Summary of impacts and issues at RFJ [3]

Resource	Issues
Engineering	Risky construction adjacent to the two 200,000 barrel fuel oil tanks. Need for extensive cooling water piping between condensers and cooling towers. Potential need to relocate intake structures. Potential need to relocate one or more high voltage transmission lines, and or gas line.
Aquatic Biota	Net reduction in IM&E.
Terrestrial Resources	USFWS National Wetlands Inventory (NWI) wetlands mapping was unavailable. Potential impacts to upland forest communities.
Water Consumption	Increased evaporation with cooling tower use. However, consumptive water use is not currently regulated by a state department or regional basin commission.
Public Safety	Visibility on the state road may be compromised during cooling tower operation.
Quality of Life	Noise impacts and visible plume.
Permitting	If wetlands and Waters of the U.S. were identified on–site and were impacted during construction, they would be regulated by State and/or Federal agencies. Local ordinances, permits, and zoning requirements would likely be required.
Green House Gas	Parasitic losses and energy penalty will result in additional emissions of $CO_{2.}$
Other	

A.13 Representative Facility K (RFK)

Retrofitting RFK’s once-through cooling systems for Units 3 and 4 with CCC systems appears to be infeasible at this time. The main challenges include the lack of suitable open space, the dedicated conservation easements around the facility, and the topography at the site [40]. However, for the purposes of this study a hypothetical cooling tower has been located on a conservation easement to estimate impacts and apply those impacts to other facilities that RFK represents.

The retrofit, if it were feasible, would likely reduce cooling water intake to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, such a retrofit would introduce several new environmental concerns like an increase in air emissions, and potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are also discussed below.

The facility consists of two active generating units (Units 3 and 4) that use steam turbines as their prime mover and once-through cooling systems [41]. One hypothetical cooling tower has been sized to be shared between Units 3 and 4. The size, location and impacts of the hypothetical cooling tower are discussed below.

A.13.1 Background

RFK's Units 3 and 4 are oil- and natural gas-fired steam electricity generating units with a combined capacity of 362 MW. RFK's Units 1 and 2, each rated at 49 MW, are now retired. In the recent past, the center installed simple cycle units that have a combined generating capacity of 80 MW; but, because these units do not require cooling water, they are not discussed further herein.

RFK is located on the north shore of an island in the U.S. Northeast and draws cooling water from a harbor, which is on the south shore of the sound. The design cooling water intake rate for Units 3 and 4 is 204,000 gpm. RFK returns its heated cooling water to the RFK harbor.

The facility's northeastern boundary is on the RFK Harbor. The only open areas, along the northwest and western boundaries of the site, are easements dedicated for conservation purposes [40]. High voltage transmission lines traverse the southern boundary of the site, pass over the entire southwestern parcel of the site to the substation, and then run to the east along the southern portion of the property to the generating units [40]. Much of the surroundings are residential.

A location map of RFK is provided as Figure A-63. Key information for each active steam-electric generating unit is provided in the following table.

Table A-51
RFK engineering information [40]

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 3	181	102,000	17	1958	45.6%
Unit 4	181	102,000	18	1960	50.4%
Total	**362**	**204,000**	**NA**	**NA**	**NA**

Figure A-63
RFK site location map

A.13.2 Cooling Water Intake Structure

RFK's CWIS is located on the north side of the station [40]. The intake structure houses two intake bays per generating unit; i.e., a total of eight intake bays. However, the four intake bays associated with Units 1-2 are no longer in use.

Each active intake bay is equipped with a curtain wall, a trash rack and a conventional traveling water screen with 3/8 in square mesh openings [40]. The face of each intake bay is 12 ft wide. The trash racks are located approximately 4 ft downstream of the curtain walls; the traveling water screens are located approximately 7 ft downstream of the trash racks. Fish and debris are cleaned from the traveling water screens by a high-pressure spray system [40].

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity.

For the intake bays for Units 3 and 4[2], approach velocity under the curtain wall is 0.7 fps and approaching the traveling screens is 0.9 fps [40]. Based on these approach velocities, the through-screen velocities are expected to be approximately 1.8 fps.

A.13.3 Proposed Cooling Towers at RFK

The lack of suitable open space onsite makes locating cooling towers at RFK extremely difficult. For the purposes of this study, a cooling tower for Units 3 and 4 has been located to the north of the facility, on a conservation easement that is, at this time, not available for construction. In addition, there are several constructability, engineering and safety issues that make this location unsuitable for construction of a cooling tower. These issues are briefly discussed below. A more detailed and comprehensive evaluation is needed prior to considering a CCC retrofit at RFK.

The proposed conceptual cooling towers for Units 3 and 4 have been combined, and the location is shown in Figure A-64. The preliminary design for this facility includes a 22-cell back-to-back cooling tower oriented south-southwest to north-northeast to optimize use of space and somewhat align with the predominant summer wind direction [25]. As discussed later, this location was selected, for study purposes, after evaluating several other locations.

The advantage of this location is its proximity to the intake structure. However, this entire parcel is a hill-the northern tip is almost at sea-level, the southern tip is at approximately 105 ft (MSL). The main plant is at between 10-30 ft elevations (MSL). Depending on the geology of the location (which was not evaluated as a part of this study), the hill on which the conceptual tower is proposed would need to be cut and re-graded to provide sufficient stability and slope. Makeup water and heated cooling water from condensers would need to be pumped up to the basins.

---

[2] Given the symmetry and similarity of the intake bays for Units 3 and 4, assume approach velocities are also the same.

Given the topography of the location, a comprehensive heat transport model would need to be performed to evaluate if summer winds facilitate efficient cooling tower performance.

The design wet-bulb temperature with 1 percent exceedance in summer months for RFK is 77°F [26]; the ocean/bay water TDS is approximately 30,000 ppm. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells was determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The basic characteristics of the towers for RFK are given in the following table.

Figure A-64
RFK conceptual cooling tower location map

Table A-52
Basic characteristics of cooling towers proposed for RFK

Unit Designation		Units 3-4
Cooling Tower Water Flow Rate	gpm	204,000
Cooling Tower Range	°F	17.5
No. and Arrangement of Cooling Tower Cells		22/Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	558 x 108 x 6
Lift Pump Total	hp	2,321
Fan Total	hp	4,400
Fan Diameter	ft	32.8
Fan Housing Inside Diameter at Exit	ft	36
Air Flow Rate per Cell	acfm	1,291,008
Drift Elimination Efficiency	%	0.0005
Cooling Tower Heat Dissipation Rate per Cell	gpm	8.12E+07
Cycles of Concentration	BTU/hr	1.5
Drift Rate	gpm	1.0
Cooling Tower Evaporation Rate	gpm	3,570
Blowdown Rate	gpm	7,140
Makeup Rate	gpm	10,711

A few of the engineering challenges associated with locating cooling towers at RFK are listed below.

- The RFK site itself is fully utilized. The only open spaces are easements dedicated for conservation purposes. There is no suitable land available on the property to locate a cooling tower.
- The area on which the hypothetical cooling tower is located is a hill (and is a conservation easement). Major cutting and re-grading would be needed prior to any potential construction on it.
- Makeup and cooling water would need to be pumped up to the cooling tower basins.
- There are residential properties immediately to the northwest of the hypothetical cooling tower. No mechanism was identified to shield these homes from the noise and visual impacts.
- The main plant has been densely developed. Reconfiguring the cooling water piping would be very difficult.
- The tower dimensions given in Table A-52 is for a standard back-to-back MECT with no plume abatement. The need for plume abatement could be an issue due to the surrounding residential properties. However, plume-abated towers are limited to in-line arrangements, and locating two 11-cell in-line towers onsite does not appear to be practicable even if construction were allowable on conservation easements.

A.13.4 Alternative Cooling Towers and Locations Considered

Alternate cooling tower locations considered include the easement immediately to the southeast of the facility, the conservation easement on the northwest of the property, the space between the fuel oil tanks and the main plant, and constructing the cooling tower on a filled-in parcel in the bay.

The high voltage transmission lines are located on the sloped easement immediately to the south and southwest of the main plant. Constructing a cooling tower on an elevated property that is between the main plant and high voltage transmission lines would be risky and extremely difficult [41]. In addition to the difficulties with re-routing the cooling water pipes to this location, the transmissions lines may need to be permanently relocated.

The only open areas on the northwest and western boundaries are easements dedicated for conservation purposes; the remainder of the site is occupied by the generating facilities, fuel tanks, transmission substation, wastewater treatment facilities, parking lots, and access roads [40]. In addition to being the right-of-way for the transmission lines, the southwestern portion of the property is about 2,000 ft from the generating facilities and is also at an elevation of approximately 100 ft (MSL), and pumping cooling water back and forth would be difficult. Therefore, this location is also unsuitable for locating a cooling tower [40].

While there is some limited space between the fuel tanks and the main plant, there are underground and overhead utilities across that section of the property, and performing any construction on the slope, immediately outside the fuel tank berms and the generating units would also be risky and extremely difficult.

Filling-in a small section of the harbor to make space for cooling towers is a potential option. However, permitting such an endeavor would likely be very difficult.

Alternate cooling tower types have a larger footprint than the MECT discussed herein. Therefore installing inline mechanical draft cooling towers, hyperbolic natural draft cooling towers, or hybrid towers at RFK appears to be even more challenging at this time.

A.13.5 Aquatic Biota

Biological information for RFK was provided by the power plant [42] and is summarized in Table A-53. The given annualized impingement and entrainment numbers are based on actual cooling water usage.

Table A-53
Annual finfish impingement and entrainment–RFK

Common Name	Scientific Name	Annual Impingement (# of juveniles)	Annual Impingement (# of yearlings and older)	Total Annual Impingement (All Life Stages)	Annual Entrainment (# of eggs)	Annual Entrainment (# of yolk sac larvae)	Annual Entrainment (# of post yolk sac larvae)	Annual Entrainment (# of juveniles)	Total Annual Entrainment (All Life Stages)
Anchovies									
Bay Anchovy	*Anchoa mitchilli*	15	14	29	51,754,822	0	39,790,546	642,905	92,188,273
Basses									
White Perch	*Morone americana*	0	14	14	0	0	0	0	0
Blennies									
Feather Blenny	*Hypsoblennius hentz*	0	22	22	0	14,663	27,105	0	41,768
Blowfishes									
Northern Puffer	*Sphoeroides maculatus*	309	7	316	0	0	0	0	0
Bluefishes									
Bluefish	*Pomatomus saltatrix*	0	7	7	0	0	0	0	0
Burrfishes									
Striped Burrfish	*Chilomycterus schoepfii*	0	34	34	0	0	0	0	0
Butterfishes									
Butterfish	*Peprilus triacanthus*	1,102	1,511	2,613	978,741	0	958,279	0	1,937,020
Cods									
Fourbeard Rockling	*Enchelyopus cimbrius*	0	0	0	47,727,101	0	632,609	21,868	48,381,578
Atlantic Cod	*Gadus morhua*	0	0	0	25,942	0	0	0	25,942
Haddock	*Melanogrammus aeglefinus*	0	11	11	0	0	0	0	0
Pollock	*Pollachius virens*	0	40	40	0	0	18,291	0	18,291
Spotted Hake	*Urophycis regia*	0	48	48	0	0	0	0	0
Red Hake	*Urophycis chuss*	0	1,137	1,137	0	0	0	0	0
Croakers/Drums									
Weakfish	*Cynoscion regalis*	750	26	776	0	0	1,805,066	18,207	1,823,273
Scup/Weakfish	*Stenotomus chrysops/Cynoscion regalis*	0	0	0	21,268,026	0	0	0	21,268,026
Cusk-eels									
Striped Cusk-Eel	*Ophidion marginatum*	10	22	32	0	0	0	0	0

Table A-53
Annual finfish impingement and entrainment–RFK (continued)

Common Name	Scientific Name	Annual Impingement (# of juveniles)	Annual Impingement (# of yearlings and older)	Total Annual Impingement (All Life Stages)	Annual Entrainment (# of eggs)	Annual Entrainment (# of yolk sac larvae)	Annual Entrainment (# of post yolk sac larvae)	Annual Entrainment (# of juveniles)	Total Annual Entrainment (All Life Stages)
Eels									
American Eel	*Anguilla rostrata*	0	12	12	0	0	0	332,747	332,747
Hakes									
Silver Hake	*Merluccius bilinearis*	0	169	169	0	0	0	0	0
Herrings/Shad									
Blueback Herring	*Alosa aestivalis*	14	12	26	0	0	0	0	0
Alewife	*Alosa pseudoharengus*	18	0	18	0	0	0	0	0
Atlantic Menhaden	*Brevoortia tyrannus*	8,002	47,677	55,679	20,188,200	51,353	304,440,162	676,316	325,356,031
Atlantic Herring	*Clupea harengus*	101	121	222	0	0	23,557	0	23,557
Herring Family	*Clupea* sp.	0	0	0	0	0	53,400	0	53,400
Gobies									
Goby Family	Gobiidae sp.	0	0	0	0	27,965	25,154,617	0	25,182,582
Seaboard Goby	*Gobiosoma ginsburgi*	0	0	0	0	0	0	18,284	18,284
Gunnels									
Rock Gunnel	*Pholis gunnellus*	0	0	0	0	13,429	821,264	0	834,693
Jacks									
Mackerel Scad	*Decapterus macarellus*	0	8	8	0	0	0	0	0
Lookdown	*Selene vomer*	6	0	6	0	0	0	0	0
Killifishes									
Sheepshead Minnow	*Cyprinodon variegatus*	20	6	26	0	0	0	0	0
Mummichog	*Fundulus heteroclitus*	326	399	725	0	0	0	0	0
Striped Killifish	*Fundulus majalis*	2,893	1,219	4,112	0	0	0	0	0
Left-eye Flounders									
Gulf Stream Flounder	*Citharichthys arctifrons*	0	51	51	0	0	0	0	0
Smallmouth Flounder	*Etropus microstomus*	6	33	39	0	0	0	0	0
Fourspot Flounder	*Hippoglossina oblonga*	0	6	6	0	0	0	0	0
Summer Flounder	*Paralichthys dentatus*	0	0	0	0	0	11,760	0	11,760

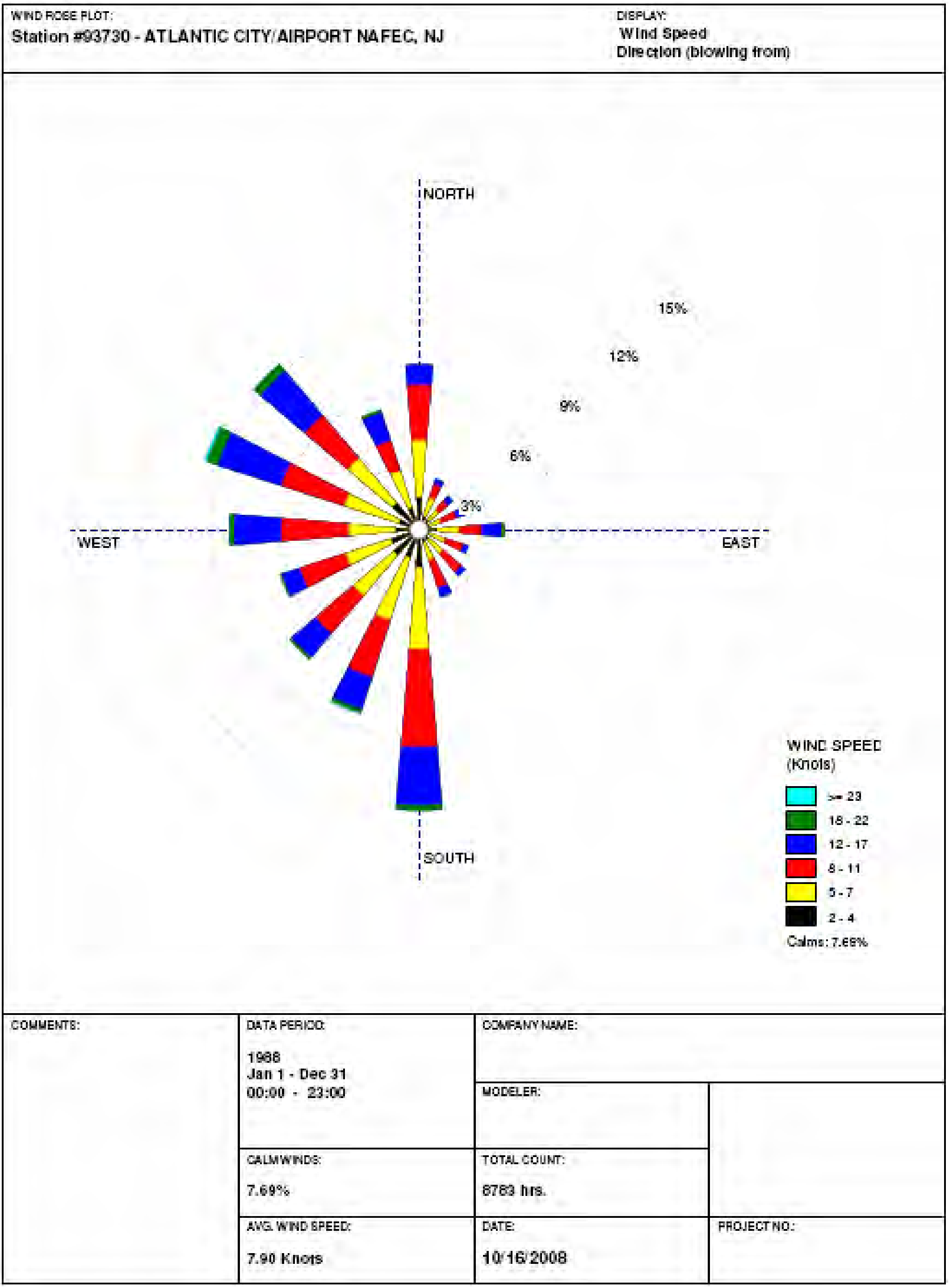
Table A-53
Annual finfish impingement and entrainment–RFK (continued)

Common Name	Scientific Name	Annual Impingement (# of juveniles)	Annual Impingement (# of yearlings and older)	Total Annual Impingement (All Life Stages)	Annual Entrainment (# of eggs)	Annual Entrainment (# of yolk sac larvae)	Annual Entrainment (# of post yolk sac larvae)	Annual Entrainment (# of juveniles)	Total Annual Entrainment (All Life Stages)
Mackerels									
Atlantic Mackerel	*Scomber scombrus*	0	0	0	421,939	0	0	0	421,939
Mullets									
Mullets	Mugilidae sp.	0	0	0	123,361	0	0	0	123,361
Pipefishes									
Lined Seahorse	*Hippocampus erectus*	0	6	6	0	0	0	0	0
Northern Pipefish	*Syngnathus fuscus*	6	49	55	0	0	236,173	15,456	251,629
Porgies									
Scup	*Stenotomus chrysops*	734	330	1,064	0	0	3,599,266	14,952	3,614,218
Right-eye Flounders									
Winter Flounder	*Pseudopleuronectes americanus*	292	349	641	621,510	9,135	12,228,403	247,239	13,106,287
Sand Lances									
American Sand Lance	*Ammodytes americanus*	0	0	0	0	0	137,893	0	137,893
Sculpins									
Grubby	*Myoxocephalus aenaeus*	14	355	369	0	63,215	274,793	13,475	351,483
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*	0	0	0	0	0	74,261	0	74,261
Shorthorn Sculpin	*Myoxocephalus scorpius*	0	0	0	0	0	12,500	0	12,500
Sea Basses									
Black Sea Bass	*Centropristis striata*	223	205	428	0	0	0	0	0
Sea Robins									
Searobins	*Prionotus* sp.	1,417	1,307	2,724	37,800,414	0	2,616,411	73,885	40,490,710
Silversides									
Silverside Family	Atherinopsidae sp.	0	0	0	0	0	426,218	0	426,218
Atlantic Silverside	*Menidia menidia*	103	1,989	2,092	0	0	560,197	313,775	873,972

Table A-53
Annual finfish impingement and entrainment–RFK (continued)

Common Name	Scientific Name	Annual Impingement (# of juveniles)	Annual Impingement (# of yearlings and older)	Total Annual Impingement (All Life Stages)	Annual Entrainment (# of eggs)	Annual Entrainment (# of yolk sac larvae)	Annual Entrainment (# of post yolk sac larvae)	Annual Entrainment (# of juveniles)	Total Annual Entrainment (All Life Stages)
Soles									
Hogchoker	*Trinectes maculatus*	0	0	0	1,606,163	0	0	0	1,606,163
Skates									
Little Skate	*Leucoraja erinacea*	0	15	15	0	0	0	0	0
Snappers									
Gray Snapper	*Lutjanus griseus*	7	0	7	0	0	0	0	0
Sticklebacks									
Threespine Stickleback	*Gasterosteus aculeatus*	0	122	122	0	0	0	0	0
Stargazers									
Northern Stargazer	*Astroscopus guttatus*	0	8	8	0	0	0	0	0
Toadfishes									
Oyster Toadfish	*Opsanus tau*	15	13	28	0	0	0	0	0
Turbots									
Windowpane	*Scophthalmus aquosus*	7	6	13	20,993,165	16,899	658,061	57,115	21,725,240
Wrasses									
Tautog	*Tautoga onitis*	529	100	629	114,617,956	29,189	100,766,225	420,448	215,833,818
Cunner	*Tautogolabrus adspersus*	1,325	400	1,725	189,424,087	0	8,707,723	238,623	198,370,433
	Total	**18,244**	**57,860**	**76,104**	**507,551,427**	**225,848**	**504,034,780**	**3,105,295**	**1,014,917,350**

A.13.6 Air Quality



WIND ROSE PLOT:
Station #93730 - ATLANTIC CITY/AIRPORT NAFEC, NJ

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:

DATA PERIOD:
1988
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:

MODELER:

CALM WINDS:
7.69%

TOTAL COUNT:
8783 hrs.

AVG. WIND SPEED:
7.90 Knots

DATE:
10/16/2008

PROJECT NO.:

Figure A-65
Wind speed and direction for RFK

A.13.7 Population Information

Figure A-66
Census blocks detailing local household numbers surrounding RFK

A.13.8 Summary of Potential Issues with Cooling Tower Implementation

Table A-54
Summary of impacts and issues at RFK [3]

Resource	Issues
Engineering	Severe space limitation. Likely not feasible to locate cooling towers at this site. Need to cut and re-grade hill. Need to provide sufficient grade and stabilize hill adjacent to the main plant. Need to pump makeup and cooling water up to the cooling tower basins, which would be at approximately 100 ft elevation differential.
Aquatic Biota	Net reduction in IM&E.
Terrestrial Resources	Potential impacts to upland forest communities.
Water Consumption	A CCC retrofit would increase consumptive use of water. However, because the source water is saline, its impact is only marginal.
Public Safety	Fogging
Quality of Life	Noise, view shed, shadowing impacts at surrounding residential properties. Salt deposition concerns [27].
Permitting	Permitting a large structure such as a cooling tower with its associated visual, noise and plume concerns would be difficult; expect significant opposition from surrounding residential communities [27]. Coastal Zone Management Regulations would be required for the construction of cooling towers adjacent to tidal waters. Proposed cooling tower locations were identified on an existing conservation easement. This would require coordination with the appropriate agencies managing the easement. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of CO_2.
Other	

A.14 Representative Facility L (RFL)

Retrofitting RFL’s once-through cooling system with CCC appears to be potentiaaly feasible with a moderate to high level of difficulty. The main challenges include the need to run large diameter pipes over long distances across the main plant area and the need to avoid operating hazards on the switchyard and transmission lines.

The retrofit would reduce cooling water intake to the plant. A corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit would likely introduces several new environmental concerns like reductions in air quality, loss of wetlands and Waters of the U.S., and potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are discussed below.

The facility consists of five generating units (Units 1-5), all of which utilize once-through cooling [43]. For study purposes, two cooling towers are proposed for this facility: one for Units 1-3 and another for Units 4 and 5. The sizes, locations, and impacts of these hypothetical cooling towers are discussed below.

A.14.1 Background

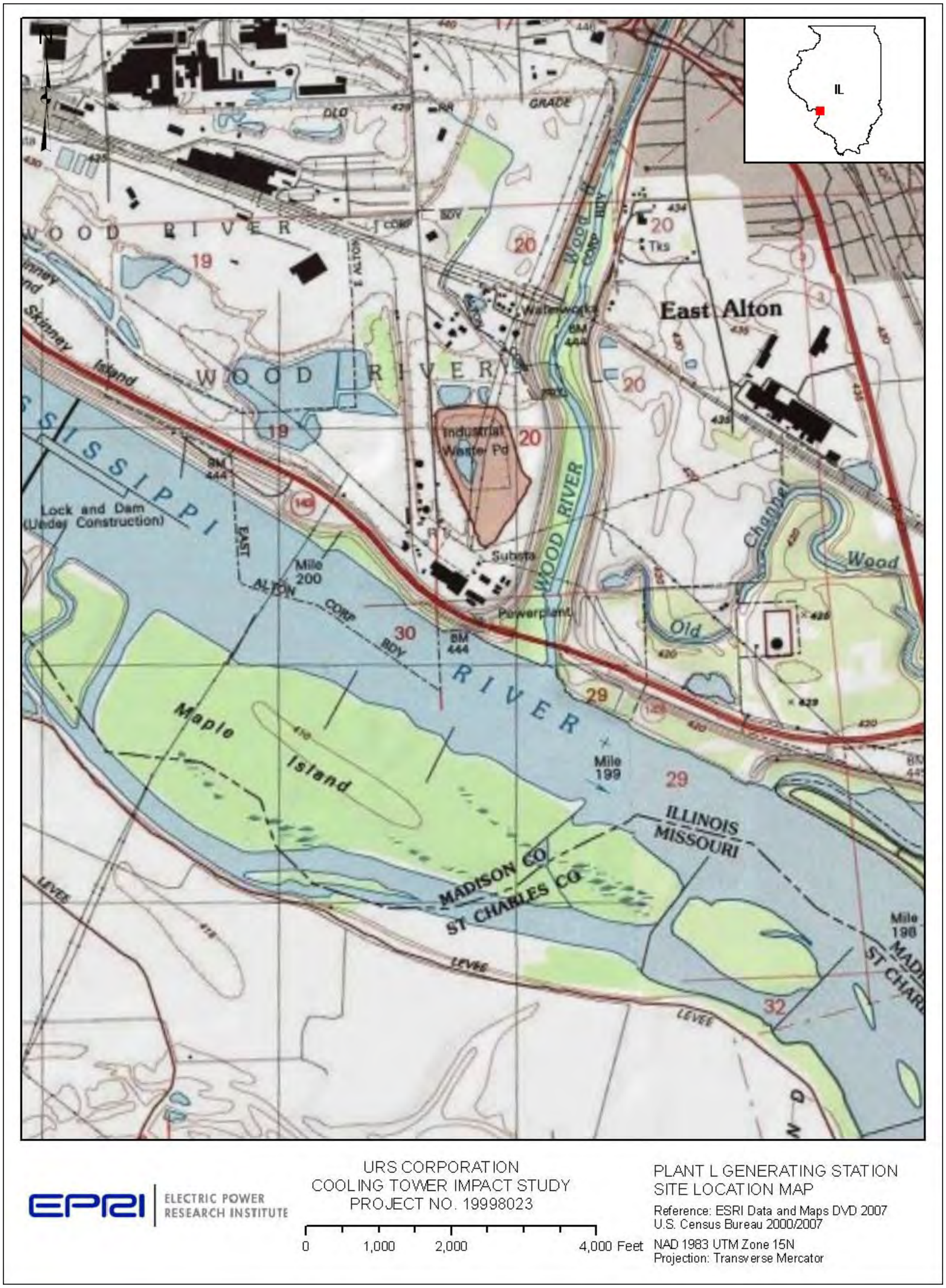
RFL is a 621 MW steam electricity generating facility located in the U.S. Midwest, on a large river [43]. The facility consists of five generating units. Unit 1-3 are peaking units fueled by natural gas and are each rated at 43 MW. Units 4 and 5 are base-load units fueled by coal and have generating capacities of 96 MW and 396 MW, respectively [43]. The facility is located approximately 20 miles northeast of a Midwestern city, and is zoned as Industrial within Enterprise Zone.

RFL withdraws once-through cooling water from the river and returns the heated water back to the same river via a discharge tunnel [43]. The river is a large navigable river with significant barge traffic. The design cooling water intake rate for the facility is 428,500 gpm; this is approximately 0.68 percent of the mean annual river flow rate locally for period 1976–1986 [43]. A lock and dam is located approximately 0.7 miles upstream of the RFL’s CWIS [43].

A location map of RFL is provided as Figure A-67. Key information for each generating unit is provided in the following table.

Table A-55
RFL engineering information [43, 27, 26]

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 1	43	74,000	20	1949	1%
Unit 2	43	74,000	20	1949	1%
Unit 3	43	74,000	20	1950	1%
Unit 4	96	66,500	15.8	1954	67%
Unit 5	396	140,000	15.8	1964	67%
Total	**621**	**428,500**	**NA**	**NA**	**NA**



URS CORPORATION
COOLING TOWER IMPACT STUDY
PROJECT NO. 19998023

PLANT L GENERATING STATION
SITE LOCATION MAP

Reference: ESRI Data and Maps DVD 2007
U.S. Census Bureau 2000/2007
NAD 1983 UTM Zone 15N
Projection: Transverse Mercator

Figure A-67
RFL site location map

A.14.2 Cooling Water Intake Structure

The RFL CWIS extends approximately 50 ft from the shoreline into the river and consists of four intake bays, each equipped with a bar rack and a traveling water screen with 3/8 in square mesh openings [43]. The traveling water screens have 10 ft wide baskets and are approximately 27 ft downstream of the bar racks [43]. Cooling water from the intake structure is conveyed to the plant via a common intake tunnel that extends approximately 32 ft from the traveling water screens [43].

RFL's traveling water screens typically operate for a 15 minute period once every hour [43]. The screens may be rotated more frequently during high debris loading events [43]. Fish and debris collected on the traveling screens are removed using high pressure spray wash systems at two locations: at the operating deck of the CWIS and approximately 20 ft below the operating deck. Fish and debris removed from screens are returned to the river.

Two circulating water pumps are associated with each condenser. The discharge tunnel that returns the cooling water to the river is located immediately above the intake tunnel. The discharge tunnel terminates at the riverbank downstream of the intake [43].

A.14.3 Proposed Cooling Towers at RFL

Limited availability of space in the vicinity of the intake structure and condensers poses a challenge to retrofitting RFL with CCC. Space is available further north of the main plant area. To optimize use of available space, for study purposes, the hypothetical cooling towers for Units 1-3 and Units 4-5 have been combined. The hypothetical cooling tower locations are shown in Figure A-68.

The preliminary design used for the study of this facility includes a 24-cell cooling tower for Units 1-3 located north of the switchyard, and a 22-cell cooling tower for Units 4-5 located to the north of the fuel tank, east of a local lane and west of the new ash pond. All cooling towers are assumed to be counter flow with back-to-back cell arrangements, and oriented north-south in alignment with the predominant summer wind direction [25].

The Units 1-3 cooling tower range was estimated to allow for the design heat discharge rate of the three units and total cooling water flow rate. The Units 4-5 cooling tower range and flow rate were also similarly estimated. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells was determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The wet-bulb temperature with 1 percent exceedance for this location is 80°F [26]; the source water TDS is between 300-400 ppm [27]. It is assumed that service water needs would remain approximately the same after the CCC retrofit. The basic characteristics of the towers for RFL are given in Table A-56 [24].

Figure A-68
RFL conceptual cooling tower location map

Table A-56
Basic characteristics of cooling towers proposed for RFL

Unit Designation		Units 1-3	Units 4-5
Cooling Tower Water Flow Rate	gpm	222,000	206,500
Cooling Tower Range	°F	20	15.8
No. and Arrangement of Cooling Tower Cells		24/ Back-to-back	22/ Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	608 x 108 x 6	558 x 108 x 6
Lift Pump Total	hp	2,469	2,297
Fan Total	hp	4,800	4,400
Fan Diameter	ft	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36
Drift Elimination Efficiency	%	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	9.26E+07	7.42E+07
Cycles of Concentration		6	6
Drift Rate	gpm	1.1	1.0
Cooling Tower Evaporation Rate	gpm	4,440	3,263
Blowdown Rate	gpm	888	653
Makeup Rate	gpm	5,329	3,916

A few of the engineering challenges associated with locating cooling towers at RFL are listed below.

- The Units 1-3 cooling tower has been located immediately north of the switchyard. Ice formation on transmission lines could be potentially hazardous. In order to minimize potential hazards, a cooling tower located so close to the switchyard and transmission lines would likely need plume-abatement. However, plume-abated towers can only be arranged in-line. There may be insufficient space for plume-abated towers.
- There is no available space in the immediate vicinity of the intake structures, intake tunnel or the turbine buildings. Therefore, the hypothetical cooling towers have been located further north of the main plant areas. Long runs of large diameter pipes would be needed to convey cooling water between the condensers and the cooling towers. These pipes would have to cross the main plant area and other existing overhead and buried infrastructure as well.

- RFL is adjacent to a highway and a lane. Fogging and icing during cooling tower operation could occasionally reduce visibility on the highway and local roads and, therefore, pose a hazard to driving.

A.14.4 Alternative Cooling Towers and Locations Considered

Alternate cooling tower locations include the plant area immediately southeast of the turbine buildings, and the area far northwest of the coal pile.

Due to its close proximity to the intake tunnel and condensers, the area immediately southeast of the turbine buildings would likely have been the preferred site for the 22-cell tower (Units 4-5) conceptualized for this study. However, this location has already been identified for a new environmental project and, therefore, is unavailable for cooling towers.

While the area far northwest of the coal pile is a potential location for a cooling tower, routing large diameter pipes approximately 3,000 ft each way between the cooling towers and condensers and crossing the coal pile and the lane would also be very difficult.

The feasibility of natural draft, dry or hybrid towers would need to be further evaluated. These alternate types of towers are more costly and less efficient than the MECTs proposed herein (See Section 6 for additional information on alternative towers).

A.14.5 Aquatic Biota

Biological information for RFL was provided by the power plant [44] and is summarized in Table A-57. The given annualized impingement numbers are based on actual cooling water usage.

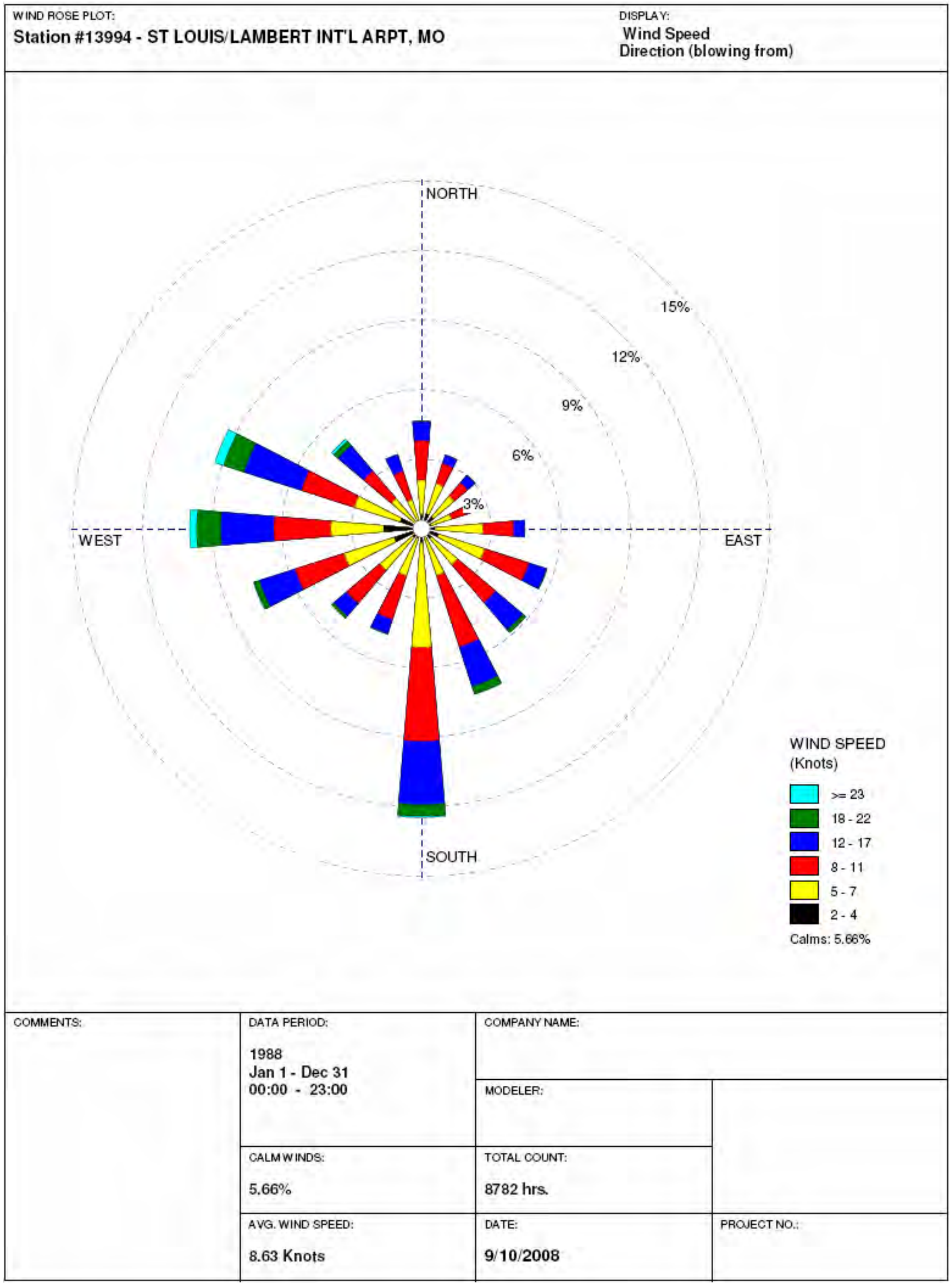
Table A-57
Annual finfish impingement–RFL

Common Name	Scientific Name	Annual Impingement (# of fish)
Basses		
White Bass	*Morone chrysops*	155
Carps/Minnows		
Goldfish	*Carassius auratus*	57
Common Carp	*Cyprinus carpio*	215
Silver Carp	*Hypophthalmichthys molitrix*	18
Silver Chub	*Macrhybopsis storeriana*	15
Emerald Shiner	*Notropis atherinoides*	105
Bullhead Minnow	*Pimephales vigilax*	23
Carpsuckers		
River Carpsucker	*Carpiodes carpio*	119
Drums/Croakers		
Freshwater Drum	*Aplodinotus grunniens*	25,717

Table A-57
Annual finfish impingement–RFL (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)
Freshwater Catfishes		
Blue Catfish	*Ictalurus furcatus*	419
Channel Catfish	*Ictalurus punctatus*	1,331
Flathead Catfish	*Pylodictis olivaris*	177
Herrings/Shad		
Skipjack Herring	*Alosa chrysochloris*	36
Gizzard Shad	*Dorosoma cepedianum*	32,980
Mooneyes		
Goldeye	*Hiodon alosoides*	11
Mooneye	*Hiodon tergisus*	316
Sturgeons		
Shovelnose Sturgeon	*Scaphirhynchus platorynchus*	18
Sunfishes		
Sunfish, unid.	*Lepomis* sp.	14
Green Sunfish	*Lepomis cyanellus*	94
Warmouth	*Lepomis gulosus*	11
Orangespotted Sunfish	*Lepomis humilis*	11
Bluegill	*Lepomis macrochirus*	927
Largemouth Bass	*Micropterus salmoides*	38
White Crappie	*Pomoxis annularis*	17
Black Crappie	*Pomoxis nigromaculatus*	24
	Total	**62,847**

A.14.6 Air Quality


WIND ROSE PLOT:
Station #13994 - ST LOUIS/LAMBERT INT'L ARPT, MO

DISPLAY:
Wind Speed
Direction (blowing from)

COMMENTS:

DATA PERIOD:
1988
Jan 1 - Dec 31
00:00 - 23:00

COMPANY NAME:

MODELER:

CALM WINDS:
5.66%

TOTAL COUNT:
8782 hrs.

AVG. WIND SPEED:
8.63 Knots

DATE:
9/10/2008

PROJECT NO.:

Figure A-69
Wind speed and direction for RFL

A.14.7 Population Information

Figure A-70
Census blocks detailing local household numbers surrounding RFL

A.14.8 Summary of Potential Issues with Cooling Tower Implementation

Table A-58
Summary of impacts and issues at RFL [3]

Resource	Issues
Engineering	The Units 1-3 tower has been located immediately north of the switchyard. The addition of water vapor to the atmosphere during cooling tower operation may cause icing and subsequent damage of nearby high voltage transmission lines during cold weather. The proposed locations require conveyance of cooling water over long distances.
Aquatic Biota	Net reduction in IM&E.
Terrestrial Resources	Potential impacts to wetlands.
Water Consumption	The retrofit would increase the consumptive use of water, but it is currently not regulated by a state department or regional basin commission.
Public Safety	Due to icing and fogging, visibility and driving conditions on the highway and on the lane in the vicinity of RFL may occasionally be affected due to cooling tower operation.
Quality of Life	Noise impacts and visible plume.
Permitting	Loss of wetlands and Waters of the U.S. would be regulated by State and/or Federal agencies. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of $CO_{2.}$
Other	

A.15 Representative Facility M (RFM)

Retrofitting RFM’s once-through cooling system with CCC appears to be feasible, but is deemed difficult. The choices for locating cooling towers onsite is very limited, with most likely the only available space being in a flood-prone area between the plant and the river/lake, which presents a significant engineering and construction challenge.

A CCC retrofit, in general, greatly reduces cooling water intake to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the retrofit. However, this retrofit introduces several new potential environmental concerns such as reduced visibility during navigation, floodplain impacts, and others. These issues also are discussed below.

The facility currently consists of three generating units (Units 1-3), all of which utilize once-through cooling systems [45]. For study purposes, three cooling towers, one per generating unit, are proposed for this facility. The sizes, locations and impacts of these hypothetical cooling towers are discussed below.

A.15.1 Background

RFM is a 990 MW coal-fired steam electricity generating facility. The facility is located on a 499 acre reservation in a highly urbanized area, on the south shore of an oxbow lake that is hydraulically connected to a large river [46]. RFM withdraws up to 345,000 gpm of cooling water from the large river [45]. In addition to the three steam turbines, there are 20 gas turbines at RFM that can provide another 621 MW of power during periods of peak demand [46]. The gas turbines do not require cooling water in order to operate.

In the immediate vicinity of the facility are industrial sites; residential properties are located approximately three miles away [46]. A location map of RFM is provided as Figure A15-1. Key information for each generating unit is provided in the following table.

Table A-59
RFM engineering information [45]

Generating Unit	Rated Capacity (MW)	Cooling Water Flow Rate (gpm)	Condenser ΔT (°F)	Year On-line	Capacity Factor, 2004
Unit 1	330	115,000	20	1959	64%
Unit 2	330	115,000	20	1959	52%
Unit 3	330	115,000	20	1959	51%
Total	**990**	**345,000**	**NA**	**NA**	**NA**

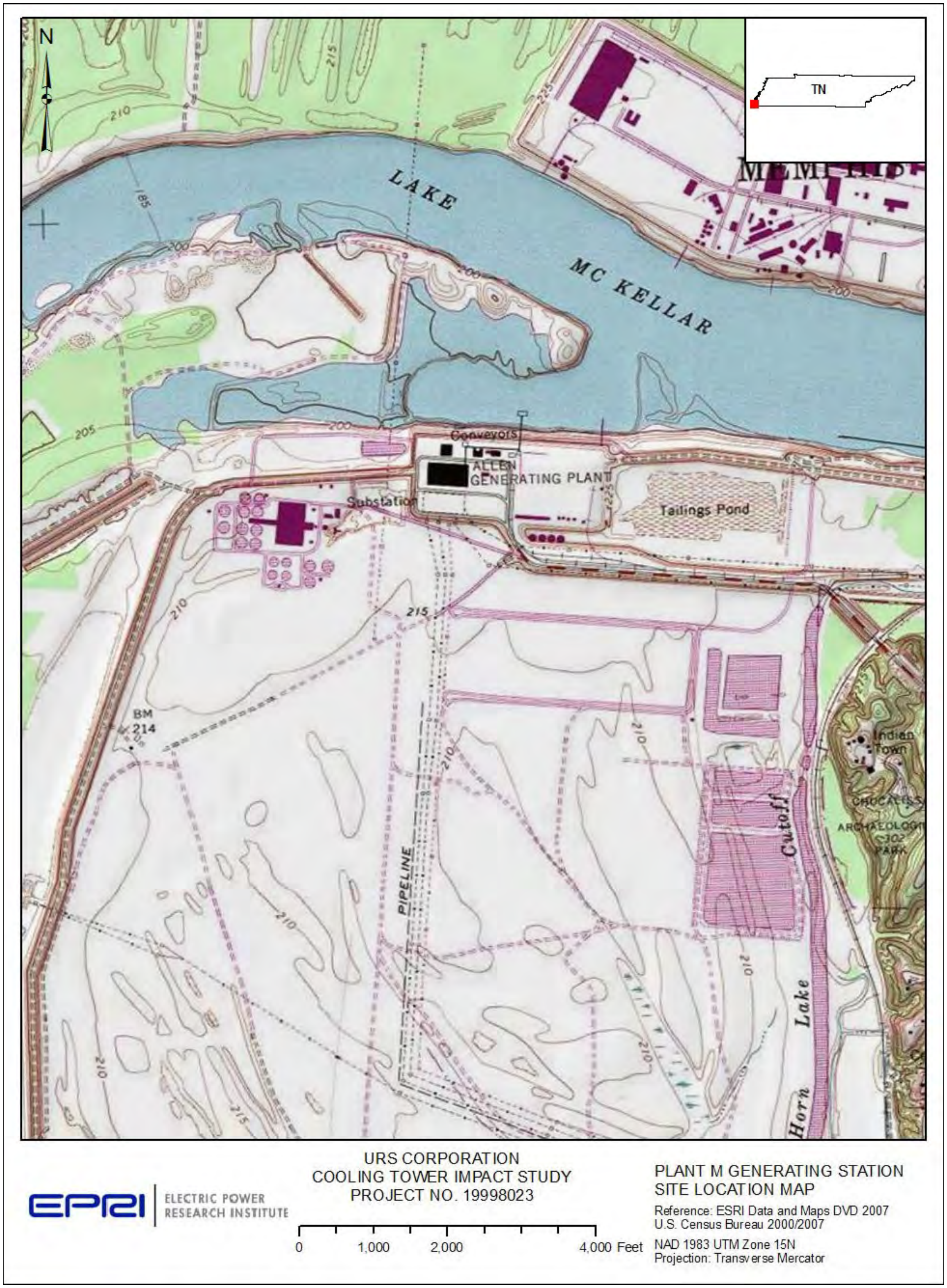


Figure A-71
RFM site location map

A.15.2 Cooling Water Intake Structure

RFM withdraws cooling water via a CWIS having three submerged intake chamber openings (one per generating unit), with each chamber having three traveling water screens and two cooling water pumps. A single trash rack, with steel bars set on 5 in centers, spans across the entire CWIS [47]. Cooling water passes through the trash rack, the 3/8 in square openings of the nine traveling water screens, and the back end of the three chambers before entering a common manifold where the water is transported to the condensers [47] via circulating water tunnels (one per unit).

The heated cooling water is returned to the large river via a series of pipes, tunnels, and an open channel [45].

A.15.3 Proposed Cooling Towers at RFM

The conceptual design for this facility includes three 14-cell back-to-back cooling towers, one per generating unit, located immediately northwest of the main plant area. This section of the property is prone to flooding [27]; however, this is the only space available. The conceptual cooling tower locations are shown in Figure A-72. Design and construction of cooling towers on the floodplain would be challenging. The cooling towers are oriented southwest to northeast to allow for locating of towers within the available space.

The conceptual cooling towers have been located to the west of the existing intake structure. The circulating water pipes likely also would be installed in the floodplain and tied-in at the intake structure.

The design wet-bulb temperature used for RFM is 81°F [26]; the source water TDS is approximately 200 ppm. For study purposes, all cooling tower cells have been sized at 50 ft x 50 ft x 55 ft and the number of cells was determined by allowing for a cooling water throughput of approximately 10,000 gpm per cell. The basic characteristics of the towers for RFM are given in the following table [24].

Figure A-72
RFM conceptual cooling tower location map

Table A-60
Basic characteristics of cooling towers proposed for RFM

Unit Designation		Unit 1	Unit 2	Unit 3
Cooling Tower Water Flow Rate	gpm	115,000	115,000	115,000
Cooling Tower Range	°F	20	20	20
No. and Arrangement of Cooling Tower Cells		14/ Back-to-back	14/ Back-to-back	14/ Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	358 x 108 x 6	358 x 108 x 6	358 x 108 x 6
Lift Pump Total	hp	1,279	1,279	1,279
Fan Total	hp	2,800	2,800	2,800
Fan Diameter	ft	32.8	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36	36
Drift Eliminator Efficiency	%	0.0005	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	8.22E+07	8.22E+07	8.22E+07
Cycles of Concentration		8	8	8
Drift Rate	gpm	0.6	0.6	0.6
Cooling Tower Evaporation Rate	gpm	2,300	2,300	2,300
Blowdown Rate	gpm	329	329	329
Makeup Rate	gpm	2,629	2,629	2,629

Several of the engineering challenges associated with locating cooling towers at RFM are listed below.

- Sections of the RFM property suitable for construction are either already utilized or are earmarked for new projects. Undeveloped sections of the property are less desirable for construction. The proposed cooling towers have been located in the floodplain. Engineering and construction at this location would be challenging.
- RFM is located on a large lake near a navigable river. Compromised visibility during cooling tower operation could be hazardous to navigation.
- The cooling water flow rate needs to be engineered to limit cooling water tunnel pressure to between 8-10 ft [27].
- Cooling water may need to cross the U.S. Army Corps of Engineers (USACE) flood levy [27].
- The local POTW currently discharges via the RFM cooling water discharge tunnel [27]. The CCC retrofit would eliminate the dilution that RFM affords the POTW discharge. A replacement dilution source might be needed.
- The relatively high wet bulb temperature at this facility would result in a correspondingly high ‘cold water’ temperature and a relatively high energy penalty.

A.15.4 Alternative Cooling Towers and Locations Considered

Several alternate cooling tower locations were considered for this site. These include the currently inactive ash pond at the western edge of the property; the strip of land immediately to the south of the switchyard, the available space to the southeast of the coal pile, and the strip of property on the riverbank to the northeast of the coal pile.

The inactive ash pond is currently earmarked for a new environmental project; and the precipitator pad drainage and roof drains are routed through this location [27]. In addition, the control of this property would revert back to the City at its discretion [27].

The area immediately south of the switchyard was eliminated due to lack of space, close proximity to the switchyard and the potential need to relocate high voltage transmission lines should cooling towers be located in its vicinity.

There is insufficient space for three cooling towers on the section of property southeast of the coal pile; this location would require cooling water pipes to be routed directly across the site.

The section of property northeast of the coal pile is also flood-prone; this location is further away from the intake structures and would, therefore, require additional lengths of pipe if potential cooling towers were located here.

There appears to be insufficient space for hyperbolic natural draft, dry or hybrid cooling towers at RFM.

A.15.5 Aquatic Biota

Biological information for RFM was provided by the power plant [48] and is summarized in Table A-61. The given annualized impingement numbers are based on actual cooling water usage.

Table A-61
Annual finfish impingement–RFM

Common Name	Scientific Name	Annual Impingement (# of fish)
Basses		
White Bass	*Morone chrysops*	102
Yellow Bass	*Morone mississippiensis*	347
Striped Bass	*Morone saxatilis*	53
Carp		
Largescale Stoneroller	*Campostoma oligolepis*	4
Common Carp	*Cyprinus carpio*	4
Silver Carp	*Hypophthalmichthys molitrix*	19,646
Silver Chub	*Macrhybopsis storeriana*	350

Table A-61
Annual finfish impingement–RFM (continued)

Common Name	*Scientific Name*	Annual Impingement (# of fish)
Golden Shiner	*Notemigonus crysoleucas*	140
Emerald Shiner	*Notropis atherinoides*	385
Bluntnose Minnow	*Pimephales notatus*	91
Fathead Minnow	*Pimephales promelas*	189
Drums/Croakers		
Freshwater Drum	*Aplodinotus grunniens*	24,647
Freshwater Catfishes		
Black Bullhead	*Ameiurus melas*	4
Yellow Bullhead	*Ameiurus natalis*	18
Blue Catfish	*Ictalurus furcatus*	2,916
Channel Catfish	*Ictalurus punctatus*	2,741
Flathead Catfish	*Pylodictis olivaris*	63
Herring/Shad		
Skipjack Herring	*Alosa chrysochloris*	56,109
Gizzard Shad	*Dorosoma cepedianum*	83,773
Threadfin Shad	*Dorosoma petenense*	30,440
Gars		
Longnose Gar	*Lepisosteus osseus*	4
Shortnose Gar	*Lepisosteus platostomus*	7
Lampreys		
Chestnut Lamprey	*Ichthyomyzon castaneus*	7
Paddlefishes		
Paddlefish	*Polyodon spathula*	375
Perches		
Logperch	*Percina caprodes*	494
Sauger	*Stizostedion canadense*	564
Walleye	*Stizostedion vitreum*	14
Silversides		
Brook Silverside	*Labidesthes sicculus*	28
Suckers		
River Carpsucker	*Carpiodes carpio*	67
Quillback	*Carpiodes cyprinus*	25
Smallmouth Buffalo	*Ictiobus bubalus*	14
Sturgeon		
Shovelnose Sturgeon	*Scaphirhynchus platorynchus*	4

Table A-61
Annual finfish impingement–RFM (continued)

Common Name	*Scientific Name*	Annual Impingement (# of fish)
Sunfishes		
Flier	*Centrarchus macropterus*	7
Green Sunfish	*Lepomis cyanellus*	7
Warmouth	*Lepomis gulosus*	35
Bluegill	*Lepomis macrochirus*	994
Longear Sunfish	*Lepomis megalotis*	151
Smallmouth Bass	*Micropterus dolomieu*	28
Spotted Bass	*Micropterus punctulatus*	4
Largemouth Bass	*Micropterus salmoides*	14
White Crappie	*Pomoxis annularis*	305
Black Crappie	*Pomoxis nigromaculatus*	4
	Total	**225,173**

A.15.6 Population Information

Figure A-73
Census blocks detailing local household numbers surrounding RFM

A.15.7 Summary of Potential Issues with Cooling Tower Implementation

Table A-62
Summary of impacts and issues at RFM [3]

Resource	Issues
Engineering	Severe space limitation. Need to construct in floodplain. May need to relocate some existing infrastructure to accommodate cooling towers and associated piping. Potential for interference with underground utilities.
Aquatic Biota	Net reduction in IM&E.
Terrestrial Resources	Potential impacts to floodplain. State park located adjacent to the facility.
Water Consumption	The consumptive use of water would increase if a CCC retrofit were implemented, but it is currently not regulated by a state department or regional basin commission.
Public Safety	Visibility during navigation on navigable waterways in the vicinity of the facility may be compromised during cooling tower operations.
Quality of Life	Noise impacts.
Permitting	Impacts to floodplains would be regulated by State and/or Federal agencies. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of CO_2.
Other	

A.16 Representative Facility N (RFN)

Retrofitting RFN’s once-through cooling system with CCC appears to be potentially feasible with an average level of difficulty.

The retrofit would reduce cooling water intake rate to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit would introduce several new environmental concerns like reductions in air quality for plant workers, plume carry-over to adjoining residential properties, and potential loss of wetlands and Water of the U.S. These issues are also discussed below.

The facility consists of four generating units (Units 1-4). Units 1 and 2 utilize once-through cooling systems; Unit 3 and 4 utilize CCC [49]. This study assumes that one additional cooling tower would be shared by Units 1 and 2. The size, location and impacts of the hypothetical cooling tower are also discussed below.

A.16.1 Background

RFN is a 1,025 MW coal-fired steam electricity generating facility located in the U.S. Midwest. The facility consists of four generating units: Units 1 and 2, each rated at 70 MW, utilize once-through cooling; Units 3 and 4, rated at 350 MW and 535 MW, respectively, utilize CCC [24]. RFN is located on the eastern shore of a lake, which is one of several lakes within the reservoir. The reservoir was formed by damming a large river [49]. The design intake cooling water flow rate for Units 1 and 2 is 108,000 gpm.

While separated from the energy center by the lake, there is a significant residential presence in the area southeast of the plant [27]. In addition, the lake/river area is used by recreational boaters, anglers, wild rice harvesters, and hunters [27]. Additional industrial facilities and residences are located within a mile of the proposed cooling tower location. These include a greenhouse, a utility vehicle manufacturer, an environmental learning center for schoolchildren, and several Habitat for Humanity homes [27]. RFN's surroundings are zoned as heavy industrial and manufacturing [3].

A location map of RFN is provided as Figure A-62. Key information for units that utilize once-through cooling is provided in the following table.

Table A-63
RFN engineering information for units that utilize once-through cooling [24, 27]

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 1	70	54,000	14.1	1958	76%
Unit 2	70	54,000	14.2	1960	75%
Total	**140**	**108,000**	**NA**	**NA**	**NA**

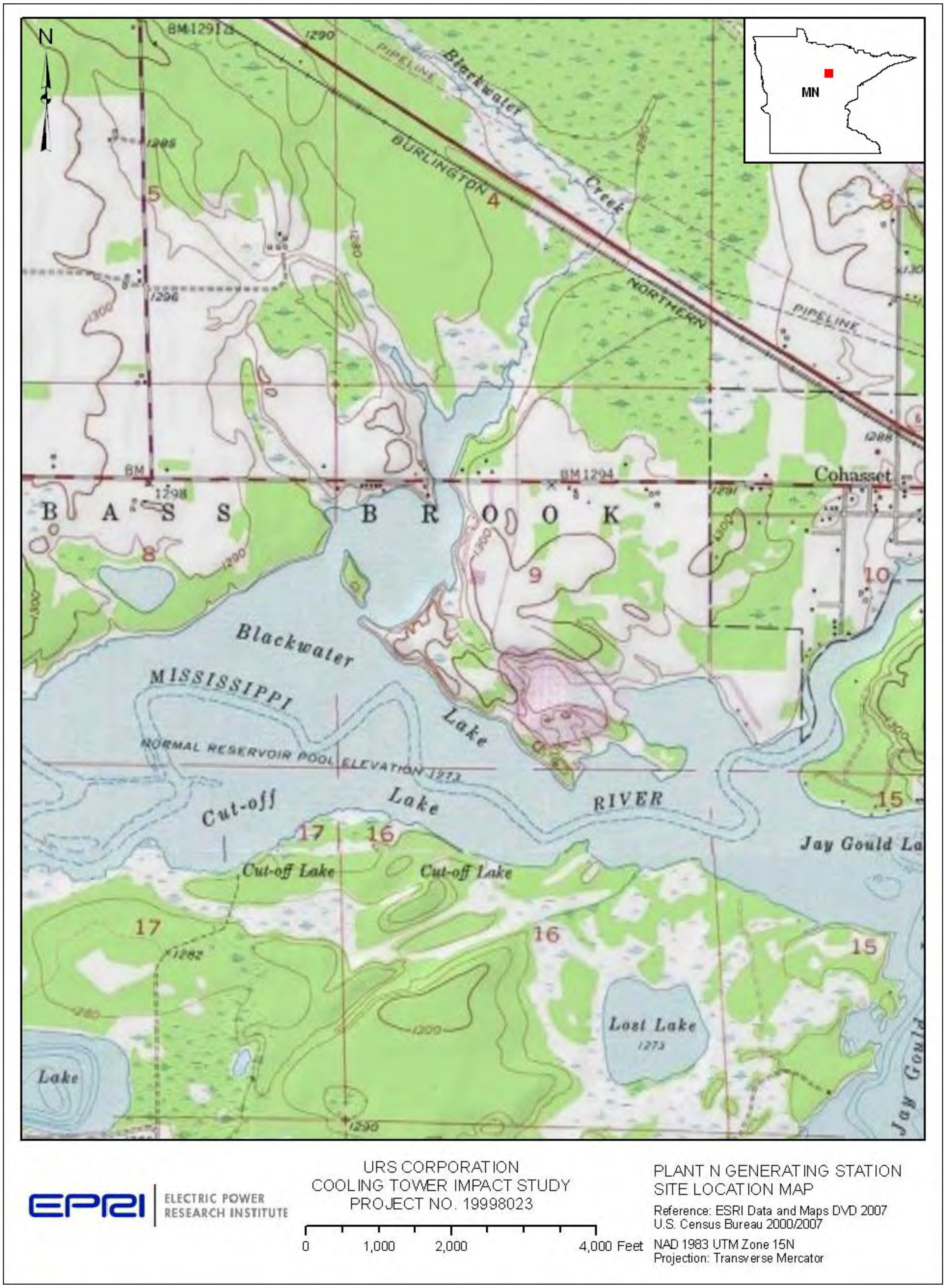


Figure A-74
RFN site location map

A.16.2 Cooling Water Intake Structure

RFN's cooling water for Units 1 and 2 and station makeup and service water are withdrawn through a single shoreline screen house located on the eastern shore of the lake. The screenhouse has two bays, one serving each unit [49].

The intake bays are each 11.5 ft wide and have a curtain wall, trash rack, and vertical traveling screen. The trash racks consist of 3/8 in wide steel bars on 3 in centers. Two 7 ft wide traveling water screens with 3/8 in square mesh openings are located approximately 9.5 ft downstream of the trash racks. The screens are normally rotated for 20-30 minutes three times daily and cleaned by a high pressure spraywash. Debris and any fish removed from the screens are washed into a trough on the front side of the screens and deposited in a trash basket [49], and later landfilled [3].

Four vertical mixed flow circulating water pumps, located downstream of the screens, provide the circulating water to the once-through units (two dedicated pumps per unit). Makeup and service water pumps are located upstream of the circulating water pumps. Once-through cooling water is discharged east of the facility through a discharge canal and is not re-circulated back to the intake, except occasionally during the winter. During winter months, to prevent sheet ice from causing intake operational problems, a portion of the heated cooling water is discharged at the front of the intake structure [49].

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity [49].

Velocities approaching the trash racks and traveling water screens are 0.6 fps and 1 fps, respectively. These velocities had been calculated at the low water level and design flow capacity [49].

A.16.3 Proposed Cooling Towers at RFN

The preliminary conceptual design used for the study of this facility includes one 12-cell cooling tower that would be shared by Units 1 and 2. This tower is assumed to be located approximately 2,000 feet to the southeast of the main plant near the discharge canal, and is shown in Figure A16-2. Unlike the existing cooling towers for Units 3 and 4, the cooling tower proposed herein for Units 1 and 2 would be a back-to-back tower without plume-abatement. Similar to the existing cooling towers, the proposed cooling tower would be oriented north-south to coincide with the predominant summer wind direction.

In order to accommodate a closed-cycle cooling tower, several existing infrastructure would need to be modified. The main effort would be for rerouting cooling water pipes-downsizing the pipes/tunnels from the intake structure, and installing new pipes to route cooling water between condensers and cooling tower basin. It is assumed that the existing intake structure would continue to be utilized, albeit in a reduced capacity. Significant buried infrastructure would need to be relocated to route these cooling water pipes.

The design wet-bulb temperature used for RFN is 75°F [3]; the source water TDS is assumed to be 200 ppm. The basic characteristics of the towers for RFN are given in the following table [24].

Figure A-75
RFN conceptual cooling tower location map

Table A-64
Basic characteristics of cooling towers proposed for RFN

Unit Designation		Units 1 and 2
Cooling Tower water flow rate	gpm	108,000
Cooling Tower Range	°F	18
No. and Arrangement of Cooling Tower Cells		12/Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	308 x 108 x 6
Lift Pump Total	hp	1,201
Fan Total	hp	2,400
Fan Diameter	ft	32.8
Fan Housing Inside Diameter at Exit	ft	36
Drift Elimination Efficiency	%	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	6.37E+07
Cycles of Concentration		8
Drift Rate	gpm	0.5
Cooling Tower Evaporation Rate	gpm	1,528
Blowdown Rate	gpm	218
Makeup Rate	gpm	1,747

Several engineering challenges associated with locating cooling towers at RFN are listed below.

- While there is seemingly significant open space onsite, there is no suitable space in close proximity to the intake structures and turbine buildings. The two larger generating units already utilize CCC, and the proposed cooling tower needs to be located a sufficient distance away from the existing cooling towers to minimize potential for interference. Therefore this facility would need to run long lengths of the piping between condensers and the cooling tower basin.
- The state department of health and department of natural resources regulate consumptive water use [24]. Installation of a CCC system would increase the consumptive use of water.
- The tower dimensions given in Table A-64 are for standard back-to-back MECT with no plume abatement. The impacts of plume, fogging and icing during winter months may be severe. The facility relies on daily shipments of coal via the adjacent railroad loop; plume icing or fogging could create both safety and operational challenges for rail delivery [27].
- RFN would need exemptions from local height and noise prior to cooling tower construction [3].

A.16.4 Alternative Cooling Towers and Locations Considered

The preference for siting of cooling towers would be at locations closer to the main plant and the intake structure to minimize disturbance onsite and away from the existing cooling towers to minimize interference, and also away from the switchyard to prevent hazardous conditions due to icing. But it is not possible to meet all these requirements at RFN. Alternate cooling tower locations considered include the section of property between the main plant and the lake and immediately to the northwest of the intake structures; the section of property to the east of the coal pile; and the section of property to the east of the switchyard.

Much of the property surrounding the lake floods; therefore, the section of property between the lake and the main plant was deemed unsuitable. The section of property east of the coal pile is a significant distance from the intake structure, discharge canal and the condensers, and would require long runs of pipe to convey cooling water. The section of property to the east of the switchyard was dismissed due to potential icing and other hazards.

Further study would be needed to show whether other cooling tower options, such as natural draft, would be viable at this site; however, there would have to be constraints imposed that would require RFN to use such alternative types of towers, which are more expensive and less efficient than the MECTs proposed herein (See Section 6 for additional information on alternative towers).

A.16.5 Aquatic Biota

Biological information for RFN was provided by the power plant [50] and is summarized in Table A16-3. The given annualized impingement numbers are based on actual cooling water usage.

Table A-65
Annual finfish impingement and entrainment–RFN

Common Name	Scientific Name	Annual Impingement (# of fish)
Bowfins		
Bowfin	*Amia calva*	153
Suckers		
White Sucker	*Catostomus commersonii*	7
Sunfishes		
Black Crappie	*Pomoxis nigromaculatus*	281
Bluegill	*Lepomis macrochirus*	18
Largemouth Bass	*Micropterus salmoides*	91
Pumpkinseed	*Lepomis gibbosus*	26
Rock Bass	*Ambloplites rupestris*	259

Table A-65
Annual finfish impingement and entrainment–RFN (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)
Carps/Minnows		
Bigeye Chubs	*Hybopsis* sp.	4
Common Shiner	*Luxilus cornutus*	4
Fathead Minnow	*Pimephales promelas*	266
Spottail Shiner	*Notropis hudsonius*	47
Pikes/Pickerels		
Northern Pike	*Esox lucius*	861
Freshwater Catfishes		
Black Bullhead	*Ameiurus melas*	420
Brown Bullhead	*Ameiurus nebulosus*	15
Tadpole Madtom	*Noturus gyrinus*	931
Yellow Bullhead	*Ameiurus natalis*	22
Cods		
Burbot	*Lota lota*	142
Perches		
Iowa Darter	*Etheostoma exile*	22
Walleye	*Sander vitreum*	1,843
Yellow Perch	*Perca flavescens*	642
Trout-perches		
Troutperch	*Percopsis omiscomaycus*	4
Salmons/Trouts		
Cisco	*Coregonus artedi*	37
Mudminnows		
Central Mudminnow	*Umbra limi*	84
	Total	**6,178**

A.16.6 Population Information

Figure A-76
Census blocks detailing local household numbers surrounding RFN

A.16.7 Summary of Potential Issues with Cooling Tower Implementation

Table A-66
Summary of impacts and issues at RFN [3, 49, 51, 52]

Resource	Issues
Engineering	Need to relocate existing infrastructure to accommodate the Units 1 and 2 cooling tower.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions. *Legionella* concerns for plant staff during maintenance [27].
Terrestrial Resources	Potential impacts to wetlands and on-site open waters. Protected species, gray wolf (State and Federally-listed threatened) habitat was identified on-site and bald eagle (State-listed species of special concern) foraging habitat was identified on-site.
Water Consumption	The large river in the vicinity of RFN is already considered to be impaired due to its elevated mercury concentrations, and consumptive water use is currently regulated by the state department of natural resources [3]. The consumptive use of water would increase if Units 1 and 2 also convert to CCC, and would concentrate existing river water constituents into a blowdown stream [27].
Solid Waste	Sulfuric acid or other pH-adjusting materials/anti-scalants would likely be needed to control scaling on the cooling tower [27].
Public Safety	
Quality of Life	Noise impacts and visible plume.
Permitting	Water appropriations permit modification, possible non-degradation review for increased mercury concentration in cooling tower blow-down, modification of NPDES permit [27]. Sensitive Environmental Areas of Impaired Waters. Loss of wetlands and Waters of the U.S. would be regulated by State and/or Federal agencies. Potential impacts to protected species/habitats would require coordination with State and/or Federal agencies. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of CO_2.
Other	

A.17 Representative Facility O (RFO)

Retrofitting RFO’s once-through cooling system with CCC appears to be very difficult due to space constraints and of questionable feasibility.

The retrofit would reduce cooling water intake to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit would introduce several new environmental concerns like potential impacts to protected species and sensitive wetlands areas, reduced visibility on local roadways, railroad and navigable waterways, reductions in air quality, and potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are also discussed below.

The facility currently consists of one active generating unit (Unit 3), which utilizes a once-through cooling system [53]. Unit 1 has been completely dismantled; Unit 2 is a boiling water nuclear reactor that is being decommissioned [27]. For the purposes of this study, one cooling tower is proposed for this facility; the size, location and impacts of the hypothetical cooling tower are also discussed below.

A.17.1 Background

RFO is a 360 MW coal-fired steam electricity generating facility located in the U.S. Midwest [53]. The facility is located in an agricultural/residential area on the east bank of a large river [27]. The RFO’s CWIS, whose design intake rate is 175,000 gpm, withdraws cooling water from the large river [24].

A location map of RFO is provided as Figure A-76. Key information for the generating unit is provided in Table A-67.

Table A-67
RFO engineering information [24]

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 3	360	175,000	22	1969	69%
Total	**360**	**175,000**	**NA**	**NA**	**NA**

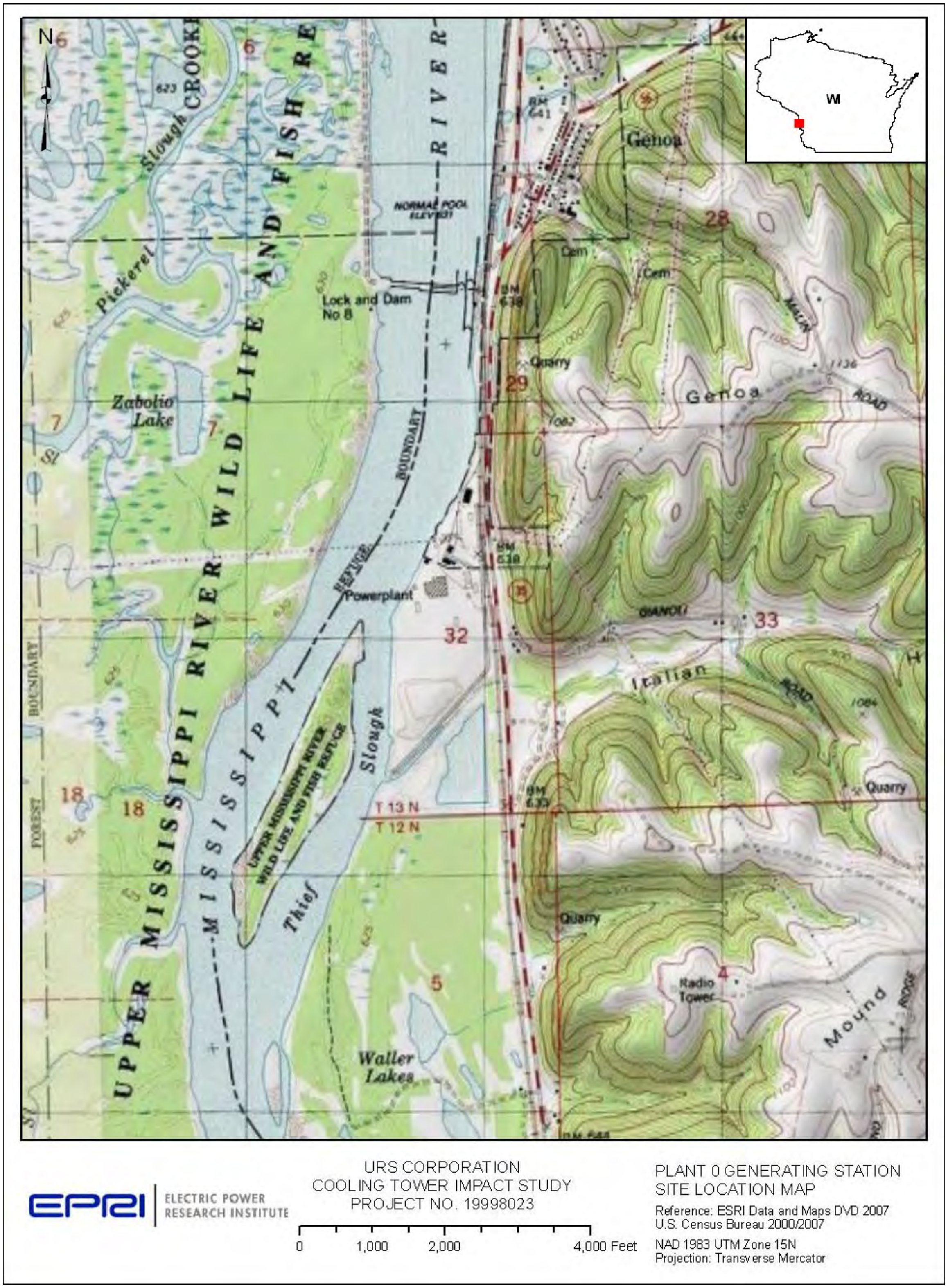


Figure A-77
RFO site location map

A.17.2 Cooling Water Intake Structure

RFO uses one shoreline CWIS to withdraw cooling water from the large river. The CWIS includes a diversion wall, trash racks and traveling water screens that are used to keep fish and debris out of the circulating water system. Two circulating water pumps, located downstream of the screens, supply river water to the once-through steam turbine condensers and the closed-cycle cooling system that serves the auxiliary equipment [53].

The RFO CWIS consists of three intake bays each with a skimmer wall, trash rack and traveling water screen. A sheet pile diversion wall designed to divert debris past the CWIS extends into the river in front of the intake [53] and then parallel to the shoreline. The wall extends almost completely around the face of the CWIS, with the only opening on the downstream side. The river water must first travel past the debris barrier and then upstream to enter the CWIS. The face of the CWIS has a skimmer wall to control floating objects from entering the cooling water system. The trash racks, located downstream of the skimmer wall, have 3 in openings to prevent large debris from reaching the traveling screens. The traveling screens are 8 ft wide and have 1/4 in square mesh openings. The three screen bays merge into two circulating water pump bays. After flowing through the condensers, the water is discharged through a seal well to the river [53].

Every three hours the screens are rotated and cleaned by a front wash spray system. The facility is designed so that any impinged fish and debris collected on the screens would be conveyed with the screen wash water back to the river [53].

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity.

Under design conditions (low water elevation and design flow) the calculated velocity of cooling water approaching the traveling screens is 1 fps. Given the above approach velocities, the through-screen velocities may be expected to be approximately 2 fps.

A.17.3 Proposed Cooling Towers at RFO

The hypothetical cooling tower location is shown in Figure A-77. Limited availability of space on site poses a particular challenge to retrofitting RFO with a cooling tower.

The preliminary design used for the study of this facility includes an 18-cell back-to-back cooling tower located on the northern corner of the property, adjacent to the switchyard, and oriented southwest-northeast to optimize use of space.

Drift impacts of the proposed cooling tower on cables and switchgear need to be further evaluated. Existing infrastructure and underground utilities would need to be relocated or demolished, as appropriate, to accommodate potential cooling towers and associated piping.

The design wet-bulb temperature used for RFO is 77°F [26]; the source water TDS is approximated at 300-400 ppm. The basic characteristics of the tower for the RFO are given in Table A-68.

Figure A-78
RFO conceptual cooling tower location map

Table A-68
Basic characteristics of cooling towers proposed for RFO

Unit Designation		Unit 3
Cooling Tower water flow rate	gpm	175,000
Cooling Tower Range	°F	22
No. and Arrangement of Cooling Tower Cells		18 Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	458 x 108 x 6
Lift Pump Total	hp	1,946
Fan Total	hp	3,600
Fan Diameter	ft	32.8
Fan Housing Inside Diameter at Exit	ft	36
Drift Elimination Efficiency	%	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	1.07E+08
Cycles of Concentration		6
Drift Rate	gpm	0.9
Cooling Tower Evaporation Rate	gpm	3,150
Blowdown Rate	gpm	770
Makeup Rate	gpm	4,621

Several engineering-related challenges associated with locating cooling towers at RFO are listed below.

- The RFO site itself is fully utilized-there is little available land on the property. Existing buildings and utilities would need to be moved or removed to make space for the proposed cooling tower.
- The hypothetical cooling tower is currently located adjacent to the switchyard. Excavation and maneuvering heavy equipment at this location may be difficult and hazardous. There may be insufficient laydown area during construction.
- The source waterbody is currently listed as impaired [3]; discharging the blowdown may be a concern.
- The potential impact of drift on the high voltage transmission lines and the switchyard needs further evaluation.
- RFO is adjacent to a major highway and the railroad. Operation of the cooling tower could impact visibility.
- The new environmental projects being implemented in the vicinity of the proposed location would make access and construction at this location more difficult [27].
- The state department of natural resources regulates consumptive water use [3]. A CCC retrofit would increase consumptive water use.

- The tower dimensions given in Table A-68 are for standard back-to-back MECT with no plume abatement. The need for plume abatement could be an issue due to the location of the highway and the switchyard. However, plume-abated towers are limited to in-line arrangements, and locating in-line towers onsite may not be practicable.

A.17.4 Alternative Cooling Towers and Locations Considered

There are limited potential cooling tower sites at RFO. The main plant area is fully utilized, and the cooling tower cannot be located in the coal pile. The closed ash landfill, immediately south of the coal pile, is capped; no construction is allowed under the landfill closure permit [27]. The adjacent lands are a part of a fish and wildlife refuge and, therefore, cannot be used for siting cooling towers.

There appears to be insufficient space for inline mechanical draft cooling towers, hyperbolic natural draft cooling towers, or hybrid towers. The layout of the RFO property does not seem suitable for circular mechanical draft cooling towers.

A.17.5 Aquatic Biota

Biological information for RFO was provided by the power plant [54] and is summarized in Table A-69. The given annualized impingement numbers are based on estimated actual cooling water usage based on stated design flow capacities and reported hours of operation for each unit.

Table A-69
Annual finfish impingement–RFO

Common Name	Scientific Name	Annual Impingement (# of fish)
Black Basses		
Black Bass	*Micropterus*	1,347
Carps/Minnows		
Carp	Cyprinidae	786
Minnows	Cyprinidae	1,722
Drums/Croakers		
Freshwater Drum	*Aplodinotus grunniens*	9,444
Freshwater Catfish		
Catfishes	Ictaluridae	857
Herrings/Shad		
Gizzard Shad	*Dorosoma cepedianum*	4,195
Perches		
Yellow Perch	*Perca flavescens*	209
Darters	Percidae	209
Sunfishes		
Sunfishes	Centrarchidae	29,747
Other		
Other		3,883
	Total	**52,399**

A.17.6 Population Information

Figure A-79
Census blocks detailing local household numbers surrounding RFO

A.17.7 Summary of Potential Issues with Cooling Tower Implementation

Table A-70
Summary of impacts and issues at RFO [3]

Resource	Issues
Engineering	Severe space limitation. Need to relocate existing infrastructure (waste water treatment, maintenance building) to accommodate cooling towers. Potential for interference with underground utilities. Need to construct around power lines and switchyard.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions.
Terrestrial Resources	Protected species, peregrine falcon (State-listed threatened) was identified on-site utilizing a nest box. Sensitive wetlands areas located across the river from the facility. National fish & wildlife refuge located along river, state wildlife management area. Facility is adjacent to USACE wetlands & islands restoration project.
Water Consumption	The CCC retrofit would increase the consumptive use of water, which is regulated by the state department of natural resources.
Solid Waste	
Public Safety	The retrofit would cause fogging of roadways, railroad and navigable waterways.
Quality of Life	Visible plume
Permitting	Potential impacts to protected species/habitats would require coordination with State and/or Federal agencies. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty would result in additional emissions of $CO_{2.}$
Other	

A.18 Representative Facility P (RFP)

Retrofitting RFP’s once-through cooling system with a CCC system appears to be potentially feasible, with a moderate level of difficulty.

The retrofit will reduce cooling water intake to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit introduces several new environmental concerns like reductions in air quality and potential impacts to local agriculture. These issues are also discussed below.

The facility consists of two generating units (Units 1 and 2), both of which utilize once-through cooling systems [55]. For study purposes, two cooling towers, one per unit, are proposed for this facility. The sizes, locations and impacts of these hypothetical cooling towers are also discussed below.

A.18.1 Background

RFP is a 1,070 MW coal-fired steam electricity generating facility located in the U.S. Midwest and consists of two base-load generating units that utilize once-through cooling water systems. The cooling water is withdrawn through a submerged intake located on a canal off of a reservoir, a cooling lake built to support the generating station [55]. The facility is located on a large property with wooded and open spaces in a rural area, approximately 100 mi southwest of a large Midwest city; the RFP property is surrounded by farmland. Units 1 and 2 are each rated at 535 MW [24]. The heated cooling water is returned to the reservoir via a discharge channel on the western side of the plant [56].

The normal volume of the reservoir, located in a large river basin, is approximately 12,900 acre-ft. A dam is located approximately 1.5 mi southwest of the plant, in the southern portion of the reservoir. A river water intake system provides makeup water to the reservoir, as needed, to offset evaporation, plant use, lake discharge, etc. Pumping from the river stops when river flow falls below the minimum regulatory flow established by the state [55, 56].

A location map of RFP is provided as Figure A-80. Key information for each generating unit is provided in Table A-71.

Table A-71
RFP engineering information [24, 57]

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ∆T (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 1	535	168,000	27.53	1982	69%
Unit 2	535	168,000	27.53	1981	79%
Total	**1,070**	**336,000**	**NA**	**NA**	**NA**

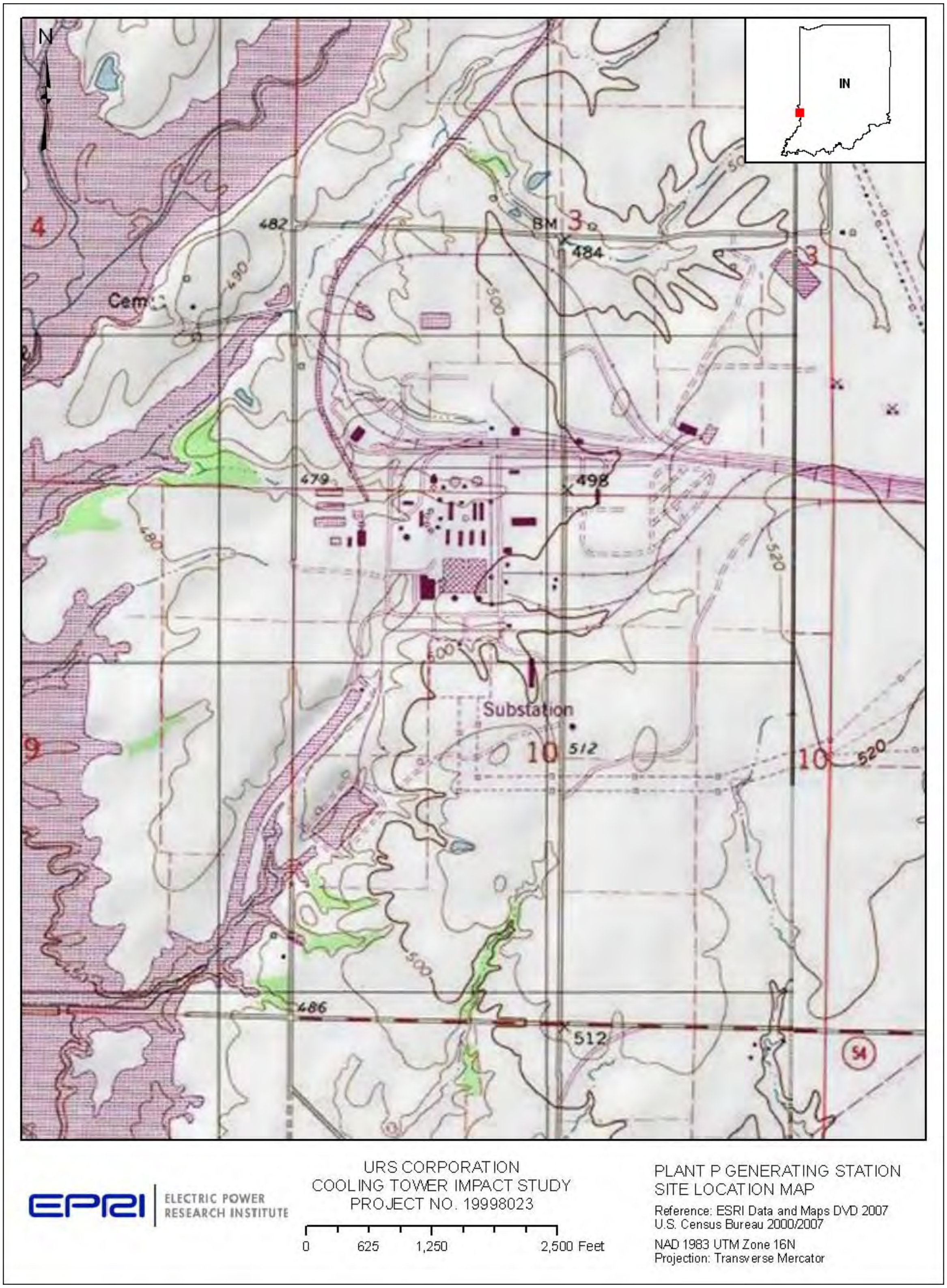


Figure A-80
RFP site location map

A.18.2 Cooling Water Intake Structure

Cooling water for RFP is withdrawn through a single screen house located at the end of an intake canal that is approximately 1/2 mi long. The screenhouse has four bays, two per unit [55]. Each bay is 13.3 ft wide and has a trash rack and a vertical traveling water screen. The trash racks have 3/8 in wide steel bars with approximately 4 in clear spacings.

Traveling water screens are located approximately 16 ft downstream of the trash racks. The traveling screens are 12 ft wide and approximately 40 ft high. The screens consist of 3/8 in square mesh openings. The screens can rotate continuously [55] and are cleaned once per 8 hour shift [56] by low and high pressure spray wash systems. The low-pressure spay wash system removes fish from the front face of the screens and the high-pressure system removes debris from the backside of the screens. Fish and debris removed from the screens are collected in a trough located downstream of the screen and disposed of in a local municipal landfill [55, 56].

RFP is equipped with four circulating water pumps, two per unit, to operate the facility's once-through cooling system and to meet ancillary water requirements [56].

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity.

Approach velocities at different locations along the intake canal and intake bays using RFP's design intake rate are provided in Table A-72.

Table A-72
Approach velocities at various locations along the intake bays in RFP's CWIS [55, 56]

Location along Intake Bay	With Extreme Low Water Conditions	At Full Pond Water Conditions
In the upstream section of intake canal (fps)	0.7	0.4
In the intake canal immediately upstream of the intake structure (fps)	0.4	0.3
Approaching Trash Racks (fps)	1.0	0.7
Approaching Traveling Screens (fps)	1.1	0.7

Given the above approach velocities, the through-screen velocities may be expected to be between 1.4 and 2.2 fps.

A.18.3 Proposed Cooling Towers at RFP

The preliminary design conceptualized for RFP includes two 18-cell cooling towers, one tower per unit, located to the southwest of the main plant and immediately to the west of the intake structure. Both cooling towers are assumed to be back-to-back, and oriented with the predominant southwesterly summer wind [25]. These hypothetical cooling tower locations are shown in Figure A-81.

The design wet-bulb temperature used for RFP is 79°F [26]; and the source water TDS is approximately 400 ppm [24]. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells was determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The basic characteristics of the towers for RFP are given in the following table [24].

Figure A-81
RFP conceptual cooling tower location map

Table A-73
Basic characteristics of cooling towers proposed for RFP

Unit Designation		Unit 1	Unit 2
Cooling Tower Water Flow Rate	gpm	168,000	168,000
Cooling Tower Range	°F	27.53	27.53
No. and Arrangement of Cooling Tower Cells		18/Back-to-back	18/Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	458 x 108 x 6	458 x 108 x 6
Lift Pump Total	hp	1,869	1,869
Fan Total	hp	3,600	3,600
Fan Diameter	ft	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36
Drift Elimination Efficiency	%	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	1.29E+08	1.29E+08
Cycles of Concentration		6	6
Drift Rate	gpm	0.8	0.8
Cooling Tower Evaporation Rate	gpm	4,625	4,625
Blowdown Rate	gpm	925	925
Makeup Rate	gpm	5,551	5,551

A few of the engineering challenges associated with potentially locating cooling towers at RFP are listed below.

- Potential ice formation on transmission lines and in the switchyard due to westerly winter wind [27].
- Disposal of cooling tower blowdown may be an issue at this facility. RFP discharges to a reservoir in which mixing zones are not allowed; water quality standards need to be met at end of pipe [27]. TDS concentration in the cooling tower blowdown may be too high to meet the water quality standard [27].

A.18.4 Alternative Cooling Towers and Locations Considered

Alternate cooling tower locations include the space immediately west of the switchyard; the open space east of the switchyard, the space southwest of the switchyard; and the space immediately west of the main plant.

Spaces closer to the switchyard are less desirable than the proposed location due to potential ice formation on transmission lines. Spaces away from the intake canal are less desirable due to the long runs of cooling water piping that would be required. Spaces to the south and east of the switchyard are less desirable because of the primary transmission right-of-way.

The tower information given in Table A18-3 is for standard back-to-back MECTs with no plume abatement. Alternate cooling tower types may be viable at this site; however, the capital cost associated with alternative cooling tower types is greater than of the MECTs proposed herein. There would have to be additional constraints imposed that would require RFP to use non-MECTs, which are more costly and less efficient than MECT (See Section 6 for additional information on alternative towers).

A.18.5 Aquatic Biota

Biological information for RFP was provided by the power plant [56] and is summarized in Table A-74. The given annualized impingement numbers are based on actual cooling water usage.

Table A-74
Annual finfish impingement–RFP

Common Name	Scientific Name	Annual Impingement (# of fish)
Carps/Minnows		
Spotfin Shiner	*Cyprinella spiloptera*	92
Common Carp	*Cyprinus carpio*	359
Emerald Shiner	*Notropis atherinoides*	8
Bluntnose Minnow	*Pimephales notatus*	8
Bullhead Minnow	*Pimephales vigilax*	311
Freshwater Catfish		
Channel Catfish	Ictalurus punctatus	3,411
Flathead Catfish	Pylodictis olivaris	94
Herrings/Shad		
Gizzard Shad	*Dorosoma cepedianum*	17
Threadfin Shad	*Dorosoma petenense*	264,668
Silversides		
Inland Silverside	*Menidia beryllina*	603
Sunfishes		
Green Sunfish	*Lepomis cyanellus*	400
Bluegill	*Lepomis macrochirus*	2,930
Longear Sunfish	*Lepomis megalotis*	220
Unidentified Sunfish	*Lepomis* sp.	8
Largemouth Bass	*Micropterus salmoides*	115
White Crappie	*Pomoxis annularis*	13
Black Crappie	*Pomoxis nigromaculatus*	13
Top Minnows		
Western Mosquitofish	*Gambusia speciosa*	21
	Total	**273,292**

A.18.6 Population Information

Figure A-82
Census blocks detailing local household numbers surrounding RFP

A.18.7 Summary of Potential Issues with Cooling Tower Implementation

Table A-75
Summary of Impacts and Issues at RFP [3]

Resource	Issues
Engineering	Cooling tower blowdown may not meet the water quality standard for TDS required for direct discharge to the reservoir [27]. Potential ice formation on transmission lines.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions [27].
Terrestrial Resources	Agricultural areas are located adjacent to the facility.
Water Consumption	Consumptive water use would increase if the facility's once-through cooling system were retrofitted with a CCC system; however, consumptive water use is not currently regulated by state department or regional basin commission.
Solid Waste	
Public Safety	
Quality of Life	Noise impacts and visible plume.
Permitting	TDS concentration in the cooling tower blowdown may not meet water quality requirements for lake/reservoir discharge [27]. Local ordinances, permits and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of $CO_{2.}$
Other	

A.19 Representative Facility Q (RFQ)

Retrofitting RFQ's once-through cooling system with CCC appears to be potentially feasible. The main difficulties include the need to relocate the former ash pond and the need to install long lengths of large diameter pipe between the cooling towers and condensers along the riverbank.

The facility consists of three active generating units (Units 2-4). Units 2 and 3 utilize once-through cooling systems [58]; Unit 4 already utilizes CCC. All units operate in peaking mode.

The hypothetical CCC system conceptualized for Units 2 and 3 assumes that one new cooling tower would be shared between these two units. The retrofit would reduce cooling water intake to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit introduces several new environmental concerns like reductions in air quality, potential impacts to wetlands and protected species, and potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are also discussed below.

A.19.1 Background

RFQ is a 713 MW steam electricity generating facility, with only 360 MW generation associated with once-through cooling [58]. This facility is located in New England between a river and a highway. Its surroundings are zoned as heavy industrial, manufacturing, residential and open space [3].

Units 2 and 3 utilize oil and gas to fuel the boilers. RFQ withdraws its cooling water from a river at a design intake rate of 155,700 gpm [58]. The river is tidally influenced throughout the lower 60 miles. However, the reach of the river at RFQ is fresh; the salt wedge ends approximately 10 mi downstream of the facility [58].

A location map of RFQ is provided as Figure A-83. Key information for each generating unit is provided in Table A-76.

Table A-76
RFQ engineering information [24, 58]

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Capacity Factor for 2006
Unit 2	120	56,700	18	1958	15%
Unit 3	240	99,000	21	1968	11%
Total	**360**	**155,700**	**NA**	**NA**	**NA**

Figure A-83
RFQ site location map

A.19.2 Cooling Water Intake Structure

The water for the once-through cooling systems is withdrawn from the river through one shoreline intake structure on the south bank. The water first flows under a curtain wall before entering the intake bays. There are two intake bays per unit, and each bay has a trash rack and a standard through-flow traveling screen with 3/8 in mesh openings. Two circulating water pumps are located in a common suction chamber at the end of each unit's intake bays [58].

All through-flow traveling screens are rotated intermittently. Fish and debris washed from the screens are sluiced to a trash basket [58], and ultimately landfilled [27]. When the river temperature drops to 45°F or below, the once-through units shut down one of the two available circulating water pumps.

While Unit 1 no longer generates electricity and its intake structure is no longer in operation, the intake and discharge of cooling water is still permitted under the facility's National Pollutant Discharge Elimination System (NPDES) permit. Makeup water for the Unit 4 cooling tower is drawn from the discharge of the Units 1, 2 and 3 once-through cooling water systems [58].

The heated cooling water from the once-through units is discharged to the river by separate but adjacent weir-type seal pits located on the riverbank downstream of the intake structures. A re-circulation system with 10,000 gpm capacity routes heated water from the discharge into the screen wells for ice control when necessary during the winter months [58].

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity. The approach velocities in the intake bays at Unit 2 and Unit 3 are 1.1 fps and 1.3 fps, respectively [58]. Through-screen velocities at these two units are 1.9 fps at Unit 2 and 2.3 fps at Unit 3 [58].

A.19.3 Proposed Cooling Towers at RFQ

For study purposes, the hypothetical cooling tower for this facility has been located on the far east end of the site due to lack of available space in the vicinity of the turbine buildings or intake structures. Routing the cooling water pipes between the cooling tower and condensers would be difficult. To optimize use of available space the proposed cooling towers for Units 2 and 3 have been combined. The hypothetical cooling tower location is shown in Figure A-84.

The preliminary design for this facility includes a 16-cell cooling tower for Units 2 and 3, arranged back-to-back and oriented parallel to the property boundary (rather than with the predominant southern summer wind).

It is expected that the cooling water pipe would be routed along the northern boundary of the property, although construction on the steep riverbank would be difficult.

The design wet-bulb temperature used for RFQ is 76°F [24]; the source water TDS is approximately 200 ppm [58]. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells has been determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The basic characteristics of the tower for RFQ are given in Table A-77.

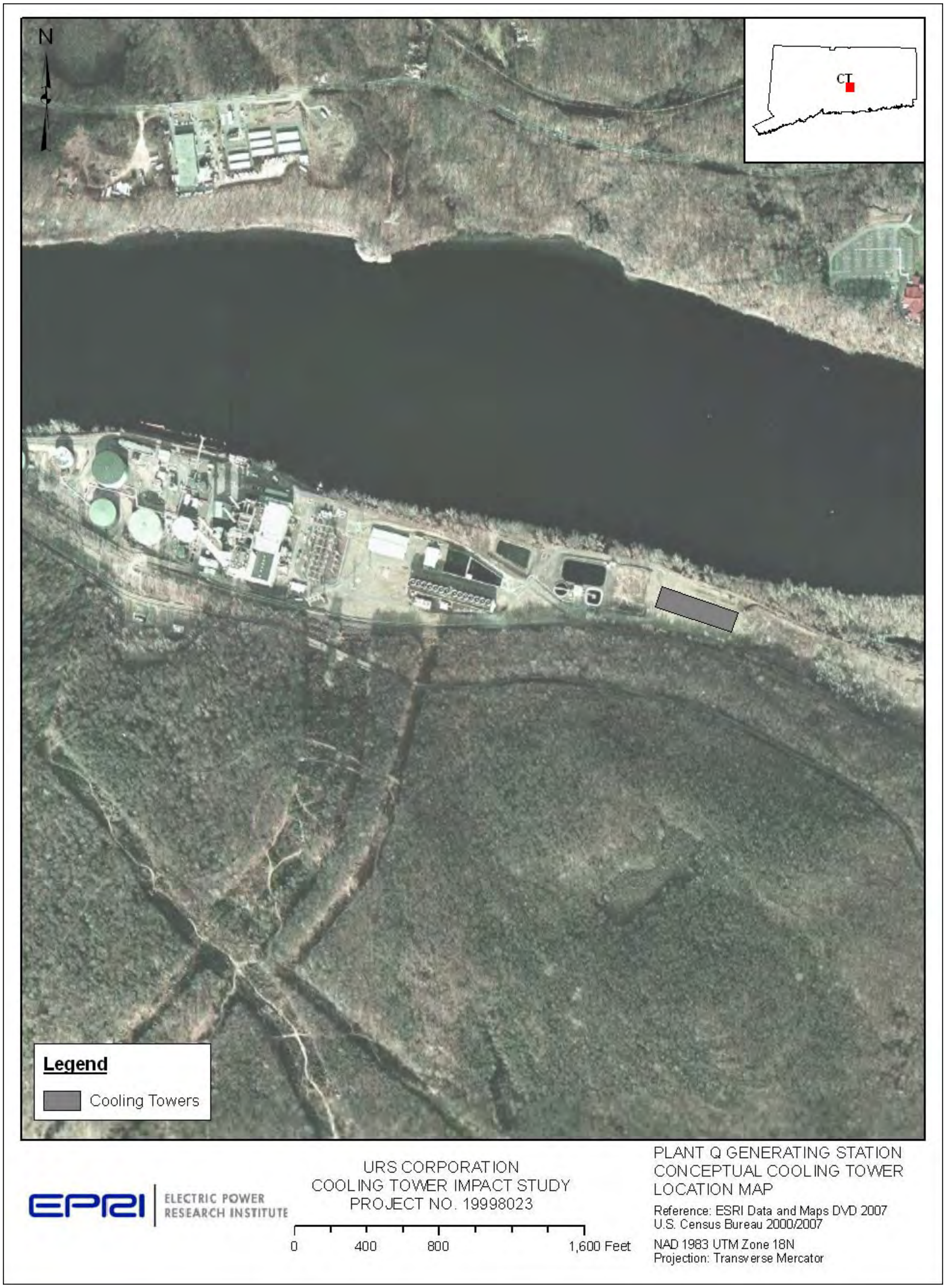


Figure A-84
RFQ conceptual cooling tower location map

Table A-77
Basic characteristics of cooling towers proposed for RFQ

Unit Designation		Units 2 and 3
Cooling Tower Water Flow Rate	gpm	155,700
Cooling Tower Range	°F	20
No. and Arrangement of Cooling Tower Cells		16/Back-to-back Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	408 x 108 x 6
Lift Pump Total	hp	1,732
Fan Total	hp	3,200
Fan Diameter	ft	32.8
Fan Housing Inside Diameter at Exit	ft	36
Drift Elimination Efficiency	%	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	9.69E+07
Cycles of Concentration		8
Drift Rate	gpm	0.8
Cooling Tower Evaporation Rate	gpm	3,100
Blowdown Rate	gpm	443
Makeup Rate	gpm	3,543

A few of the engineering challenges associated with locating cooling towers at RFQ are listed below.

- The proposed location is the former ash pond where the ash is 22 ft deep and below which is bedrock. The ash and surrounding soils may need to be moved to an alternate location and the tower would likely be built on pilings [27].
- Existing buildings and utilities would need to be moved or removed to install cooling water pipes each way between condensers and the cooling tower. Installing large diameter pipes in the riverbank would be challenging.

A.19.4 Alternative Cooling Towers and Locations Considered

Due to lack of suitable space in the vicinity of the turbine building and intake structure, no other locations were considered.

There would have to be additional constraints imposed that would cause RFQ to use an alternate cooling tower type such as a hybrid, dry or natural tower, which would be more expensive and less efficient than the MECT proposed herein (See Section 6 for additional information on alternative towers).

A.19.5 Aquatic Biota

Biological information for RFQ was provided by the power plant [59] and is summarized in Table A-78. The given annualized impingement numbers are based on actual cooling water usage.

Table A-78
Annual finfish impingement–RFQ

Common Name	Scientific Name	Annual Impingement (# of fish)
Basses		
White Perch	*Morone americana*	35
Striped Bass	*Morone saxatilis*	1
Carps/Minnows		
Common Carp	*Cyprinus carpio*	6
Golden Shiner	*Notemigonus crysoleucas*	1
Shiner, unid.	*Notropis* sp.	559
Dace, unid.	*Rhinichthys* sp.	10
Eels		
American Eel	*Anguilla rostrata*	84
Freshwater Catfish		
Catfish	*Ameiurus* sp.	167
Herrings/Shad		
Alewife	*Alosa pseudoharengus*	23
American Shad	*Alosa sapidissima*	7
Herring	*Clupea harengus*	15
Gizzard Shad	*Dorosoma cepedianum*	1
Killifishes		
Banded Killifish	*Fundulus diaphanus*	26
Lampreys		
Sea Lamprey	*Petromyzon Marinus*	32
Mudminnows		
Central Mudminnow	*Umbra limi*	2
Pikes/Pickerels		
Northern Pike	*Esox lucius*	25
Chain Pickerel	*Esox niger*	1
Perches		
Yellow Perch	*Perca flavescens*	474
Soles		
Hogchoker	*Trinectes maculatus*	19
Sticklebacks		
Stickle back	*Gasterosteus* sp.	4
Sunfishes		
Rock Bass	*Ambloplites rupestris*	17
Sunfish, unid.	*Lepomis* sp.	834
Smallmouth Bass	*Micropterus dolomieu*	4
Largemouth Bass	*Micropterus salmoides*	11
White Crappie	*Pomoxis annularis*	10
Black Crappie	*Pomoxis nigromaculatus*	16
Other		
Unidentified	N/A	24
	Total	**2,408**

A.19.6 Population Information

Figure A-85
Census blocks detailing local household numbers surrounding RFQ

A.19.7 Summary of Potential Issues with Cooling Tower Implementation

Table A-79
Summary of impacts and issues at RFQ [3]

Resource	Issues
Engineering	Need to move ash and soils to alternate location and potentially construct cooling tower on pilings. Need to route large diameter pipes each way between the cooling tower and condensers along the riverbank.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions.
Terrestrial Resources	Potential impacts to wetlands. Protected species, bald eagle (State listed endangered) foraging habitat identified on-site. Agricultural/Cropland located adjacent to the facility.
Water Consumption	Consumptive water use is regulated by the state department of environmental protection and state department of public health [3]. Retrofitting the once-through cooling systems utilized by Units 2 and 3 with a closed cycle cooling tower will increase consumptive water use.
Solid Waste	
Public Safety	
Quality of Life	Noise impacts and visible plume.
Permitting	Loss of wetlands and Waters of the U.S. would be regulated by State and/or Federal agencies. Potential impacts to protected species/habitats would require coordination with State and/or Federal agencies. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of CO_2.
Other	

A.20 Representative Facility R (RFR)

Retrofitting RFR’s once-through cooling system with a CCC system appears to be feasible, but deemed difficult at this time. The main challenge is the need to route cooling water pipes between the cooling tower and condensers over and under existing utilities.

The retrofit would reduce cooling water intake to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit would likely introduce several new environmental concerns like impacts to nearby croplands and upland forests, reductions in air quality, and potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are also discussed below.

The facility consists of one active generating unit (Unit 3), which utilizes a once-through cooling system [60]. For study purposes, one cooling tower would be used to retrofit RFR's once-through cooling system. The size, location and impacts of the hypothetical cooling tower are also discussed below.

A.20.1 Background

RFR is now a 170 MW coal-fired steam electricity generating facility located in the U.S. South. Units 1 and 2 were decommissioned in 2003 [60]. RFR operates primarily as a peaking power facility coming on line during periods of high electricity demand [61]. The facility is located on a large wooded property, which in turn is surrounded by wooded, agricultural or open spaces [3], but is within a few miles of residential, commercial and industrial properties.

RFR is located near the eastern bank of a river [60] and withdraws its cooling water from the river via a CWIS at a design intake rate of 98,333 gpm [24]. The CWIS and the main plant are located on the two sides of a major highway. The river is a part of the larger multi-river basin. RFR is located along the lower portion of the river, a long free-flowing reach influenced by releases from two upstream hydropower dams. Seasonal flows are highest during winter months. The river downstream of RFR flows freely about 58 miles to the headwaters of a lake [61].

A location map of RFR is provided as Figure A-86. Key information for the generating unit is provided in the following table.

Table A-80
RFR engineering information [24]

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 3	170	98,333	18	1964	39%
Total	**170**	**98,333**	**NA**	**NA**	**NA**

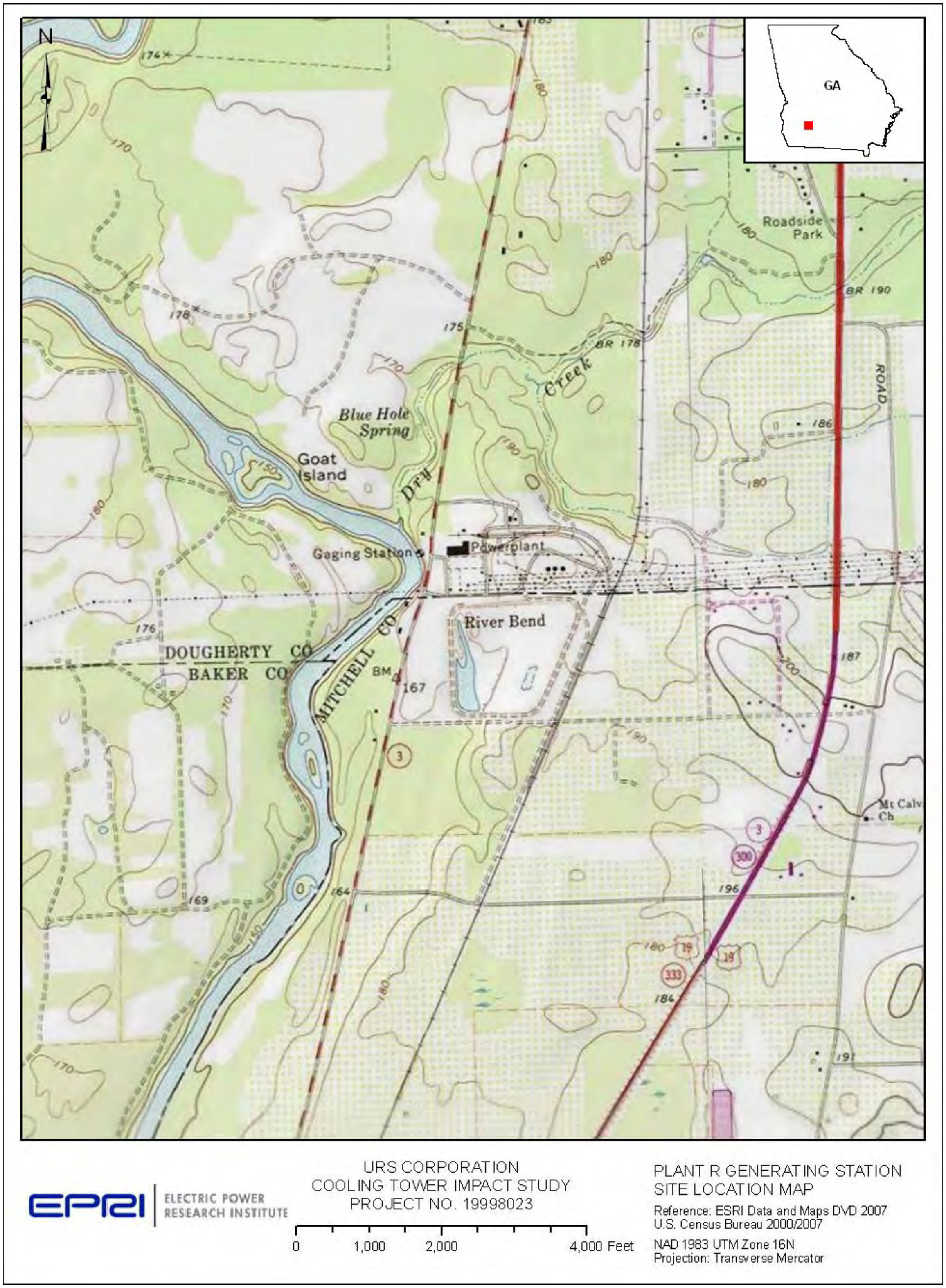


Figure A-86
RFR site location map

A.20.2 Cooling Water Intake Structure

RFR’s CWIS is located at the shoreline on the eastern bank of a river and contains three conventional through-flow traveling water screens oriented parallel to river flow [60]. The screens are equipped with mesh that has 3/8 in square openings [60]. A spray system to control floating debris is positioned above the water surface along the face of the CWIS [62]. Under normal operations, RFR uses three circulating pumps to supply cooling water to the steam condenser for Unit 3 [61].

Screened materials are sluiced back to the river immediately downstream of the CWIS via a vertical corrugated pipe that descends approximately 25 ft to an open concrete chute that discharges over rip-rap to the river [60, 61].

Following passage through the plant, cooling water is conveyed via a tunnel that discharges to the river at the river bank approximately 100 ft downstream of the screen-wash discharge [60].

A.20.3 Proposed Cooling Towers at RFR

Several underground and overhead utilities are currently installed in the immediate vicinity of the main plant. In addition, the CWIS and the main plant are separated by a major highway. Installing large diameter cooling water pipes between condensers and the cooling tower is, therefore, difficult. The hypothetical cooling tower location is shown in Figure A20-2.

The preliminary design for this facility includes one 10-cell back-to-back cooling tower for Unit 3 located, for study purposes, immediately east of the highway, south of the 115 kV transmission line, and north of the 46 kV transmission line. Winds from the east or southeast are more common than from other directions; however there is no predominant summer wind direction identified for this location [62]. The cooling tower is oriented north-south due to buried and overhead utilities.

The design wet-bulb temperature used for RFR is 80°F [26]; the source water TDS is approximately 800 ppm [27]. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells was determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The basic characteristics of the towers for RFR are given in the following table [24].

Figure A-87
RFR conceptual cooling tower location map

Table A-81
Basic characteristics of cooling towers proposed for RFR

Unit Designation		Unit 3
Cooling Tower Water Flow Rate	gpm	98,333
Cooling Tower Range	°F	18
No. and Arrangement of Cooling Tower Cells		10/Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	258 x 108 x 6
Lift Pump Total	hp	1,094
Fan Total	hp	2,000
Fan Diameter	ft	32.8
Fan Housing Inside Diameter at Exit	ft	36
Drift Elimination Efficiency	%	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	8.86E+07
Cycles of Concentration		4
Drift Rate	gpm	0.5
Cooling Tower Evaporation Rate	gpm	1,770
Blowdown Rate	gpm	590
Makeup Rate	gpm	2,360

Several engineering challenges associated with locating cooling towers at RFR are listed below.

- The vicinity of the main plant area at RFR is fully utilized. Therefore the hypothetical cooling tower has been located to the south of the primary transmission right of way. Potential construction near high voltage transmission lines would be difficult.
- The cooling water pipes between the potential cooling tower and condensers would need to cross several transmission lines.
- Operation of the cooling tower could impact visibility on the highway adjacent to the proposed cooling tower.
- The tower dimensions given in Table A-81 are for a standard back-to-back MECT with no plume abatement. The need for plume abatement could be an issue due to the tower's proximity to the highway. However, plume-abated towers are limited to in-line arrangements.

A.20.4 Alternative Cooling Towers and Locations Considered

Alternate cooling tower locations considered include the clearing near the CWIS; the space immediately south of the parking lot between the switchyard and the highway; an east-west oriented tower immediately south of the 115 kV transmission lines; and the space between the fuel tanks and the main plant.

A cooling tower near the CWIS would require the cooling water pipes to cross the highway, and is therefore a less preferred location.

Locating the cooling tower immediately to the south of the parking lot between the switchyard and the highway would require relocation of several high voltage transmission lines and transmission towers.

Locating an east-west oriented cooling tower immediately to the south of the 115 kV transmission lines would require relocation of the 46 kV transmission lines.

Locating the cooling tower between the fuel tanks and the main plant area would require relocation of the 230 kV transmission lines and the oil pipes.

An alternate location(s) would need to be identified if the facility were required to install an inline mechanical draft cooling tower, a hyperbolic natural draft cooling tower, or a hybrid tower. The feasibility of these alternate towers was not evaluated.

A.20.5 Aquatic Biota

Biological information for RFR was provided by the power plant [61] and is summarized in Table A-82. The given annualized impingement numbers are based on actual cooling water usage.

Table A-82
Annual finfish impingement–RFR

Common Name	Scientific Name	Annual Impingement(# of fish)
Carps/Minnows		
Common Carp	*Cyprinus carpio*	11
Weed Shiner	*Notropis texanus*	33
Freshwater Catfish		
Channel Catfish	*Ictalurus punctatus*	260
Flathead Catfish	*Pylodictis olivaris*	33
Herrings/Shad		
Alabama Shad	*Alosa alabamae*	76
Threadfin Shad	*Dorosoma petenense*	304
Perches		
Gulf Darter	*Etheostoma swaini*	11
Blackbanded Darter	*Percina nigrofasciata*	11
Sunfishes		
Redbreast Sunfish	*Lepomis auritus*	65
Green Sunfish	*Lepomis cyanellus*	11
Dollar Sunfish	*Lepomis marginatus*	11
Largemouth Bass	*Micropterus salmoides*	54
	Total	**881**

A.20.6 Population Information

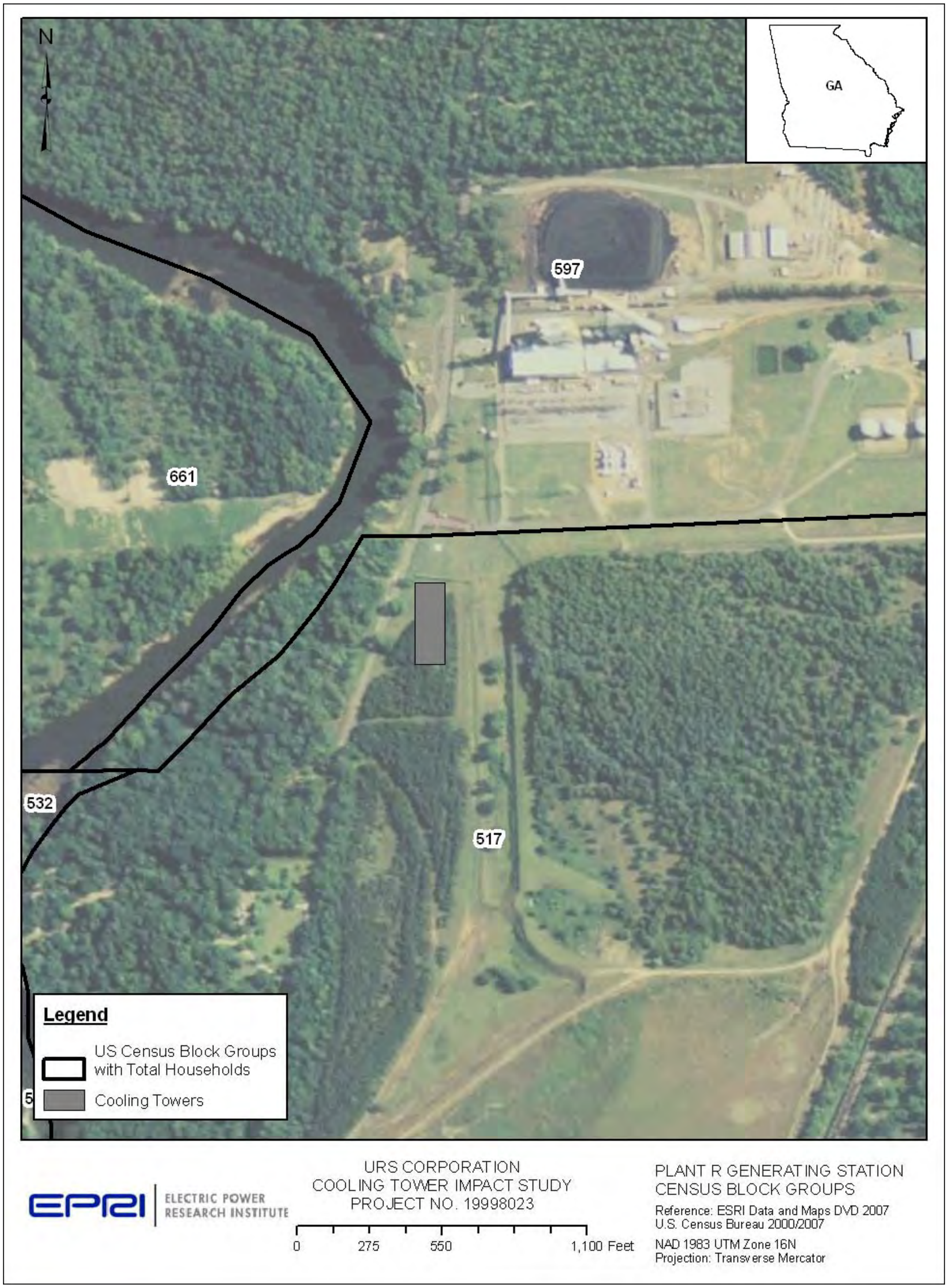


Figure A-88
Census blocks detailing local household numbers surrounding RFR

A.20.7 Summary of Potential Issues with Cooling Tower Implementation

Table A-83
Summary of impacts and issues at RFR [3, 27]

Resource	Issues
Engineering	Need to construct around power lines. Potential for interference with underground utilities.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions.
Terrestrial Resources	Potential impacts to upland forest communities. Agricultural/Croplands located adjacent to the facility.
Water Consumption	A CCC retrofit would increase the consumptive use of water. Water withdrawal is currently regulated.
Solid Waste	
Public Safety	Visibility on the highway in the general vicinity of the facility may be compromised during cooling tower operation.
Quality of Life	Visible plume
Permitting	Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of $CO_{2.}$
Other	

A.21 Representative Facility S (RFS)

Retrofitting RFS's once-through cooling system with CCC appears to be potentially feasible, but very difficult. The challenges include locating four large cooling towers close enough to the main plant to minimize the length of cooling water pipes, but far enough so as not to hinder security within the protected area due to potential fogging.

The retrofit would reduce cooling water intake to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit would likely introduce several new environmental concerns like potential impacts to nearby sensitive wetlands and upland forest communities, reductions in air quality, and potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are also discussed below.

The facility consists of two generating units that utilize once-through cooling systems [63]. For study purposes, four cooling towers are proposed for this facility, two cooling towers per generating unit. The sizes, locations and impacts of these hypothetical cooling towers are also discussed below.

A.21.1 Background

RFS is a 1,824 MW nuclear-fueled base-load steam electric generating facility consisting of two boiling water reactors [63, 64]. The facility is located in the U.S. Midwest on the east bank of a large river, approximately 500 river miles upstream of the confluence with another large river [63]. The facility is located on a 765 acre tract [65] and is surrounded by several small and large cities [64]. A location map of RFS is provided as Figure A-89.

Water to cool RFS' condensers is withdrawn from the river at a maximum rate of 1,011,000 gpm; one or more circulating water pumps may be shutdown during reduced power production or when ambient river water temperature is low [63].

Key information for each generating unit is provided in the following table.

Table A-84
RFS engineering information

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 1	912	505,500	30	1972	81%
Unit 2	912	505,500	30	1972	77%
Total	**1,824**	**1,011,000**	**NA**	**NA**	**NA**

Figure A-89
RFS site location map

A.21.2 Cooling Water Intake Structure

RFS' CWIS is located on the western side of the plant site. Condenser cooling water is withdrawn from the river through a canal that is perpendicular to the river flow. The canal is approximately 235 ft long and approximately 180 ft wide and 12 ft deep where it meets the river [63].

A floating boom, extending down to a depth of approximately 3 ft, traverses the mouth of the canal to deflect floating debris and trash. At the other end of the canal at the entry to the CWIS are trash racks with bars spaced 2.5 in apart [63]. The CWIS consists of six intake bays, three per unit. Each intake bay is 26 ft wide and is equipped with two 10 ft wide traveling water screens with 3/8 in square mesh openings [63]. Fish and other materials impinged on the traveling screens are washed off and collected in a trash basket. Each intake bay has one circulating water pump [63].

The intake velocity at the mouth of the canal at design conditions is approximately 1 fps [63].

A.21.3 Proposed Cooling Towers at RFS

The preliminary design for this facility includes four 26-cell back-to-back hypothetical cooling towers, two per generating unit. All towers would be oriented north-south. For study purposes, the Unit 1 towers have been located over the current dredge ponds, and the Unit 2 towers have been located southwest of the dredge ponds but north of the southern boundary of the fish hatchery that surrounds the facility. The locations of the conceptual cooling towers are shown in Figure A-90.

Several existing infrastructure would need to be moved or removed to install the multiple large diameter cooling water pipes between the condensers and cooling towers.

The design wet-bulb temperature used for RFS is 79°F [26]; the source water TDS is approximately 200 ppm [27]. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells has been determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The basic characteristics of the towers for RFS are given in the following table.

Figure A-90
RFS conceptual cooling tower location map

Table A-85
Basic characteristics of cooling towers proposed for RFS

Unit Designation		Unit 1		Unit 2	
Cooling Tower Flow Rate	gpm	252,750	252,750	252,750	252,750
Cooling Tower Range	°F	30	30	30	30
No. and Arrangement of Cooling Tower Cells		26/ Back-to-back	26/ Back-to-back	26/ Back-to-back	26/ Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	658 x 108 x 6	658 x 108 x 6	658 x 108 x 6	658 x 108 x 6
Lift Pump Total	hp	2,811	2,811	2,811	2,811
Fan Total	hp	5,200	5,200	5,200	5,200
Fan Diameter	ft	32.8	32.8	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36	36	36
Drift Elimination Efficiency	%	0.0005	0.0005	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU /hr	1.46E+08	1.46E+08	1.46E+08	1.46E+08
Cycles of Concentration		8	8	8	8
Drift Rate	gpm	1.3	1.3	1.3	1.3
Cooling Tower Evaporation Rate	gpm	7,583	7,583	7,583	7,583
Blowdown Rate	gpm	1,083	1,083	1,083	1,083
Makeup Rate	gpm	8,667	8,667	8,667	8,667

Several engineering challenges associated with locating cooling towers at RFS are listed below.

- A facility-sponsored helper cooling tower study (to run approximately 50 percent of the cooling water flow to reduce the discharge temperature) found that available space onsite would not accommodate cooling towers to cool all of RFS' cooling water [66].
- Constructing the lift pump station to route heated cooling water from condensers to the cooling towers over the existing discharge collection area would be a design and construction challenge [66].
- A 4,160 volt (V) power source would likely be needed to supply the cooling tower substation [66]. The substation would need to be designed and constructed, and a suitable onsite or offsite power source selected to feed the substation [66].
- A significant amount of earthwork and relocation of existing buried infrastructure would be required [66].

- Visibility on the large navigable river may be, at times, limited during cooling tower operation.
- The tower dimensions given in Table A-85 are for standard back-to-back MECTs with no plume abatement. Plume-abated towers, if required, are limited to in-line arrangements, and locating multiple in-line towers onsite may not be practicable.

A.21.4 Alternative Cooling Towers and Locations Considered

Two other hypothetical cooling tower configurations were evaluated for this facility. The first configuration involved locating all back-to-back cooling towers oriented north-south along the southern site boundary. The second configuration involved locating the four cooling towers, also oriented north-south, along the northern site boundary. Both configurations would have required downsizing the fish hatchery that surrounds the facility. Cooling water was preliminarily expected to be conveyed back and forth via a divided tunnel installed within a modified section of the fish hatchery. The cooling tower makeup water would be drawn through the existing intake structure and the cooling tower blowdown line would tie-in to the existing cooling system outfall.

The first configuration was eliminated because the towers would be too close to the site's southern boundary and neighbors [27]. The second configuration was eliminated because of difficulties with routing the blowdown to a location downstream of the existing intake structure (preferably the current discharge).

There appears to be insufficient space for inline mechanical draft cooling towers, hyperbolic natural draft cooling towers, dry towers or hybrid towers at this facility.

A.21.5 Aquatic Biota

Biological information for RFS was provided by the power plant [64] and is summarized in Table A-86. The given annualized impingement numbers are based on design cooling water usage assuming all pumps are continuously operating (nuclear facility).

Table A-86
Annual finfish impingement–RFS

Common Name	Scientific Name	Annual Impingement (# of fish)
Basses		
White Bass	*Morone chrysops*	3,330
Yellow Bass	*Morone mississippiensis*	258
Bowfins		
Bowfin	*Amia calva*	20

Table A-86
Annual finfish impingement–RFS (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)
Carps/Minnows		
Spotfin Shiner	*Cyprinella spiloptera*	97
Common Carp	*Cyprinus carpio*	1,101
Silvery Minnow	*Hybognathus regius*	863
Silver Chub	*Macrhybopsis storeriana*	781
Golden Shiner	*Notemigonus crysoleucas*	32
Emerald Shiner	*Notropis atherinoides*	2,218
River Shiner	*Notropis blennius*	164
Spottail Shiner	*Notropis hudsonius*	586
Fathead Minnow	*Pimephales promelas*	32
Bullhead Minnow	*Pimephales vigilax*	47
Carpsuckers		
Carpsucker spp.	*Carpiodes* sp.	1,008
Drums/Croakers		
Freshwater Drum	*Aplodinotus grunniens*	62,197
Freshwater Catfish		
Black Bullhead	*Ameiurus melas*	117
Yellow Bullhead	*Ameiurus natalis*	6
Channel Catfish	*Ictalurus punctatus*	18,987
Stonecat	*Noturus flavus*	28
Tadpole Madtom	*Noturus gyrinus*	262
Flathead Catfish	*Pylodictis olivaris*	172
Herrings/Shad		
Gizzard Shad	*Dorosoma cepedianum*	766,598
Gars		
Longnose Gar	*Lepisosteus osseus*	559
Shortnose Gar	*Lepisosteus platostomus*	72
Lampreys		
Silver Lamprey	*Ichthyomyzon unicuspis*	45
Mooneyes		
Mooneye	*Hiodon tergisus*	897
Mudminnows		
Central Mudminnow	*Umbra limi*	287

Table A-86
Annual finfish impingement–RFS (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)
Perches		
Yellow Perch	*Perca flavescens*	361
Logperch	*Percina caprodes*	129
Walleye	*Sander vitreus*	206
Pikes/Pickerels		
Grass Pickerel	*Esox americanus vermiculatus*	6
Northern Pike	*Esox lucius*	38
Silversides		
Brook silverside	*Labidesthes sicculus*	12
Suckers		
River Carpsucker	*Carpiodes carpio*	62
Quillback	*Carpiodes cyprinus*	15
Highfin Carpsucker	*Carpiodes velifer*	8
Buffalo Spp.	*Catostomidae* sp.	81
Smallmouth Buffalo	*Ictiobus bubalus*	110
Bigmouth Buffalo	*Ictiobus cyprinellus*	21
Spotted Sucker	*Minytrema melanops*	30
Shorthead Redhorse	*Moxostoma macrolepidotum*	320
Sunfishes		
Rock Bass	*Ambloplites rupestris*	44
Green Sunfish	*Lepomis cyanellus*	78
Pumpkinseed	*Lepomis gibbosus*	875
Warmouth	*Lepomis gulosus*	8
Orangespotted Sunfish	*Lepomis humilis*	496
Bluegill	*Lepomis macrochirus*	59,893
Smallmouth Bass	*Micropterus dolomieu*	20
Largemouth Bass	*Micropterus salmoides*	2,798
White Crappie	*Pomoxis annularis*	272
Black Crappie	*Pomoxis nigromaculatus*	524
	Total	**927,171**

A.21.6 Population Information

Figure A-91
Census blocks detailing local household numbers surrounding RFS

A.21.7 Summary of Potential Issues with Cooling Tower Implementation

Table A-87
Summary of impacts and issues at RFS [3, 27, 66]

Resource	Issues
Engineering	This is a very large nuclear facility. Engineering a retrofit of its cooling system would be extremely difficult. Several existing infrastructure would need to be relocated to accommodate cooling towers.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions.
Terrestrial Resources	Potential impacts to upland forest communities. Sensitive wetlands areas located across the river from the facility.
Water Consumption	Consumptive water use would increase if the once-through cooling system were replaced with a closed-cycle system. However, consumptive water use is not currently regulated by a state department or regional basin commission.
Solid Waste	
Public Safety	
Quality of Life	Visible plume
Permitting	Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Prolonged shutdown for cooling system tie-ins and condenser re-optimization could result in additional burning of fossil fuels and greenhouse gas emissions. Nearly 6 million tons of CO_2 is estimated to be emitted due to retrofit-related downtime, if the retrofit were to be performed within 8 months.
Other	

A.22 Representative Facility T (RFT)

Retrofitting RFT's once-through cooling system with CCC appears to be very difficult. The main challenge is the need to route large diameter pipes between condensers and cooling towers over areas with overhead or underground infrastructure, including a major highway.

The retrofit would likely reduce cooling water intake to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit would introduce several new environmental concerns like reductions in air quality, and potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are also discussed below.

The facility consists of six active generating units (Units 1-4, 6 and 7) all of which utilize once-through cooling systems [67]. For study purposes, four cooling towers are proposed for this facility-one for Units 1 and 2, a second for Units 3 and 4, and two additional cooling towers for Units 6 and 7. The sizes, locations and impacts of these hypothetical cooling towers are discussed below.

A.22.1 Background

For the purposes of this study, RFT is considered to be a 1,419 MW[3] coal-fired steam electricity generating facility located in the U.S. Midwest, approximately 37 mi northeast of a major city [68]. RFT is surrounded by woods, croplands, residential development and another power plant, and the location is zoned as commercial/retail, light industrial/manufacturing and residential [3]. The plant is on the west bank of a river [68].

The source water for RFT is a river. The river extends about 39 mi, from its head at the outlet of a Great Lake, to the delta of another lake. The river is comprised of three distinct reaches. The plant's intake is located within the middle reach, which is about 1/2 mi wide and has channel depths varying from 27 ft to 50 ft. The river serves as the principal outlet for the upper Great Lakes (Lakes Superior, Michigan, and Huron) drainage basin, consisting of more than 222,400 square miles (mi^2) [69]. It has a relatively short retention time and its discharge rate is relatively constant.

Units 1-4, 6 and 7 together require approximately 774,306 gpm of cooling water [24]. The heated cooling water is returned to the river.

RFT is co-located with another facility; much of the undeveloped land is across from a major highway. Several wildlife enhancement projects are ongoing on this property. A location map of RFT is provided as Figure A22-1. Key information for each generating unit is provided in Table A22-1

Table A-88
RFT engineering information

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 1	168	92,361	18	1953	57%
Unit 2	156	92,361	18	1953	45%
Unit 3	156	92,361	18	1954	51%
Unit 4	168	92,361	18	1954	58%
Unit 6	321	161,806	20	1961	63%
Unit 7	450	243,056	27	1969	63%
Total	**1,419**	**774,306**	**NA**	**NA**	**NA**

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[3] Units 1-4, 6 and 7 have a combined generating capacity of 1,419 MW. Unit 5 has not operated since 1979 and is currently on economic reserve [71]. This study assumes that Unit 5 would not need to be retrofitted with CCC.

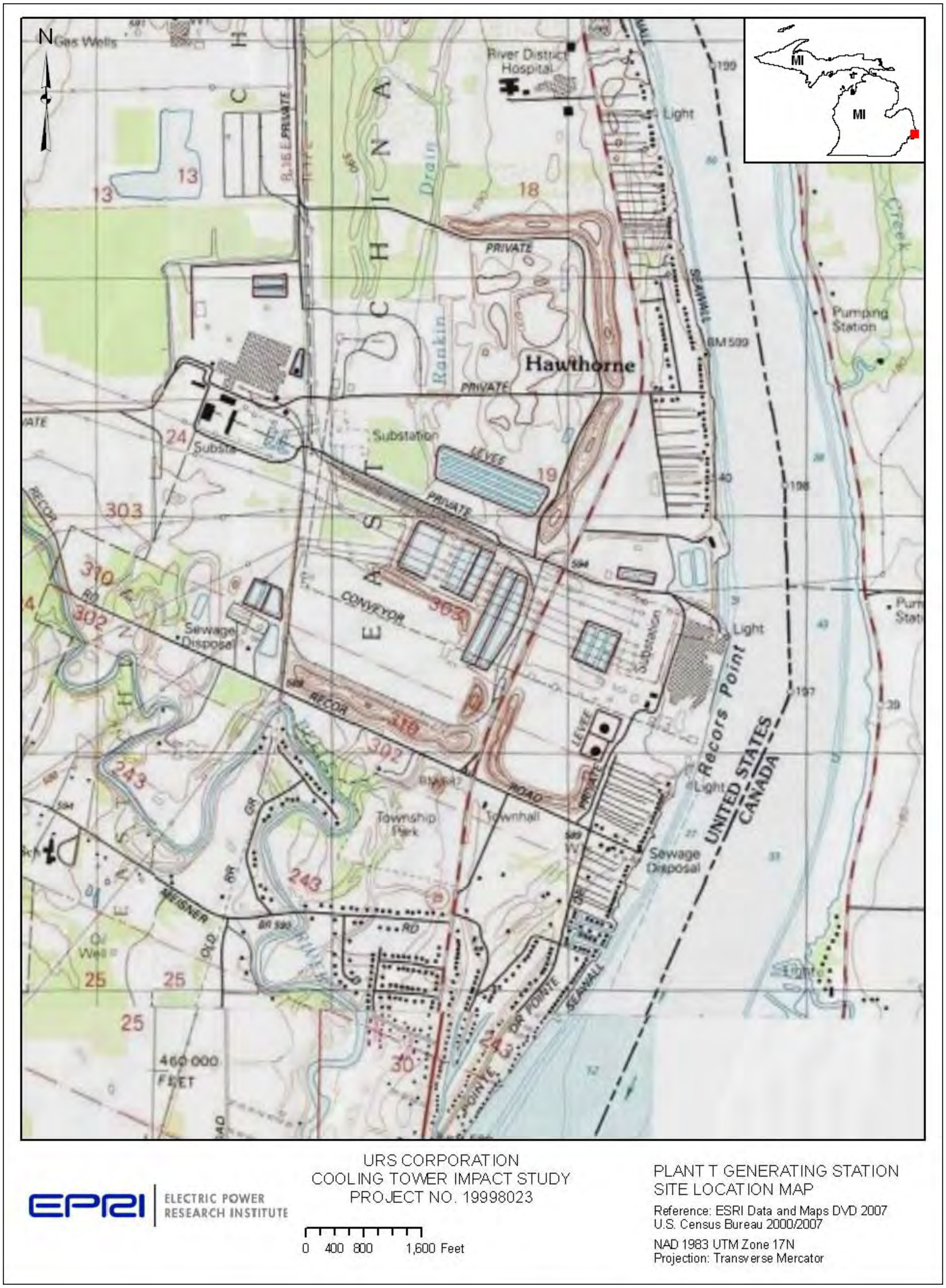

Figure A-92
RFT site location map

A.22.2 Cooling Water Intake Structure

Three submerged shoreline intake structures (screenhouses) are used to draw cooling water from the river. Units 1-3 use Screenhouse 1; Units 4-6 use Screenhouse 2; and Unit 7 uses Screenhouse 3. Each screenhouse contains a curtain wall, trash racks, a warm water recirculation canal, traveling water screens, and cooling water pumps [68].

Screenhouses 1 and 2 each contain nine traveling water screens; Screenhouse 3 contains three traveling water screens. All screens use mesh with 3/8 in square openings. All Screenhouse 1 screens are 5 ft and 6 in wide. Screenhouse 2 has three 5 ft and 6 in wide screens and six 10 ft wide screens. All Screenhouse 3 screens are 10 ft wide. Screens in Screenhouses 1 and 2 are manually controlled and are normally rotated once per shift, or more frequently when conditions require. Screenhouse 3 screens operate automatically based on a pressure differential [68]. Material cleaned off the screens is returned to the river via a fish and debris trough. No fish return system, as designated for this evaluation, exists at the facility, though.

A total of 17 vertical cooling water pumps are installed in the screenhouses: six in Screenhouse 1, eight (three of which are associated with Unit 5 and not in regular use) in Screenhouse 2, and three in Screenhouse 3 [68].

The heated cooling water is returned to the river through a discharge canal located approximately 300 ft downstream of the Screenhouse 1.

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity.

Approach velocities under the curtain wall are 1.46 fps, 1.43 fps, and 1.29 fps for Screenhouse 1, 2, and 3, respectively [68]. Approaching the traveling screens, approach velocities are 1.41 fps, 1.33 fps, and 1.74 fps for the three screenhouses, respectively [68]. Given these approach velocities, the through-screen velocities are expected to be approximately between 2.66 and 3.48 fps.

A.22.3 Proposed Cooling Towers at RFT

The potential need to install long runs of large diameter pipes, relocate existing infrastructure, and perform construction work in the vicinity of high voltage transmission lines and another power plant’s large diameter circulating water pipes would make the CCC retrofit at RFT very difficult. To optimize use of available space, the hypothetical cooling towers for Units 1 and 2, and Units 3 and 4 have been combined. Given that Unit 5 has been on economic reserve since 1979, this study assumes that Unit 5 would be retired if a CCC retrofit were required. The hypothetical cooling tower locations are shown in Figure A-93.

The preliminary design for this facility includes a 20-cell cooling tower for Units 1 and 2; another 20-cell cooling tower for Units 3 and 4; an 18-cell tower for Unit 6 and a 26-cell tower for Unit 7. For study purposes, all cooling towers are anticipated to be back-to-back, and oriented southwest to northeast to coincide with the predominant summer wind direction [25]. The towers are proposed to be located northwest of the main plant area across from the highway, between the high voltage transmission corridor and the other power plant's cooling water pipe corridor.

The cooling towers themselves would likely not require relocation of existing infrastructure. However, cooling water pipes that would need to be installed between the cooling towers and condensers may require relocation or modification of the wastewater settling basins, chemical wastewater treatment basin and/or the proposed fly ash treatment facility.

The design wet-bulb temperature used for RFT is 76°F [26]; the source water TDS is assumed to be less than 200 ppm. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells has been determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The basic characteristics of the towers for RFT are given in Table A-89.

Figure A-93
RFT conceptual cooling tower location map

Table A-89
Basic characteristics of cooling towers proposed for RFT

Unit Designation		Units 1 and 2	Units 3 and 4	Unit 6	Unit 7
Cooling Tower Water Flow Rate	gpm	184,722	184,722	161,806	243,056
Cooling Tower Range	°F	18	18	20	27
No. and Arrangement of Cooling Tower Cells		20/ Back-to-back	20/ Back-to-back	18/ Back-to-back	26/ Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	508 x 108 x 6	508 x 108 x 6	458 x 108 x 6	658 x 108 x 6
Lift Pump Total	hp	2,055	2,055	1,800	2,703
Fan Total	hp	4000	4000	3,600	5,200
Fan Diameter	ft	32.8	32.8	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36	36	36
Drift Elimination Efficiency	%	0.0005	0.0005	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	8.32E+07	8.32E+07	8.99E+07	1.26E+08
Cycles of Concentration		8	8	8	8
Drift Rate	gpm	0.9	0.9	0.8	1.2
Cooling Tower Evaporation Rate	gpm	3,325	3,325	3,236	6,563
Blowdown Rate	gpm	475	475	462	938
Makeup Rate	gpm	3,801	3,801	3,699	7,501

Several engineering challenges associated with locating cooling towers at RFT are listed below.

- The main plant area at the RFT site is fully utilized. Therefore the hypothetical cooling towers have been preliminarily located away from the turbine buildings. Large diameter pipes would need to be routed over relatively long distances to convey cooling water between the condensers and the cooling towers.
- For study purposes, the cooling towers are assumed to be located northwest of the switchyard. Potential ice formation on transmission lines could be hazardous.

- A major highway and several local roads run through the plant property. Operation of cooling towers could potentially impact visibility. In addition, fogging and icing caused by cooling towers could pose a potential hazard on the roads.
- Installing several large diameter pipes under the highway would be challenging.
- The tower dimensions given in Table A-89 are for standard back-to-back mechanical draft evaporative cooling towers with no plume abatement. The need for plume abatement could be an issue due to the location of the switchyard, highways, and residential properties. Locating plume-abated towers would be even more challenging.
- RFT's cooling towers would likely require exemptions from local height and noise ordinances [3].
- The synergistic effects of RFT and the other co-located power plant's potential CCC retrofits need further evaluation.

A.22.4 Alternative Cooling Towers and Locations Considered

The section of property immediately north of the main plant area, south of the other power plant's cooling water pipes and west of the highway were considered for the Unit 1-2, Unit 3-4 and Unit 6 towers. This location would have required the relocation of the wastewater and chemical wastewater treatment basins in their entirety; and termination of the lease to a third party for the fly ash treatment facility.

Alternate cooling tower types (such as natural draft, hybrid, or dry) may be viable at this site; however, there would have to be additional constraints imposed that would require RFT to use non-MECTs, which are more costly and less efficient than the MECTs proposed herein (See Section 6 for additional information on alternative towers).

A.22.5 Aquatic Biota

Biological information for RFT was provided by the power plant [68] and is summarized in Table A-90. The given annualized impingement and entrainment numbers are based on actual cooling water usage.

Table A-90
Annual finfish impingement and entrainment–RFT

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Basses				
White Perch	*Morone americana*	940		
White Bass	*Morone chrysops*	128		
Bowfins				
Bowfin	*Amia calva*	3		
Carps/Minnows				
Central Stoneroller	*Campostoma anomalum*	4		
Goldfish	*Carassius auratus*	4		
Carps/Minnow	Cyprinidae	0	11,334	927,989
Common Carp	*Cyprinus carpio*	50		
Golden Shiner	*Notemigonus crysoleucas*	10		
Emerald Shiner	*Notropis atherinoides*	2,761		868,279
Spottail Shiner	*Notropis hudsonius*	219		33,785
Bluntnose Minnow	*Pimephales notatus*	42		
Cods				
Burbot	*Lota lota*			4,878
Drums/Croakers				
Freshwater Drum	*Aplodinotus grunniens*	31	14,583	
Freshwater Catfishes				
Brown Bullhead	*Ameiurus nebulosus*	87		7,330
Channel Catfish	*Ictalurus punctatus*	96		
Stonecat	*Noturus flavus*	7		
Northern Madtom	*Noturus stigmosus*	5		

Table A-90
Annual finfish impingement and entrainment–RFT (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Gars				
Longnose Gar	*Lepisosteus osseus*	5		
Gobies				
Round Goby	*Neogobius melanostomus*	804		3,190,476
Tubenose Goby	*Proterorhinus marmoratus*	22		
Herrings/Shad				
Alewife	*Alosa pseudoharengus*	22		2,202,867
Gizzard Shad	*Dorosoma cepedianum*	138,723		546,006
Lampreys				
Chestnut Lamprey	*Ichthyomyzon castaneus*	23		
Silver Lamprey	*Ichthyomyzon unicuspis*	24		
American Brook Lamprey	*Lethenteron appendix*	18		
Sea Lamprey	*Petromyzon marinus*	28		15,275
Mooneyes				
Mooneye	*Hiodon tergisus*	13		
Mudminnows				
Central Mudminnow	*Umbra limi*	5		
Perches				
Yellow Perch	*Perca flavescens*	3,737	8,186	367,826
Logperch	*Percina caprodes*	3,988		43,264
Walleye	*Sander vitreus*	115		

Table A-90
Annual finfish impingement and entrainment–RFT (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Pikes/Pickerels				
Northern Pike	*Esox lucius*	4		
Salmons/Trouts				
Cisco	*Coregonus artedi*	32		
Lake Whitefish	*Coregonus clupeaformis*	5		7,500
Rainbow Trout	*Oncorhynchus mykiss*	4		
Lake Trout	*Salvelinus namaycush*	8		
Sculpins				
Mottled Sculpin	*Cottus bairdii*	15		
Deepwater Sculpin	*Triglopsis thompsonii*			145,331
Silversides				
Brook Silverside	*Labidesthes sicculus*	30		
Smelts				
Rainbow Smelt	*Osmerus mordax*	7,029	39,225	6,039,390
Suckers				
Suckers	Catostomidae		10,030	16,208
White Sucker	*Catostomus commersoni*	262	10,830	1,288,468
Northern Hog Sucker	*Hypentelium nigricans*	4		
Redhorses	*Moxostoma* sp.	17		

Table A-90
Annual finfish impingement and entrainment–RFT (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)	Annual Entrainment (# of eggs)	Annual Entrainment (# of larvae)
Sunfishes				
Rock Bass	*Ambloplites rupestris*	1,308		
Green Sunfish	*Lepomis cyanellus*	62		7,548
Pumpkinseed	*Lepomis gibbosus*	33		
Bluegill	*Lepomis macrochirus*	532		
Sunfish Hybrid	*Lepomis* x *Lepomis*	4		
Smallmouth Bass	*Micropterus dolomieui*	1,516	8,459	27,907
Largemouth Bass	*Micropterus salmoides*	122		
White Crappie	*Pomoxis annularis*	46		
Black Crappie	*Pomoxis nigromaculatus*	7		
Sticklebacks				
Threespine Stickleback	*Gasterosteus aculeatus*	40		
Ninespine Stickleback	*Pungitius pungitius*	4		
Trout-perches				
Trout-Perch	*Percopsis omiscomaycus*	587		6,865
	Totals	**163,586**	**102,647**	**15,747,192**

A.22.6 Population Information

Figure A-94
Census blocks detailing local household numbers surrounding RFT

A.22.7 Summary of Potential Issues with Cooling Tower Implementation

Table A-91
Summary of impacts and issues at RFT [3]

Resource	Issues
Engineering	Space limitations in the vicinity of the intake structure and turbine buildings. Need to relocate existing infrastructure to accommodate cooling water pipes. Potential for interference with underground utilities. Need to construct around power lines and switchyard.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions. A retirement facility is located immediately to the north of the facility; its residents may be more sensitive to cooling tower emissions than the general population [3].
Terrestrial Resources	
Water Consumption	The consumptive use of water would increase if the once-through cooling system were retrofitted with a CCC system. However, consumptive water use is not currently regulated by a state department or regional basin commission.
Solid Waste	
Public Safety	
Quality of Life	Noise impacts.
Permitting	Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty could facilitate additional emissions of $CO_{2.}$
Other	

A.23 Representative Facility U (RFU)

Retrofitting RFU’s once-through cooling system with CCC appears to be potentially feasible with an average level of difficulty. The main challenge is the need to install large diameter pipes from the proposed cooling tower to the condensers along a reinforced/stabilized riverbank.

The retrofit would reduce cooling water intake to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit would likely introduce several new environmental concerns like potential impacts to a protecte species, reductions in air quality, and potential reduction in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. A potential CCC retrofit at another power plant located to the east of RFU would likely compound the environmental impacts on the surroundings.

The facility consists of one generating unit (Unit 1), which utilizes a once-through cooling system [24]. For study purposes, one cooling tower is proposed for this facility. The size, location and impacts of the hypothetical cooling tower are discussed below.

A.23.1 Background

RFU is a 188 MW base load electricity generating facility that utilizes Powder River Basin (PRB) coal [24]. This facility is located in the Northcentral part of the U.S. The facility is located in an agricultural/light industrial/residential area [3] on the western shore of a large river approximately 40 mi downstream of a dam [70], which controls the flow in the river. RFU withdraws cooling water from the river at a design intake rate of 100,000 gpm [24].

The dam was completed in April of 1953, forming a lake, the largest of the river main stem reservoirs. RFU intakes are located within this reach [24].

A location map of RFU is provided as Figure A-95. Key information for RFU's generating unit is provided in the following table.

Table A-92
RFU engineering information

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 1	188	100,000	19	1966	91%
Total	**188**	**100,000**	**NA**	**NA**	**NA**

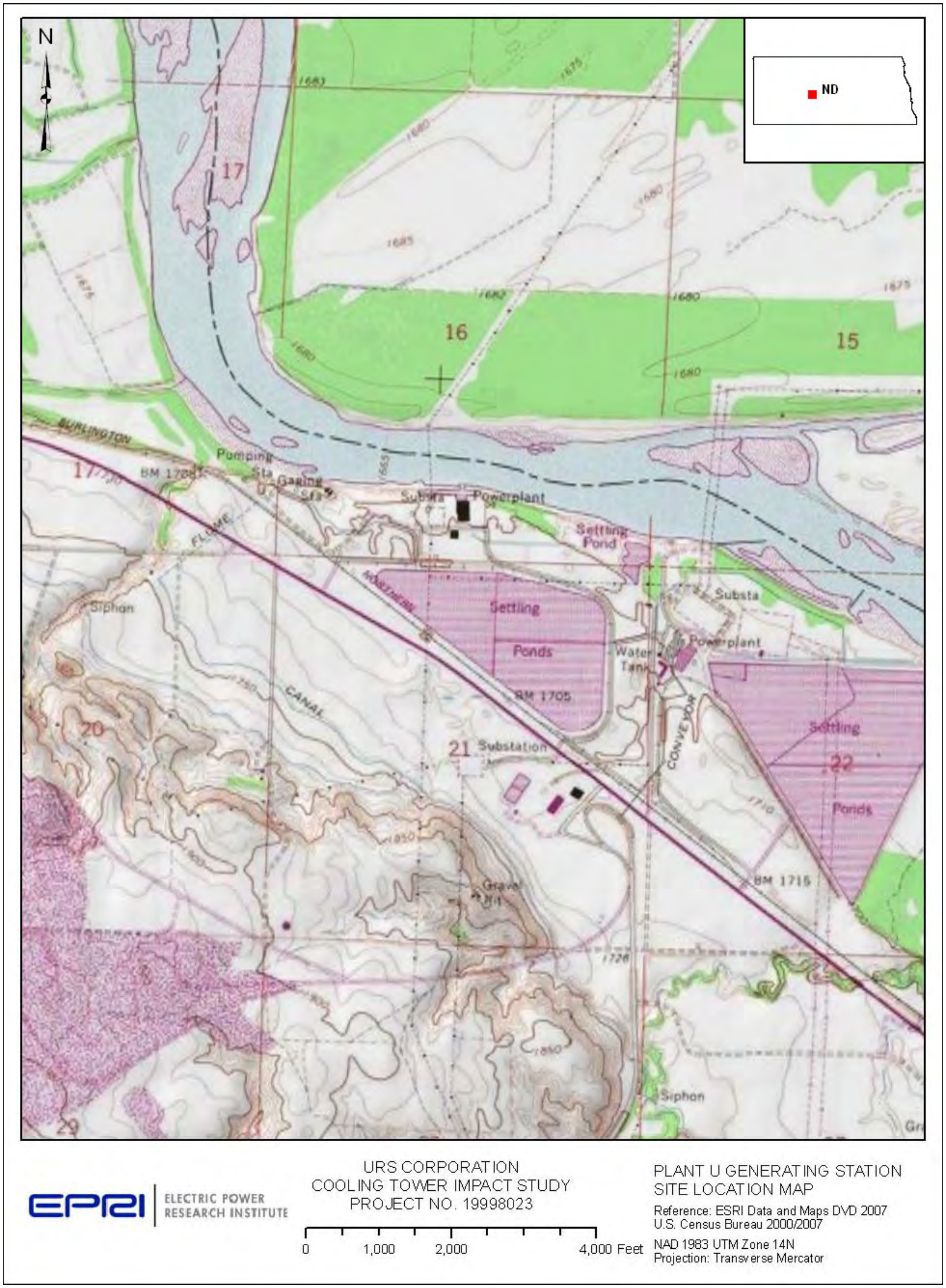

Figure A-95
RFU site location map

A.23.2 Cooling Water Intake Structure

Cooling water for RFU's Unit 1 is withdrawn through a shoreline intake structure, which consists of a forebay, trash racks and traveling water screens. The forebay is about 53 ft long and 35 ft wide. A vertical divider wall that separates the two intake bays is located about 63 ft downstream from the forebay entrance. Trash racks are located in each intake bay, approximately 10 ft downstream from the entrance to the intake bays. A monorail-mounted trash rake is used to clean the trash racks. A curtain wall is located downstream of the trash racks. Two traveling water screens are located about 6 ft downstream of the curtain wall. These two screens are 10 ft wide and have 1/4 in square mesh openings [70]. A vertical cooling water pump is located downstream of the traveling water screen at the end of each intake bay [70].

The screens are rotated twice a day for 45 minutes and cleaned with a high-pressure spraywash. Fish and debris removed from the screens are washed into a trough located in front of the screens. Fish and debris sprayed off the screens are collected in a trash basket and disposed of in a landfill [70].

Heated cooling water is discharged about 50 ft downriver of the CWIS through an open pipe [70].

The approach velocity at an intake bay often determines if aquatic organisms capable of swimming can swim away from a traveling screen and avoid becoming impinged. In general, an approach velocity of 0.5 fps is considered to be a *de minimis* level at or below which such organisms should be able to resist impingement; organisms are further challenged at higher approach velocities. The approach velocity near the screen face generally runs about 1/2 the through-screen velocity.

Approach velocities, assuming design flow conditions and low water elevation, in the forebay is 0.4 fps, in the screenbays is 0.6 fps, and approaching the traveling screens is 0.7 fps [70]. Given these approach velocities, the through-screen velocity is expected to be approximately 1.4 fps.

A.23.3 Proposed Cooling Towers at RFU

A potential CCC retrofit at RFU is challenged by the limited availability of suitable space onsite. The preliminary design for this facility includes one 10-cell back-to-back cooling tower located to the east of the main plant area. The hypothetical cooling tower is oriented southeast to northwest to coincide with the predominant wind direction [25], and located immediately to the east of the stormwater pond and the warehouse. This location is shown in Figure A-96.

Existing stormwater drains, electric service to buildings, and other underground utilities would need to be relocated to accommodate potential cooling towers and associated piping [27]. This facility has experienced riverbank collapses [27]. Appropriate riverbank reinforcement and armoring would therefore be needed if the large diameter cooling water pipes were to be routed along the riverbank.

The design wet-bulb temperature used for RFU is 74°F [26]; the source water TDS is approximately 400 ppm [25]. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells has been determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The basic characteristics of the towers for RFU are given in the following table.

Figure A-96
RFU conceptual cooling tower location map

Table A-93
Basic characteristics of cooling towers proposed for RFU

Unit Designation		Unit 1
Cooling Tower Water Flow Rate	gpm	100,000
Cooling Tower Range	°F	19
No. and Arrangement of Cooling Tower Cells		10/Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	258 x 108 x 6
Lift Pump Total	hp	1,112
Fan Total	hp	2,000
Fan Diameter	ft	32.8
Fan Housing Inside Diameter at Exit	ft	36
Drift Elimination Efficiency	%	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	9.51E+07
Cycles of Concentration		6
Drift Rate	gpm	0.5
Cooling Tower Evaporation Rate	gpm	1,900
Blowdown Rate	gpm	380
Makeup Rate	gpm	2,281

Several engineering challenges associated with locating cooling towers at RFU are listed below.

- RFU’s main plant area is fully utilized. Existing utilities would need to be relocated to allow for a potential cooling tower.
- The riverbank may require reinforcement and significant armoring if the cooling water pipes were to be routed along it.
- RFU would likely experience a greater than average energy penalty due to a CCC retrofit. The average annual summer surface temperature in the lake is 66ºF, which is colder than all other main stem reservoirs in this river [70]. The dam intake is located approximately 160 ft below the lake’s surface (at full pool). The water entering the river is, therefore, much colder, and remains cold even during the hottest summer months. Maximum water temperatures in the channel usually do not exceed 68ºF even at locations 70 mi downstream of the dam [70]. Given the hypothetical cooling tower design for this facility, the ‘cold water’ temperature during summer months would be approximately 84°F.
- Another power station is located immediately to the east of this facility. Should both facilities retrofit the existing once-through systems with closed-cycle cooling towers, the synergistic effects of both towers may need to be considered (interference, noise, etc.).

A.23.4 Alternative Cooling Towers and Locations Considered

Alternate cooling tower locations considered include the northwestern section of the property, the section to the west of the coal pile, the closed ash disposal area, the existing stormwater pond, and the section to the far east of the main plant.

If the cooling tower were located on the northwestern section of the property or to the west of the coal pile, the large diameter cooling water pipes would need to cross the high voltage transmission lines that extend northward from the switchyard (to across the river) and westward from the switchyard [27]. Rerouting the transmission lines, even if it were only for the period of construction, would be very difficult.

Construction on the closed ash disposal area would not be allowable per permit requirements.

Relocating the stormwater pond would require a significant portion of the site's drainage to be modified [27].

The section to the far east of the main plant would require additional piping than the proposed location.

Further study would be needed to show whether alternate cooling tower types, such as natural draft, dry and hybrid, are viable at this site; however, there would have to be additional constraints imposed that would require RFU to use such towers, which are more costly and less efficient than the MECTs proposed herein (See Section 6 for additional information on alternative towers).

A.23.5 Aquatic Biota

Biological information for RFU was provided by the power plant [71] and is summarized in Table A-94. The given annualized impingement numbers are based on actual cooling water usage.

Table A-94
Annual finfish impingement–RFU

Common Name	Scientific Name	Annualized Impingement
Carpsuckers		
Carpsucker sp.	*Carpiodes* sp.	112
Carps/Minnows		
Emerald Shiner	*Notropis atherinoides*	1,233
Fathead Minnow	*Pimephales promelas*	154
Freshwater Catfishes		
Black Bullhead	*Ameiurus melas*	56
Herring/Shad		
Gizzard Shad	*Dorosoma cepedianum*	1,806

Table A-94
Annual finfish impingement–RFU (continued)

Common Name	Scientific Name	Annualized Impingement
Perches		
Yellow Perch	*Perca flavescens*	14
Saugeye	*Sander vitreus* x *Sander canadense*	14
Pikes/Pickerels		
Northern Pike	*Esox lucius*	14
Mooneyes		
Goldeye	*Hiodon alosoides*	28
Smelts		
Rainbow Smelt	*Osmerus mordax*	3,052
Suckers		
Longnose Sucker	*Catostomus catostomus*	85
White Sucker	*Catostomus commersoni*	14
	Totals	**6,582**

A.23.6 Population Information

Figure A-97
Census blocks detailing local household numbers surrounding RFU

A.23.7 Summary of Potential Issues with Cooling Tower Implementation

Table A-95
Summary of Impacts and Issues at RFU [3]

Resource	Issues
Engineering	Need to relocate existing utilities to accommodate cooling towers.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions.
Terrestrial Resources	Protected species, piping plover (State and Federally-listed endangered) was identified on-site.
Water Consumption	The state regulates consumptive water use [3]. Closed cycle cooling towers will increase consumptive water use.
Solid Waste	
Public Safety	
Quality of Life	Visible Plume
Permitting	Potential impacts to protected species/habitats would require coordination with State and/or Federal agencies. Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Parasitic losses and energy penalty will result in additional emissions of CO_2.
Other	

A.24 Representative Facility V (RFV)

Retrofitting RFV’s once-through cooling system with CCC appears to be potentially feasible, but is deemed difficult.

The retrofit would reduce cooling water intake to the plant. As discussed below, a corresponding decrease in IM&E may also be expected from the CCC retrofit. However, this retrofit would likely introduce several new environmental concerns like additional greenhouse gas emissions due to prolonged shutdowns, reduced visbility roadways and around the nearby airport, potential impacts to upland forest communities, reductions in air quality, and potential reductions in quality of life in the vicinity of the facility due to alterations in viewshed, increased noise, etc. These issues are discussed below.

Three cooling towers are preliminarily proposed for this facility’s single generating unit. The sizes, locations and impacts of these hypothetical cooling towers are discussed below.

A.24.1 Background

RFV is a base-load single-unit 975 MW nuclear-fueled steam electric generating facility located in the U.S. Southeast [72]. RFV is located in a rural area and is surrounded by agricultural properties [3].

This facility is located on the south shore of a reservoir [73], and uses once-through cooling water from the reservoir [72].

The cooling water source reservoir, recognized by the NRC as a 6,500 acre “cooling pond,” is the upper reservoir for a pumped storage facility (PSF). The PSF pumps water from a lower reservoir, a freshwater impoundment of the mainstem river, into cooling water source reservoir. The lower reservoir was enlarged in 1977 from 1,853 acres to 4,398 acres for added pumped storage exchange with the cooling water source reservoir and to address evaporative losses from the cooling water source reservoir due to RFV operations [74]. The Federal Energy Regulatory Commission (FERC) regulates the operations of the PSF [74].

A location map of RFV is provided as Figure A-98. Key information for the RFV generating unit is provided in the following table [24].

Table A-96
RFV engineering information

Unit	Rated Capacity (MW)	Design Cooling Water Flow Rate (gpm)	Design Condenser ΔT (°F)	Year On-line	Average Capacity Factor, 2002-2006
Unit 1	975	533,100	25	1982	95%
Total	**975**	**533,100**	**NA**	**NA**	**NA**

Figure A-98
RFV site location map

A.24.2 Cooling Water Intake Structure

RFV withdraws its once-through cooling water from the reservoir via a single shoreline CWIS [72].

The CWIS is designed to withdraw water from below a skimmer wall that extends from the water surface to a depth of 9.5 ft. The skimmer wall is designed to exclude floating debris from entering the cooling water system and to optimize withdrawal of cooler water from the water column at the pump house [74].

The CWIS has three pump bays, each with two entrances. Each entrance is 13 ft wide and 25.5 ft high, and is equipped with a steel trash rack with 10 in spacings and a vertical traveling screen with 3/8 in square mesh openings [74].

Under normal operations, the traveling screens are activated by a timer approximately every 12 hours or more frequently if the differential pressure across the screens becomes excessive. High pressure screen wash water is used to clean the screens of debris and impinged organisms. The screen wash water is then returned to the intake pumps downstream of the traveling screens [74]. Debris and fish impinged on the six vertical traveling screens in the CWIS are collected at a central location for ultimate disposal in a landfill [3, 72].

The heated cooling water is conveyed to a discharge bay and then returned to the reservoir via a 1,000 ft discharge canal [72].

A.24.3 Proposed Cooling Towers at RFV

To optimize use of available space and cooling tower performance, the hypothetical CCC retrofit design for RFV’s single generating unit includes three cooling towers: two 16-cell towers and one 18-cell tower. The towers would be arranged back-to-back and oriented with the predominant summer wind of southwest to northeast [25].

For study purposes, the towers have been located on high ground east of the discharge bay/canal [27]. These locations are shown in Figure A-99. Currently wooded and vegetated sections would need to be cleared to erect the cooling towers, and provide laydown and access routes during construction. The cooling water conveyance pipes between the condensers and cooling towers would need to cross the existing cooling water piping and other discharge piping [27]. Potential pipe routes, with consideration for least obtrusive infrastructure relocation and pipe crossings, would need to be further evaluated.

The design wet-bulb temperature used for RFV is 78°F [26]; the source water TDS is assumed to be approximately 200 ppm. For study purposes, all cooling tower cells have been sized at 50 ft by 50 ft by 55 ft, and the number of cells has been determined to allow for cooling water throughput of approximately 10,000 gpm per cell. The basic characteristics of the towers for RFV are given in the following table [24].

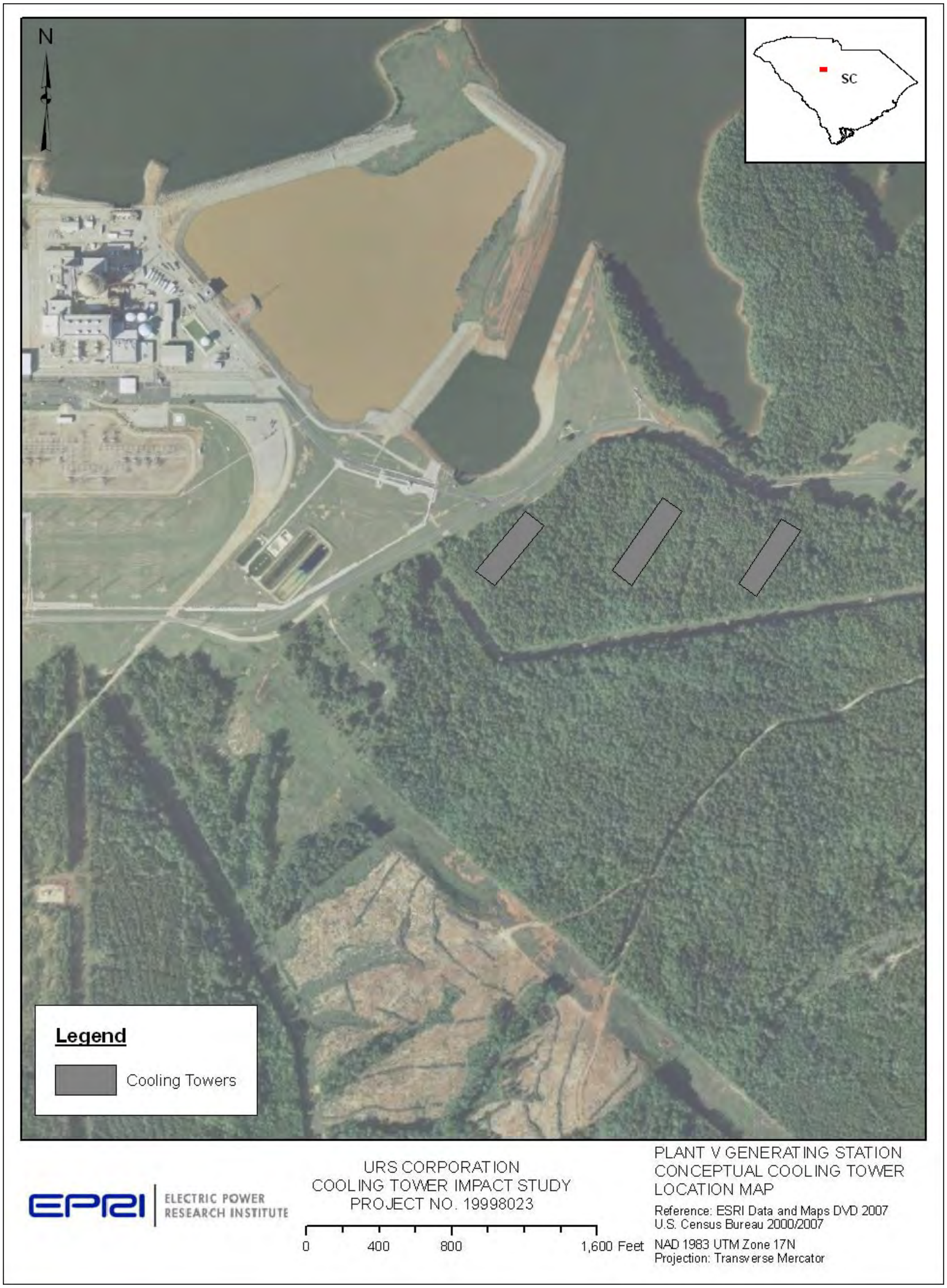

Figure A-99
RFV conceptual cooling tower location map

Table A-97
Basic characteristics of cooling towers proposed for RFV

Unit Designation		Unit 1		
Cooling Tower Eater Flow Rate	gpm	170,600	170,600	191,900
Cooling Tower Range	°F	25	25	25
No. and Arrangement of Cooling Tower Cells		16/ Back-to-back	16/ Back-to-back	18/ Back-to-back
Cell Size (L x W x H)	ft	50 x 50 x 55	50 x 50 x 55	50 x 50 x 55
Cooling Tower Basin Size (L x W x H)	ft	408 x 108 x 6	408 x 108 x 6	458 x 108 x 6.
Lift Pump Total	hp	1,897	1,897	2,134
Fan Total	hp	3,200	3,200	3,600
Fan Diameter	ft	32.8	32.8	32.8
Fan Housing Inside Diameter at Exit	ft	36	36	36
Drift Elimination Efficiency	%	0.0005	0.0005	0.0005
Cooling Tower Heat Dissipation Rate per Cell	BTU/hr	1.33E+08	1.33E+08	1.33E+08
Cycles of Concentration		8	8	8
Drift Rate	gpm	0.9	0.9	1.0
Cooling Tower Evaporation Rate	gpm	4,265	4,265	4,798
Blowdown Rate	gpm	609	609	685
Makeup Rate	gpm	4,875	4,875	5,484

Several engineering challenges associated with locating cooling towers at RFV are listed below.

- More than 10 high voltage transmission lines traverse the RFV site. Installing large diameter cooling water pipes under or around these transmission lines would be challenging [73].
- Potential construction would need to be performed around the water and wastewater piping, telephone and electrical cable, cooling water piping, fiber optics and storm drains [27].
- The tower dimensions given in Table A-98 are for standard back-to-back MECTs with no plume abatement. In the event that plume abated towers were required at this site, such towers would be limited to in-line arrangement, and locating multiple in-line towers onsite would be more difficult.
- Consumptive water use is already regulated by the state. A potential CCC retrofit would increase consumptive use.
- Closed-cycle cooling towers would be utilized for the two proposed generators [73]. The synergistic impacts associated with all cooling towers would need to be evaluated.

A.24.4 Alternative Cooling Towers and Locations Considered

The construction of the two new generating units is scheduled to be completed in 2016 and 2019. Much of the land that currently appears to be available is earmarked for Units 2 and 3 [27] and their associated facilities. CCC is planned for the two new units [73].

Given the multiple transmission rights-of-way and switchyard, and distance to the intake structure and outfall, areas to the south of the facility were not evaluated as potential cooling tower sites [27]. The existing facility and new facilities occupy a ridge line. Areas to the west are, therefore, unavailable for potential cooling towers [27].

The area to the northwest of the reactor was considered for two or three potential cooling towers for Unit 1 [27]. This location was eliminated due to unsuitability of topography and proximity to the meteorological tower and planned raw water intake lines for the two new generating units [27].

The suitability or feasibility of inline mechanical draft cooling towers, hyperbolic natural draft cooling towers, or hybrid towers were not evaluated.

A.24.5 Aquatic Biota

Biological information for RFV was provided by the power plant [74] and is summarized in Table A-98. The given annualized impingement numbers are based on actual cooling water usage.

Table A-98
Annual finfish impingement–RFV

Common Name	Scientific Name	Annual Impingement (# of fish)
Basses		
White Perch	*Morone americana*	752
Freshwater Catfish		
Snail Bullhead	*Ameiurus brunneus*	28
White Catfish	*Ameiurus catus*	209
Flat Bullhead	*Ameiurus platycephalus*	42
Blue Catfish	*Ictalurus furcatus*	975
Channel Catfish	*Ictalurus punctatus*	947
Herrings/Shad		
Gizzard Shad	*Dorosoma cepedianum*	348
Threadfin Shad	*Dorosoma petenense*	4,011
Perches		
Yellow Perch	*Perca flavescens*	488

Table A-98
Annual finfish impingement–RFV (continued)

Common Name	Scientific Name	Annual Impingement (# of fish)
Sunfishes		
Flier	*Centrarchus macropterus*	14
Hybrid Sunfish	*Lepomis* sp.	14
Warmouth	*Lepomis gulosus*	14
Bluegill	*Lepomis macrochirus*	84
	Total	**7,926**

A.24.6 Population Information

Figure A-100
Census blocks detailing local household numbers surrounding RFV

A.24.7 Summary of Potential Issues with Cooling Tower Implementation

Table A-99
Summary of impacts and issues at RFV [3, 27, 73]

Resource	Issues
Engineering	The facility is planning a major expansion. Any potential construction associated with cooling towers for the existing unit has to be appropriately coordinated with already planned construction of Units 2 and 3. Synergistic impacts of all potential cooling towers need to be evaluated. Need to construct around power lines and switchyard.
Aquatic Biota	Net reduction in IM&E.
Human Health	Increased particulate matter emissions.
Terrestrial Resources	Potential impacts to upland forest communities.
Water Consumption	Consumptive water use is already regulated by the state. A potential CCC retrofit would increase consumptive use [3].
Solid Waste	
Public Safety	Fogging on roadways and around airport (located approx 10 mi from the facility) could be hazardous to travelers [3].
Quality of Life	Noise impacts and visible plume.
Permitting	Local ordinances, permits, and zoning requirements would likely be required.
Greenhouse Gas	Prolonged shutdown for cooling system tie-ins and condenser re-optimization could result in additional burning of fossil fuels and greenhouse gas emissions. Over 3.5 million tons of CO_2 is estimated to be emitted due to retrofit-related downtime, if the retrofit were to be performed within 8 months.
Other	

A.25 Representative Facility W (RFW)

Modeling of RFW was limited to Aquatic Biota.

A.25.1 Background

RFW is located along the U.S. Southeast, along the Atlantic coast. The station is a four unit, oil-fired, steam electric generation plant with a net plant output of 1,142 MW. The facility uses a once-through cooling design, drawing cooling water from a harbor that is connected to the Atlantic Ocean via an 800 ft wide channel. The cooling water system has a combined capacity of approximately 899,000 gpm.

A.25.2 Cooling Water Intake Structure

Cooling water is withdrawn from the harbor through four 12 ft diameter, 250 ft long pipes that lead to a 1,900 ft long open canal that widens into a basin adjacent to the cooling water intakes. The canal is approximately 100 ft wide and has a depth at low tide of 13 ft.

The facility uses four cooling water intake structures adjoining one another, one for each unit. All intakes are located below the waterline and are prescreened through trash racks before entering the forebays. Each unit has two intake bays, each equipped with one single-entry 1/8 in x 1/2 in vertical traveling screen with high-pressure spray wash. Through-screen intake velocities for Units 1 and 2 are 1.93 fps and for Units 3 and 4 are 2.9 fps. Screen wash water is discharged into troughs equipped with trash baskets and then returned to the intake basin. The material collected in the baskets is deposited into a roll-off dumpster for offsite disposal.

A.25.3 Aquatic Biota

Biological information for RFW was provided by the power plant [75] and is summarized in Table A-100 and A-101. The given annualized impingement and entrainment numbers are based on actual cooling water usage.

Table A-100
Annual finfish and invertebrate impinged–RFW

Common Name	Scientific Name	Annualized Impingement
Fish		
Anchovy	*Anchoa* sp.	1,434
Bandtail Puffer	*Sphoeroides spengleri*	3,821
Big-Eye Anchovy	*Anchoa lamprotaenia*	36,155
Bonefish	*Albula* sp.	605
Broad-Striped Anchovy	*Anchoa hepsetus*	6,829
Checkered Puffer	*Sphoeroides testudineus*	3,370
Grunt	*Haemulon* sp.	425
Gulf Pipefish	*Syngnathus scovelli*	213
Herring	Clupeidae	304
Houndfish	*Tylosurus crocodilus*	397
Jenny Mojarra	*Eucinostomus gula*	303
Ladyfish	*Elops saurus*	303
Lined Seahorse	*Hippocampus erectus*	375
Lookdown	*Selene vomer*	590
Mojarra	*Eucinostomus* sp.	811
Planehead Filefish	*Stephanolepis hispida*	521
Sargassumfish	*Histrio histrio*	220

Table A-100
Annual finfish and invertebrate impinged–RFW (continued)

Common Name	Scientific Name	Annualized Impingement
Sharpnose Pufferfish	*Canthigaster rostrata*	200
Silver Mojarra	*Eucinostomus argenteus*	1,646
Southern Puffer	*Sphoeroides nephelus*	369
Tidewater Mojarra	*Eucinostomus harengulus*	1,316
Tomtate	*Haemulon aurolineatum*	1,236
Other		3,111
Fish Total		**64,554**
Invertebrates		
Atlantic Brief Squid	*Lolliguncula brevis*	1,271
Blotched Swimming Crab	*Portunus spinimanus*	147
Blue Crab	*Callinectes sapidus*	526
Brown Shrimp	*Farfantepenaeus aztecus*	82
Caribbean Reef Squid	*Sepioteuthis sepioidea*	446
Carridean Shrimp	*Caridea*	928
Flatface Swimming Crab	*Portunus depressifrons*	382
Florida Stone Crab	*Menippe mercenaria*	1103
Lesser Blue Crab	*Callinectes similis*	232
Ornate Blue Crab	*Callinectes ornatus*	312
Panaeid Shrimp	*Farfantepenaeus* sp.	132
Penaeid Shrimp	*Rimapenaeus* sp.	953
Penaeid Shrimp	Penaeidae	600
Pink Shrimp	*Farfantepenaeus duorarum*	3,323
Pistol Shrimp	*Alpheus* sp.	109
Portunid Crab	Portunidae	153
Portunus Crab	*Portunus* sp.	505
Roughneck Shrimp	*Rimapenaeus constrictus*	698
Sargassum Swimming Crab	*Portunus sayi*	1,088
Snapping Shrimp	Alpheidae	241
Swimming Crab	*Callinectes* sp.	437
Other		693
Invertebrate Total		**14,362**

Table A-101
Annual finfish and invertebrates entrained–RFW

Common Name	Scientific Name	Annual Entrainment
Fish		
Jack-Wrasse-Drum Complex	Carangidae/Labridae/Sciaenidae Complex	485,611,006
Croakers & Drum	Sciaenidae	207,645,095
Blennies	Blenniidae	114,668,111
Grunt-Drum-Grouper Complex	Haemulidae/Sciaenidae/Serranidae Complex	105,732,883
Herring	Clupeidae	93,865,688
Jack-Grunt-Hake-Flounder-Grouper Complex	Carangidae/Haemulidae/ Merlucciidae/Paralichthyidae/ Sciaenidae/Serranidae complex	92,914,646
Perch-like Fishes	Perciformes	88,886,585
Jack-Grunt-Drum-Grouper Complex	Carangidae/Haemulidae/ Sciaenidae/Serranidae complex	87,275,750
Other		465,908,196
Unidentifiable		8,513,978,690
Fish Total		**10,256,486,650**
Invertebrates		
Short Tailed Crab	Brachyura	13,556,487,058
Caridean Shrimp	Caridea	8,157,176,064
Anomuran Crab (Non-Thalasinidea)	Anomura	3,390,008,648
Ghost And Mud Shrimp	Thalassinidea	1,192,745,985
Sergestid Shrimp	Sergestoidea	525,534,473
Mantis Shrimp	*Squilla empusa*	432,270,379
Other		1,177,970,023
Invertebrate Total		**28,432,192,631**

A.26 Representative Facility X (RFX)

Modeling of RFX was limited to Aquatic Biota.

A.26.1 Background

RFX is located along the U.S. North Atlantic coast. The station consists of four generating units that use oil as the primary fuel and have a combined net generating capacity of 843 MW. The generating units use a once-through cooling design, drawing saline water directly from the ocean. The facility utilizes two CWISs, one for Units 1-3 and one for Unit 4. The intake structures are situated along the shoreline and have a design flow rate of 364,000 gpm.

A.26.2 Cooling Water Intake Structure

Both CWISs are oriented parallel to tidal flow in a small embayment. The embayment is connected to the deep water by two channels cut through the rock ledge on the sea bottom. The CWISs are protected by debris booms and trash racks which prevent debris and large material from entering the forebays. Units 1 & 2 each have a single intake bay measuring 15.5 ft wide by 8.0 ft high. Unit 3 has a single intake bay with a trash rack opening of 21.0 ft by 8.0 ft high and Unit 4 has four intake bays with an opening size of 17.0 ft wide by 20.5 ft high. The intake bays are entirely submerged under normal tidal conditions.

All of the intake bays are equipped with vertical traveling water screens with 3/8 in square mesh to screen debris from the cooling water. Unit 1, 2 and 3 traveling screens operate at a fixed speed of 10 feet per minute (fpm). Each screen is equipped with a high-pressure spray system that washes fish, crabs, and debris from the ascending side of the screen into a common trough for each screen house. Fish and debris are carried in the trough back to the source waterbody. Unit 4 traveling screens have a dual pressure screen wash systems and Ristroph modifications. The low pressure spray side for Unit 4 washes fish and debris into a fish trough (ascending side of screen) The fish return trough currently discharges to the debris holding bin.

Velocities at the opening of the CWISs range from 0.4 fps (Unit 4) to 2.2 fps (Units 1&2). Through screen velocities range from 1.1 to 1.9 fps.

A.26.3 Aquatic Biota

Biological information for RFX was provided by the power plant [76] and is summarized in Table A-102. The given annualized impingement and entrainment numbers are based on actual cooling water usage.

Table A-102
Annual impingement and entrainment–RFX

Common Name	Scientific Name	Larval Entrainment	Egg Entrainment	Annual Impingement
Alewife	*Alosa pseudoharengus*			97
American Eel	*Anguilla rostrata*			3
American Lobster	*Homarus americanus*	68,722		55
American Plaice	*Hippoglossoides platessoides*	86,981	146,133	
American Sand Lance	*Ammodytes americanus*	768,757		
American Shad	*Alosa sapidissima*			4
Atlantic Cod	*Gadus morhua*	146,001	108,023	2
Atlantic Herring	*Clupea harengus*	1,763,013		109
Atlantic Mackerel	*Scomber scombrus*		3,842,425	
Atlantic Menhaden	*Brevoortia tyrannus*		21,925	
Atlantic Silverside	*Menidia menidia*			3
Atlantic Tomcod	*Microgadus tomcod*			2
Bay Anchovy	*Anchoa mitchilli*		253,932	5
Blueback Herring	*Alosa aestivalis*			105
Cancer sp. Crab	*Cancer* sp.	10,981,818		170
Cunner	*Tautogolabrus adspersus*	12,097,891	105,702,810	919
Fourbeard Rockling	*Enchelyopus cimbrius*	258,811	18,945,739	
Fourspine Stickleback	*Apeltes quadracus*			197
Grubby	*Myoxocephalus aenaeus*	12,878,441		399
Jonah Crab	*Cancer borealis*			3
Killifish sp.	*Fundulus* sp.			9
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*	13,571,943		4
Lumpfish	*Cyclopterus lumpus*	33,176		92
Mummichog	*Fundulus heteroclitus*			53

Table A-102
Annual impingement and entrainment–RFX (continued)

Common Name	Scientific Name	Larval Entrainment	Egg Entrainment	Annual Impingement
Northern Pipefish	*Syngnathus fuscus*	308,368		434
Pollock	*Pollachius virens*		21,040	
Radiated Shanny	*Ulvaria subbifurcata*	974,456		
Rainbow Smelt	*Osmerus mordax*	2,032,894		42
Red Hake	*Urophycis chuss*			11
Red/Spotted Hake	*Urophycis sp.*	11,229		
Rock Crab	*Cancer irroratus*			152
Rock Gunnel	*Pholis gunnellus*	29,433,668		25
Rough Silverside	*Membras martinica*	18,032		
Shorthorn Sculpin	*Myoxocephalus scorpius*	27,141		27
Silver Hake	*Merluccius bilinearis*		1,301,440	2
Striped Bass	*Morone saxatilis*	33,710		
Threespine Stickleback	*Gasterosteus aculeatus*			66
Unidentifiable				17
White Hake	*Urophycis tenuis*			16
Windowpane	*Scophthalmus aquosus*	477,423	2,989,538	22
Winter Flounder	*Pseudopleuronectes americanus*	911,538	557,137	857
Wrymouth	*Cryptacanthodes maculatus*	1,731,953		2
Total		**88,615,966**	**133,890,142**	**3,807**

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B
IMPACT METHODOLOGY

Calculations performed for this study were made using spreadsheet software (e.g., Excel), computer models (e.g., AERMOD), or scientific calculators. All digits were retained throughout the multi-step calculations and are often presented in this appendix. However, this implies a level of accuracy not obtainable with the methodology used in the study. Therefore, most values have been rounded for inclusion in the main document's text and tables.

B.1 Human Health Related to Air Impact

B.1.1 Modeling

B.1.1.1 AERMOD Modeling Approach

The purpose of the air quality dispersion modeling analysis was to estimate offsite ambient concentration and deposition impacts attributable to the installation of wet cooling towers. To meet this objective, the USEPA AERMOD modeling system was used. The AERMOD modeling system consists of meteorological and terrain preprocessing programs (AERMET and AERMAP, respectively) and the AERMOD dispersion model. AERMOD is the recommended USEPA model for use in a wide variety of regulatory applications. It is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases, and multiple sources (including, point, area and volume sources). It contains algorithms to calculate both concentration and deposition.

B.1.1.1.1 Meteorological Data Processing (AERMET)

Meteorological data for AERMOD were processed with the most recent release of the AERMET meteorological pre-processor. AERMET merges a surface data set with an upper air data, to provide a quality assessed meteorological data set for input to AERMOD. AERMET processes the data in three stages, as follows:

Meteorological data are extracted from archive data files and the data are processed through various quality assessment checks;

All data available for 24-hour periods are merged and stored together in a single file; and

The merged meteorological data are read and the necessary parameters to be used in the dispersion modeling are estimated. The AERMET processor requires hourly estimates of wind speed, direction, temperature, cloud cover as well as the 1200 Greenwich Mean Time (GMT) sounding to generate the requisite data for modeling.

Surface characteristics in the form of albedo, surface roughness and Bowen ratio, plus standard meteorological observations, are input to AERMET. AERMET then calculates the planetary boundary layer (PBL) parameters:

- friction velocity (u*);
- Monin-Obukhov length (L);
- convective velocity scale (w*);
- temperature scale(Θ*);
- convective boundary layer (CBL) height (zi);
- stable boundary layer (SBL) height (h); and
- surface heat flux (H).

These parameters are then passed to the meteorological interface module where vertical profiles are calculated, from similarity expressions, for wind speed (u), wind direction, lateral and vertical turbulent fluctuations (σv, σz), potential temperature gradient (δσ, δz), and potential temperature (Θ).

For each site, meteorological data from nearby representative National Weather Service (NWS) stations were identified. These data included hourly surface data and twice daily rawinsonde data which were obtained from www.webmet.com. For this study, a single year of meteorological data was used. The most recent data years available were identified and the year with a minimum amount of calm surface winds and missing upper air rawinsonde data were selected for use.

Surface albedo, roughness height and Bowen ratio representative of the study area are also required by AERMET. Seasonal/quarterly estimates of these data were developed using USEPA data and recommendations [1, 2].

B.1.1.1.2 Receptor Grid and Terrain Grid

Receptor grids were developed for each site from USGS 30-meter Digital Elevation Model (DEM) data. A dense Cartesian grid with 100-meter receptor spacing was developed for the near field, out to approximately two km from the subject site with a less dense polar grid with 36 radials beyond the dense Cartesian grid. Onsite receptors were eliminated from the analysis. Terrain elevations were obtained using BLINE BEAST software. USGS 30-meter Digital Elevation Model (DEM) data were obtained from www.webgis.com.

B.1.1.1.3 AERMOD Model Options

AERMOD was used to estimate both ambient concentration and deposition attributable to the proposed wet cooling towers. For concentration estimates, AERMOD was run in regulatory default mode.

To estimate deposition, the dry deposition DDEP option of AERMOD was used. Particle deposition values, particle size distribution and mass fraction, consistent with the drift droplet size distribution were input to AERMOD. A droplet density of one g/cm^3 was used.

B.1.1.2 SACTI

The potential for fogging, icing, and shadowing impacts were estimated using the Seasonal Annual Cooling Tower Impact (SACTI) model, Version 11-01-90. SACTI is a validated and recognized cooling water tower plume model that has been applied in numerous cooling tower studies across the US. It was developed by Argonne National Laboratory at the request of the Electric Power Research Institute (EPRI) to address potential impacts from cooling towers such as plume visibility, ground-level fogging, ground-level icing, and plume shadowing. It is based on studies conducted by Argonne National laboratory to evaluate the performance of numerous cooling tower plume and drift models.

B.1.1.2.1 Model Input Data

Input data for SACTI includes proposed cooling water tower design and operational data, along with hourly meteorological data. The model creates a set of receptors based on model default parameters.

Although SACTI contains algorithms for cooling water towers arranged singly or in clusters, it can evaluate only 30 cells in a single run. Proposed cooling towers at the BTPs exceeded this limitation; as a result, for the Beta Test modeling each facility was split into multiple model runs as a “work around” (Table B-1).

Table B-1 lists the number of runs executed for each facility during the Beta Test and the towers included in each model run.

Table B-1
SACTI model setup for BTPs

Beta Test Plant	Number of SACTI Runs	Towers Included in Each Model Run
BTCA1	2	Run 1: Units 1, 2, 3, 4 Run 2: Units 5, 6
BTPA	3	Run 1: Units 1, 2 Run 2: Units 3, 4 Run 3: Tower 5
BTPB	2	Run 1: Units 1, 2 Run 2: Units 3, 4
BTPC	2	Run 1: Units 1,2 Run 2: Unit 3
BTPD	2	Run 1: Units 1, 2 Run 2: Units 3, 4
BTPE	2	Run 1: Unit 2 Run 2: Unit 3
BTCA2	3	Run 1: Unit 2 East Run 2: Unit 2 West Run 3: Unit 3

The 30 cell limit was also reached or exceeded for additional facilities modeled, except for RFK. Several test evaluation runs using the SACTI model confirmed that multi-tower plume interaction is an important factor. Therefore, for facilities that exceeded the allowed number of cells, the following approach was used. All dual arrays were modeled as single arrays and the total number of cells was reduced to the values shown in Table B-2. This preserved the configuration of the towers in terms of number of towers, length, and alignment of towers to allow for plume interactions between the towers.

Table B-2 contains information on the actual number of cells included in this phase of SACTI modeling along with a listing of the number of towers located at the facility.

Table B-2
SACTI model setup for representative facilities

Representative Facility	Original # of Cells	Modeled # of Cells	Percent of Cells Modeled	Towers
RFF	62	13	21%	4 dual
RFG	60	14	23%	4 dual
RFH	136	18	13%	6 dual
RFI	30	15	50%	2 single
RFJ	46	23	50%	2 dual
RFK	22	22	100%	1 dual
RFL	46	13	28%	2 dual

The test evaluation run used an example facility, with a multiple tower configuration, which limited the number of cells to a value less than 30. The analysis compared results using a “split-run” modeling approach (Beta Test) and a “representative configuration” modeling approach. Results indicated slightly better agreement when using a “representative configuration” when compared to a “split-run” approach. It should be noted, depending on a facility’s exact configuration, the “split-run” or “representative configuration” both modeling methods have merits. However, since the “representative configuration” produced slightly more conservative results, this methodology was selected. By using this modeling approach, the important factor of plume interactions between the towers was maintained.

Meteorological data-For each representative facility, a five-year (1986-1990) meteorological data set was evaluated using hourly surface data from the nearest airport. Table B1-3 contains a listing of all the meteorological surface stations included in the analysis for each facility and displays the year that best represents the five-year period. This year was modeled in SACTI to produce final results. Hourly surface data variables such as wind direction, wind speed, temperature, relative humidity, cloud cover, and ceiling heights were converted from SAMSON format to CD 144 format in order to be input to SACTI.

For the Beta Test modeling, upper air data were created from data provided in Appendix A of the SACTI User’s Manual. For the final phase of modeling, twice daily (morning and afternoon) mixing height data from a nearby National Weather Service upper air site were included in the SACTI modeling analysis. These data were obtained from the USEPA SCRAM website (http://www.epa.gov/scram001/).

Table B-3
Surface data sources for each beta test plant and representative facility

Facility	Data Source	Selected Year from a 5-year Period (1986-1990)
BTCA1	Los Angeles Intl. Airport	1986
BTPA	Mobile Airport	1986
BTPB	Muskegon County Airport	1986
BTPC	New Castle Bellanca Field	1986
BTPD	Charlotte Cannon Airport	1986
BTPE	Harrisburg Airport	1988
BTCA2	San Diego Airport	1986
RFF	Detroit Airport	1986
RFG	Cincinnati Airport	1990
RFH	Wilmington Airport	1989
RFI	O’Hare Airport	1988
RFJ	Shreveport, LA	1990
RFK	Atlantic City Airport	1988
RFL	St. Louis Airport	1988

Receptors-SACTI uses a polar receptor grid with the origin located at the center of the cooling tower housing. Receptors are located on 16 wind direction radials spaced at 22.5-degree intervals. Along each radial, default receptors are spaced at 100-meter intervals, out to 1,600 meters from origin for fogging and icing simulations. Plume shadowing impacts were modeled out to a distance of 8,000 meters with 200 meters between receptors, and visible plumes were modeled to a distance of 10,000 meters with 100-meter spacing between receptors.

Cooling Tower Design Data-For each cooling water tower at each representative facility, the following engineering design data were entered into SACTI (Table B-4). Mechanical-draft evaporative cooling tower engineering design data for each representative facility’s proposed cooling towers are presented in Section 3 of the main report.

Table B-4
Engineering data used in SACTI modeling for each BTP

Site Longitude	Tower Type
Site Latitude	Tower Height
Number of Tower Housings	Tower Length
Number of Cells	Tower Width
Maximum Heat Dissipation Rate	Exit Diameter of Fans
Maximum Total Tower Air Flow	Effective Diameter
Max Drift Loss Rate	Design Water Circulation Rate
Tower Orientation (angle measured East of North)	

B.1.1.2.2 SACTI Model Programs

The SACTI model is comprised of four different programs: PREP, MULT, TABLES, and PAGEPLOT. The PREPROCESSOR program (PREP) prepares meteorological data and a portion of cooling water tower design input parameters. Its basic functions are to:

- Read in the hourly surface meteorological data and remove any invalid or missing records;
- Calculate parameters needed by the rest of the programs;
- Calculate the cooling tower exit conditions for each hourly record;
- Generate typical plume and representative fogging cases representing the weather conditions determined from statistical analysis of the meteorology; and
- Create output files that contain the information needed by the other programs.

The plume dispersion modeling program (MULT, previously known as the PLUME program) determines plume predictions for cases determined in the PREP program. MULT performs all calculations for each plume category and creates output files for the TABLES program.

The TABLES program reads output from the MULT file and generates output tables, including predicted seasonal impacts by distance and wind direction.

The PAGEPLOT program reads the TABLES output and generators line printer output data plots. This program executed for each SACTI model performed, but the resulting data plots were not used to generate final output plots used in this report. Rather, all output data from the TABLES program were plotted in a separate program, so that additional local information could be shown on each plot.

Downwash Considerations-SACTI has the capability to evaluate downwash effects of nearby structures using the “external plate” option, which would result in the model considering enhanced turbulent mixing of the plume and increased vapor plume dilution as a result of the additional structures. As a conservative measure, this option was not used for any of the representative facilities. Only downwash effects from the proposed cooling tower(s) were considered.

B.1.2 National Scaling

B.1.2.1 PM

Cooling tower emissions, PM(total), PM_{10} and $PM_{2.5}$, were scaled to other Phase II facilities based on source waterbody salinity. Freshwater source waterbodies included large and small rivers, lakes and reservoirs and the Great Lakes. Saline waterbodies included ocean, estuary and tidal rivers. For each grouping, a line, forced through the origin, was fitted to PM plotted against cooling water usage (flow) (Figure B-1 and B-2)[1]. Relationships were strong (R^2 values > 0.83) and resulted in the following equations:

Freshwater: $y = 0.015x$ ($R^2 = 0.8733$)

Saline: $y = 0.3136x$ ($R^2 = 0.83$)

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[1] RFG was determined to be an outlier and was omitted from this analysis.

These equations were used to estimate PM emissions for all facilities not modeled. PM_{10} and $PM_{2.5}$ were estimated from PM by using the mean ratio of PM_{10} and $PM_{2.5}$ to PM from modeled facilities within each salinity category. Results are presented in Section 6.3.1.1.

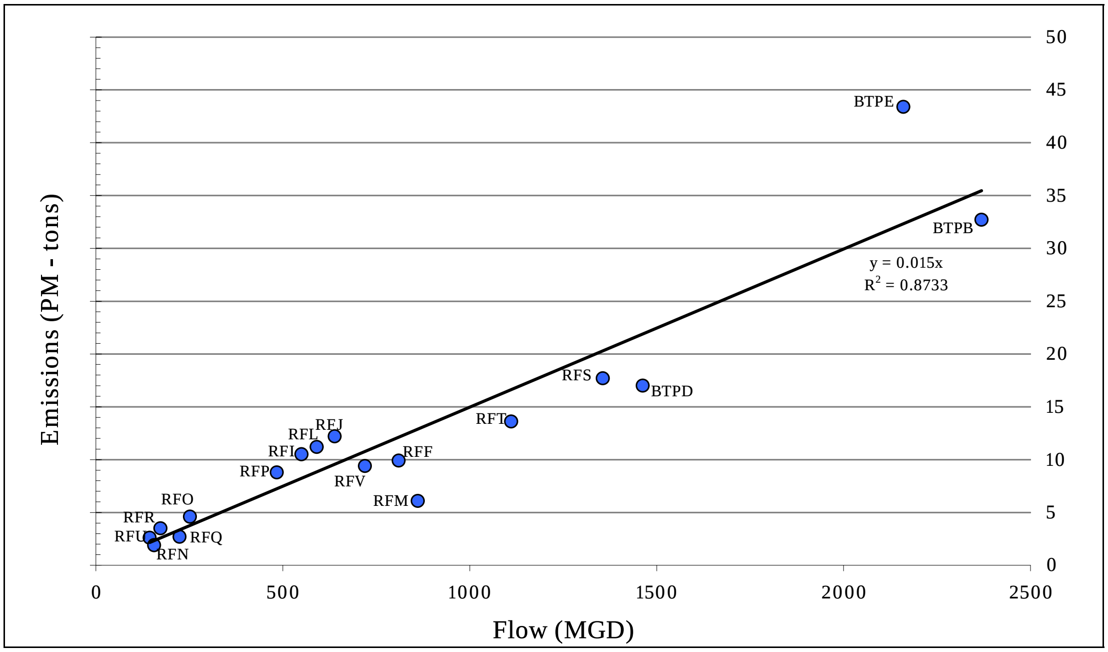

Figure B-1
PM plotted against cooling water usage (flow) for freshwater facilities (BTPs and RFs) line fitted to data is forced through origin

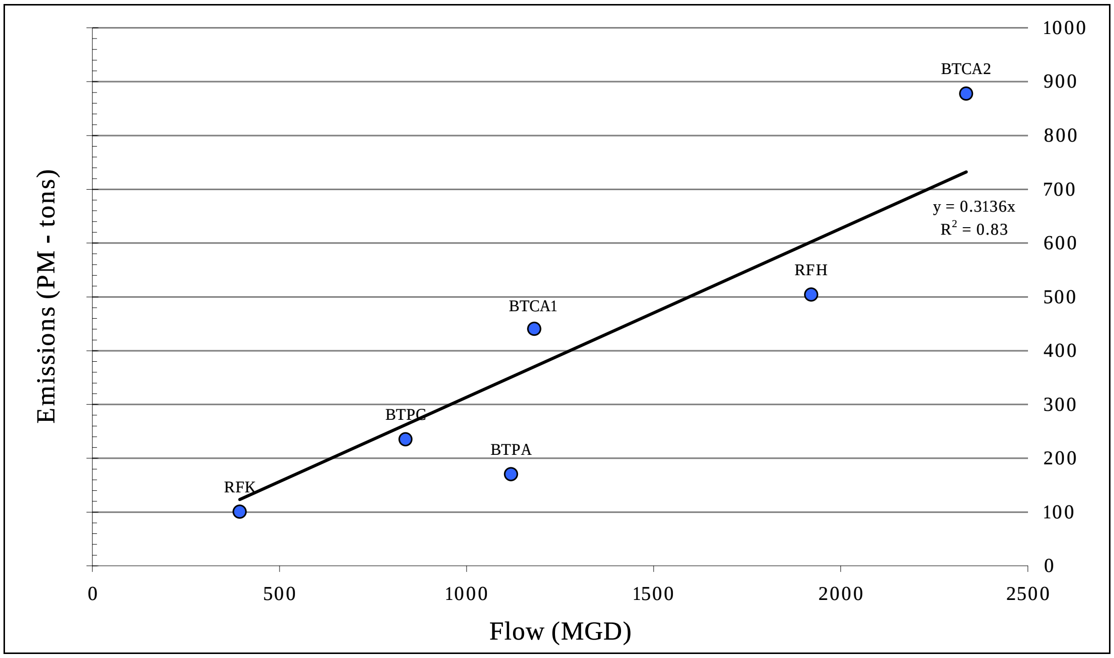

Figure B-2
PM plotted against cooling water usage (flow) for saline facilities (BTPs and RFs) line fitted to data is forced through origin

B.1.2.2 Exposed Population

The potential populations exposed to increased mortality or morbidity was calculated by grouping modeled BTPs/RFs into the nine salinity/population. The BTP/RF with the maximum exposed population was chosen to represent the other facilities in that subgroup (Table B-5). Note that because there were no BTPs/RFs in the SR/GL-Low Population subgroup, the results for RFS, the only freshwater BTP/RF in a Low Population area, were used for estimating the other facilities in that subgroup. Numbers exposed by BTP/RF are given in Table F-1, Appendix F. Results are presented in Section 6.3.1.2.

Table B-5
Exposed populations subgroups and facilities chosen to represent each

Exposed Populations Subgroups	Representative Facility[a]
LR/RL – High Population	RFL
LR/RL – Medium Population	RFJ
LR/RL – Low Population	RFS
SR/GL – High Population	RFI
SR/GL – Medium Population	BTPB
SR/GL – Low Population	RFS
O/E/TR – High Population	RFK
O/E/TR – Medium Population	RFH
O/E/TR – Low Population	BTPC

[a] Representative facilitates for LR/RL and SR/GL waterbody categories are similar due to their status as freshwater source waterbodies and will have similar water quality characteristics.

B.2 Terrestrial Resources

B.2.1 Long-term Loss of Wildlife Habitat, Wetlands, and Critical Habitat

B.2.1.1 Quantification

Terrestrial resources are identified as wildlife habitat and tidal or non-tidal wetlands, including critical habitats which support rare, threatened or endangered species. The construction of a cooling tower may result in the temporary or permanent loss of these resources. Temporary losses will be restored and permanent losses will be avoided to the extent practicable.

The most current site-specific information available was reviewed for each facility, including national and state databases, GIS mapping data, recent aerial photography, National Wetlands Inventory (NWI) maps, and published facility reports in order to determine the location and extent of on-site and nearby terrestrial and wet land resources. This information is provided in Appendix A. Where terrestrial resource impacts were unavoidable, the cooling tower footprint and a perimeter area of permanent disturbance were overlain on a site-specific natural resource GIS map to compute permanent losses. The impact areas was determined by the need for roadway/maintenance access around the area of cooling tower footprints, and in some cases the need for vegetation clearance to allow for sufficient air flow surrounding the cooling towers. Once this total impact area had been calculated, vegetation types were determined and mapped to allow calculation of specific vegetation impacts/loss.

B.2.1.2 Monetization

While many of the costs and benefits associated with terrestrial impacts are born by land owners, some are experienced by society as a whole. The costs and benefits experienced by society as a whole are referred to as externalities and, in this section, WTP to avoid the loss of positive externalities as the result of cooling tower construction and operation is estimated.

In creating and implementing multiple private programs designed to preserve land in its natural state, society has revealed a WTP to maintain positive externalities that flow from private land. The existence of government sponsored programs designed to achieve the same goal coupled with the assumption that governments are an agent acting on behalf of society is consistent with this revealed WTP.

Typically, WTP for habitat preservation is highest for unique, rare, or threatened habitats. As such, little information exists in the literature on the WTP to preserve non-unique/rare habitats. Therefore, the WTP for these habitats cannot be determined, and this analysis focuses on the estimation of a per-unit WTP for the preservation of positive externalities flowing from unique habitats and applies that WTP to impacted acres.

Cooling tower construction would impact wetland habitat at several facilities. However, federal and some state regulations require that wetland impacts be mitigated by creation of new wetlands or restoration of existing wetlands. As such, there is no net loss of wetland services associated with cooling tower construction in wetlands and WTP estimates to avoid construction impacts in wetlands are not estimated. However, because impacts to the wetland at BTCA1 may not fall under state and federal regulations, a net environmental change would occur and WTP to avoid this impact has been estimated.

Among the BTPs, three impacts may have impacts to unique habitat. First, construction of a cooling tower at BTPB would result in the conversion of 21.3 acres of forested dune habitat to an industrial land use. Second, abandonment of once through cooling at BTCA1 would result in the loss of a primary source of water for an adjacent 25 acre wetland site, which is predicted to severely degrade the wetland. Finally, the cooling tower construction at BTCA2 would result in the conversion of 0.17 acres of coastal bluff scrub habitat into an industrial cover type.

The WTP to avoid impacts to great lakes coastal dunes was estimated based on a recent land purchase offer for similar habitat. In 2006, 402 acres of undeveloped shoreline, dune, forest and pasture acreage was purchased for development at an average cost of $100,700 per acre in 2007 dollars [3]. Prior to that purchase, government and local groups had offered $97,400 per acre in 2007 dollars to purchase and preserve the parcel [3]. Therefore, WTP to pay to avoid impacts to coastal dune habitat is assumed to be up to $97,400 per acre or $5,201 per acre annually:

$$AnnualWTP = 0.0534 \times WTP$$

where 0.0534 is an estimate of annual rent[2] based on a real interest rate of 4.2 percent and a depreciation rate of 1.14 percent. Thus the total annual WTP to avoid impacts to 21.3 acres of coastal dunes at BTPB is estimated to be $110,785.

The WTP to avoid degradation of the 25 acre wetland site adjacent to BTCA1 was estimated from government grant information. Data describing 2005-2006 projects funded by Southern California's Wetlands Recovery Project reveal a WTP of approximately $3,860 (in 2007 dollars) per acre or $206 per acre annually for improvements to wetlands [4]. Therefore, the total annual WTP to avoid degradation of the 25 acre wetland adjacent to BTCA1 is estimated to $5,153.

No transactions were identified revealing a WTP to avoid impacts to very small parcels of coastal bluff scrub habitat. As such potential WTP to avoid impacts to 0.17 acres of coastal bluff scrub habitat at BTCA2 was not estimated.

B.2.1.3 Monetization Uncertainty and Omissions

With respect to the two specific impacts identified at BTPs, the $5,200 per acre annual WTP estimate for coastal dune preservation may overstate actual WTP. The transaction upon which we based our assessment was related to a large, undeveloped shoreline parcel. WTP to preserve the same habitat in the vicinity of industrial or commercial/residential areas may be less than $5,200 per acre.

Potential WTP to avoid impacts to 0.17 acres of coastal bluff scrub habitat at BTCA2 was not estimated. Estimates of WTP to avoid terrestrial impacts to non-unique habitats were not generated. These omissions would tend to bias estimates in a downward direction.

B.2.1.4 National Scaling

As addressed in Section 6.3.2.1 of the main text, based on the information collected in this study, the loss of critical habitat associated with a national closed-cycle cooling retrofit may be summarized as:

- Four of the 24 plants studied, or 17 percent, estimated potential loss of critical habitat during the closed-cycle cooling retrofit;
- Based on the EPRI Questionnaire, 29 of the 209 facilities responding indicated terrestrial or wetland resources would be impacted by closed-cycle cooling retrofit. Wetlands were cited in seven responses, with the remaining facilities reporting potential critical habitats such as protected dunes, lakes, threatened and endangered species habitat, and refuges. Thus, unique, rare, or threatened habitats may be lost at up to 22 (11 percent) of the facilities surveyed; and
- Based on these two subsamples, between 47 and 72 of the Phase II facilities may experience potential loss of critical habitat as a result a closed-cycle cooling retrofit.

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[2] Annual rent can also be estimated by assigning a discount rate and time horizon. An annual rent of 0.0534 is approximately equal to a 3% discount rate applied over a 30 year time horizon.

A WTP to preserve non-unique, non-rare habitats could not be developed because of the lack of information in the literature. Therefore, the loss of over 2,800 acres of mostly herbaceous/shrub-scrub, upland forest and open water habitat can not be monetized. Potential wetland impacts that may occur nationally are not monetized because federal and some state regulations require that these losses be mitigated by creation of new wetlands or restoration of existing wetlands. As such, there is no net loss of wetland services associated with cooling tower construction in wetlands.

WTP estimates exist for the preservation of critical habitats, thus allowing monetization of potential loss. Based on the seven facilities studied, the total WTP associated with critical habitat loss is $116,000. However, the quantity, type, and value of the critical habitat loss are site-specific. Only three of the seven BTPs were estimated to impact any critical habitat and the WTP to avoid one could not be calculated due to a lack of information (Section 4.2.1.2 of the main text). Using this small subset of facilities, the arithmetic average WTP is $16,563. This is likely an underestimate because the WTP to avoid loss of coastal scrub-shrub habitat at BTCA2 is expected to be positive, but is not quantifiable, and therefore was assumed to be $0. However, this statistic is more appropriate for scaling than the median WTP value, which is $0, because the median would underestimate the national impacts more.

Based on the results of the EPRI Questionnaire and the BTP/RF evaluation (i.e., 47-72 Phase II facilities may experience potential loss of critical habitat as a result a closed-cycle cooling retrofit) and the average WTP ($16,563), the national annual WTP to avoid this loss may be $778,000 - $1.19 million.

B.2.2 Salt and Mineral Drift Effects on Vegetation and Soils

B.2.2.1 Quantification

Salt and mineral drift from mechanical-draft evaporative cooling towers may adversely affect native vegetation, soils and crops. Potential effects on vegetation were quantified by two methodologies, as described below:

- Method 1, as applied to native vegetation, uses the model outputs of deposition rates in kilograms per hectare per month of sodium chloride (NaCl) and other mineral salts to compare with threshold values in the literature indicating when vegetative cover may be damaged by salt deposition. An adjustment was made to the fossil fuel plants to incorporate actual plant operating data compared to design capacity. It was assumed that this proportion could be applied to the area impacted by salt deposition in a linear fashion. This is a currently unverified assumption; and
- Method 2, which is applied only to agricultural lands, quantifies the amount of salt that would be deposited on various agricultural soil types and identifies expected yield reductions associated with that salt deposition, which are then monetized. Salt or mineral deposition from mechanical-draft evaporative cooling towers at each BTP was determined using the AERMOD model described in Section B1.1.1. Salt drift deposition are overlain on maps showing specific soil types, crops, and native vegetation derived from Soil Survey Geographic (SSURGO) and NLCD databases (Appendix C). In non-arid regions, deposition of salt on plant leaves can reduce agricultural productivity in both the short and long run. In

> arid regions, the primary long run effect driving productivity reductions is the accumulation of salts in the soil. Potential effects of salt deposition would therefore, be analyzed separately for arid and non-arid regions. However, all BTPs are located in non-arid regions.

The modeled distribution of mineral drift rates at each facility using Method 1 are compared to order-of-magnitude thresholds of impact derived from the NRC [5]. The ranges used represent no impact, possible visible leaf damage (moderate), and potential damage sufficient to require mitigation actions (high).

B.2.2.2 Monetization

This analysis assumes agricultural costs are sunk and non-recoverable over the relevant time horizon. As such, average annual lost revenue is the appropriate measure of annual WTP to avoid productivity reductions. If farmers can recover some portion of production costs, these methods would overestimate average annual WTP over the life of the cooling tower.

Average annual lost revenue was estimated by multiplying lost productivity (which is the product of the salt deposition rate and the average yield reduction) by the area of agricultural land impacted and the average annual rent per hectare of cropland for each respective state [6].

The primary uncertainty associated with WTP estimates associated with salt deposition is the ability of farmers to mitigate potential impacts by altering production processes and or switching to more salt tolerant crops. Our assessment of WTP associated with impacts to non-arid regions assumes that the potential impacts to any one operation are of a magnitude such that losses are less than the cost associated with mitigating behavior. To the extent that farmers can mitigate potential impacts, average annual WTP has been overestimated.

B.2.2.3 National Scaling

As discussed in Section 6.3.2.2 of the main text, the uncertainties associated with salt and mineral drift impacts and the lack of information to develop a WTP dictate that salt and mineral drift effects are not scaled.

B.2.3 Noise Impacts on Terrestrial Wildlife

A threshold of >60 dBA is used to represent the noise level where wildlife may be adversely impacted [8]. The acres of habitat modeled to receive greater than 60 dBA from the cooling towers at the BTPs are estimated from noise model output (Appendix C) and habitat maps developed for Section B2.1. Impacts were not monetized.

B.2.3.1 National Scaling

As discussed in Section 6.3.2.3, although the area impacted by noise from a cooling tower may be substantial (greater than 200 acres) specific wildlife census data were lacking and therefore, it was not possible to quantify how much, and to what degree, the wildlife population may be impacted. Additionally, no data were available to monetize the impact.

The number of facilities that may be affected by this issue was estimated for each source waterbody class, though. Using the responses to the EPRI Questionnaire, the percentage of facilities identifying at least one terrestrial or semi-aquatic protected species either on-site or nearby the station were estimated and applied to the national list.

B.2.4 Impacts of Fogging and Icing on Terrestrial Vegetation

Using the results of SACTI modeling (B1.1.2), fogging and icing may occur at the rate of tens of hours/year at eight and two of the 18 evaluated facilities, respectively (Section 4.2.4 of the main text). Fogging and/or icing at this rate may cause detectable damage to nearby vegetation according to the NRC. However, a WTP to avoid this damage was not calculated.

B.2.4.1 National Scaling

As discussed in Section 6.3.2.4 of the main text, fogging at the rate of tens of hours per year (the rate of fogging and/or icing may cause detectable damage to vegetation [7]) is predicted to occur at eight of the 18 calculated facilities (44.4 percent; six LR/RL and two SR/GL) and icing was predicted at this level at two of 18 facilities (11.1 percent; SR/GL) (Section 4.2.4).

These impacts have not been monetized or scaled nationally. However, detrimental effects on local vegetation from humidity-associated increased fogging or icing may impact as many as 174 Phase II facilities (115 LR/RL and 59 SR/GL).

B.3 Water Resources

B.3.1 Water Consumption

B.3.1.1 Quantification

The in-stream evaporative water loss due to the thermal discharge from once-through facilities was estimated using the Edinger-Geyer Method. A series of papers by Edinger and Geyer present a consumptive water loss estimation method based on basic heat budget [9, 10, 11]. A summary of this method is given below.

The heat removal rate of circulating water from condensers is a function of the quantity and temperature of the steam being condensed and the condenser efficiency [12]. The predictable nature of heat removal rate of circulating water allows the quantification of heat rejection rate.

Heat exchange between a waterbody and the atmosphere is governed by atmospheric radiation, conduction, convection and evaporation [13]. The majority of heat loss from a waterbody is through evaporation, which is dependent upon the latent heat of evaporation. Edinger and Geyer developed a method to calculate, what they termed, *the evaporative loss coefficient*. This evaporative loss coefficient multiplied by the power plant's heat rejection rate gives the consumptive water loss due to evaporation (EE) induced by a power plant's thermal discharge. The primary formulae used are given below.

Evaporative loss due to thermal discharge, $EE = H_r \times C$

The advantage of this method is that it uses only the following quite readily available inputs.

- Td, dew point temperature, in °F;
- Ts, the background temperature of the receiving waterbody, in °F;
- u, wind speed, in miles per hour;
- Q, the circulating water flow rate; and
- ΔT, the temperature differential across the condenser (a constant for a given generating unit), in °F.

Evaporative loss coefficient, *C*, in cfs per 10^9 Btu/hr, due to thermal discharge is:

$$C = \left(\frac{4450}{L}\right)\frac{B(K - 15.7)}{(0.26 + B)K}$$

The latent heat of vaporization is given by, $L = 1093 - 0.56T_s$

The slope of saturated water vapor pressure, in mmHg/°F, is estimated as $B = 0.255 - 0.0088T + 0.000204T^2$

T is defined as, $T = \frac{1}{2}(T_s + T_d)$

The surface heat exchange coefficient, in Btu/ft^2/°F, is given by, $K = 15.7 + (B + 0.26)f(u)$

The wind function used is, $f(u) = 70 + 0.7u^2$

H_r, the plant's heat rejection rate, in Btu/hr, $H_r = \rho Q c \Delta T$

ρ is the density of water. An approximate value of 62.37 lbm/ft^3 was used.

c is the specific heat of water. An approximate value of one Btu/lbm/°F was used.

This method has already been tested and applied at several sites in Pennsylvania. It was therefore tested at the BTPs that use non-ocean water (Great Lake, Tidal River, Lake, Reservoir and Estuary) and checked against benchmarks in power industry literature. These comparisons are discussed below.

In addition, for two facility locations (Great Lakes and Tidal River), the calculations were performed at the monthly scale and at the annual scale to assess if results are comparable. Results at the annual scale were within the range of values calculated using monthly data. Therefore, annual average values were used to calculate in-stream evaporative loss from other facilities.

This calculation requires two types of data-ambient conditions data and power plant data. Ambient conditions data required to calculate the evaporative loss coefficient include dew point temperature, background temperature of the receiving waterbody, and wind speed. Power plant data required to calculate the plant’s heat rejection rate include circulating water flow rate and the temperature differential across the condenser.

The primary data need for calculating the plant’s heat rejection rate was the circulating water flow rate during a given time interval. Where pumping rates were unavailable, the total circulating water flow rate was adjusted by the plant’s capacity utilization rate for that time interval. Capacity utilization, in turn, was estimated using the plant’s generation data as reported in the Energy Information Administration’s 906-920 database.

B.3.1.2 Monetization

The analysis of WTP to avoid consumptive water loss does not include an analysis of WTP for potential reductions in the availability of water for extractive uses such as drinking water or irrigation. Such an analysis requires not only an understanding of the local price charged for water, it requires an in depth understanding of the laws regulating water usage, the future supply of and demand for water, and an understanding of a society’s ability to adjust to changing conditions via behavioral or technological change. Further, even in desert areas such as Albuquerque New Mexico, in depth economic analysis often suggests marginal changes in water availability have relatively low economic impacts.

As such, and noting that recent legal decisions limit CWA §316(b) evaluations to a comparison of environmental impacts and eliminates the use of common cost-benefit analysis, the analysis of consumptive water loss contained herein is limited to WTP to avoid changes that could affect recreational enjoyment derived from activities such as boating, rafting, fishing, and general water based recreation. While the impacts of water losses conceivably alter the value of aquatic habitat, this is expected to be *de minimis*, and extremely difficult to measure reliably. Therefore, we restrict attention to potential recreation effects.

If water consumption is great enough to change water levels in a waterbody, these recreational activities could be affected; it is assumed if water consumption is not great enough to change water levels, then WTP to avoid water consumption is zero. Therefore, potential WTP to avoid consumptive water loss from very large source water bodies (oceans, bays, the Great Lakes, large lakes, and reservoirs) are omitted from this analysis (WTP is assumed to be zero).

Similarly, in areas where water withdrawal is regulated by water rights and those water rights are fully subscribed, there would be no reduction in stream flows and therefore no WTP to avoid an environmental change. Lack of measurable changes in water level may also occur on small water bodies if the consumptive water loss is correspondingly low.

Where water levels change, the approach to estimating WTP to avoid consumptive water loss relies on benefits transfer ideas outlined by Rosenberger and Loomis [14]. Rosenberger and Loomis note that consumer surplus is the value of a recreation activity beyond what must be paid to participate in the activity [14]. Rosenthal and Brown show that when changes are marginal, consumer surplus is equivalent to a virtual market price for a recreation activity [15]. That is, in estimating the change in consumer surplus associated with a change in in-stream service flows, our methods also estimate WTP to avoid that change.

USDOI reviews economic valuation studies that investigate WTP for in stream flow based on recreational behavior [16]. The analysis includes 20 studies, all of which provide values based on river uses including fishing, whitewater rafting, sightseeing, and kayaking. The selection of any one WTP estimate for use in benefits transfer is site specific.

B.3.1.3 National Scaling

As discussed in Section 6.3.3.1, the net evaporative water loss was calculated for seven (five fossil and two nuclear) BTPs/RFs located on freshwater bodies (Section 4.3.1). It is assumed that evaporative water loss from a cooling tower was a function of generation (MW-hr) and water loss at other Phase II facilities may be determined using the mean rate of water loss per MW-hr at calculated facilities. It was determined that water loss was also dependant on fuel type, nuclear or fossil.

The mean net evaporative freshwater loss for nuclear facilities on SR/GL and LR/RL was 415 gals/MW-hr and 479 gal/MW-hr, respectively. The mean net evaporative freshwater loss for representative fossil plants evaluated on SR/GL was 291 gal/MW-hr and 315 gal/MW-hr for fossil plants on LR/RL. These results were used for scaling evaporative water loss to other Phase II facilities (Table B-6). A WTP was not available to monetize the additional evaporative water loss and is not included in the national scaling. Results are discussed in Section 6.3.3.1.

Table B-6
National scaling of consumptive water loss figures

Source Waterbody Type	Fuel Category	Facility	Generation Capacity (MW)	Yearly Generation (MW-hr)	Evaporative Loss Rate (Gal/MW-hr)	Evaporative Loss (MGY)
LR/RL	Nuclear	BTPE	2,200	18,315,500	479	8,800
		Remaining Facilities	27,600	202,726,000	479	97,000
		Nuclear Subtotals	*29,800*	*221,041,500*	*957*	*105,800*
	Fossil	BTPD	2,100	13,797,000	244	3,400
		RFU	200	1,314,000	382	500
		RFJ	500	3,285,000	320	1,100
		Remaining Facilities	125,900	827,163,000	315	260,900
		Fossil Subtotals	*128,700*	*845,559,000*	*1,262*	*265,900*
	LR/RL Subtotals		**158,500**	**1,066,600,500**	**2,219**	**371,700**
SR/GL	Nuclear	BTPB	2,200	15,673,800	415	6,500
		Remaining Facilities	5,900	49,338,400	415	20,500
		Nuclear Subtotals	*8,100*	*65,012,200*	*830*	*27,000*
	Fossil	RFI	600	3,942,000	268	1,100
		RFR	100	657,000	313	200
		Remaining Facilities	52,300	343,611,000	291	99,800
		Fossil Subtotals	*53,000*	*348,210,000*	*872*	*101,100*
	SR/GL Subtotals		61,100	413,222,200	1,702	128,100
Grand Totals			**219,600**	**1,479,822,700**	**3,921**	**499,800**

B.3.2 Source Waterbody Debris Removal

B.3.2.1Quantification

The estimated amount of trash removed by the existing CWIS was obtained from the facilities (EPRI Questionnaire) and converted to a common unit of tons per year. A best professional judgment density of 275 pounds per cubic yard of trash was used. Questionnaire responses included “minimal” and “several,” which were assumed to be zero tons and three tons, respectively.

B.3.2.2 Monetization

There are two changes in solid waste streams associated with converting once through cooling to cooling towers: change in the volume of trash removed from source water bodies and the creation of new solid waste flow associated with cooling tower sludge. This report estimates the lower bound on society’s WTP to avoid a reduction in the removal of trash from source water bodies. While theory suggests that society would have a positive WTP to avoid the creation of a new solid waste stream (cooling tower sludge) existing data do not support monetization of this environmental change.

In creating and implementing multiple volunteer programs designed to remove solid waste from water bodies, society has revealed a WTP to remove trash from water bodies and place that trash into the proper solid waste stream. The existence of government sponsored programs designed to achieve the same goal coupled with the assumption that governments are an agent acting on behalf of society is consistent with this revealed WTP. This report estimates a per-unit WTP for trash removal based on these volunteer and government programs and apply it to projected reductions in trash removal.

WTP for trash removal was calculated from existing data describing volunteer and government sponsored coastal and river clean-up programs (Table B-7). For the volunteer efforts (International Coastal Cleanup, the Streambank Cleanup and Lakeshore Enhancement [SCALE] Program, and the Coastal Cleanup Day), it was assumed that each participant volunteered four hours valued at $8.91 per hour.[3] The Santa Monica project used government employees and so labor costs are already incorporated.

Annual WTP to avoid reductions in trash removal is estimated as the product of the tons of trash that would no longer be removed from water bodies and placed into the proper waste stream, the percent reduction in water flow, and the average revealed WTP to remove a ton of trash from water bodies and shorelines ($1,132), as follows:

Annual WTP = trash removed (ton) x percent flow reduction (%) x average WTP ($/ton).

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[3] The value of each participant’s time is based on the value of travel time which was an average of literature values converted to 2007$ [65, 66].

It is assumed that the reduction in the amount of trash removed by the intake screens is directly proportional to the estimated flow reduction with closed-cycle cooling. Percent flow reduction is site-specific and was calculated for each plant.

A summary of the programs and the inferred WTP is provided in Table B-7.

WTP to avoid the creation of a new solid waste stream associated with cooling tower sludge has been omitted. This omission tends to bias WTP estimates in a downward direction. As with all estimates there is variation around the mean WTP estimate.

Table B-7
Summary of cleanup programs

Program/Body of Water	Tons of Trash	Number of Participants	Cost of Program (2007$)	WTP for Trash Removal per Ton (2007$)
International Coastal Cleanup/Lake Erie, PA [17]	21.2	600	—	$1,009
SCALE/IL Streams and Lakes [18]	269	10205	$55,000	$1,557
Coastal Cleanup Day/CA Pacific Coast [19]	4252	50375	—	$422
Santa Monica Bay Communities/Los Angeles Co., CA Beaches [19]	4000	N/A	$6,156,000	$1,539

B.3.2.3 National Scaling

As discussed in Section 6.3.3.2, a national estimate of the amount of trash removed by the existing cooling water intake structure was calculated using responses to the EPRI Questionnaire and as well as direct correspondence with some facilities. 206 facilities on the Phase II list responded; 81 responses were not usable because the questions were not answered in part or whole, and assumptions could not be made. Of the remaining 125 facilities, the following conservative assumptions were used:

- 45 facilities that either left the answer blank or replied “No” or “Don’t Know” to the question “Do you remove debris?” were assumed to remove zero tons annually;
- 32 responses such as “minor amounts,” “small amount”, or “minimal” in response to the quantity of debris removed were assumed to remove zero tons annually; and
- “Several” was assumed to mean “three” in calculations of amount of debris removed.

The estimated amount of man-made trash currently removed annually from the EPRI Questionnaire respondents totaled 289 tons/yr with a mean of 2.3 tons/year/facility. The amount of trash removed was normalized for plant size (i.e., by design cooling water flow in MGD) and the ratio was used to estimate the amount of human trash currently being removed nationally for the stations for which data were not available. An estimated 886 tons of man-made debris is removed annually by all Phase II facilities.

A retrofit to closed-cycle cooling will reduce the amount of water being withdrawn by 97 percent, on average (a range of 93 - 99 percent reduction was calculated for the facilities studied; see Section 4.3.2). Concomitantly, the volume of trash that is currently being removed during once-through cooling water withdrawal will also be reduced by approximately 97 percent. The national-level WTP to avoid this consequence was estimated for facilities in each waterbody category, as shown on Table 6-11 (Section 6.3.3.2) of the main text.

B.4 Public Safety and Security

B.4.1 Quantification

For each facility SACTI (see Section B1.1.2) was used to calculate the probable frequency of ground-level plume fogging and icing for each cooling tower design and location.

The amount and likelihood of fogging impacts to roadways at each facility is the product of the number of hours of fog on the roadways and the number of commutes per day on those roads. The number of fog events and their duration is estimated using SACTI output and the width of the plume is approximated based on the cooling tower configuration and the relative angle of the plume and the roadway. The Annual Average Daily Traffic (commutes per day) for affected roads is obtained from Department of Transportation (DOT) for each respective state. The analysis assumes the average rate of travel on highways under normal conditions was 65 miles per hour (mph).

B.4.2 Monetization

One of the public safety impacts associated with cooling tower related environmental changes is increased roadway fogging. This section describes the methods and results of an analysis designed to estimate societies WTP to avoid roadway fogging associated with cooling tower operation. The WTP for roadway icing was not estimated because relevant data[4] were not available.

Societies WTP to avoid an increase in foggy roadway conditions can be thought of as having two components: a WTP to avoid costs associated with increases in the severity and frequency of car accidents and a WTP to avoid increased travel time. Travel time increases themselves can be thought of as having two distinct sources: a general slowing of traffic when foggy conditions are encountered and accident related delays.

Existing literature provides the information necessary to estimate fog related increases in the severity of accidents. Societies WTP to avoid that increase is estimated as a function of property loss and damage, direct medical and mental health costs, the cost of ambulance and police services, insurance administrative costs, and productivity loss. Estimates do not include a “pain and suffering” component and so represent an underestimate of the true WTP to avoid increases in car accident severity.

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[4] Roadway icing from CT can occur without precipitation. Accident data is only available for road icing with precipitation (e.g., snow or sleet), which is not appropriate for use in this WTP estimate.

While it is logical to assume that increases in fog may increase the frequency of accidents, the literature does not report a consensus regarding the existence or potential magnitude of such a relationship.

Existing literature describes the average rate of travel under clear conditions and rate reductions when fog is encountered. While these data do not support a full estimate of time lost to fog (such an estimate would include accident related delays as well as other car to car interactions), it does facilitate a lower bound estimate of increased commuter time. The existing economics literature describes societies' WTP to avoid increased commute time.

B.4.2.1 Accident Severity

The average monetary cost of travel accidents when fog is present was determined by weighting the cost of car accidents at various degrees of severity from Streff et al. by the portion of accidents in each severity level when fog is present estimated from the General Estimates System (GES) of the U.S. National Highway Traffic Safety Administration (NHTSA) [20, 21]. The results of these calculations are presented in Table B-8.

Each collision severity level in Streff et al. is associated with a cost that includes property loss and damage, direct medical and mental health costs, ambulance and police services, insurance administrative costs, and productivity loss but do not include pain and suffering [21]. The values were converted from 1988 dollars to 2007 dollars using a CPI of 1.75 [22]. Streff et al. uses the "KABCO" injury severity scale to categorize accidents [20]. K-level injuries represent collisions which result in death within 90 days of the occurrence. A-level injuries are incapacitating injuries which render persons incapable of performing regular activities, such as walking or driving, they were able to do prior to the injury. B-level injuries are non-incapacitating injuries which are obvious at the scene of the crash. C-level injuries are those which are reported or claimed but are not included under levels K, A, or B. O-level collisions include those in which only result in property damage.

The portion of accidents in each severity level in the presence and absence of fog[5] obtained from the NHTSA was based on data for the year 2006 [21]. The GES data are a nationally representative sample of police reported motor vehicle crashes which range from minor to fatal.

B.4.2.2 Accident Frequency

The ability of researchers to estimate the effect of site specific factors on accident probabilities is limited by the random nature of accidents, the temporal aspect of site specific factors such as weather, and statistical difficulties associated with the very low frequency events. Qi et al. used panel data describing accident rates in Norfolk, VA, and concluded that fog can significantly increase the probability of an accident [23]. However, the magnitude of the increase is relatively small. In this study, an average highway accident rate of one accident per million miles of travel is used [24]. It is assumed that fog will not affect that accident rate.

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[5] In some cases, fog was associated with other poor weather conditions such as sleet or rain.

B.4.2.3 Fog Related Changes to Rate of Travel

Four studies were identified describing changes to the rate of travel under foggy conditions, only one of which was conducted in the United States. The U.S. study reports a 15 percent average decrease in the rate of travel when fog is encountered [25].

B.4.2.4 Value of Commuting Time

Gwilliam recommends that time spent commuting and other non-work travel time be valued by multiplying household hourly income by 0.3 [26]. U.S. Census Bureau reports average household income which was converted to hourly income by the number of work hours in a year (2040) and the average number of workers per household (1.15) [27]. This implied a travel time value of \$6.34 per hour. U.S. DOT suggested a value of \$11.48 per hour [28]. This analysis uses the average of the two recommendations, \$8.91 per hour.

Given the uncertainty associated with the incremental number of accidents per year, the annual WTP to avoid an increase in the severity of car accidents is estimated as:

$$AnnualWTP = B\left(C_f - C_n\right)$$

where B is baseline number of accidents per year, C_f is the expected cost[6] of an accident under foggy conditions and C_n is the cost of an accident under non-foggy conditions.

Annual WTP to avoid increased travel time is estimated as

$$AnnualWTP = \sum_{i=1}^{I} C_i \left(\frac{d}{0.85r} - \frac{d}{r} \right) \$8.91,$$

where I indexes the number of fogging events, C_i is the number of commutes impacted during fogging event i, d is miles of roadway impacted by the plume, r is the rate of travel under normal conditions denominated as mph, 0.85r is the rate travel under foggy conditions, and \$8.91 is the value of travel time. The analysis assumed the average rate of travel under normal conditions was 65 mph.

Total Annual WTP to avoid environmental changes leading to public safety and security issues is estimated as the sum of annual WTP to avoid an increase in the severity of car accidents and annual WTP to avoid increased travel time.

Based on the data discussed above, the average cost of an accident in foggy conditions is \$37,827, which is \$12,568 higher than the cost of an accident when fog is absent. The derivation of this cost is shown in Table B-8.

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[6] Cost is defined as the sum of property loss and damage, direct medical and mental health costs, the cost of ambulance and police services, insurance administrative costs, and productivity loss. Average cost per accident data provided by Streff et al. [70].

Table B-8
Average weighted cost per accident

Severity Level	Average Cost per Accident (2007$)[a]	Percent of Accidents[b]		Weighted Cost Per Accident	
		Fog Present	Fog Absent	Fog Present	Fog Absent
K-level (Fatal)	$745,976	3.88%	2.28%	$28,914	$17,017
A-level (Incapacitating)	$28,439	20.16%	16.84%	$5,732	$4,790
B-level (Non-incapacitating)	$7,310	17.83%	21.23%	$1,303	$1,552
C-level (Other injuries)[c]	$4,832	18.60%	17.96%	$899	$868
O-level (No injuries)[d]	$2,476	39.53%	41.68%	$979	$1,032
Average Weighted Cost Per Accident				**$37,827**	**$25,259**

[a] Average cost per accident data provided by Streff et al. [20].
[b] The percent of accidents in each severity level calculated from NHTSA data [21].
[c] C-level includes includes “possible injury” and “injury, unknown severity.”
[d] O-level reflects only property damage and includes “no injury” and “no people involved in crash.”

The number of fog events and their duration were estimated using methods described in the previous section and the width of the plume was approximated based on the cooling tower configuration and the relative angle of the plume and the roadway.

The WTP estimate associated with changes to public safety omits several potential impacts. These include potential delays and safety issues related to airport operation, roadway icing, and fog related impacts associated with line of sight dependant security operations. WTP for roadway fogging is best characterized as a partial estimate in that it omits potential increases in the frequency of accidents, delays related to car to car interactions, and potential impacts on secondary roadways. In addition, fog is often associated with other poor weather conditions and the impact of fog alone is difficult to discern. Each omission biases the WTP estimate in a downward direction.

B.4.3 National Scaling

As discussed in Section 6.3.4.1 of the main text, the WTP to avoid fogging impacts on a national scale was estimated for the Phase II facilities not already estimated during the BTP/RF or California evaluations by applying the median annual WTP to avoid fogging calculated from the BTPs/RFs (Table 6-12 of the main text). The facilities were grouped by population based on U.S. census data and by proximity to roadways based on responses to the EPRI Questionnaire and best professional judgment using aerial photography of the Phase II facilities in High Population areas to determine if state or interstate roadways were present. It was assumed that there were no nearby roadways for facilities in medium and low population areas where no data was available concerning roadway. Using the median annual WTP to avoid fogging (Table 6-12 in the main text), in addition to the estimates calculated for the BTPs/RFs and California facilities, the total estimated annual WTP to avoid impacts caused by fogging nationally was estimated (see Section 6.3.4.1 of the main text).

Roadway icing is expected to occur at seven of the 24 modeled facilities (29.2 percent); assuming this is a representative subsample of all Phase II facilities, up to 124 may encounter icing problems if cooling towers were operated. Based on the modeled impacts, icing may occur at these 121 facilities between 0.3 hr/year and 23.1 hr/year (Section 4.4.1 of the main text). A WTP to avoid impacts from roadway icing could not be developed because appropriate accident data associated with these conditions is not available.

B.5 Quality of Life

B.5.1 Noise

B.5.1.1 Quantification

This study relies heavily on computer simulation modeling as the basis for the comparative analysis of noise attributable to cooling towers. Cadna/A® is used to model the generation and propagation of noise from each of the facilities. Cadna/A® is a three dimensional software program for prediction and assessment of noise levels in the vicinity of industrial facilities and other noise sources. Cadna/A® uses internationally recognized algorithms (ISO 9613-2) for the propagation of sound outdoors to calculate noise levels, and presents the resultant noise levels in an easy to understand, graphically-oriented format. The program allows for input of all pertinent features (such as terrain or structures) that affect noise, resulting in a highly accurate estimate of existing and future noise levels.

Virtual models of each of the existing facilities and other existing nearby structures were created in Cadna/A®. Digital Terrain Modeling was used to account for elevation and terrain features, and aerial photographs were used to model the existing structures. Noise emission levels were input using octave band levels to accurately estimate noise propagation and attenuation effects. The effects of over-water sound propagation are included for the appropriate areas.

All pieces of equipment that were deemed to be significant noise sources were included in the baseline noise model. Each facility was modeled as a “base load” facility and was assumed to operate 24 hours per day. Major buildings, tanks, and large equipment trains were included as barriers where appropriate. The Cadna/A model output predicted noise levels at several discrete locations and areas of equal noisiness around each plant site.

Attenuation due to spherical wave divergence, topographic features, barriers, and standard atmospheric absorption (70 percent relative humidity, 50°F) was included in the calculation of predicted noise levels. Attenuation due to wind, or temperature gradients was not subtracted from the predicted levels to provide a conservative estimate of project sound levels.

Major Components and Noise Level Data-The facilities analyzed in this study consist of three nuclear-fueled facilities, three coal-fueled, and a single natural gas-fueled facility. In terms of relative noise emissions, nuclear facilities, with many of their major components enclosed, are typically the quietest facilities, while coal facilities, with outdoor coal handling equipment are the loudest. Aside from these major differences, these facilities have many common components: turbine generators, exciters, condensers, motors, pumps, valves, and auxiliary units.

Noise models were developed for each of the facilities. These models were developed based upon typical equipment components for each type of plant and specific plant layouts obtained from aerial photography. The set of modeled sources included turbines, generators, pumps, motors, main transformers, heat recovery steam generators, and cooling systems as appropriate. Small equipment items, such as pumps less than 25 horsepower, were excluded as they were considered insignificant noise sources. If specific equipment components and source noise level data were available, they were incorporated into the model. The source level data included: limited vendor data; databases of previously modeled similar projects; and industry-standard estimated sound power values. In cases where specific equipment components or source noise level data were not available, nominal noise emissions levels from various sources were used. Equipment and associated source noise level data for each of the sites are detailed in the individual case studies.

Cooling Tower Design and Noise Levels-Noise from wet cooling towers is caused by a number of sources, including water falling into the fill and basin, fans, motors, and gears, all of which are used to provide draft in induced-draft cooling towers. Noise levels associated with mechanical (induced) draft cooling towers are higher than noise levels associated with natural draft cooling towers. Fan noise is the predominant noise source for mechanical draft cooling towers. Noise levels from these towers are based on the power of the fan motor and the number of individual cooling cells. Noise levels for natural draft cooling towers are based on the rate of water flow.

Equations for determining noise emissions from induced-draft cooling towers equipped with propeller-type fans and natural-draft cooling towers have been developed and are widely used [29, 30, 31]. These equations were developed from information extracted from consultant project files and field noise measurements. These equations were used to determine cooling tower source noise levels for input into the noise models and are shown below:

For Mechanical Draft Cooling Towers

A-Weighted Sound Power Level Prediction

$$L_w = 85 + 10 \log(\text{fan hp}) \text{ (dBA) ref 1 pW}$$

Where hp is the full-speed fan power rating.

For Natural Draft Cooling Towers

A-Weighted Sound Power Level Prediction

$$L_w = 86 + 10 \log(Q) \text{ (dBA) ref 1 pW}$$

where Q is water flow rate in gallons per minute.

B.5.1.2 Study Limitations

Facility source noise level data for this analysis were estimated based on established guidelines and noise prediction methodologies, comparisons with manufacturer's data, and limited empirical data from other facilities. Actual noise measurement data from the study sites were not available. The quantity and suitability of the data for purposes of predicting community noise levels varied by facility type.

Source noise level data for the nuclear facilities were not available. Source level data for these facilities were estimated from limited off-site community noise measurements from previously published studies. These data yield information regarding noise levels at a given location and distance from the facility; however, these are not true source level data as they are based on data specific to a given point at a given time (meteorological conditions, plant operations level, etc.) and do not necessarily reflect the characteristics of other sound propagation paths or conditions.

Source noise level data for the fossil-fueled facilities were estimated from information contained in the *Electric Power Plant Noise Guide* [29]. These data were supplemented with empirical data for select components as the referenced work was published in 1978 and may not accurately reflect noise levels of more modern equipment.

Background community noise level data were estimated based on literature data. Representative environments were selected based on aerial photography and expected activities. Localized activities greatly influence noise levels at specific locations. For example, noise levels near a major transportation corridor will be significantly higher than the assumed background community noise level.

The resultant cumulative uncertainty associated with the prediction of absolute noise levels at a specific facility from each of these affects is difficult to assess. Noise level assumptions made may be higher or lower than the actual noise levels due to differences in components, maintenance condition, etc. While the uncertainty associated with absolute noise levels is deemed to be high due to the lack of empirical data at these facilities, the comparative noise levels are based on similar assumptions and are accurate for purposes of relative comparison.

B.5.1.3 Monetization

This analysis is designed to estimate society's WTP to avoid noise level increases at homes and recreational areas surrounding the cooling tower. In this analysis, it is assumed that the quality of the acoustic environment is capitalized into the value of the housing stock and that a two dB increase in ambient noise levels represents a measurable change in the acoustic environment that would result in a decrease in the value of the local housing stock. This decrease is a component of the WTP estimate.

WTP among non-local users of recreational sites may not be capitalized into local housing stocks. While none of the BTPs warranted this analysis, this increment to WTP is estimated on a site-specific basis for RFs.

The WTP by local residents to avoid noise increases from the cooling towers is estimated using hedonic methods. Hedonic pricing methods first developed by Rosen employ observed real estate transactions to determine the marginal price and therefore marginal WTP for neighborhood amenities, land use, and environmental amenities [32, 33, 34, 35, 36, 37]. Their foundation is the model of individual choice described by Freeman [38]. An annual WTP consistent with the marginal price revealed in hedonic analysis can be estimated as a function of the real interest and depreciation rates.

The approach in this analysis to estimating WTP among non-local users of recreational sites relies on benefits transfer ideas outlined by Rosenberger and Loomis [14]. Consumer surplus is the value of a recreation activity beyond what must be paid to participate in the activity [14]. When changes are marginal, consumer surplus is equivalent to a virtual market price for a recreation activity [15]. That is, consumer surplus is a proxy for WTP.

A meta-analysis of 33 hedonic studies that estimated the effect of airport noise and property values suggested that a one dB increase in airport noise decreased housing values by 0.51 to 0.67 percent [39]. Road noise decreases property values by 0.202 percent per dB increase [40]. An average depreciation of 0.67 percent per dB increase for railroad noise has been estimated [41].

Literature-based estimates of WTP for small changes in noise levels among recreational participants have not been identified. Consistent with the literature on housing values, a 0.4 percent reduction in WTP for each dB increase in noise level and estimate potential WTP among recreational site users on a site-specific basis is assumed.

Annual WTP to avoid increased noise levels among homeowners was estimated in two steps. First, WTP was estimated as:

$$WTP = \sum_{h=1}^{H} \Delta dB \times P_a \times 0.004 ,$$

where H is the number of houses subject to a noise increment of one dB or greater, ΔdB is the change in noise levels, P_a is the median housing value, and 0.004 is the reduction in housing values associated with a one dB increase in noise levels as estimated in the literature.

This value is annualized as:

$$AnnualWTP = 0.0534 \times WTP ,$$

where 0.0534 is an estimate of annual rent[7] based on a real interest rate of 4.2 percent and a depreciation rate of 1.14 percent.

When site specific conditions warrant, annual average WTP among non-local recreational participants is estimated as:

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[7] Annual rent can also be estimated by assigning a discount rate and time horizon. An annual rent of 0.0534 is approximately equal to a 3% discount rate applied over a 30 year time horizon.

$$AnnualWTP = \frac{CS_l}{\Delta d_l} \sum_{i=1}^{I} \left(N_i\right),$$

where CS_l is the per trip consumer surplus change associated with the change in recreational attribute as estimated in the literature, Δd_l is the change in recreational attribute as measured in the literature, I is the total number of days impacted per year and i indexes these days, and N_i is the number of non-local participants impacted each day.

Total annual WTP to avoid increases in ambient noise levels is estimated as the sum of annual WTP to avoid increased noise levels among homeowners and annual WTP among non-local recreational participants.

The primary uncertainty associated with this analysis relates to perceptibility. The studies generally assess the relationship between relatively large changes in ambient noise levels and housing prices; a WTP per dB is then calculated as total change in WTP divided by total change in noise level. The literature does not contain studies that actually assess WTP for a one dB change in noise levels. In fact, a one dB change in noise levels may not be perceptible, which is reflected in the decision to evaluate changes of two db under average ambient conditions. This uncertainty may bias WTP estimates in an upward direction.

B.5.1.4 National Scaling

As discussed in Section 6.3.5.1, a significant factor to scale noise impacts was not apparent so the monetized national impacts were estimated based on three geographic regions in addition to California, where it is assumed that the variations in many of these variables (e.g., housing prices, population) would be represented by the facilities modeled:

- West, all plants west of the Mississippi River, except those in California;
- Northeast, plants in states east of the Mississippi River and north of the Mason-Dixon Line; and
- Southeast, facilities located east of the Mississippi River, but south of the Mason-Dixon Line.

The one Phase II facility in Guam was not included in the estimate because a reasonable assumption about housing values could not be made. Three Hawaiian facilities were placed in the California group, one Alaskan facility was placed in the Mid/West group, and four Puerto Rican facilities were grouped with the Southeast based on assumptions of housing values.

The arithmetic average WTP to avoid noise impacts (from Table 4-17 of the main text) was selected to represent Phase II facilities not already estimated during the BTP/RF or California evaluations (Table B-9). Results are presented in Section 6.3.5.1 of the main text.

Table B-9
Annual monetized impact associated with increased noise

Geographic Region	Facility	WTP to Avoid Noise Impacts (Human)	Average WTP by Geographic Region
CA	BTCA2	$0	$26,914
	BTCA1	$53,827	
Mid/West	RFU	$0	$45,625
	RFJ	$62,951	
	RFN	$73,925	
Northeast	RFI	$0	$23,739
	RFK	$0	
	BTPC	$0	
	RFO	$0	
	RFS	$0	
	RFF	$0	
	RFQ	$0	
	BTPE	$1,615	
	BTPB	$5,771	
	RFG	$11,126	
	RFP	$14,734	
	RFT	$29,449	
	RFL	$245,913	
Southeast	BTPA	$0	$37,260
	RFR	$0	
	RFV	$802	
	BTPD	$16,233	
	RFH	$19,642	
	RFM	$186,884	

B.5.2 Viewshed

B.5.2.1 Quantification

The percent duration of vapor plumes of various lengths and plume shadow over the one-year model period was modeled using SACTI. The output was displayed as a function of radial direction and distance for each facility (Appendix C). A lower bound estimate of the population that can view a significant visible plume is determined by superimposing percent duration of vapor plumes of various lengths over maps surrounding the BTPs (Appendix C). The maps indicate the block groups impacted, the number of households in each block group, and the proportion of the time the plume/shadow are directly overhead. Similar methods were used to identify recreational sites from which a significant plume would be directly overhead and the proportion of the year with potentially impacted viewsheds.

B.5.2.2 Monetization

This analysis is designed to estimate societies WTP to avoid viewshed deterioration related to cooling tower plumes. It is assumed that the quality of the viewshed is capitalized into the value of the local housing stock and that the introduction of a plume represents a perceptible decrease in the quality of the viewshed that would reduce property values. This decrease in property value is a component of our WTP estimate. It represents the WTP of nearby residents.

WTP to avoid impacts among non-local users of recreational areas are estimated based upon incremental changes to consumer surplus associated with varying site attributes (e.g., visible plumes or not).

B.5.2.2.1 Housing Analysis

The WTP of local residents to avoid viewshed degradation is estimated using hedonic methods. Hedonic pricing methods first developed by Rosen employ observed real estate transactions to determine the marginal price and therefore marginal WTP for neighborhood amenities, land use, and environmental amenities [32, 33, 34, 35, 36, 37]. Their foundation is the model of individual choice described by Freeman [38]. An annual WTP consistent with the marginal price revealed in hedonic analysis can be estimated as a function of the real interest and depreciation rates.

While the economics literature contains several hedonic studies that relate visual amenities to housing values, few study the introduction of a vapor plume to an already industrialized viewscape. As such, the hedonic analysis used for this project focuses on residences that could not see any component of the facility before but will now be able to see the cooling tower plume or shadow directly overhead[8]. The analysis relies heavily on work by Anstine [42].

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[8] Due to the difficulty in determining the number houses which may view the plume but are not directly underneath it, the analysis omits these houses which are not shadowed.

Anstine studied two manufacturing facilities located in Tennessee [42]. One facility used depleted uranium in its manufacturing process but had no detectable emissions. The other emitted an odor and a small visible plume but was not perceived as posing a significant risk to human health. Anstine's study showed that noticeable disamenities, such as a vapor plume and smell, are capitalized into housing values, whereas non-visible disamenities did not appear to be [42]. For the facility emitting an odor and a vapor plume, the hedonic model found that housing prices increase at a decreasing rate up to 1.2 miles from the facility. The model found 7.32 percent to be the maximum reduction in housing values as a result of the two disamenities jointly. The midpoint of this range is 3.6 percent however, this is a joint disamenity (visual and odor) and a 1.8 percent decrease in value to residences that are within 1.2 miles of the facility and that currently see no facility component but would be able to see a plume year round was assigned.

Annual WTP to avoid visual degradation among homeowners was estimated in two steps. First, WTP was estimated as:

$$WTP = \sum_{h=1}^{H} F_h \times P_a \times 0.018$$

Where H is the number of houses that cannot perceive any portion of the facility but would perceive a plume directly above, F_h is the proportion of the year during which the plume or shadow would be visible, P_a is the median housing value in the zip code, and 0.018 is the reduction in housing values associated with the introduction of a plume to a viewshed.

This value is annualized as

$$AnnualWTP = 0.0534 \times WTP ,$$

where 0.0534 is an estimate of annual rent[9] based on a real interest rate of 4.2 percent and a depreciation rate of 1.14 percent. In omitting potential WTP among homeowners who can already see a portion of the generating facility, these methods tend to underestimate total WTP.

B.5.2.2.2 Recreational Analysis

WTP to avoid impacts to non-local users of recreational areas are monetized using estimates of incremental changes to consumer surplus associated with varying site attributes. For this application we define "non-local" as those visitors whose property is not impacted by the cooling tower vapor plume. For state parks and state beaches, which typically have over 50,000 visitors annually, it was assumed that 100 percent of visitors are non-local. Visitors to Seal Beach National Refuge are also assumed to be non-local because access to the refuge is very limited and not likely driven by proximity. For neighborhood parks, non-local use is assumed to be zero.

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[9] Annual rent can also be estimated by assigning a discount rate and time horizon. An annual rent of 0.0534 is approximately equal to a 3% discount rate applied over a 30 year time horizon.

The value of a California beach trip is based on an estimated consumer surplus associated with a beach day in California of $17.41 (2007$) [43]. While this value is somewhat low compared to other economic studies, this estimate of daily consumer surplus was used with the understanding that it may understate WTP among some non-local participants at some recreational sites.

The value of recreational visits to other parks was based on recreational use values given in a meta-analysis by Rosenberger and Loomis [14]. The study gives average recreational use values for 21 activities based on geographic region. The value of a recreational visit at each state park was estimated as the average value of the activities available and converted to 2007 dollars.

The economic literature does not contain consumer surplus changes associated with the introduction of a plume to a recreational site. One might expect greater impacts than the 1.8 percent diminution associated with housing because of the outdoor nature of beach and park recreational activities. An estimate of 10 percent loss would be consistent with consumer surplus losses often asserted during tarball events following oil spills. A 1.8 percent reduction in the value of each recreational visit was conservatively applied.

There is considerable uncertainty associated with WTP among non-local recreational participants and therefore, a lower bound on the annual WTP was estimated.

B.5.2.3 National Scaling

Based on census data, the list of Phase II facilities was divided into three population density subgroups: Low (<100 people/mi^2), Medium (100-1,000 people/mi^2) and High (>1,000 people/mi^2). Based on preliminary results, the results of the Low and Medium categories were similarly low compared to those of the High population BTP/RFs. Therefore, the Low and Medium category plants were combined; the results were calculated for two population groups (High and Medium/Low). Table B5-2 presents the number of Phase II facilities in each category and the BTP/RF used for extrapolation of the national impacts.

Table B-10
Number of phase II facilities and the btps/rfs used for evaluation in each population category

Population	# of Phase II Facilities (BTPs/RFs)	Median WTP to Avoid Viewshed Degradation (2007$)
High	90 (BTCA1, RFI, RFK, RFL)	$15,405.50
Medium/Low	335 (BTCA2, BTPA, BTPB, BTPC, BTPD, BTPE, RFF, RFG, RFH, RFJ, RFM, RFN, RFO, RFP, RFQ, RFR, RFS, RFT, RFU, RFV)	$7.50

The median annual WTP to avoid viewshed degradation values estimated for the BTPs and RFs (summarized in Table 4-18 of the main text) were used to extrapolate the monetary impacts in both categories of Phase II facilities. The median value was applied to all other Phase II facilities in the category that was not previously calculated during the Beta Test, Representative Facility evaluation, or the California scale-up in the Beta Test. Results are presented in Section 6.3.5.2 of the main text.

B.6 Greenhouse Gas

B.6.1 Quantification

This section outlines the method and assumptions for calculating the quantity of carbon dioxide (CO_2) that would be emitted if fossil fuel power plants were to compensate for loss of electricity generation at representative nuclear facilities during the downtime associated with closed-cycle cooling tower retrofit.

The followings steps, using coal as an example, provide the emission factors calculation method. Similar emission factors were used for the other fuels.

The quantity of CO_2 emitted is calculated using the following steps.

$$\textit{Required makeup electricity} = \begin{array}{l} \textit{net generating capacity of unit}(MW)\times 10^6 \\ \times \textit{required downtime}(\textit{months}) \\ \times \textit{Number of hours per month} \\ \times 5\textit{yr average capacity factor} \end{array}$$

$$\textit{Amount of coal needed} = \frac{\textit{required makeup electricity}(Whr)\times 3.413(Btu/hr/W)}{\textit{heating value of coal}(Btu/ton)\times \textit{thermodynamic efficiency}}$$

$$\textit{Amount of carbon burned} = \textit{amount of coal needed (tons) x carbon content in coal}$$

$$\text{Amount of carbon dioxide generated} = \frac{\text{amount of carbon burned (tons) x molecular weight of CO}_2}{\text{Molecular weight of C}}$$

$$\text{Carbon dioxide emissions factor} = \frac{\textit{amount of carbon dioxide emitted}}{\textit{required makeup electricity}}$$

The following assumptions and parameters were derived from several engineering handbooks [44, 45, 46, 47]:

- The calculation assumes that the current composition of power plants and fuel types would makeup for generation loss during the retrofit at nuclear facilities;

- Carbon content of bituminous coal is between 60-80 percent. The calculation assumes 70 percent;
- Heat content of bituminous coal ranges from 21 million to 30 million Btu per ton. The calculation assumes 25 million Btu per ton;
- The quality of the fuel and the thermal efficiency of the power plant affect the CO_2 emissions rate from the combustion of fossil fuels to generate electricity. Typically, only about one-third of the energy contained in the fuel is converted into electricity; the remainder is emitted as waste heat. Combined-cycle facilities achieve greater efficiency. This calculation assumes that the thermodynamic efficiency of transforming the energy in coal to electricity is approximately 35 percent;
- The required downtime per generating unit for the cooling tower retrofit is plant specific. A few plants may be able to complete all tie-ins and condenser optimization during routine maintenance shutdown periods; others may need to shutdown for a longer period. PSE&G estimated six months per generating unit at its Salem Nuclear Generating Station [48]; Diablo Canyon estimated 18 months of downtime for a potential retrofit. For the purposes of this study, the calculation assumes 6 and 8 months of downtime for circulating water system tie-in, circulating water system pipe reinforcement, and condenser modifications, except for Diablo Canyon, where 18 months was used for consistency with the site-specific study. CO_2 generated over an 8 month period is provided as an upper limit; and
- CO_2 emissions factors used are: for coal two pounds of CO_2 emissions per kilowatt-hour (lbs/kWh) of net generation (sample calculation provided in Table B6-1); for petroleum 1.969 lbs/kWh, for natural gas 1.321 lbs/kWh and other fuels such as solid waste 1.378 lbs/kWh respectively [49]. The national average for all fuels (including non-fossil) is 1.341 lbs/kWh [49]; this emissions factor is used to calculate potential CO_2 emissions rates in Table B6-2.

CO_2 emissions due to a 6- or 8-month downtime period at nuclear BTPs assuming that coal would be used to generate makeup electricity are given in Tables B-11 and B-12, respectively.

CO_2 emissions due to a potential 6- or 8-month downtime period at nuclear representative facilities, assuming that the current mix of fuels would continue to be used to generate makeup electricity, are given in Table B-13.

Typical ranges for parameters associated with electricity generation using coal are given in Table B6-4. Not all extreme values would occur at the same time. If they were to occur, and all makeup generation were to be with coal, the amount of CO_2 generated may be as much as 60 percent greater than estimated in Table B-13 for each of the required downtime periods.

If all the makeup electricity generation were with natural gas, which has the lowest CO_2 emissions rate of 1.321 lbs/kWh of net generation, the amount of CO_2 generated may be as much as 18 percent less than estimated in Table B-13 for each of the required downtime periods.

If required downtime were extended to 18 months, and all extreme conditions with regard to coal were also to apply, CO_2 emissions may be as much as three times greater than that provided in Table B-13.

Table B-11
CO_2 emissions if all makeup electricity were generated with coal (6-month downtime assumed)

Facility Information		BTPB		BTPE		BTCA2	
		Unit 1	**Unit 2**	**Unit 2**	**Unit 3**	**Unit 2**	**Unit 3**
Unit net capacity	W	1030	1100	1116	1093	1070	1080
Required downtime	months	6	6	6	6	6	6
5-yr average capacity factor	%	87.2%	86.8%	94.7%	98.5%	90.1%	86.1%
Calculations							
Required makeup electricity	Whr	3.88E+12	4.13E+12	4.57E+12	4.65E+12	4.16E+12	4.02E+12
Required makeup electricity	Btu	1.33E+13	1.41E+13	1.56E+13	1.59E+13	1.42E+13	1.37E+13
Amount of coal needed	million tons	1.51	1.61	1.78	1.81	1.62	1.57
Amount of carbon burned	million tons	1.06	1.13	1.25	1.27	1.14	1.10
Amount of CO_2 generated	million tons	2.60	2.77	3.06	3.12	2.79	2.69
CO_2 per power generation	lbs/kWhr	2.0	2.0	2.0	2.0	2.0	2.0

Table B-12
CO_2 emissions if all makeup electricity were generated with coal (8-month downtime assumed)

Facility Information		BTPB		BTPE		BTCA2	
		Unit 1	**Unit 2**	**Unit 2**	**Unit 3**	**Unit 2**	**Unit 3**
Unit net capacity	W	1030	1100	1116	1093	1070	1080
Required downtime	months	8	8	8	8	8	8
5-yr average capacity factor	%	87.2%	86.8%	94.7%	98.5%	90.1%	86.1%
Calculations							
Required makeup electricity	Whr	5.18E+12	5.50E+12	6.09E+12	6.20E+12	5.55E+12	5.36E+12
Required makeup electricity	Btu	1.77E+13	1.88E+13	2.08E+13	2.12E+13	1.90E+13	1.83E+13
Amount of coal needed	million tons	2.02	2.15	2.38	2.42	2.17	2.09
Amount of carbon burned	million tons	1.41	1.50	1.66	1.69	1.52	1.46
Amount of CO_2 generated	million tons	5.18	5.51	6.10	6.21	5.56	5.37
CO_2 per power generation	lbs/kWhr	2.0	2.0	2.0	2.0	2.0	2.0

Table B-13
Estimated CO_2 emissions due to a potential 6- or 8-month retrofit downtime period (using the composite emission factor of 1.341 lbs/kWh)

Facility	Estimate of CO_2 Emissions Due to a 6-Month Downtime Period (Million Tons)	Estimate of CO_2 Emissions Due to an 8-Month Downtime Period (Million Tons)
BTPB Unit 1	2.60	3.47
BTPB Unit 2	2.77	3.69
BTPE Unit 2	3.06	4.08
BTPE Unit 3	3.12	4.16
BTCA2 Unit 2	2.79	3.72
BTCA2 Unit 3	2.69	3.59
RFH Unit 1	2.62	3.49
RFH Unit 2	2.53	3.37
RFS Unit 1	2.15	2.87
RFS Unit 2	2.04	2.72
RFV Unit 1	2.68	3.58

Other assumptions/parameters and conversion factors are provided in Table B-14.

Table B-14
Parameters and assumptions for CO_2 emissions calculations

	Value Used in Calculation	Units	Typical Range of Values
Heating value of coal	2.5E+07	Btu/ton	21-30 million Btu/ton
Thermodynamic efficiency	35%		35-42%
Required downtime	6 and 8	Months	6-8 months
Carbon content in coal	70%		60-80%
1 watt =	3.413	Btu/hr	
Molecular weight of carbon	12		
Molecular weight of CO_2	44		
Number of hours per month	720	hours	
1 ton =	2000	lbs	

B.6.2 Monetization

The existence of the carbon sequestration market reveals a societal WTP to avoid increased CO_2 emissions. In the voluntary offset market, approximately 24 million tons of sequestration were purchased at a price of approximately $3.80 per ton in 2007$ [50, 51].

WTP to avoid any net marginal change in the volume of CO_2 emitted in the near term could be estimated as

$$TotalWTP = \sum_{t=2007}^{T} \Delta C_t \times \$3.80 \div (1+r)^{t-2007},$$

Where T indexes year, ΔC_t is the change in tons of CO_2 emitted in year t, and r is the rate of discount. The average annual WTP would then be estimated by amortizing over the expected cooling tower lifespan.

To facilitate a direct comparison to other annual values reported herein, average annual WTP to avoid a one-time increase in CO_2 due to a retrofit-related shutdown at any individual nuclear facility is estimated as

$$AnnualAverageWTP = rWP \div \left((1+r)^n - 1\right),$$

where r is the discount rate, W is tons of CO_2 not released, P is the WTP per ton ($3.80), and n is the number of years over which the CO_2 release is annualized.

There are four significant uncertainties associated with this estimate of WTP.

1. The change in CO_2 was not estimated by year associated with the identification of cooling towers as BTA (that includes changes in the composition of the generating fleet). The CO_2 emissions associated with nuclear plant shut downs were estimated. Focusing on only this one component of the CO_2 change represents a partial analysis;
2. The changes are non-marginal compared to the volume of CO_2 trades made on the voluntary market and so the use of $3.80 may not be appropriate. The existence of a large non-voluntary market with lower prices suggests $3.80 likely overstates true WTP;
3. The cost of carbon sequestration is likely to decrease significantly as technological innovation permeates this emerging market. As such, the assumption of $3.80 per ton through time likely overstates true WTP for future changes associated with this one component of potential overall change in CO_2; and
4. A phased policy implementation (similar to the California policy) would allow nuclear facilities years to retrofit. Under that scenario, they may time the retrofit to coincide with a scheduled outage and so there would be a smaller net change in CO_2 emissions.

Absent a nationwide policy initiative that significantly reduces allowable CO_2 emissions, these factors suggest WTP to avoid future CO_2 emissions may be biased toward overestimation.

B.6.3 National Scaling

The same method and assumptions for calculating the quantity of CO_2 that would be emitted if fossil fuel power plants were to compensate for loss of electricity generation at representative nuclear facilities during the downtime associated with closed-cycle cooling tower retrofit was used for all other nuclear facilities (Section B6.1). Monetization followed in Section B6.2. Tables B-15 and B-16 give the required makeup generation (in MW-hr)[10], the resulting CO_2 from makeup generation from fossil facilities and the total WTP to avoid additional CO_2 in 2037 (the year facilities would convert from open-cycle cooling to closed-cycle cooling) assuming a 6-month and 8-month shutdown, respectively. These results are summarized in Tables B-17 and B6-8 and reported in Section 6.3.7 of the main text. Note: To be consistent with a site-specific study, Diablo Canyon calculations were based on a downtime period of 18 months.

Table B-15
Monetized impact of additional CO_2 from retrofit of nuclear facilities to closed-cycle cooling assuming a 6-month shutdown

Facility Name	Required Makeup Generation (MW-hr)	CO_2 (Millions of Tons)	WTP to avoid Additional CO_2
Arkansas Nuclear 1	3,022,661	2.03	$161,879
Browns Ferry	11,107,872	7.45	$594,882
Brunswick	7,226,860	4.85	$387,034
Calvert Cliffs	6,998,514	4.69	$374,805
Clinton	4,144,231	2.78	$221,944
Comanche Peak	9,258,919	6.21	$495,861
Cooper	2,767,947	1.86	$148,237
Crystal River 3	3,349,578	2.25	$179,387
Diablo Canyon	25,878,426	17.35	$1,385,919
Donald C. Cook	7,836,897	5.25	$419,705
Dresden	6,663,866	4.47	$356,883
Fort Calhoun	1,672,626	1.12	$89,577
H.B. Robinson	2,739,527	1.84	$146,715
Indian Point	8,143,888	5.46	$436,146
James A FitzPatrick	3,354,989	2.25	$179,676
Kewaunee	1,817,667	1.22	$97,345
McGuire	9,003,548	6.04	$482,185
Millstone	7,979,724	5.35	$427,354
Monticello	2,360,435	1.58	$126,413
Nine Mile Point, NY	6,943,757	4.66	$371,873

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[10] Generation (megawatt-hour [MW-hr]) for nuclear facilities, calculated from nameplate ratings (MW) obtained from the Nuclear Regulatory Commission’s website and capacity utilization data from the Energy Information Administration’s database.

Table B-15
Monetized impact of additional CO_2 from retrofit of nuclear facilities to closed-cycle cooling assuming a 6-month shutdown (continued)

Facility Name	Required Makeup Generation (MW-hr)	CO_2 (Millions of Tons)	WTP to avoid Additional CO_2
North Anna	7,191,622	4.82	$385,147
Oconee	9,651,363	6.47	$516,879
Oyster Creek	2,480,467	1.66	$132,841
Peach Bottom	9,157,728	6.14	$490,442
Pilgrim	2,737,733	1.84	$146,619
Point Beach	3,881,448	2.60	$207,871
Prarie Island	4,135,824	2.77	$221,494
Quad Cities	6,539,922	4.39	$350,245
R. E. Ginna	2,007,456	1.35	$107,509
Salem	9,857,819	6.61	$527,935
San Onofre	8,046,828	5.40	$430,948
Seabrook	4,719,622	3.16	$252,759
Sequoyah	10,021,968	6.72	$536,726
St Lucie	6,452,928	4.33	$345,586
Surry Power Station	6,193,591	4.15	$331,698
V C Summer	3,768,531	2.53	$201,824
Waterford 3	4,346,177	2.91	$232,759
Watts Bar	5,047,488	3.38	$270,318
Wolf Creek	4,582,376	3.07	$245,409
Total	**243,092,824**	**163.0**	**13,018,831**

Table B-16
Monetized impact of additional CO_2 from retrofit of nuclear facilities to closed-cycle cooling assuming an 8-month shutdown

Facility Name	Required Makeup Generation (MW-hr)	CO_2 (Millions of Tons)	WTP to avoid Additional CO_2
Arkansas Nuclear 1	4,030,214	2.70	$215,838
Browns Ferry	14,810,496	9.93	$793,176
Brunswick	9,635,814	6.46	$516,046
Calvert Cliffs	9,331,352	6.26	$499,740
Clinton	5,525,641	3.70	$295,926
Comanche Peak	12,345,225	8.28	$661,148
Cooper	3,690,596	2.47	$197,650
Crystal River 3	4,466,104	2.99	$239,182
Diablo Canyon	25,878,426	17.35	$1,385,919

Table B-16
Monetized impact of additional CO_2 from retrofit of nuclear facilities to closed-cycle cooling assuming an 8-month shutdown (continued)

Facility Name	Required Makeup Generation (MW-hr)	CO_2 (Millions of Tons)	WTP to avoid Additional CO_2
Donald C. Cook	10,449,196	7.01	$559,607
Dresden	8,885,155	5.96	$475,844
Fort Calhoun	2,230,168	1.50	$119,437
H.B. Robinson	3,652,703	2.45	$195,620
Indian Point	10,858,517	7.28	$581,528
James A FitzPatrick	4,473,319	3.00	$239,569
Kewaunee	2,423,556	1.62	$129,793
McGuire	12,004,731	8.05	$642,913
Millstone	10,639,632	7.13	$569,805
Monticello	3,147,246	2.11	$168,551
Nine Mile Point, NY	9,258,343	6.21	$495,830
North Anna	9,588,829	6.43	$513,530
Oconee	12,868,485	8.63	$689,171
Oyster Creek	3,307,290	2.22	$177,122
Peach Bottom	12,210,304	8.19	$653,923
Pilgrim	3,650,311	2.45	$195,492
Point Beach	5,175,264	3.47	$277,161
Prarie Island	5,514,432	3.70	$295,325
Quad Cities	8,719,896	5.85	$466,994
R. E. Ginna	2,676,608	1.79	$143,346
Salem	13,143,758	8.81	$703,914
San Onofre	10,729,104	7.19	$574,597
Seabrook	6,292,830	4.22	$337,012
Sequoyah	13,362,624	8.96	$715,635
St Lucie	8,603,904	5.77	$460,782
Surry Power Station	8,258,122	5.54	$442,264
V C Summer	5,024,708	3.37	$269,098
Waterford 3	5,794,902	3.89	$310,346
Watts Bar	6,729,984	4.51	$360,424
Wolf Creek	6,109,834	4.10	$327,212
Total	**315,497,624**	**211.5**	**16,896,469**

Table B-17
Estimated impacts of additional CO_2 emissions due to retrofitting nuclear phase II facilities (6-month outage)

Waterbody	Number of Facilities or Units	Required Makeup Generation (MW-hr)	CO_2 (Millions of Tons)	Annual WTP to avoid Additional CO_2
LR/RL	19	110,520,764	74	$5,918,937
SR/GL	7	32,506,081	22	$1,740,862
O/E/TR	13	100,065,980	67	$5,359,032
Totals	**39**	**243,092,824**	**163**	**$13,018,831**

Table B-18
Estimated impacts of additional CO_2 emissions due to retrofitting nuclear phase II facilities (8-month outage)

Waterbody	Number of Facilities or Units	Required Makeup Generation (MW-hr)	CO_2 (Millions of Tons)	Annual WTP to avoid Additional CO_2
LR/RL	19	147,361,019	99	$7,891,916
SR/GL	7	43,341,441	29	$2,321,150
O/E/TR	13	124,795,164	84	$6,683,402
Totals	**39**	**315,497,624**	**212**	**$16,896,469**

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C
MODEL RESULTS

C.1 AERMOD Dispersion Modeling for PM_{10} and $PM_{2.5}$

The AERMOD dispersion model was used to predict mechanical-draft evaporative cooling tower drift emissions for representative facilities. A description of the AERMOD model, inputs and assumptions are included in Appendix B. The AERMOD meteorological data requirements were met using readily available National Weather Service data. The annual and maximum 24-hr concentrations surrounding each Beta Test Plants (BTPs) and Representative Facilities (RFs) where impacts were found, as well as plots of concentration versus distance along the prevailing wind direction for BTPs are presented below.

C.1.1 BTCA1

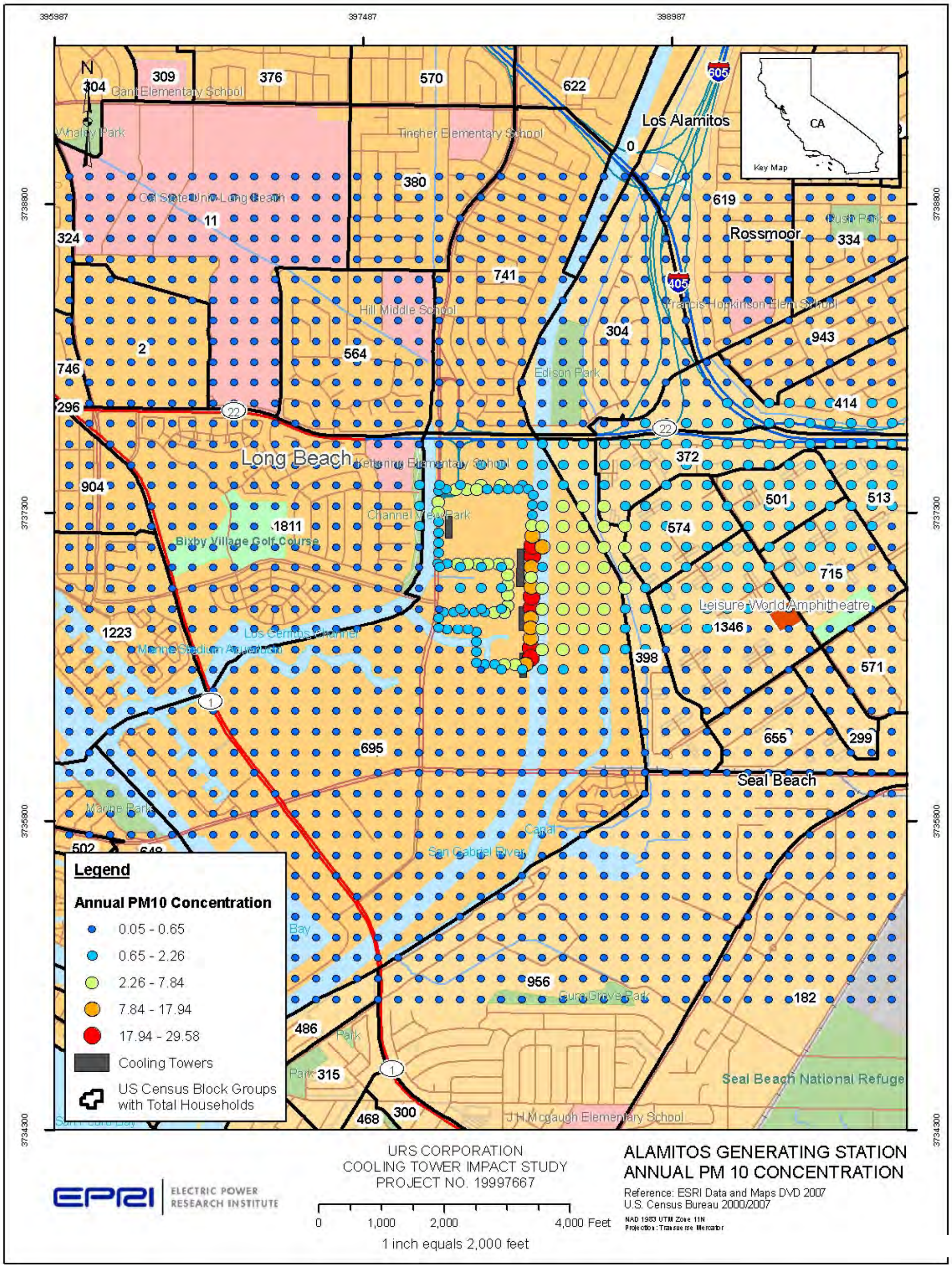


Figure C-1
BTCA1 annual PM_{10} concentration (ug/m^3)

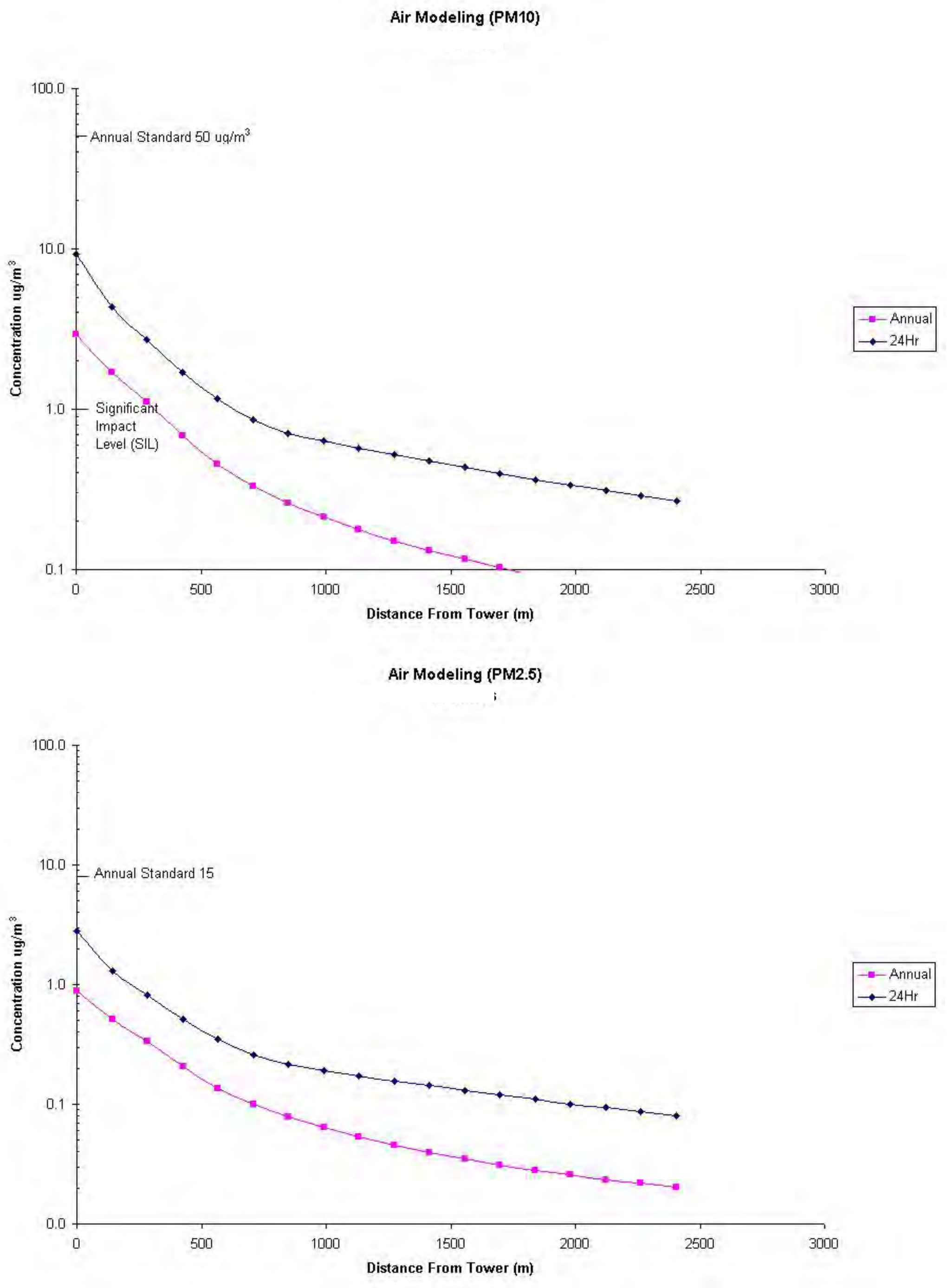


Figure C-2
BTCA1 particulate concentration along down-wind axis

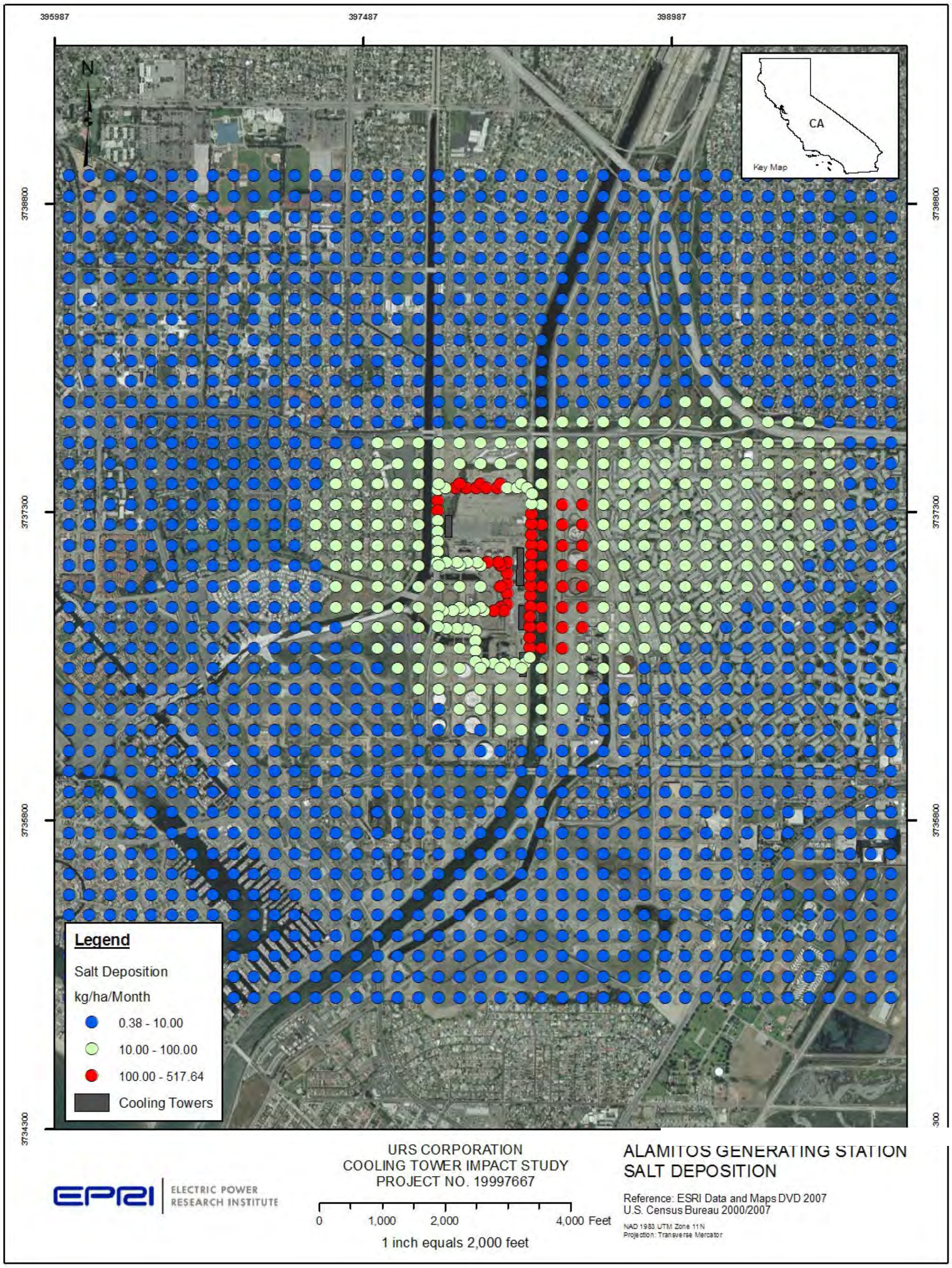


Figure C-3
BTCA1 salt deposition

C.1.2 BTPA

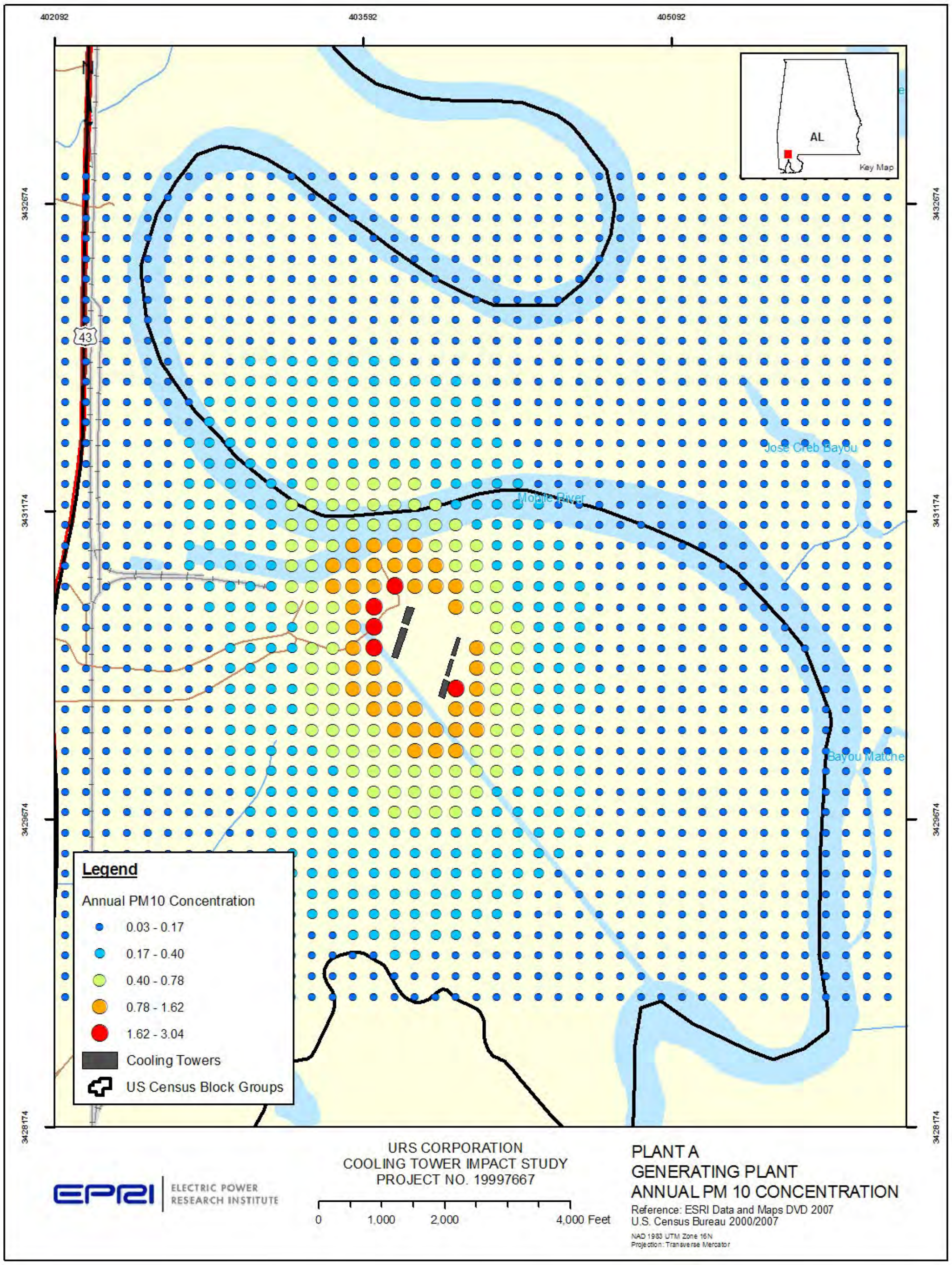
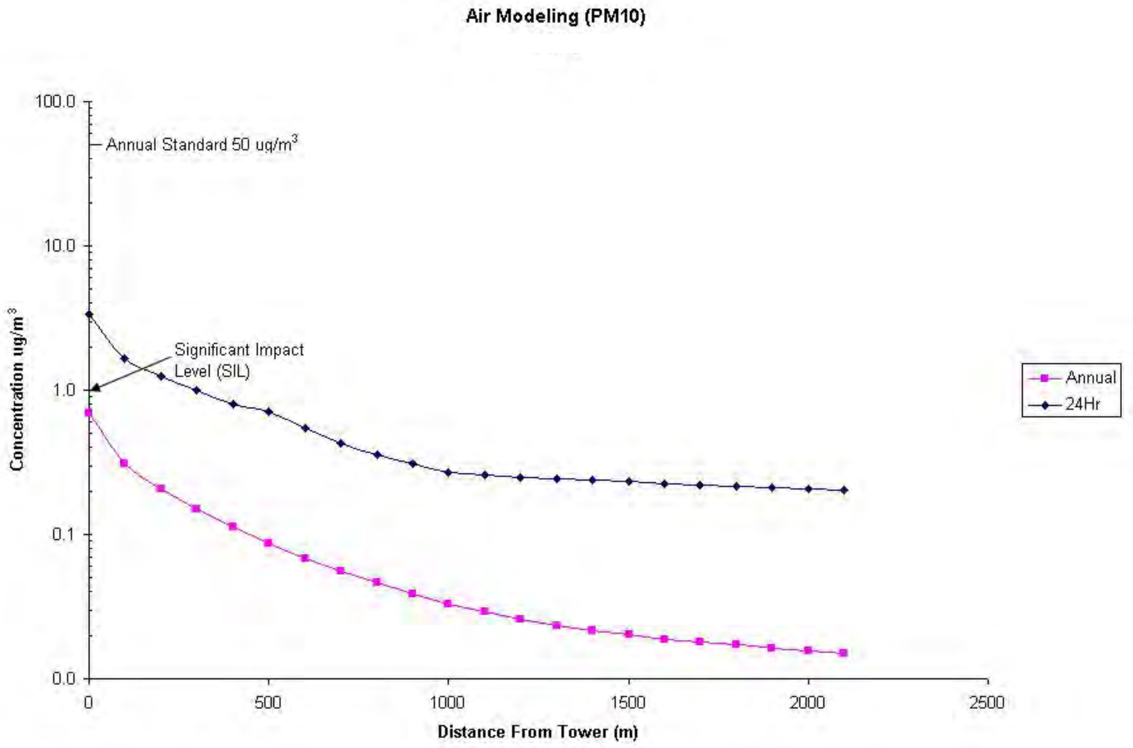


Figure C-4
BTPA annual PM_{10} concentration (ug/m^3)



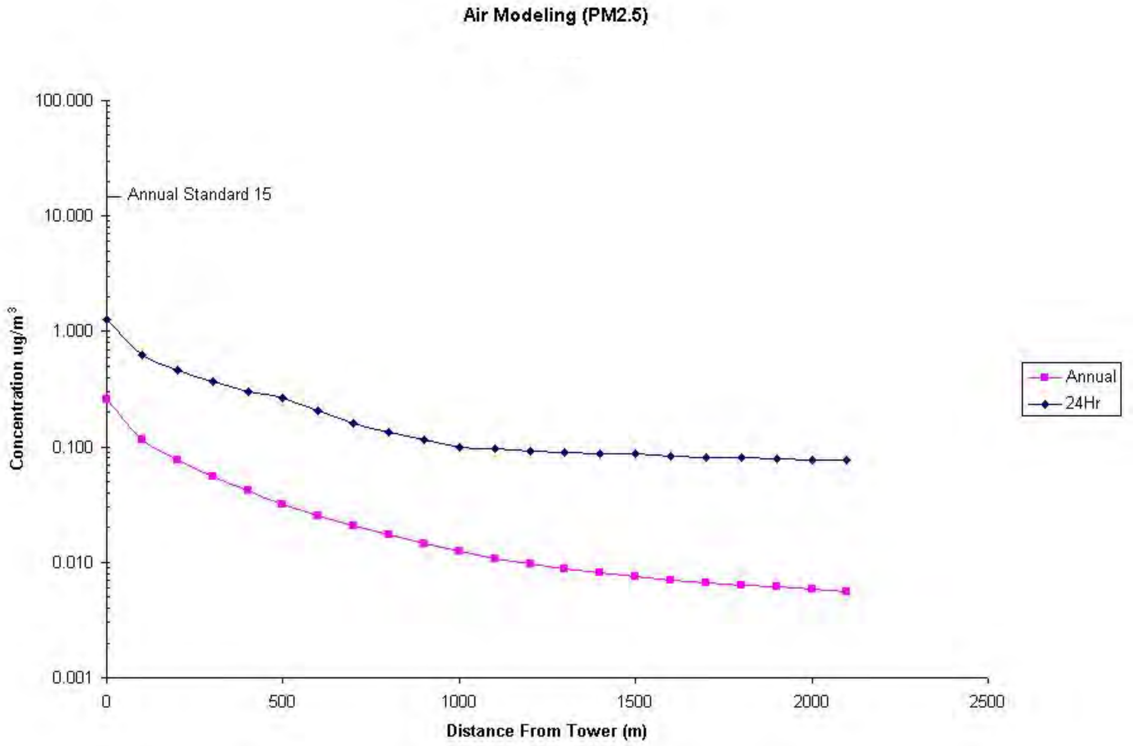


Figure C-5
BTPA particulate concentration along down wind axis

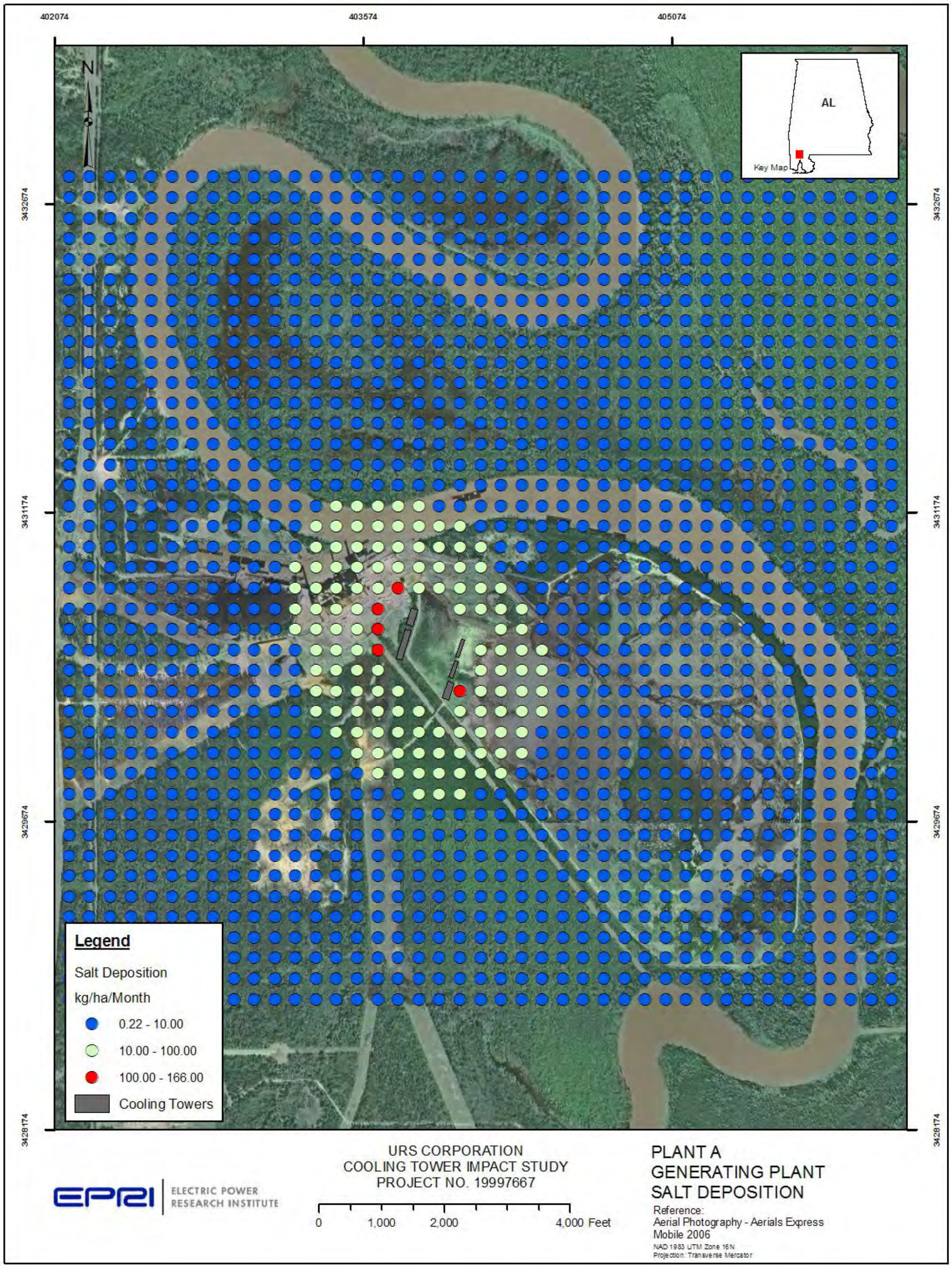


Figure C-6
BTPA salt deposition

C.1.3 BTPB

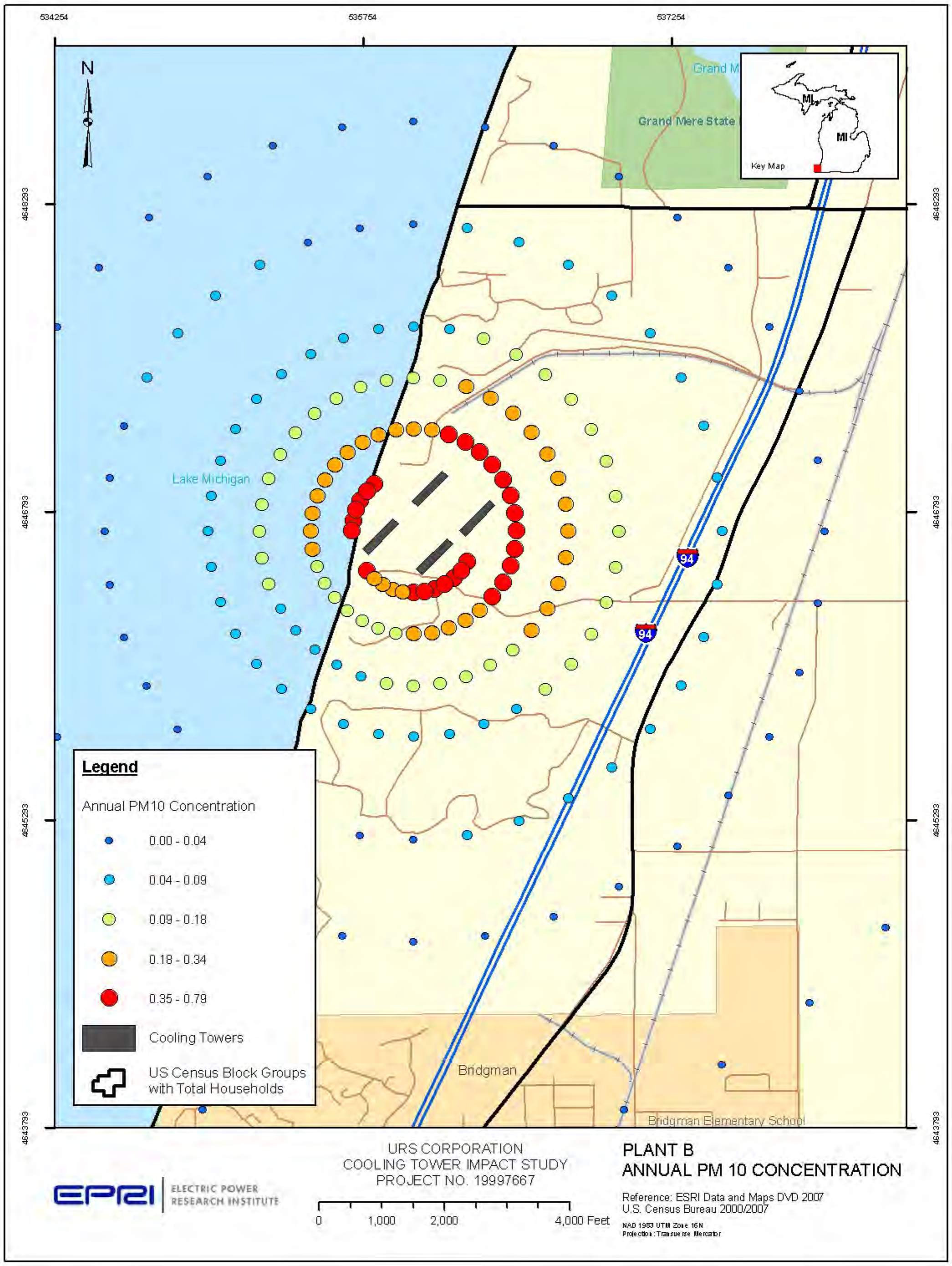
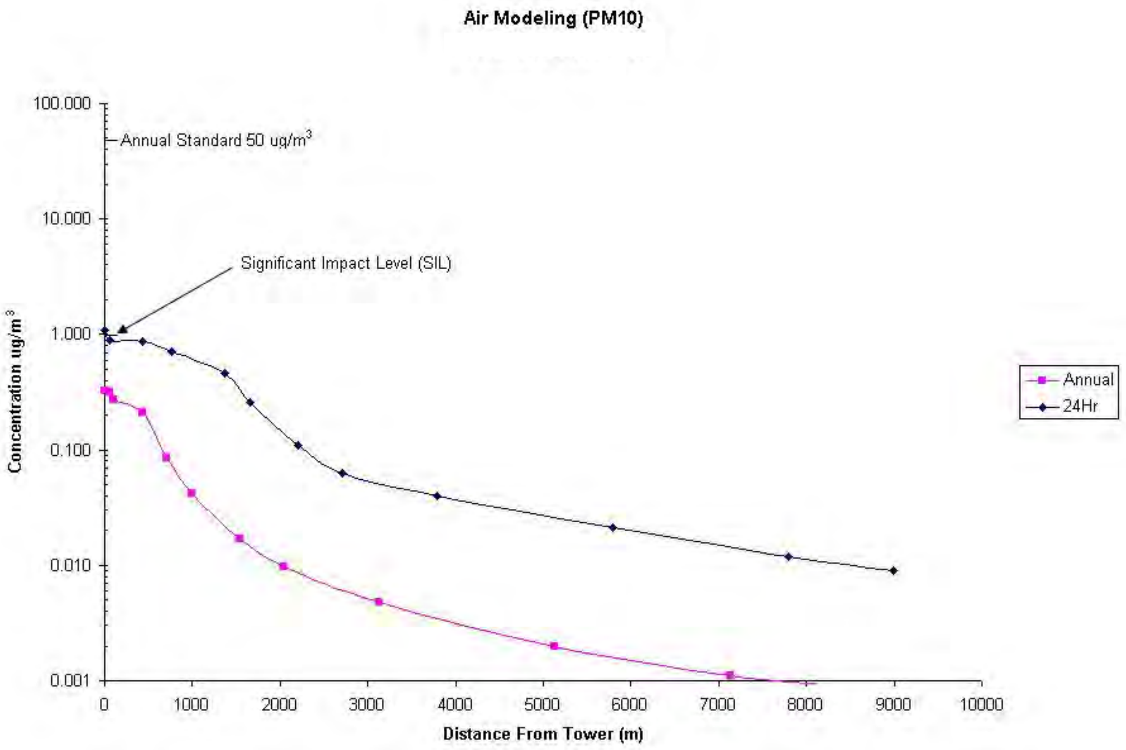


Figure C-7
BTPB PM$_{10}$ concentration (ug/m^3)



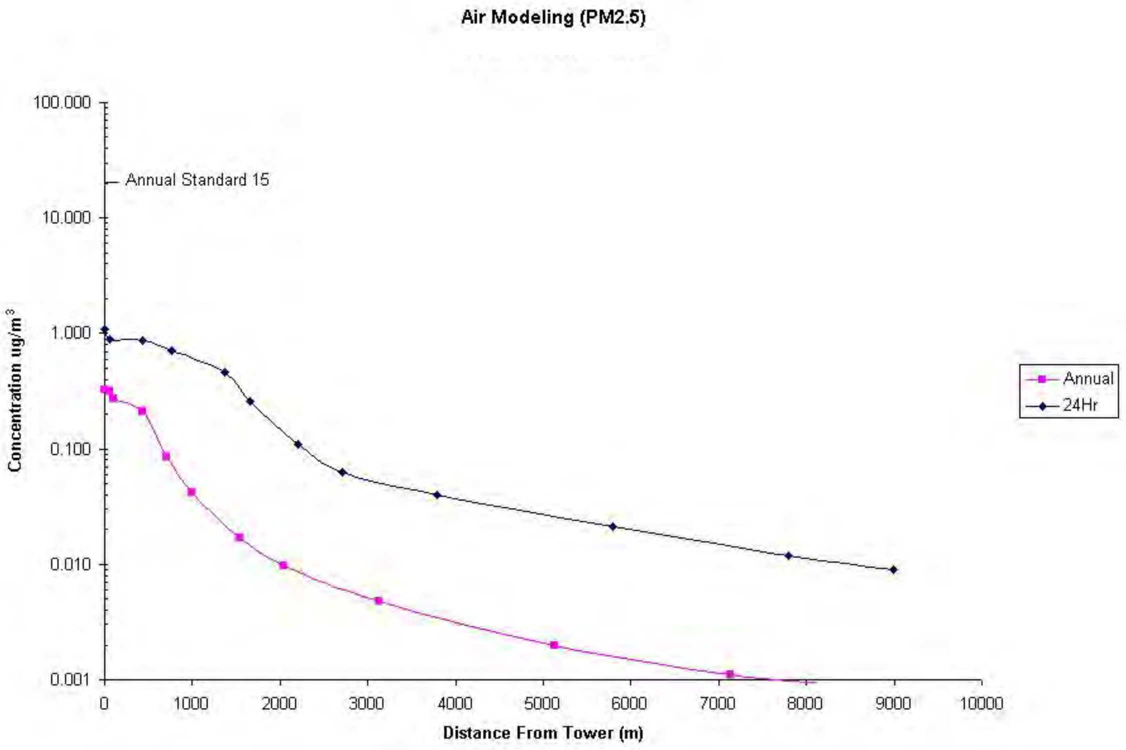


Figure C-8
BTPB particulate concentration along down wind axis

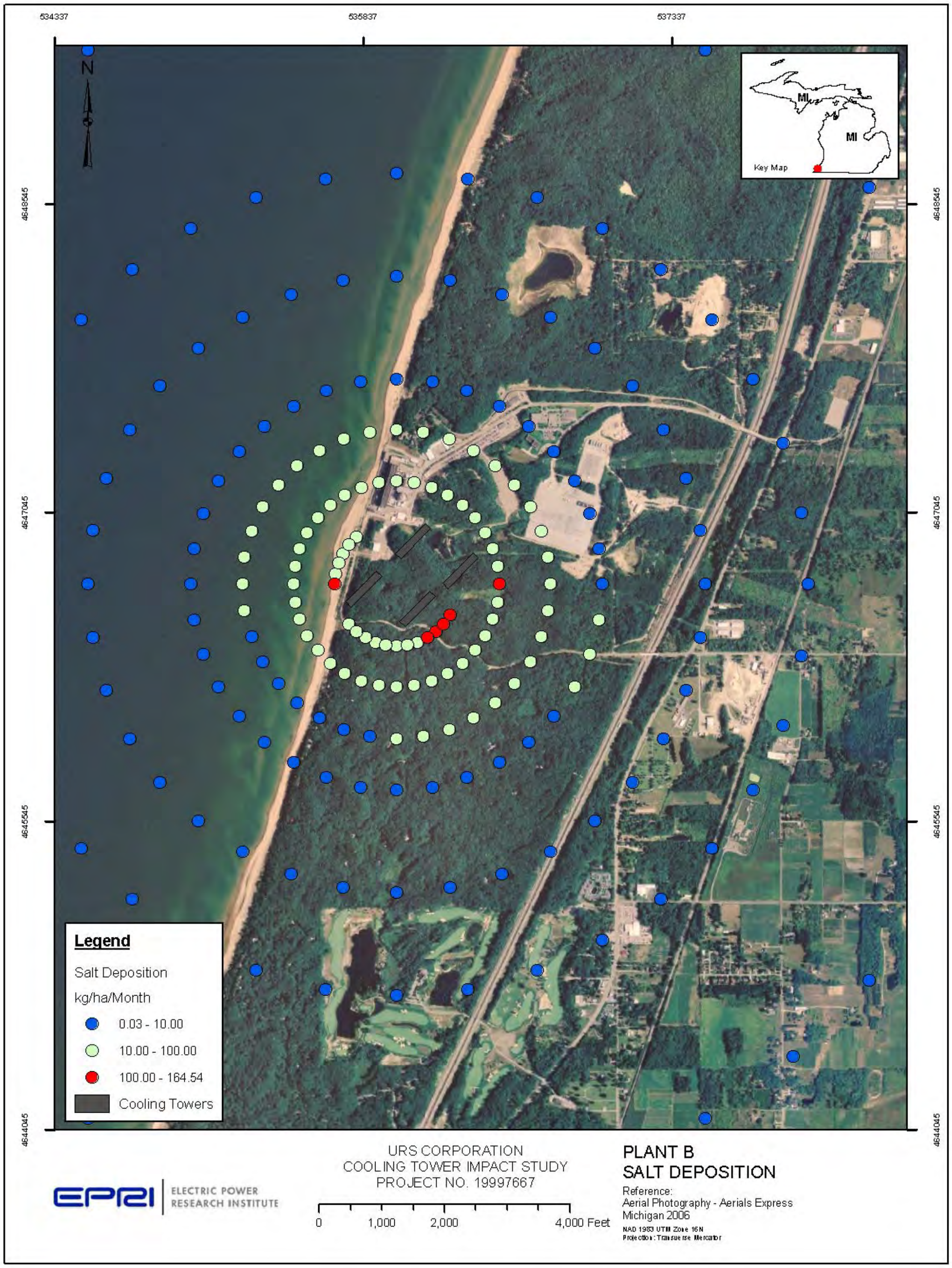


Figure C-9
BTPB salt deposition

C.1.4 BTPC

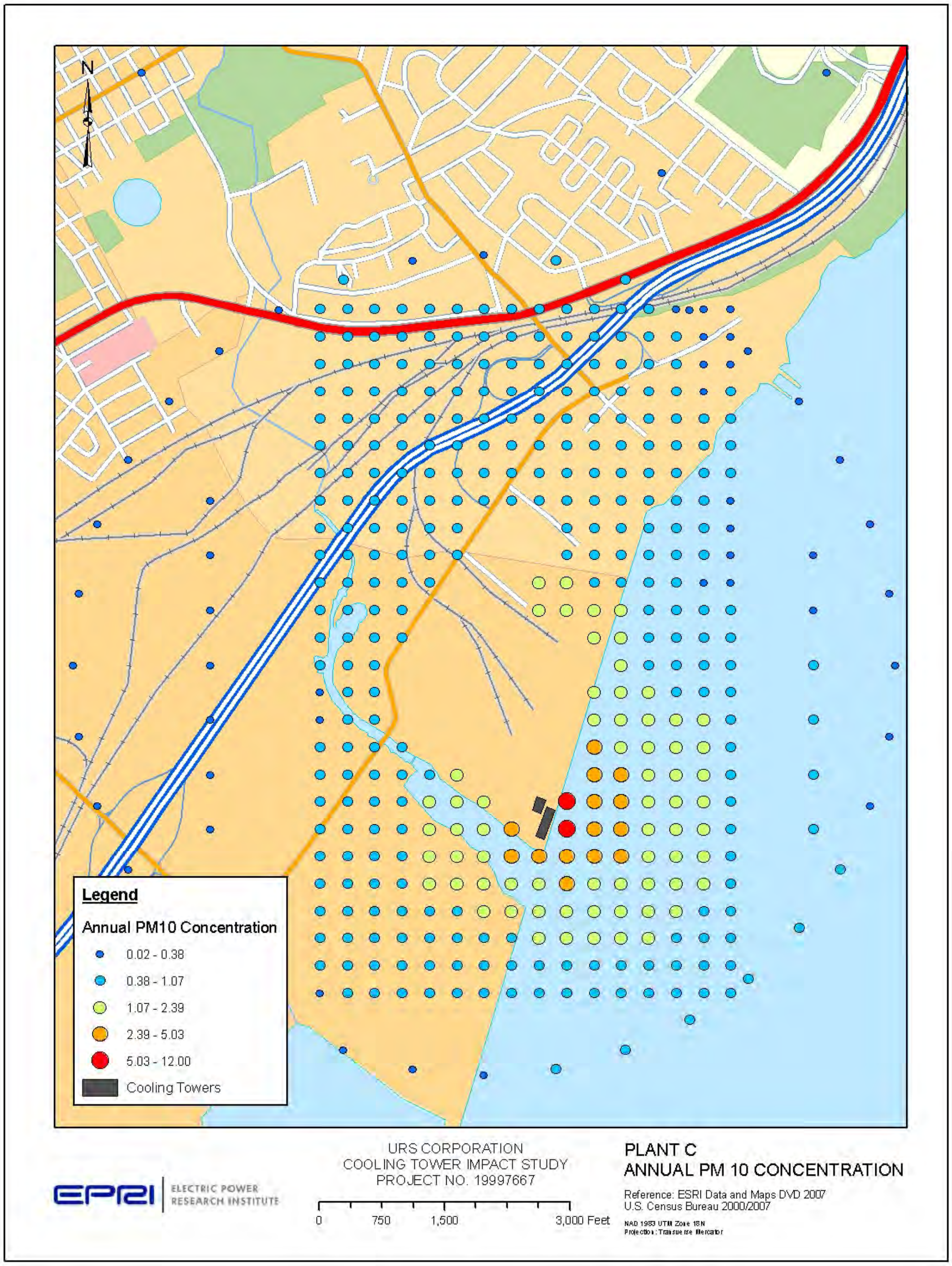
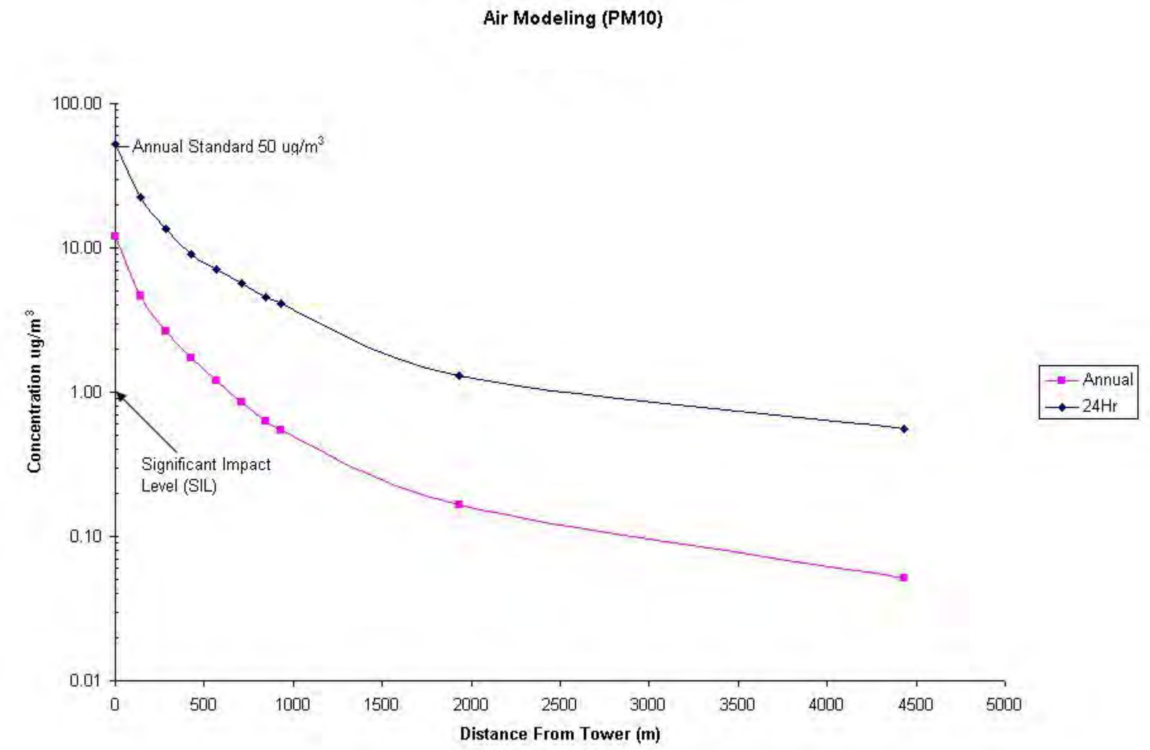


Figure C-10
BTPC PM$_{10}$ concentration (ug/m^3)



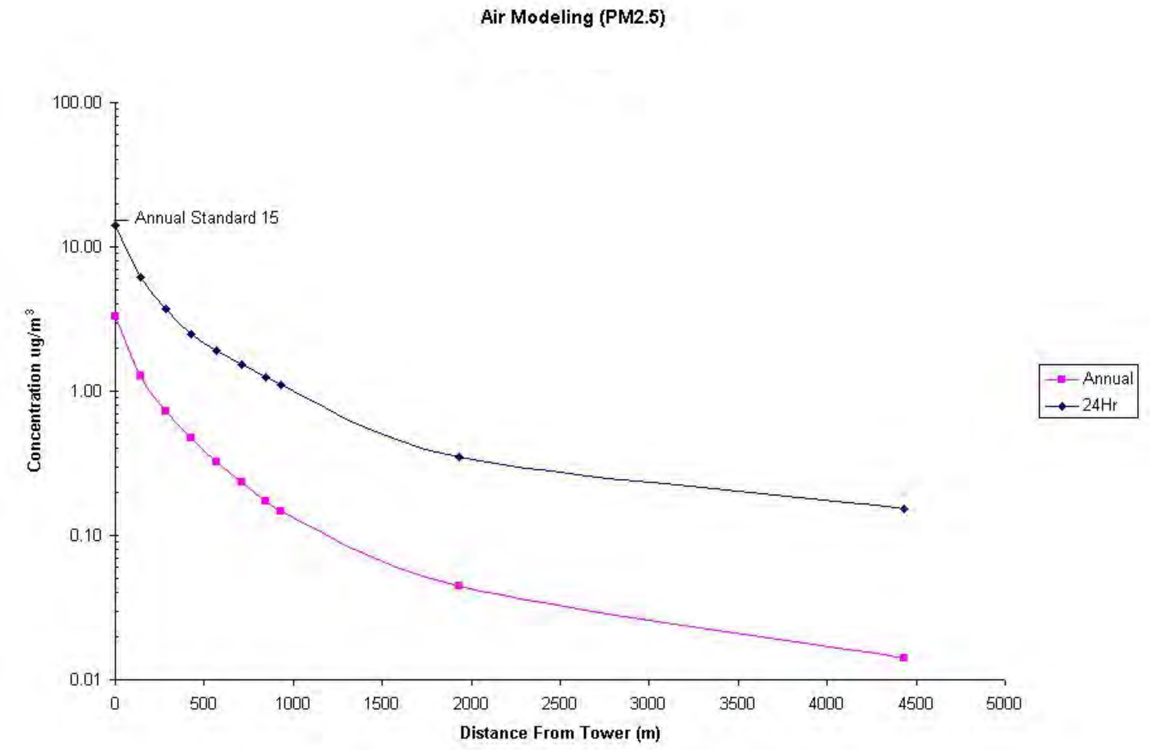


Figure C-11
BTPC particulate concentration along down wind axis

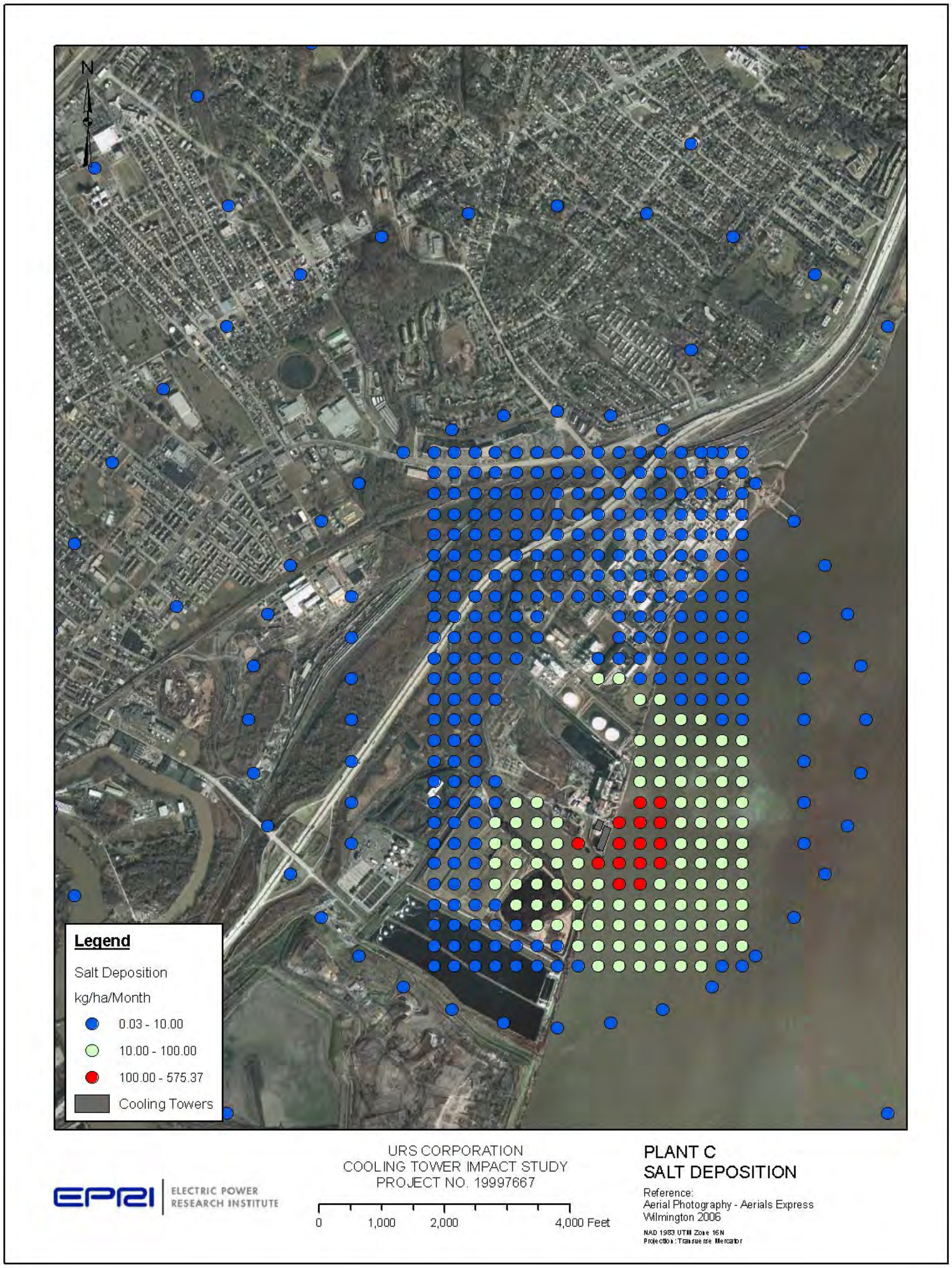


Figure C-12
BTPC salt deposition

C.1.5 BTPD

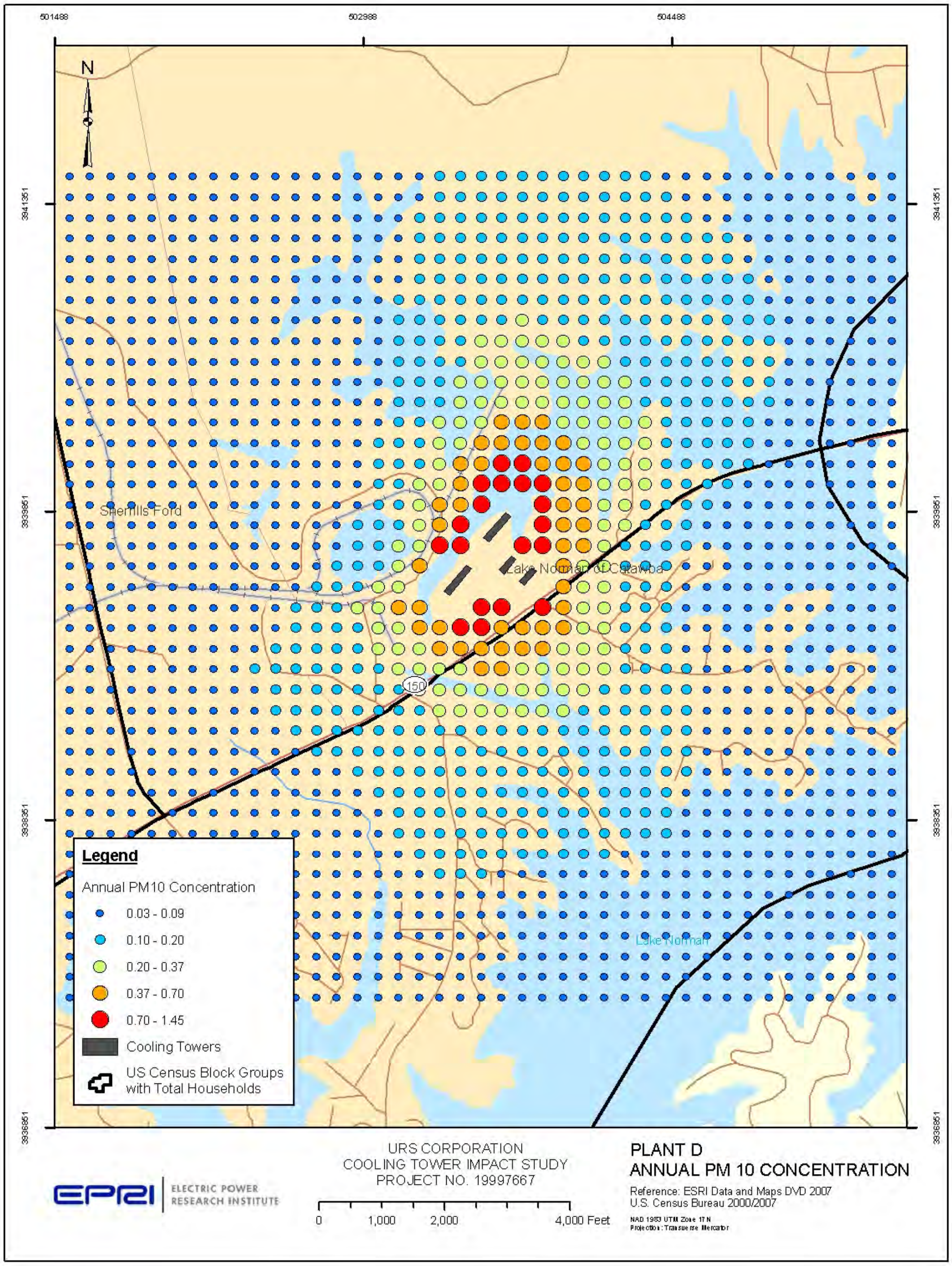
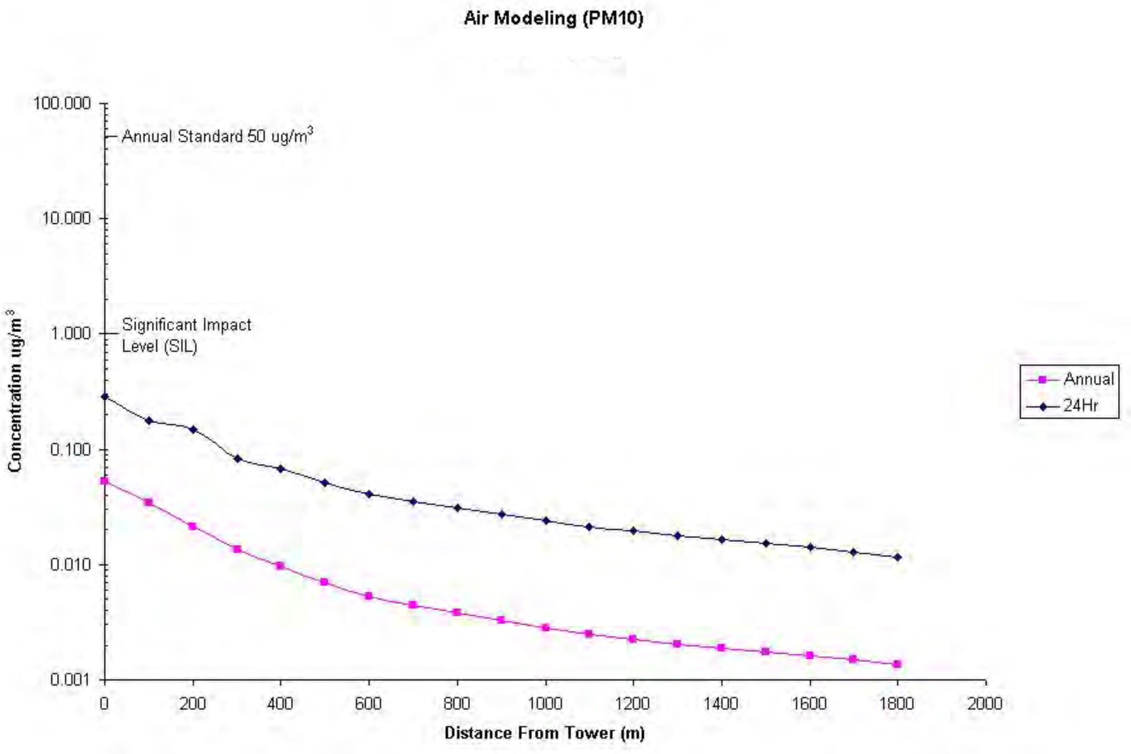


Figure C-13
BTPD PM$_{10}$ concentration (ug/m^3)



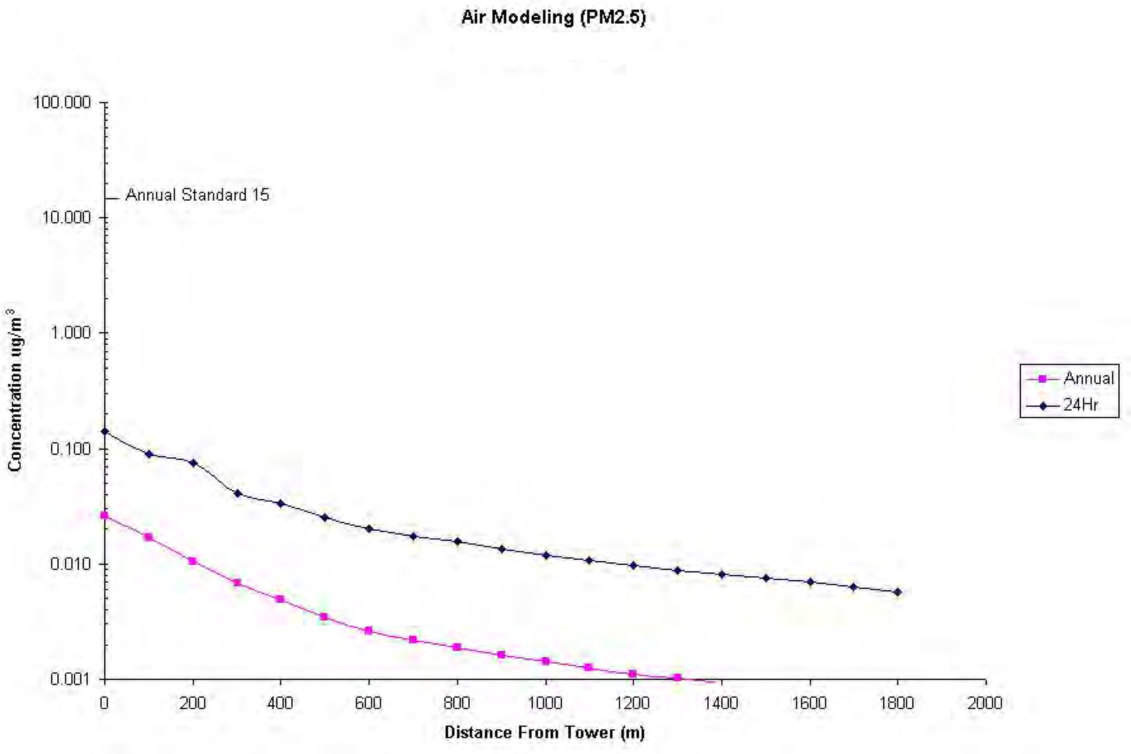


Figure C-14
BTPD particulate concentration along down wind axis

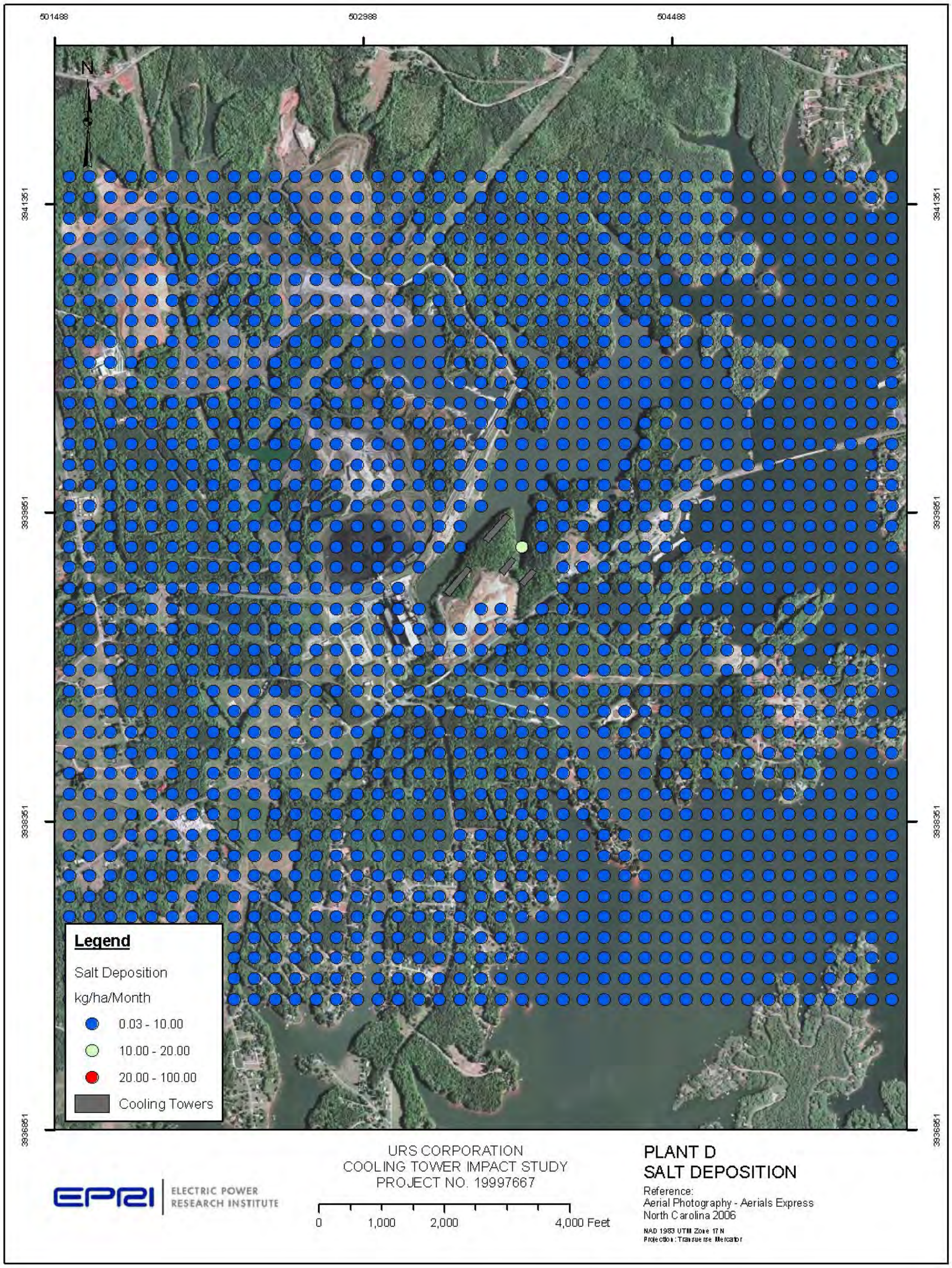


Figure C-15
BTPD salt deposition

C.1.6 BTPE

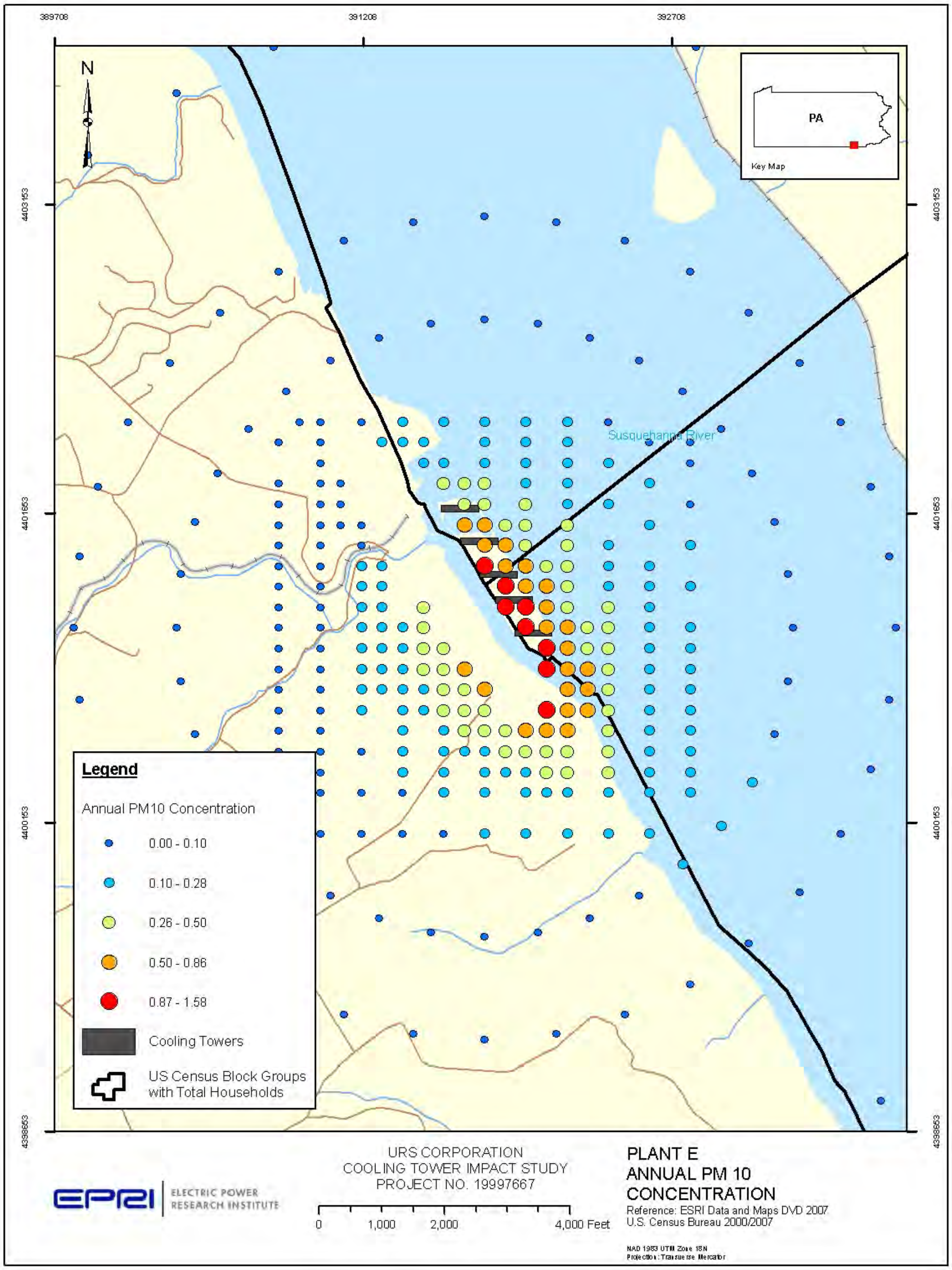
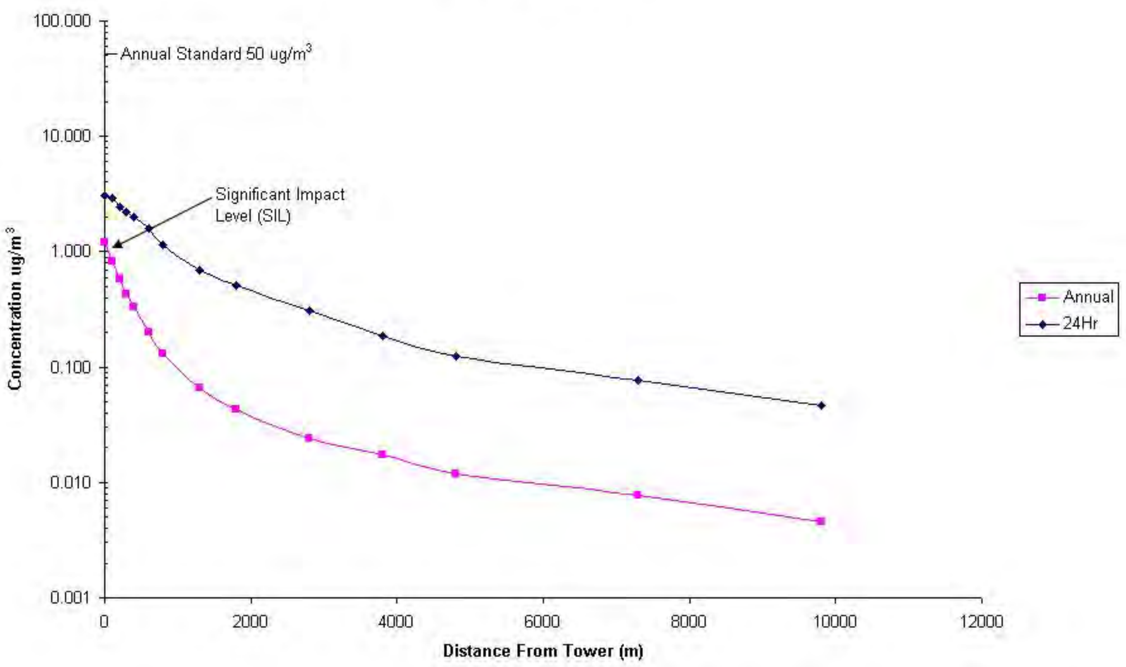


Figure C-16
BTPE PM_{10} concentration (ug/m^3)

Air Modeling (PM10)



Air Modeling (PM2.5)

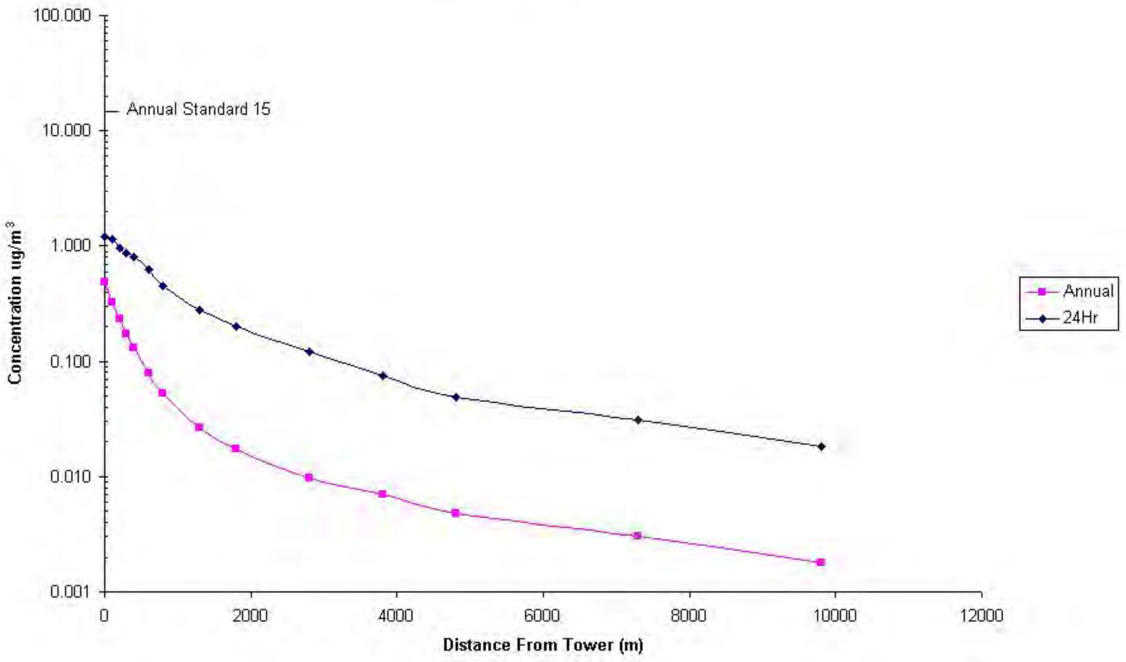


Figure C-17
BTPE particulate concentration along down wind axis

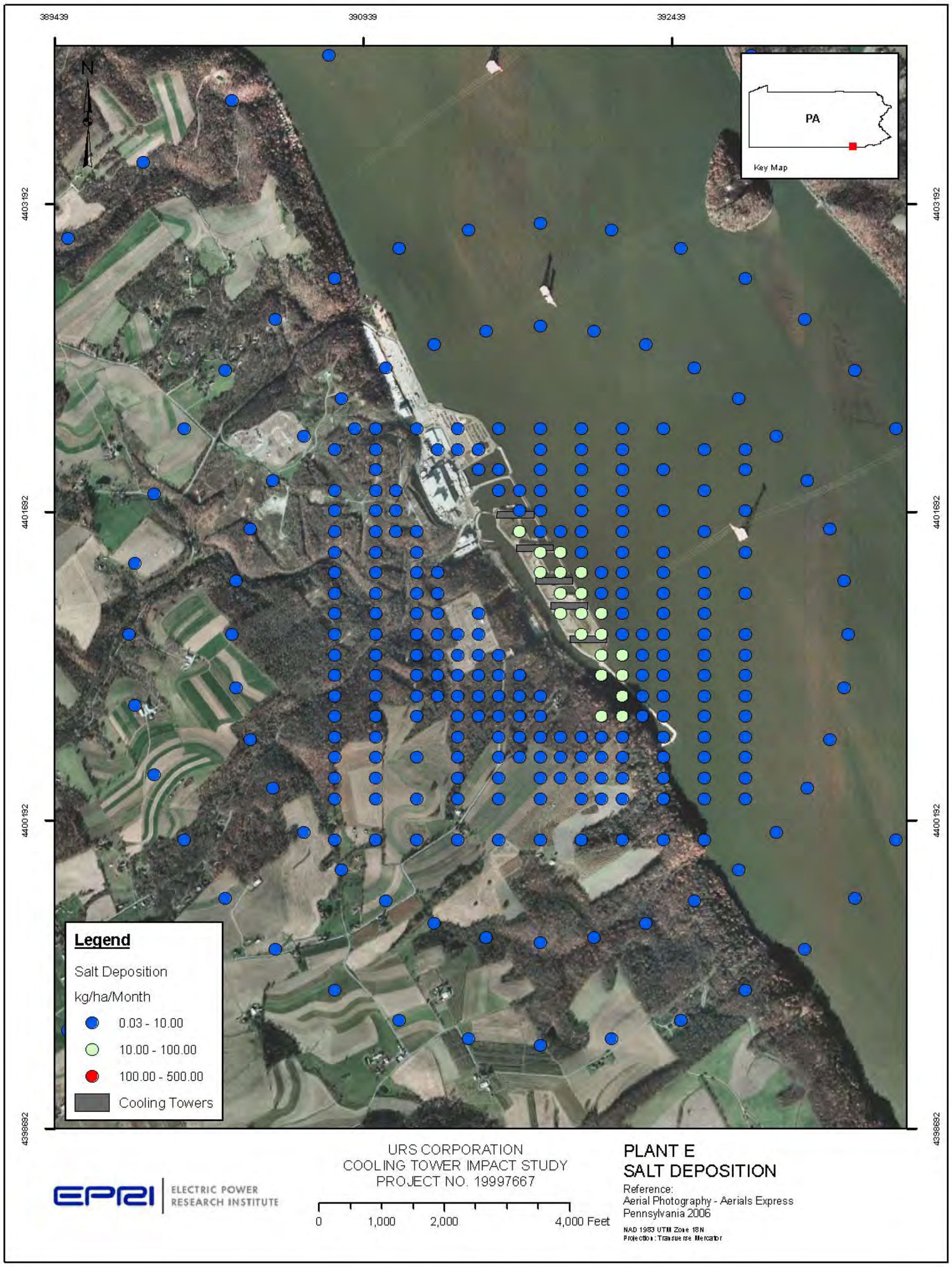


Figure C-18
BTPE salt deposition

C.1.7 BTCA2

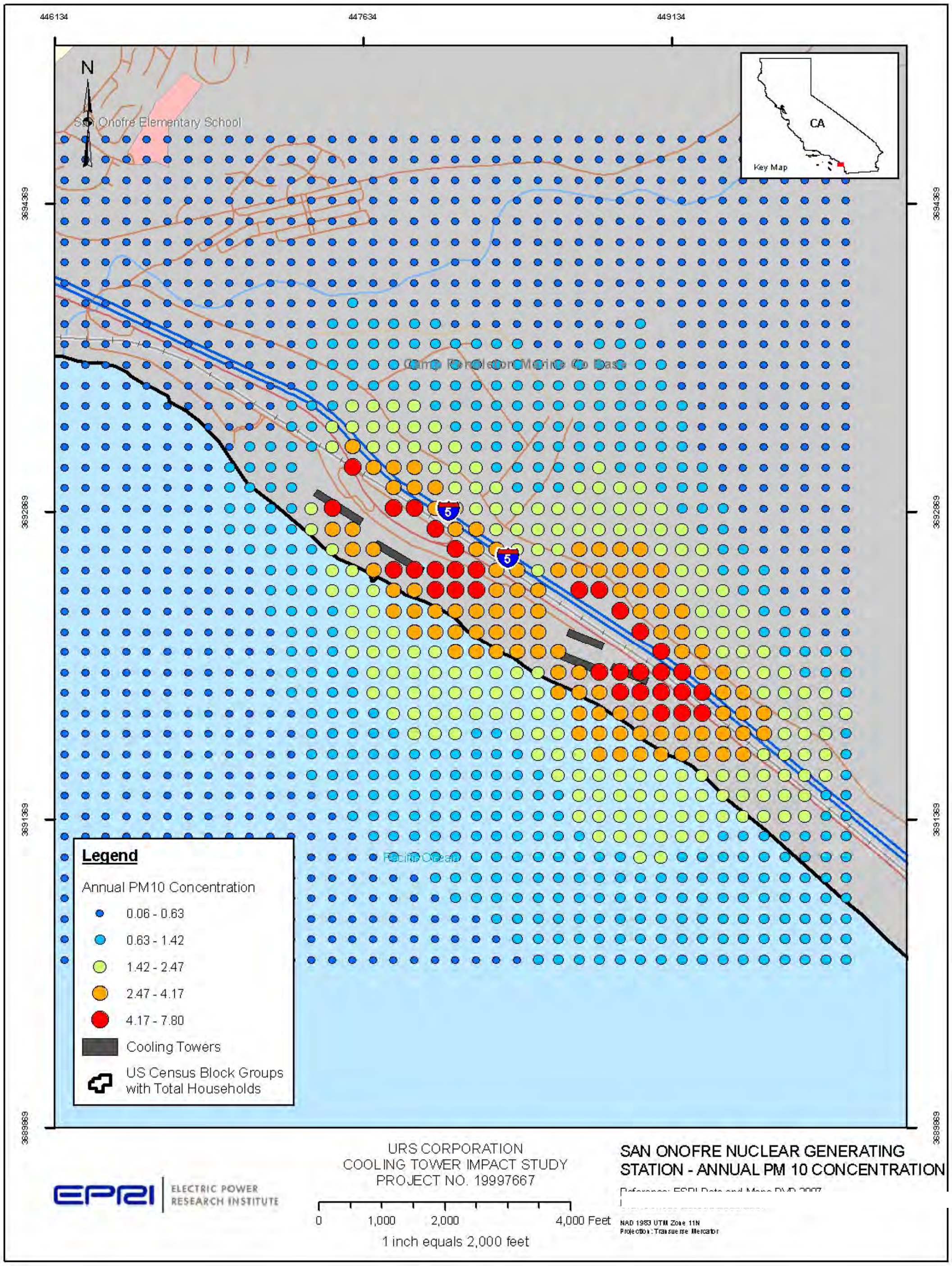


Figure C-19
BTCA2 PM_{10} concentration

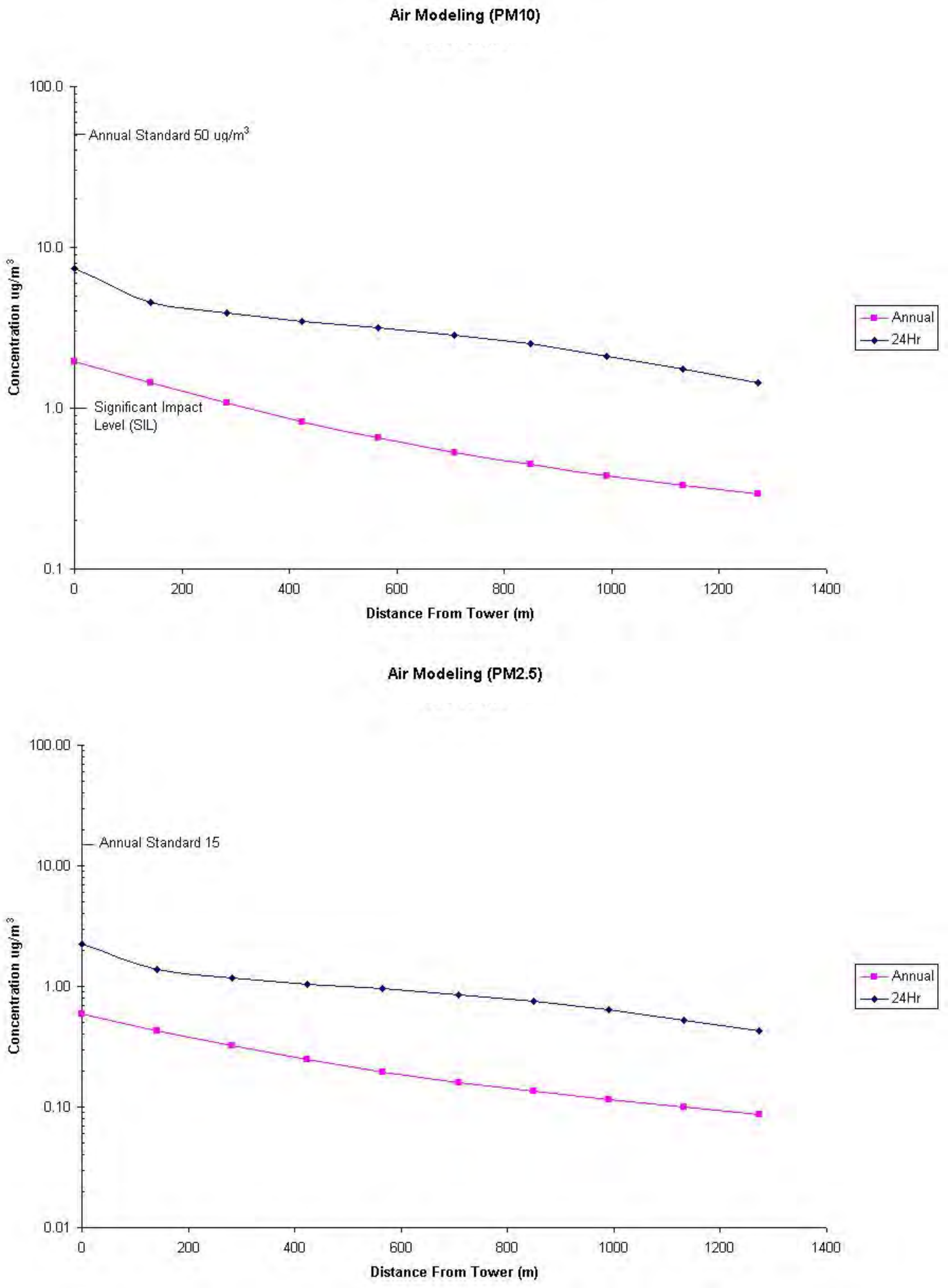


Figure C-20
BTCA2 particulate concentration along down wind axis

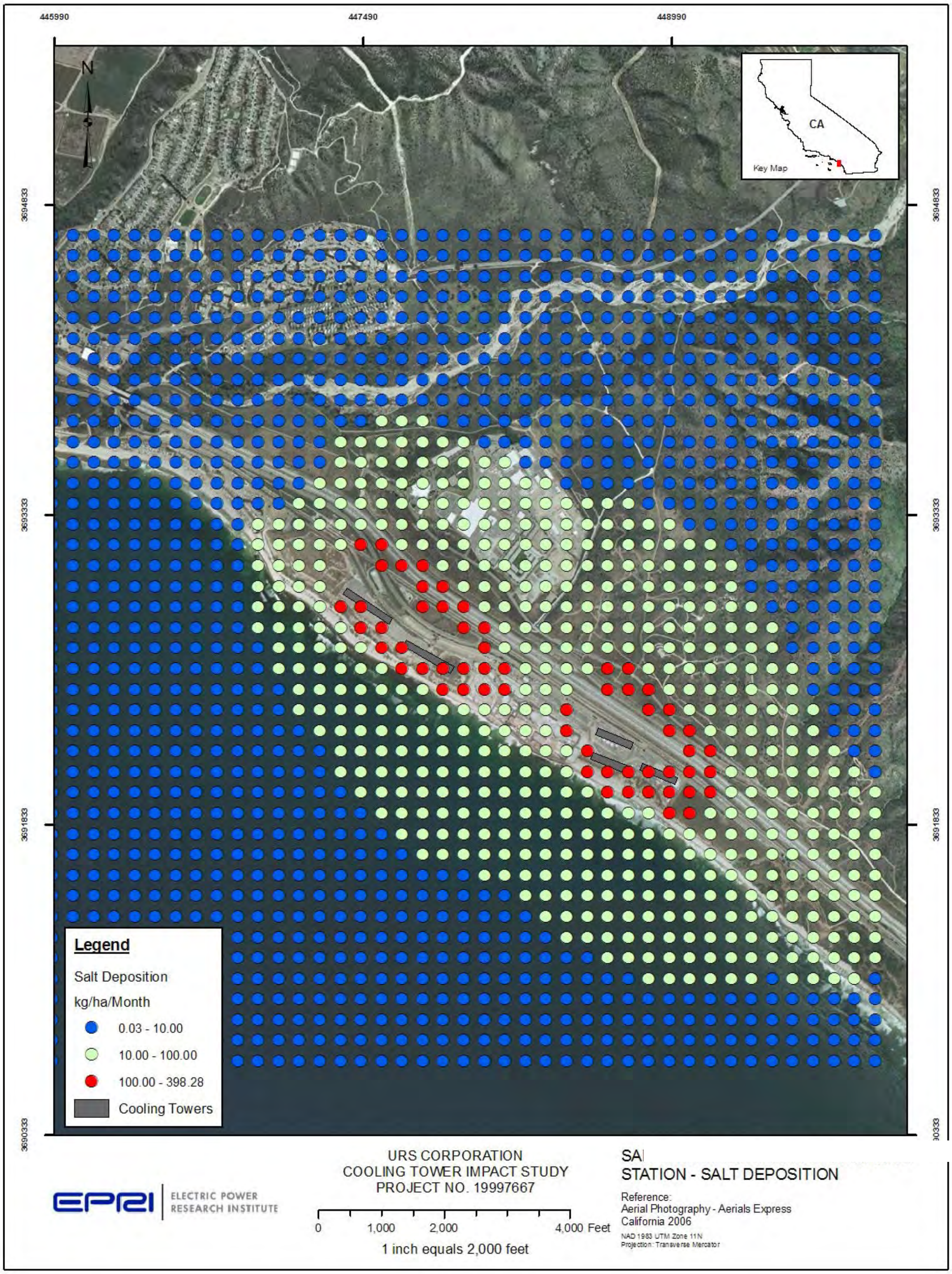


Figure C-21
BTCA2 salt deposition

C.1.8 RFH

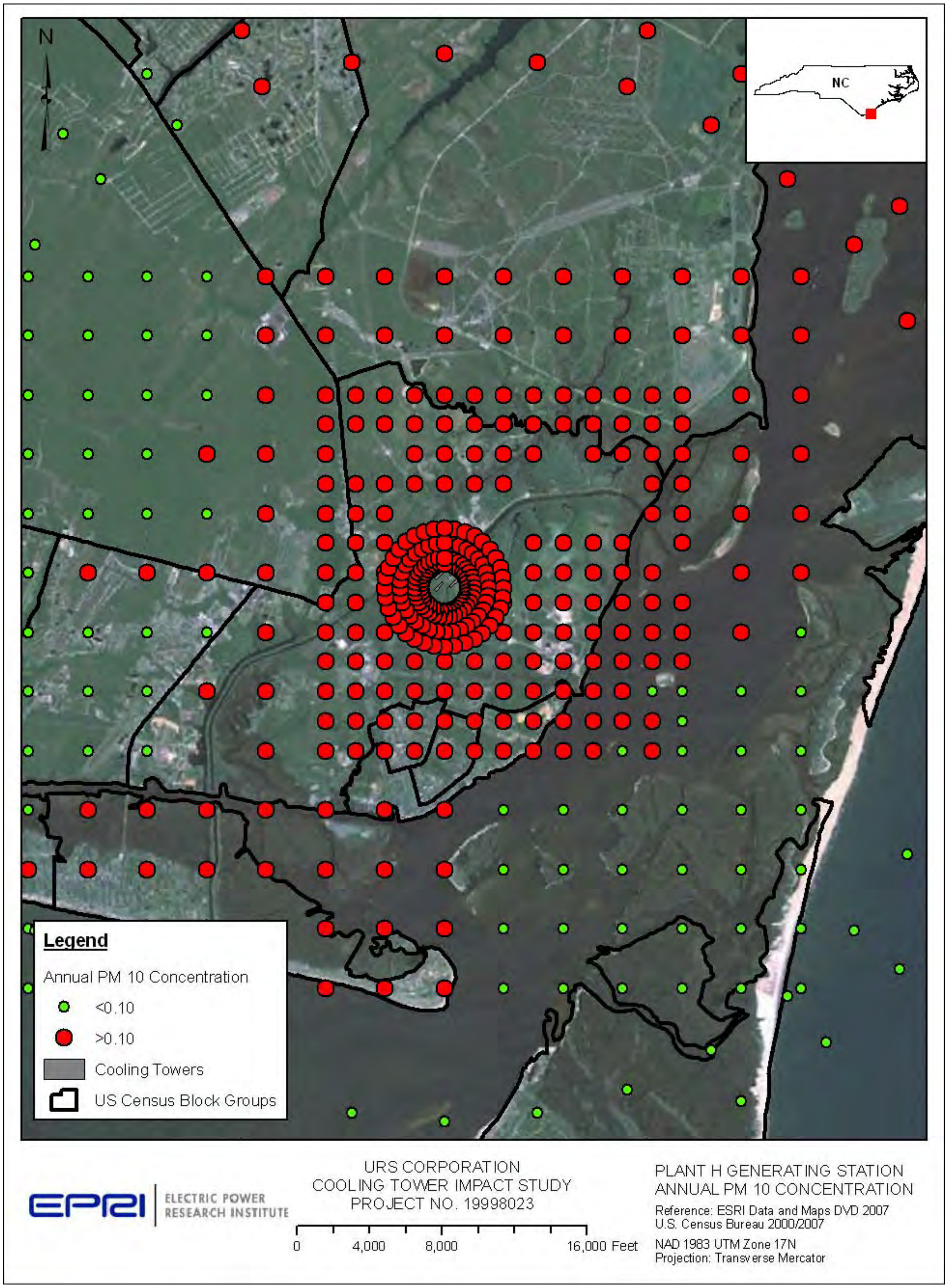


Figure C-22
RFH PM_{10} concentration

C.1.9 RFI

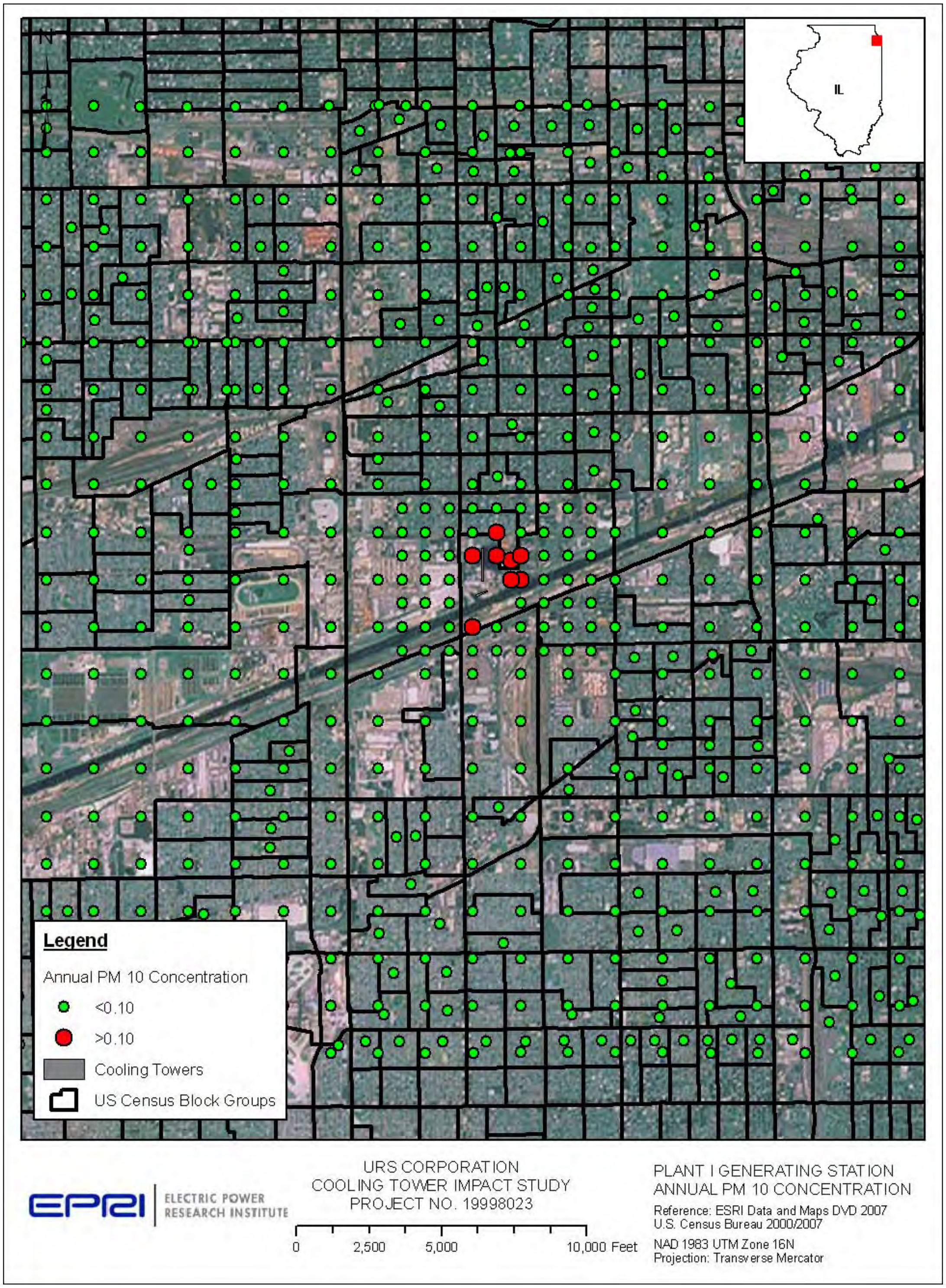


Figure C-23
RFI PM_{10} concentration

C.1.10 RFJ

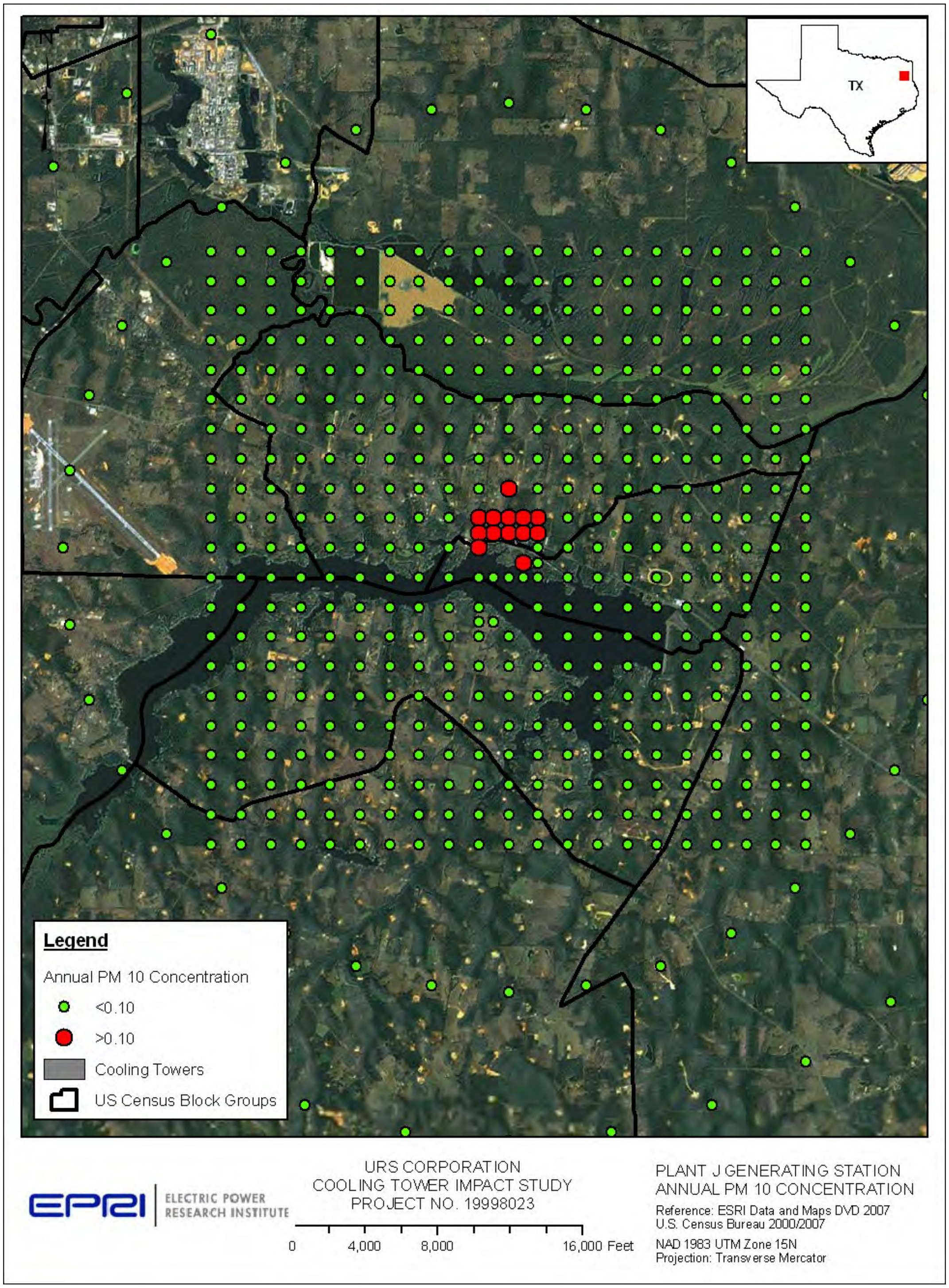


Figure C-24
RFJ PM_{10} concentration

C.1.11 RFK

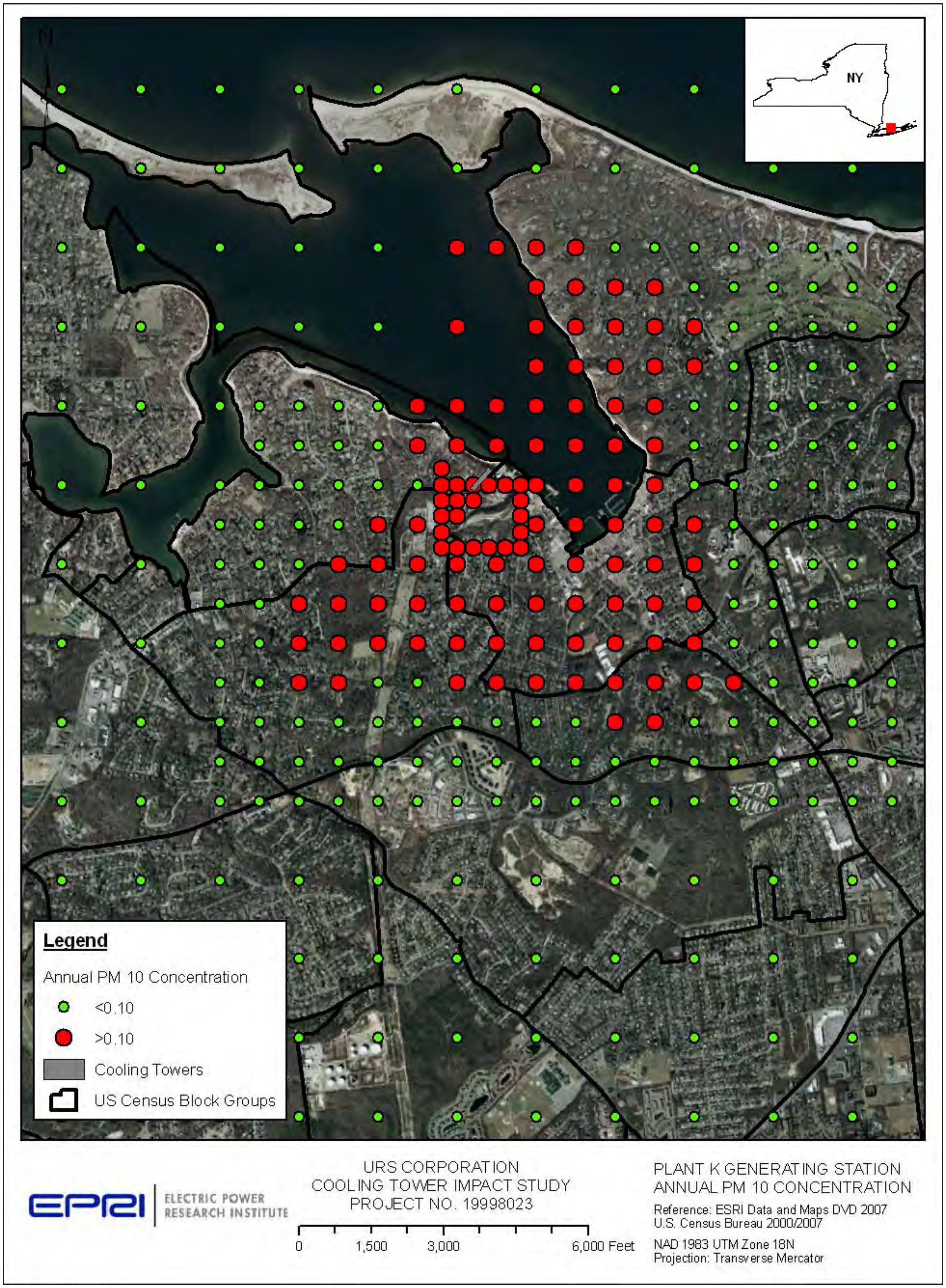


Figure C-25
RFK PM$_{10}$ concentration

C.2 SACTI Modeling – Fogging, Icing, and Visible Plume

The water plume emitted directly from cooling water towers can produce adverse environmental impacts in the area around the tower such as fogging and icing from plume condensation and the length and frequency of visible water plumes.

All seven BTPs and seven RFs included in this study were evaluated for potential fogging, icing, and plume length using the Seasonal Annual Cooling Tower Impact (SACTI) model, Version 11-01-90. SACTI is a validated and recognized cooling water tower plume model that has been applied in numerous cooling tower studies across the United States. It was developed by Argonne National Laboratory at the request of the Electric Power Research Institute (EPRI) to address potential impacts from cooling towers such as plume visibility, ground-level fogging, ground-level icing, and plume shadowing. It is based on studies conducted by Argonne National laboratory to evaluate the performance of numerous cooling tower plume and drift models.

The SACTI model output of the probable frequency of ground-level plume fogging and icing and the length and frequency of visible water plumes for each the for each tower design and location is provided in the sections below.

C.2.1 BTCA1

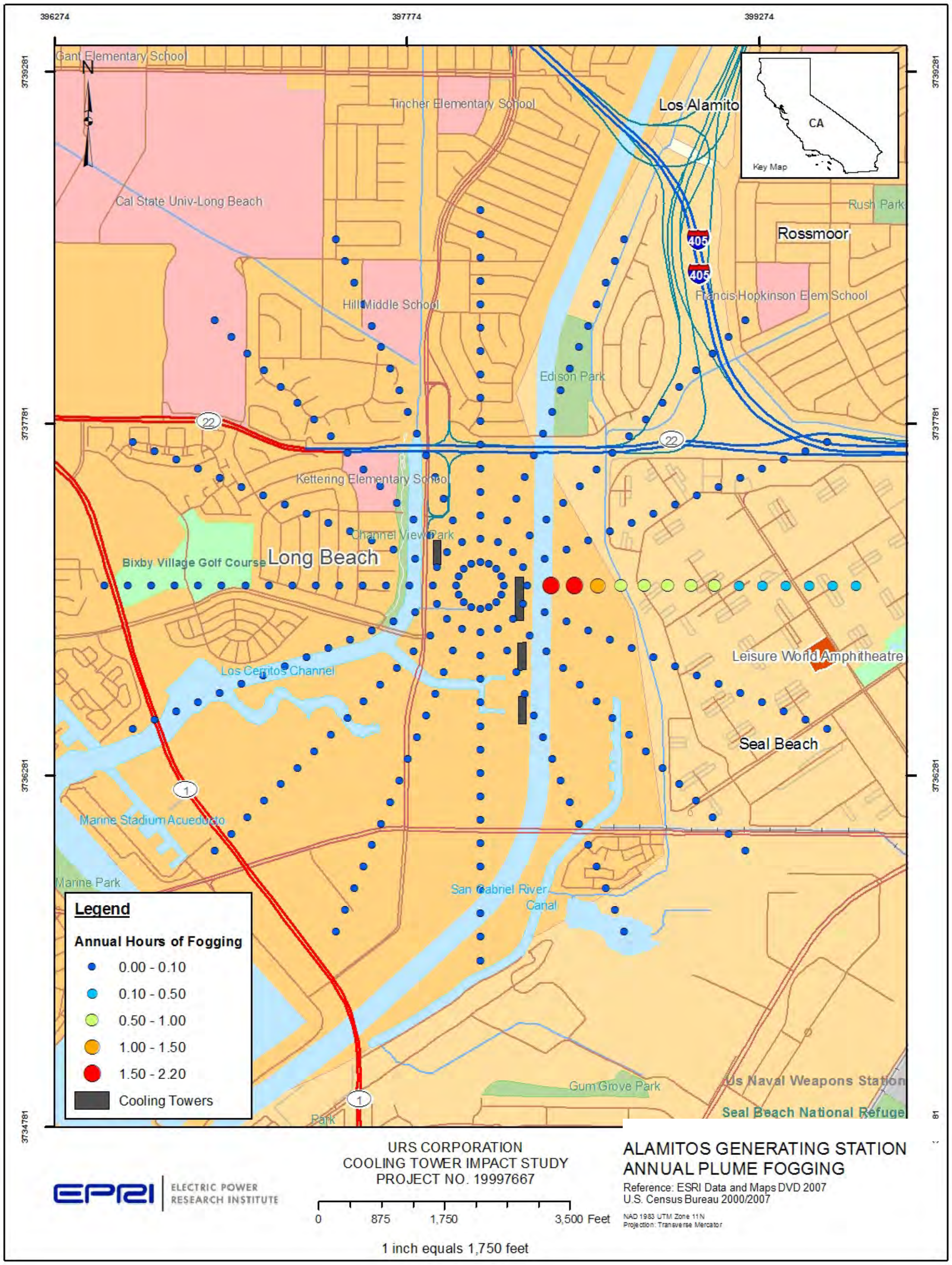


Figure C-26
BTCA1 plume fogging

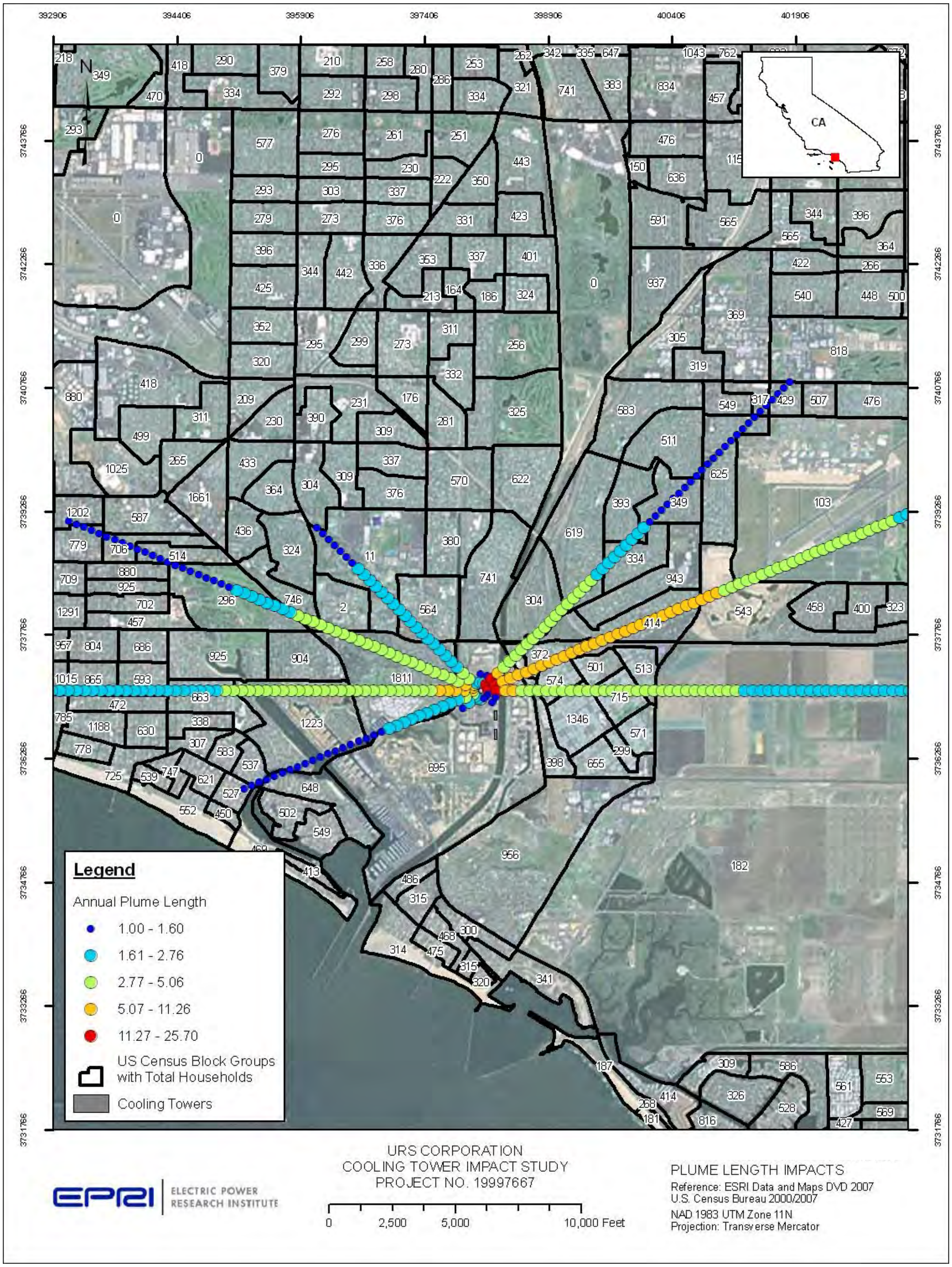


Figure C-27
BTCA1 plume length

C.2.2 BTPA

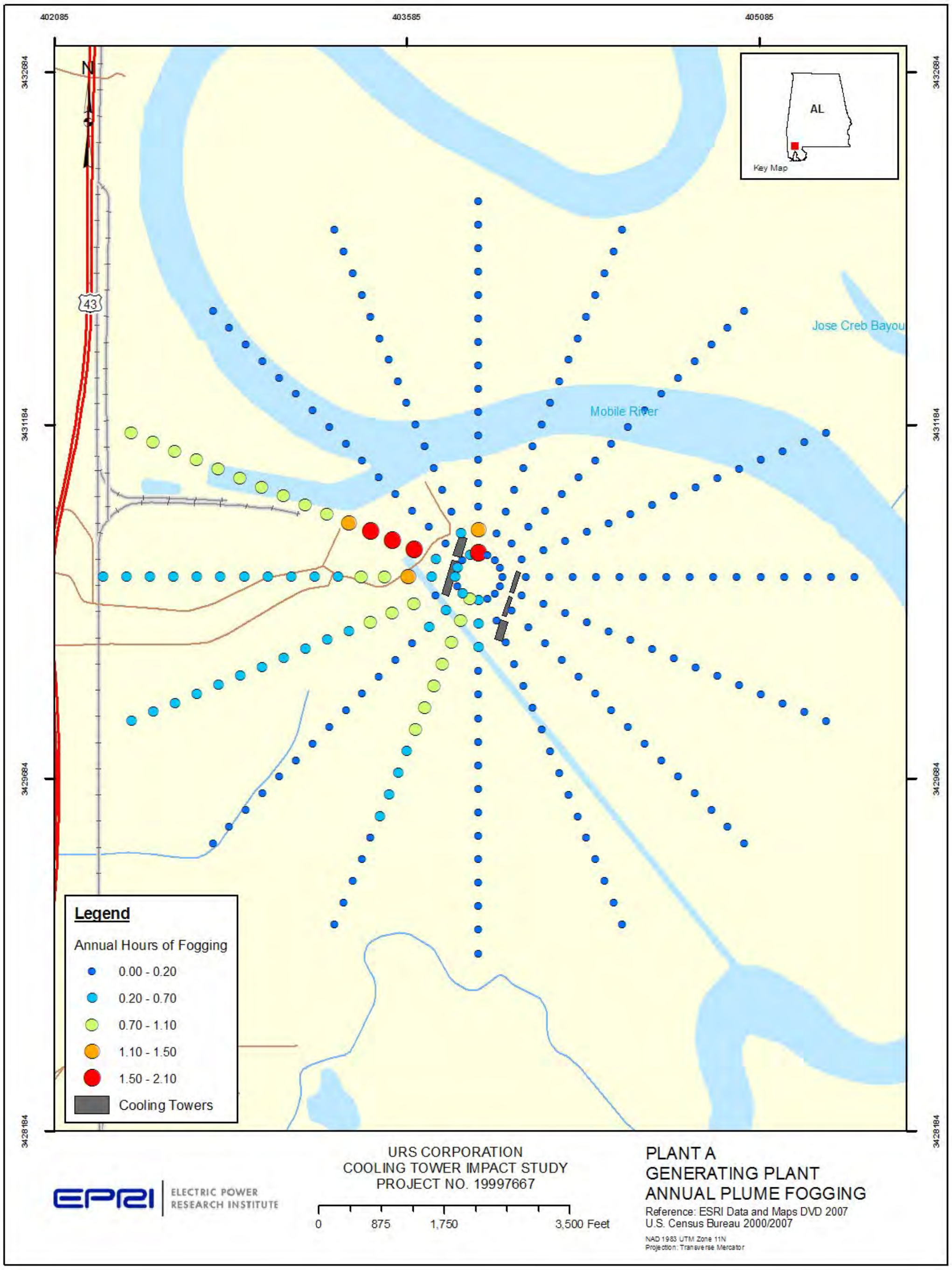


Figure C-28
BTPA plume fogging

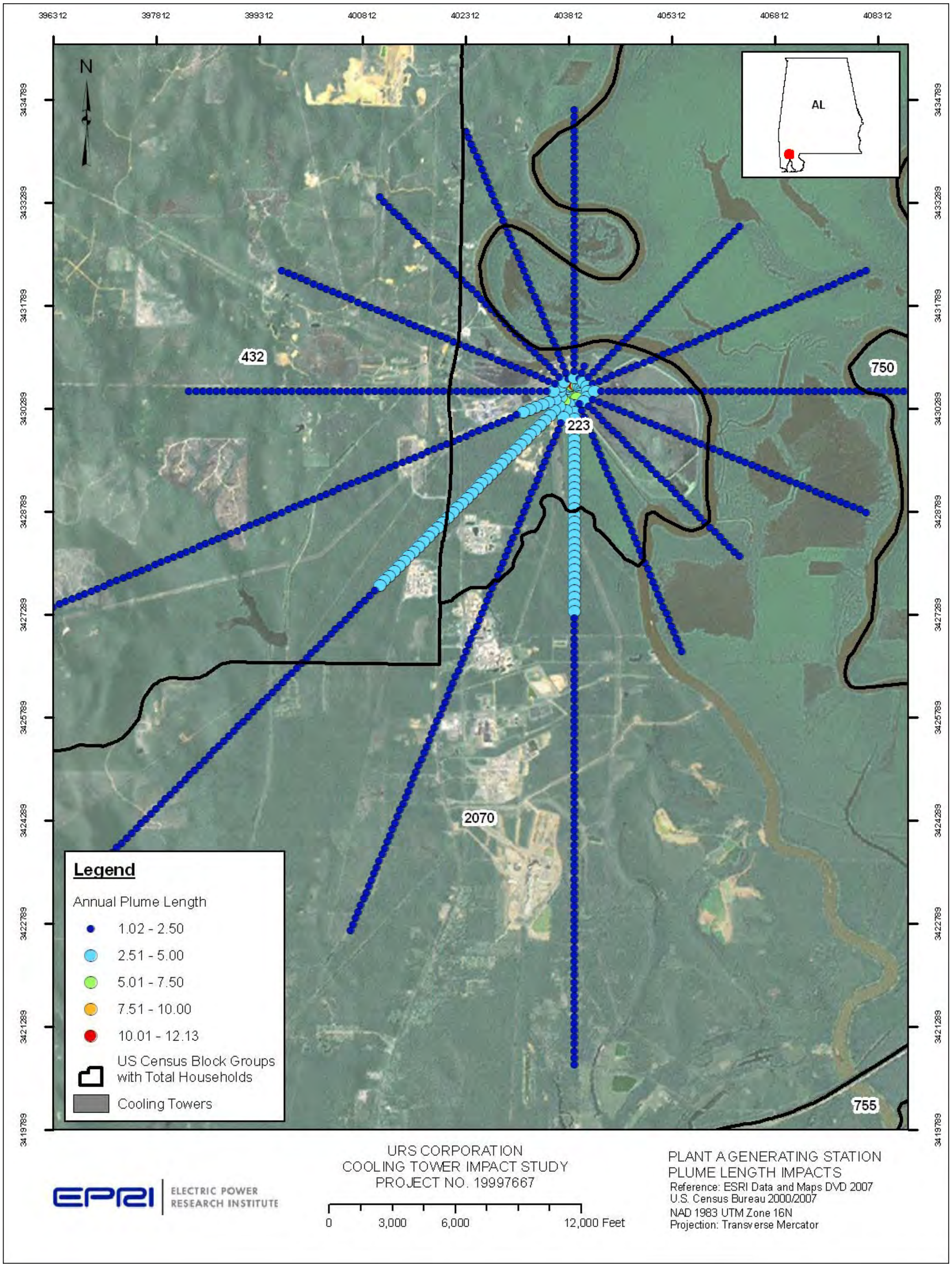


Figure C-29
BTPA plume length

C.2.3 BTPB

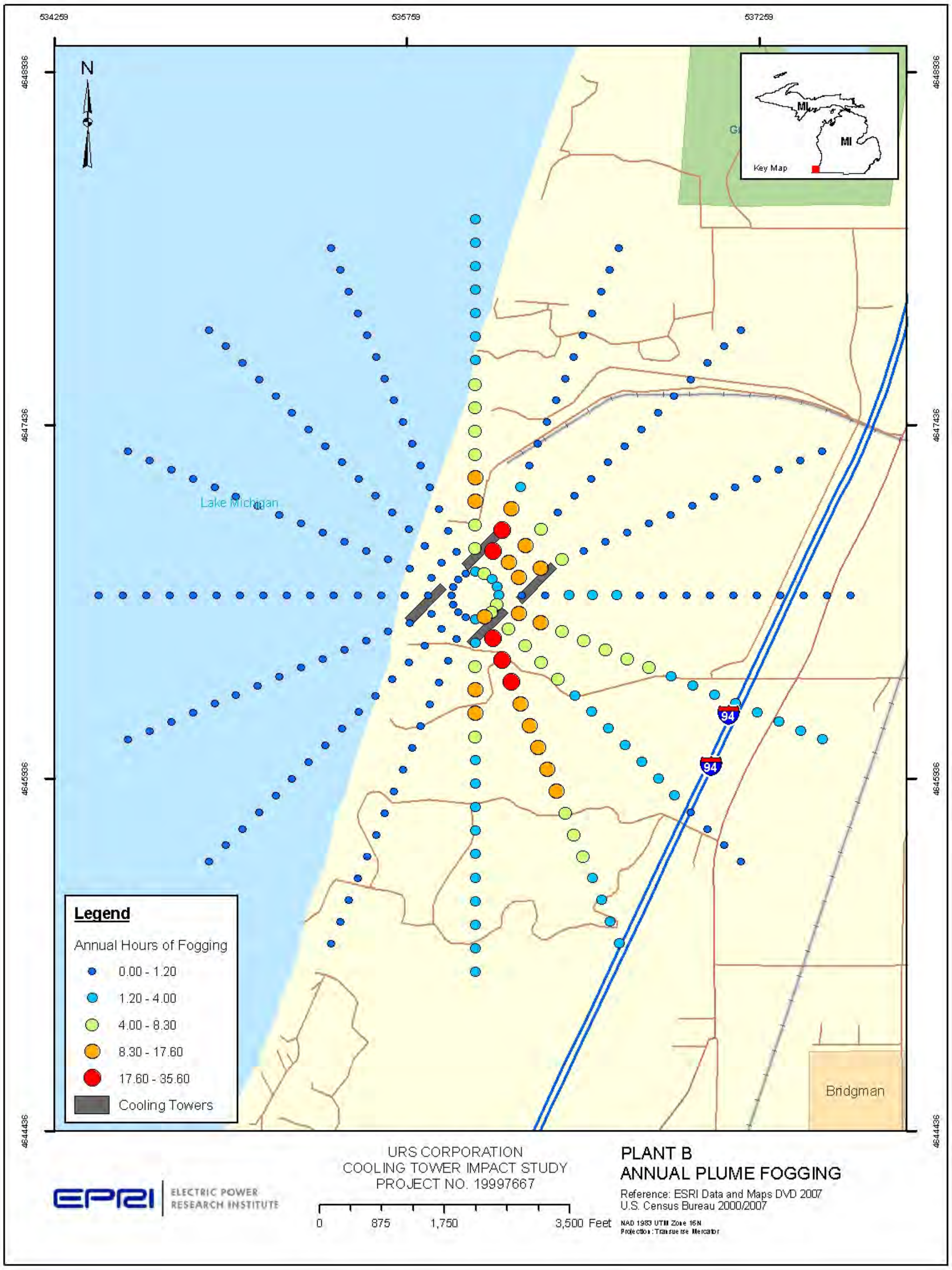


Figure C-30
BTPB plume fogging

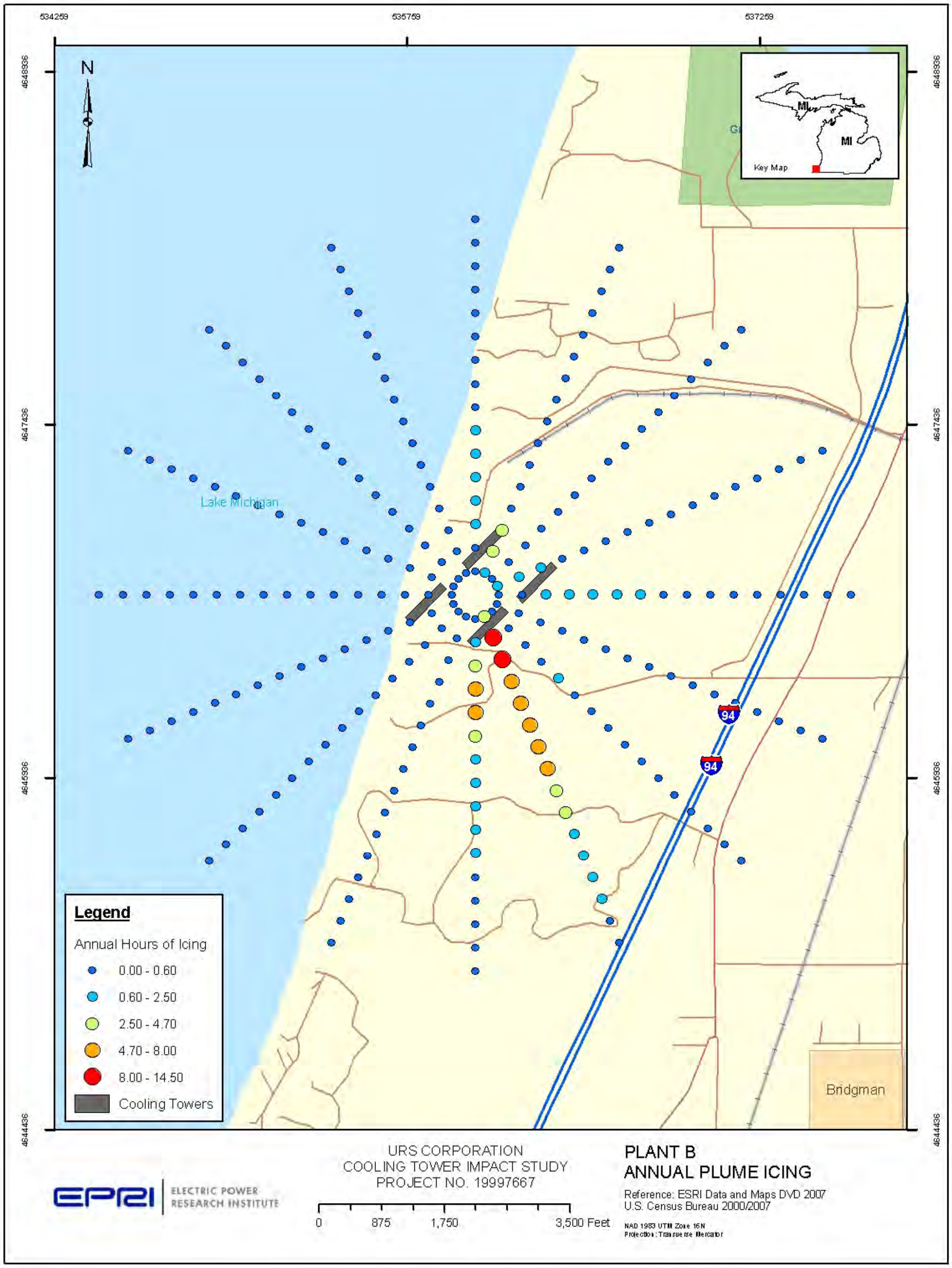


Figure C-31
BTPB plume icing

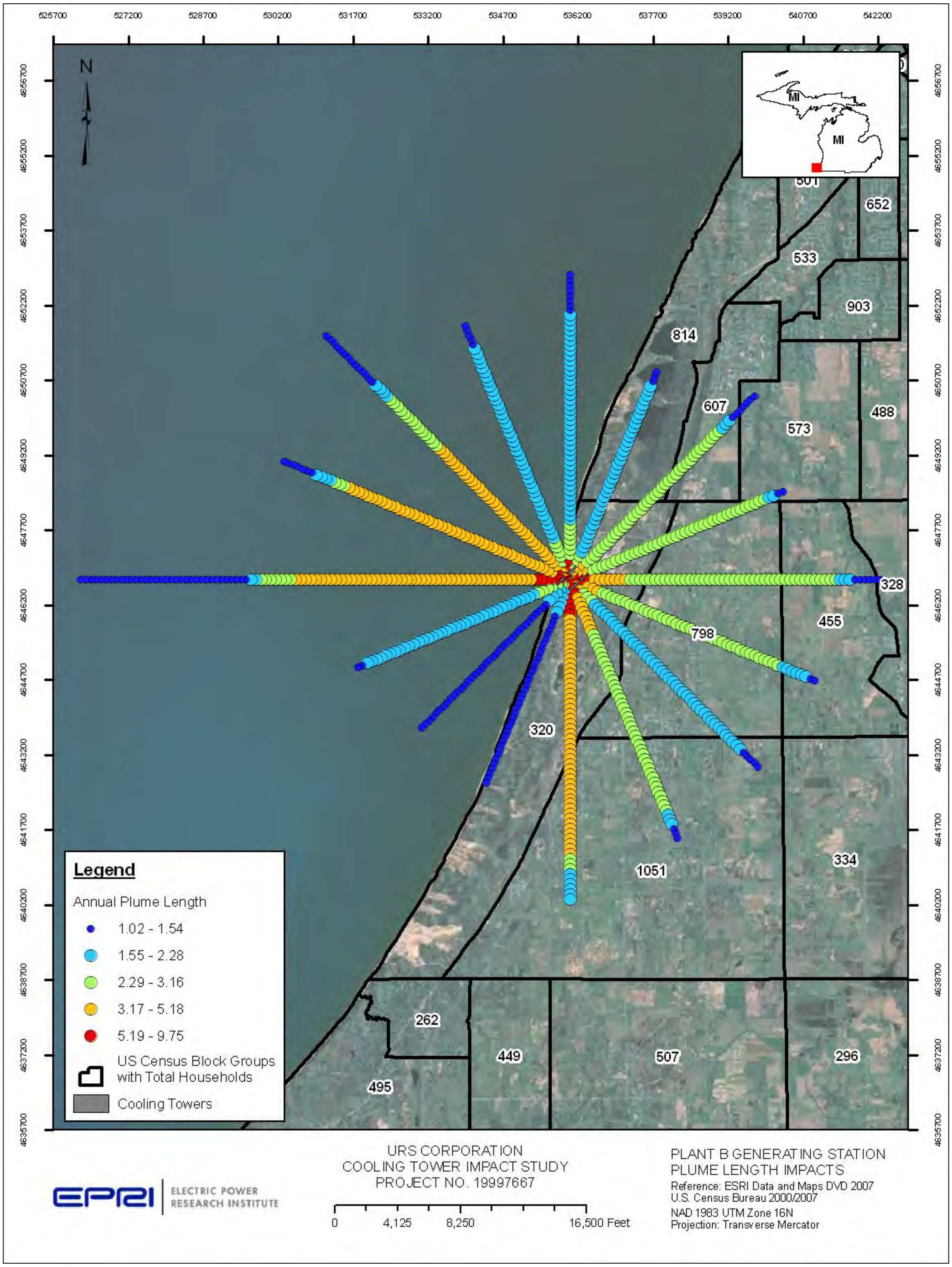


Figure C-32
BTPB plume length

C.2.4 BTPC

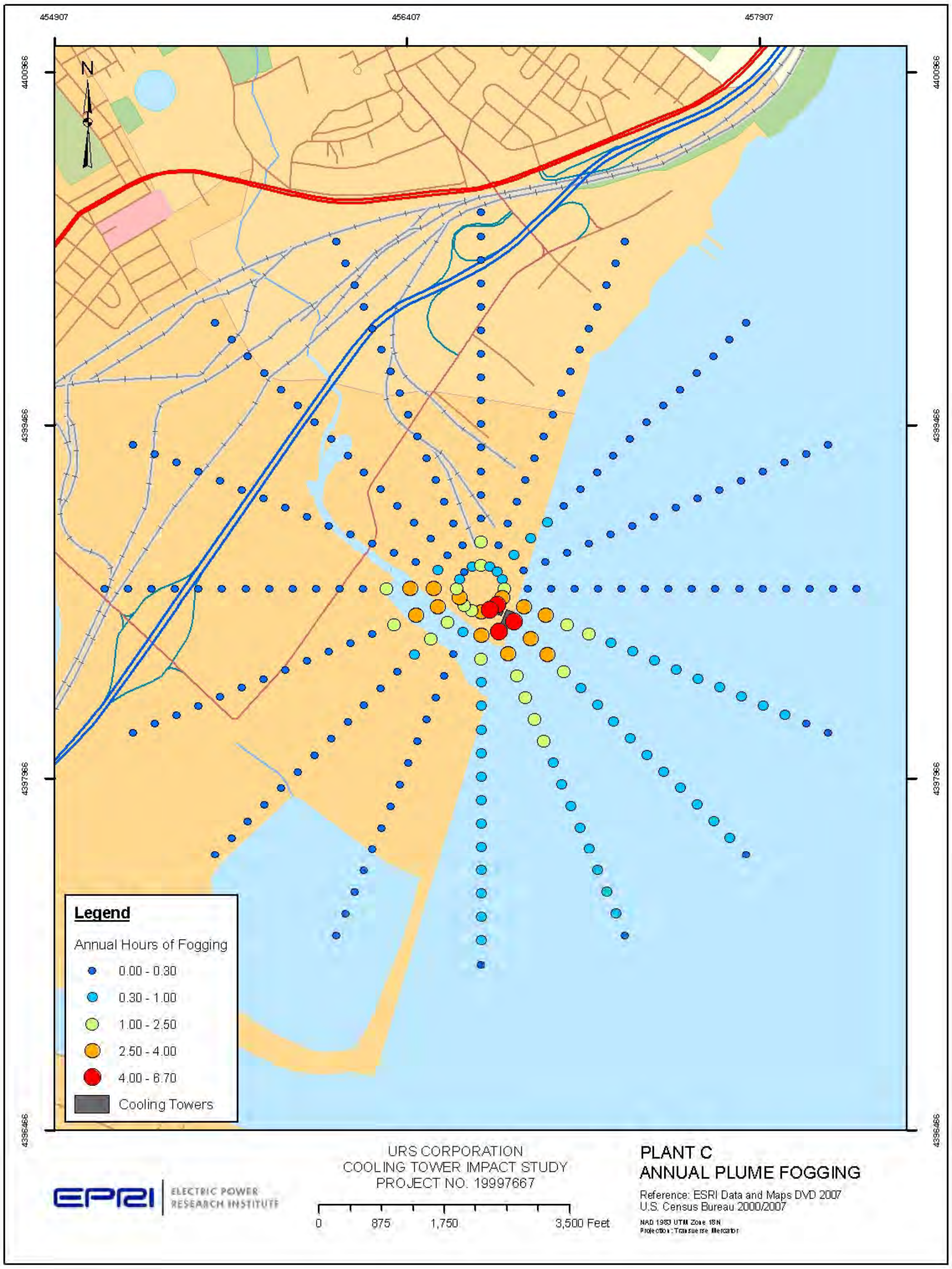


Figure C-33
BTPC plume fogging

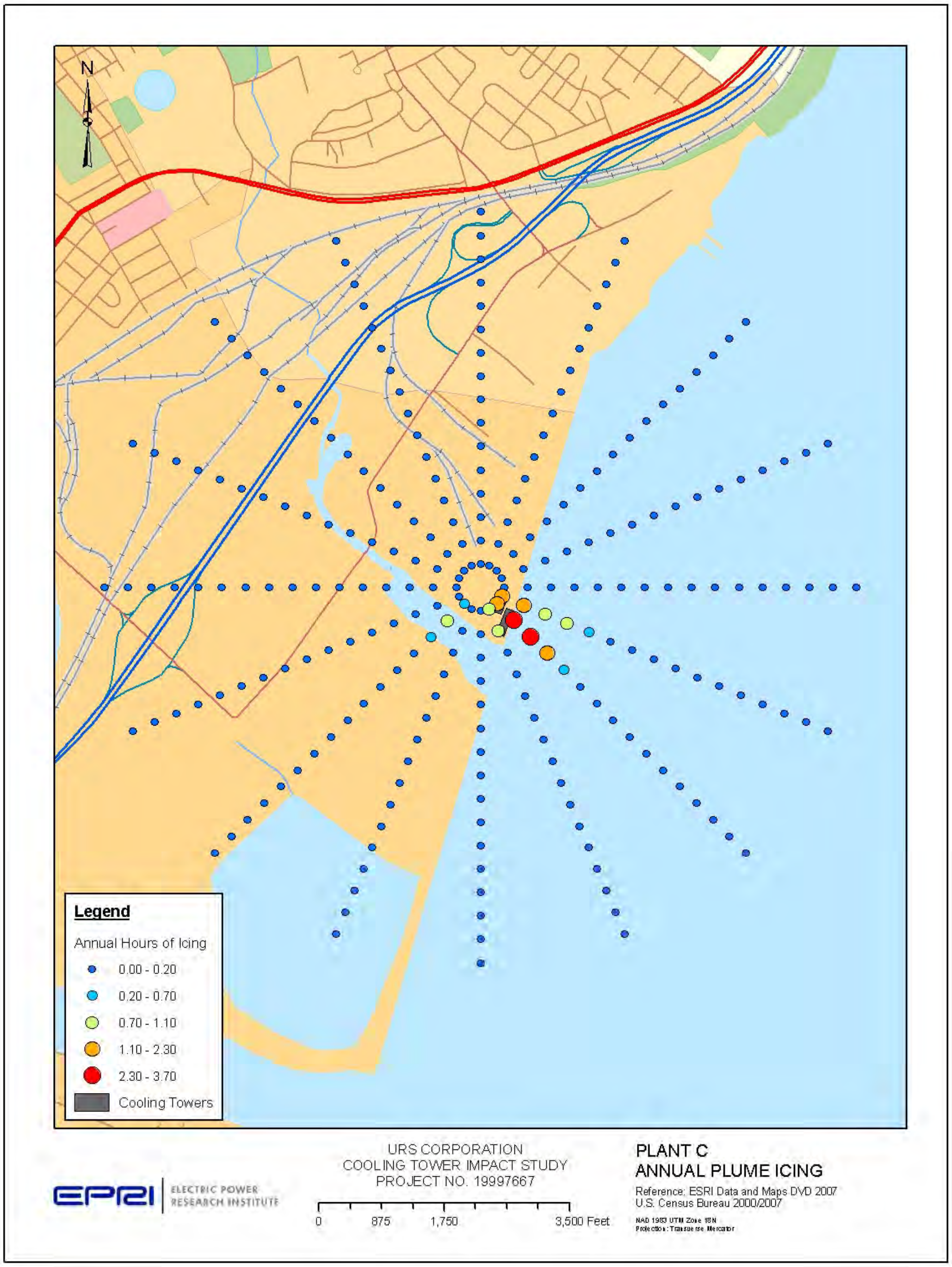


Figure C-34
BTPC plume icing

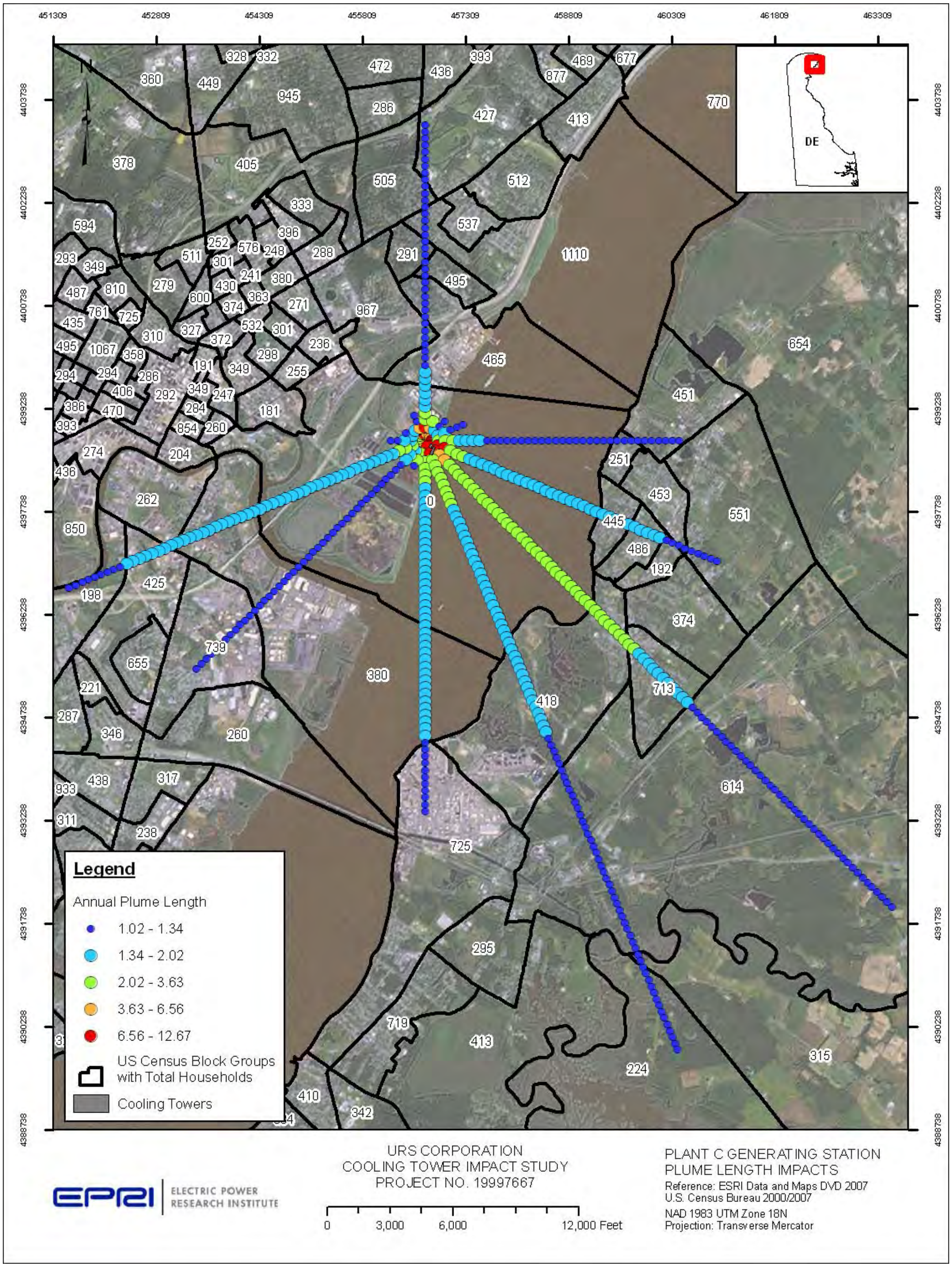


Figure C-35
BTPC plume length

C.2.5 BTPD

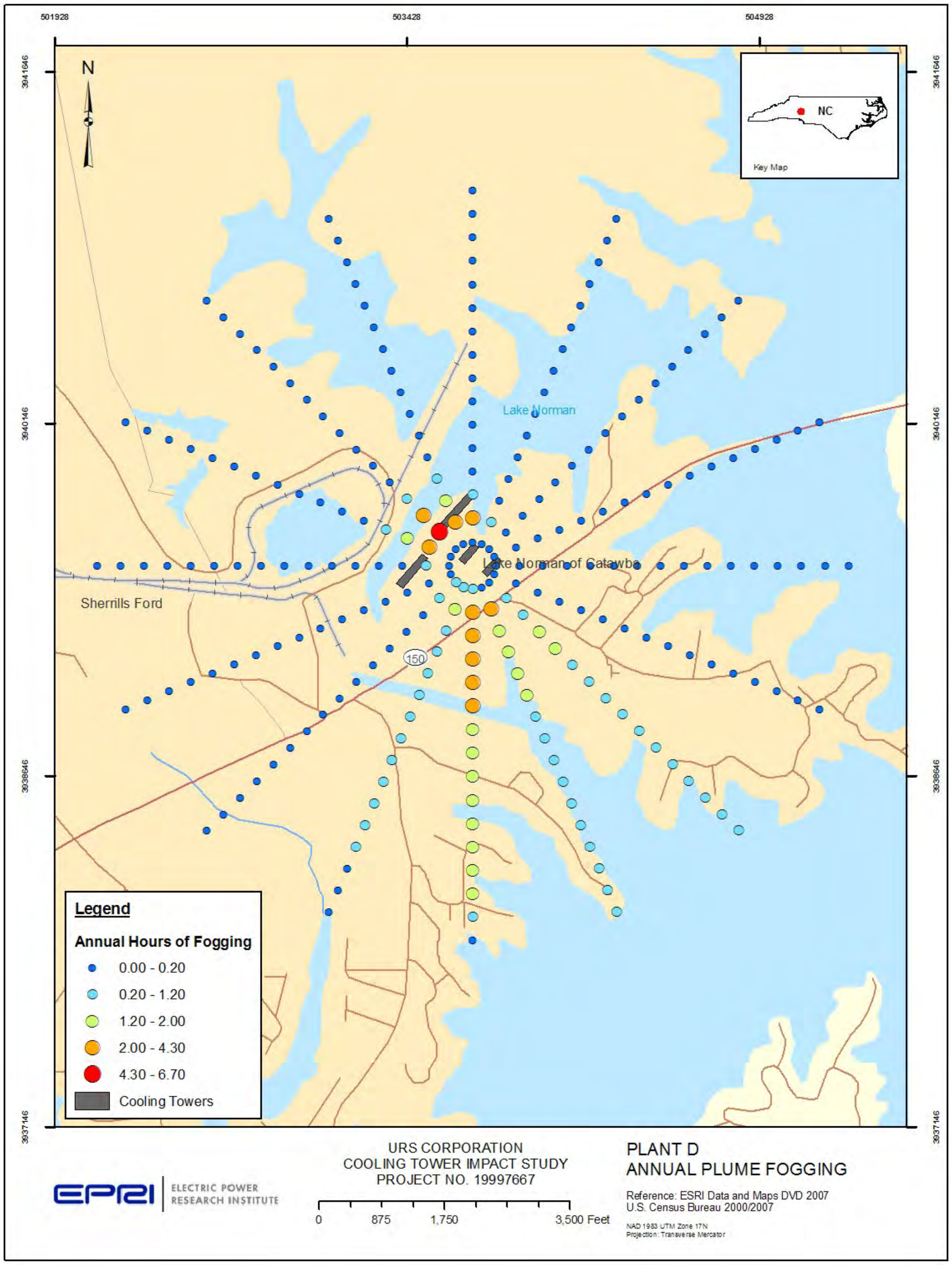


Figure C-36
BTPD plume fogging

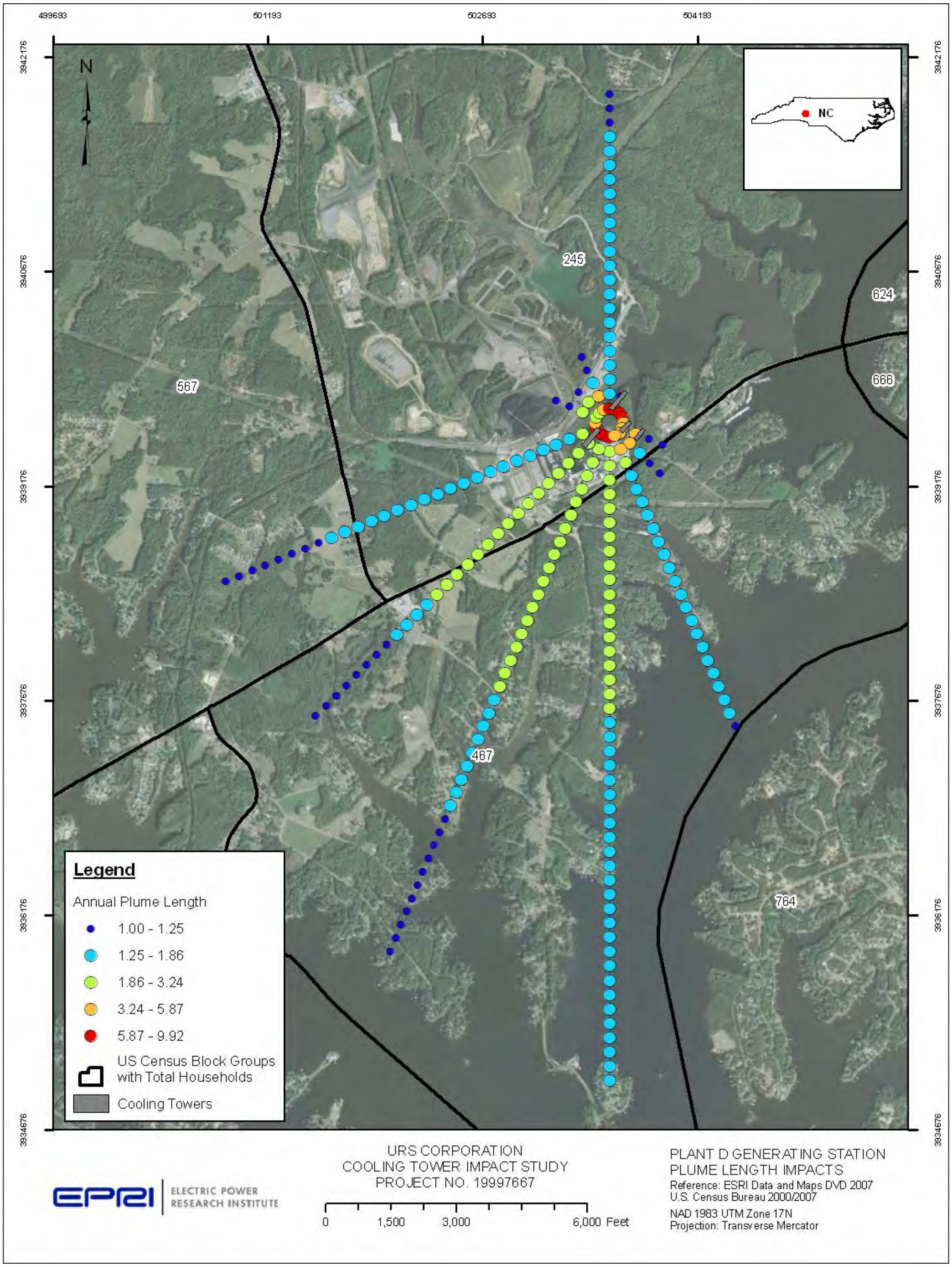


Figure C-37
BTPD plume length

C.2.6 BTPE

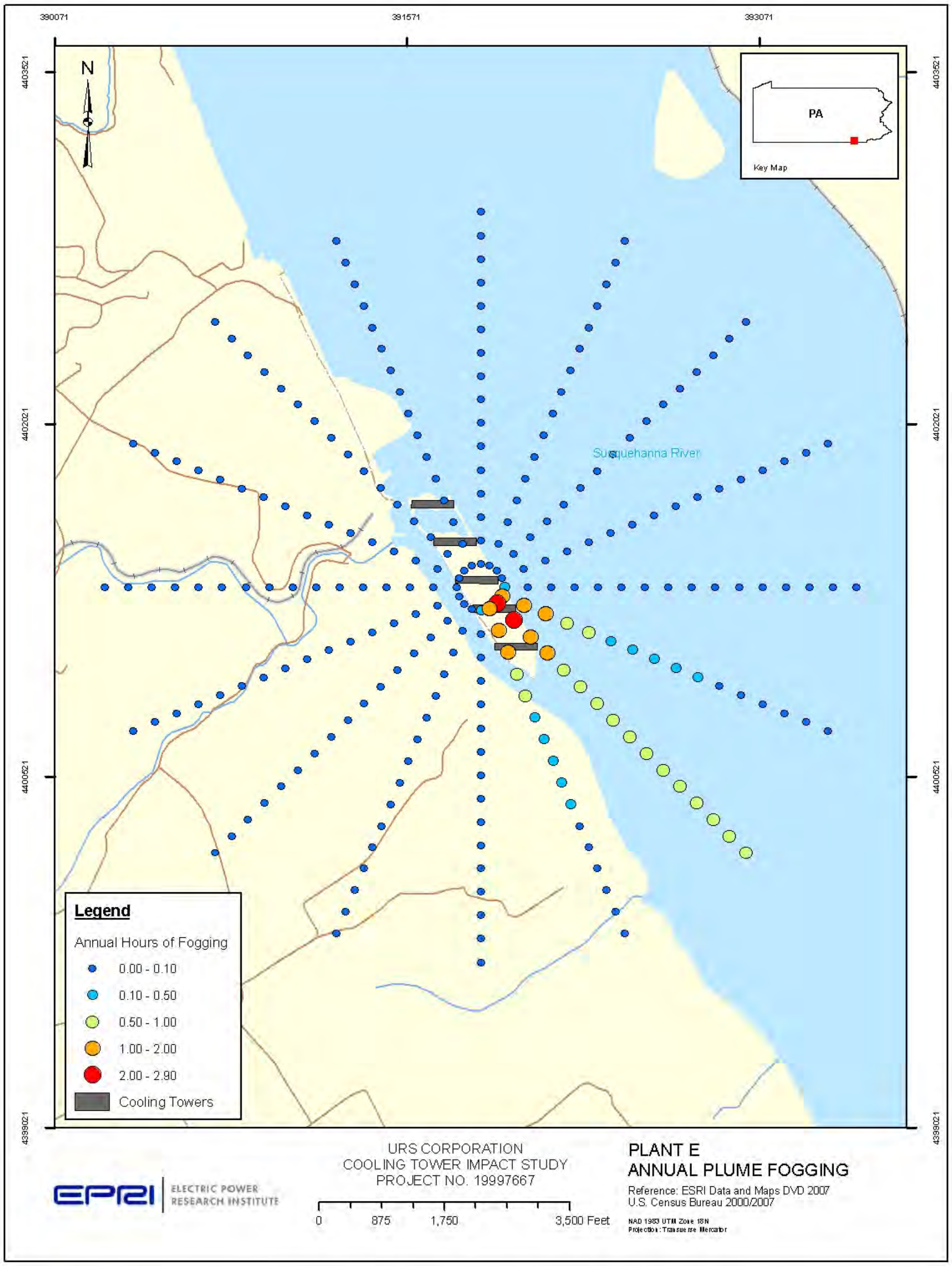


Figure C-38
BTPE plume fogging

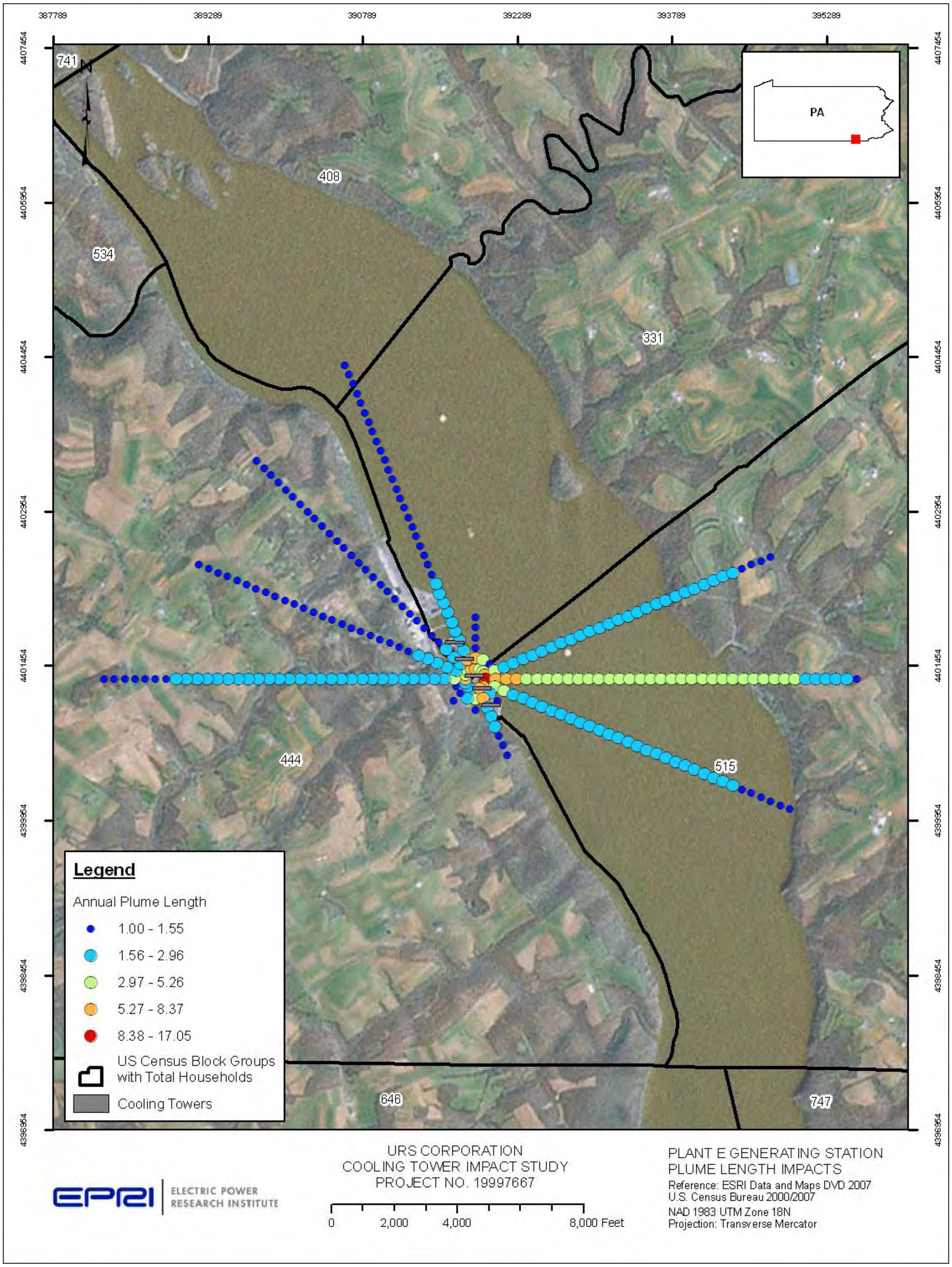


Figure C-39
BTPE plume length

C.2.7 BTCA2

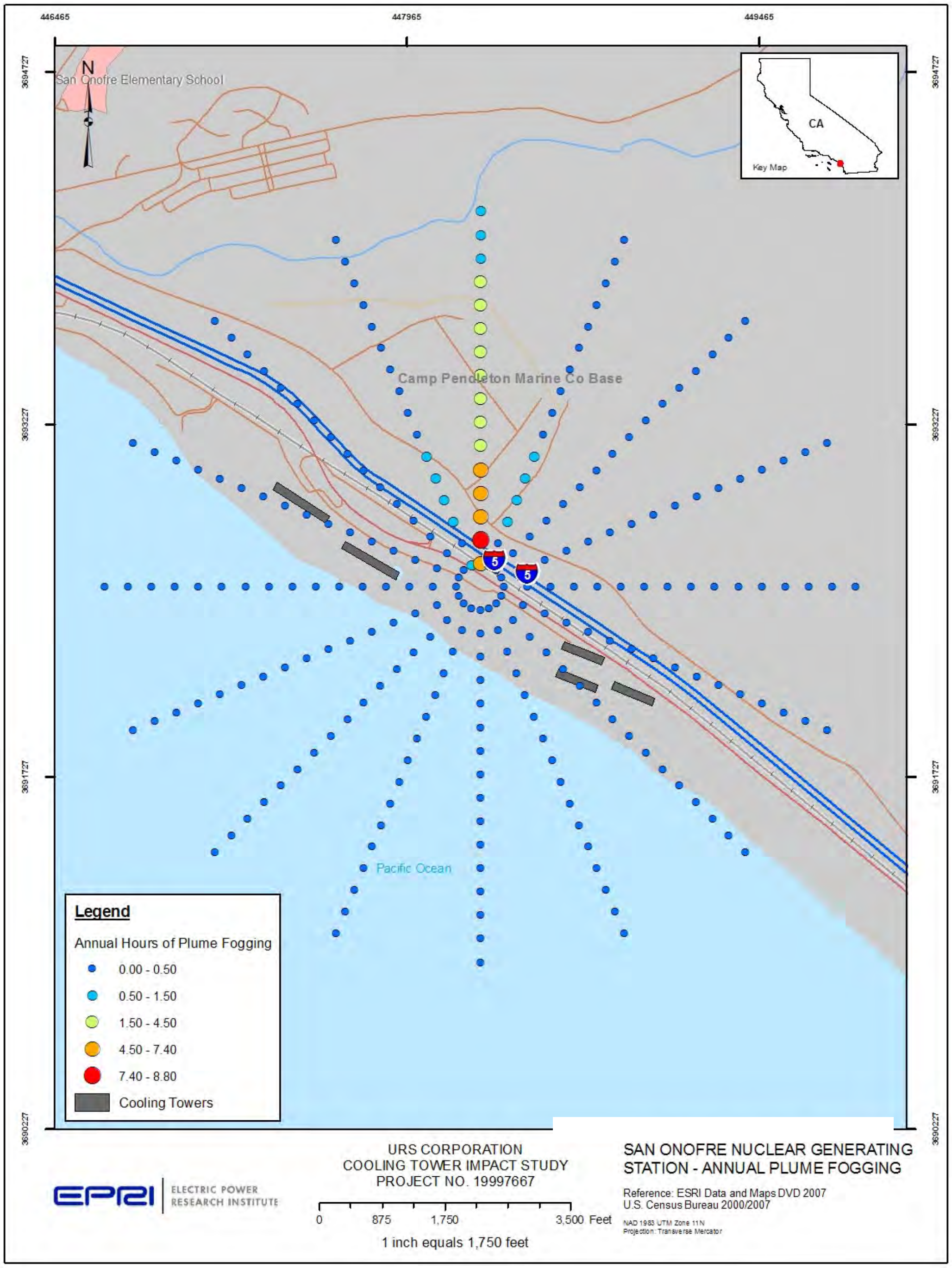


Figure C-40
BTCA2 plume fogging

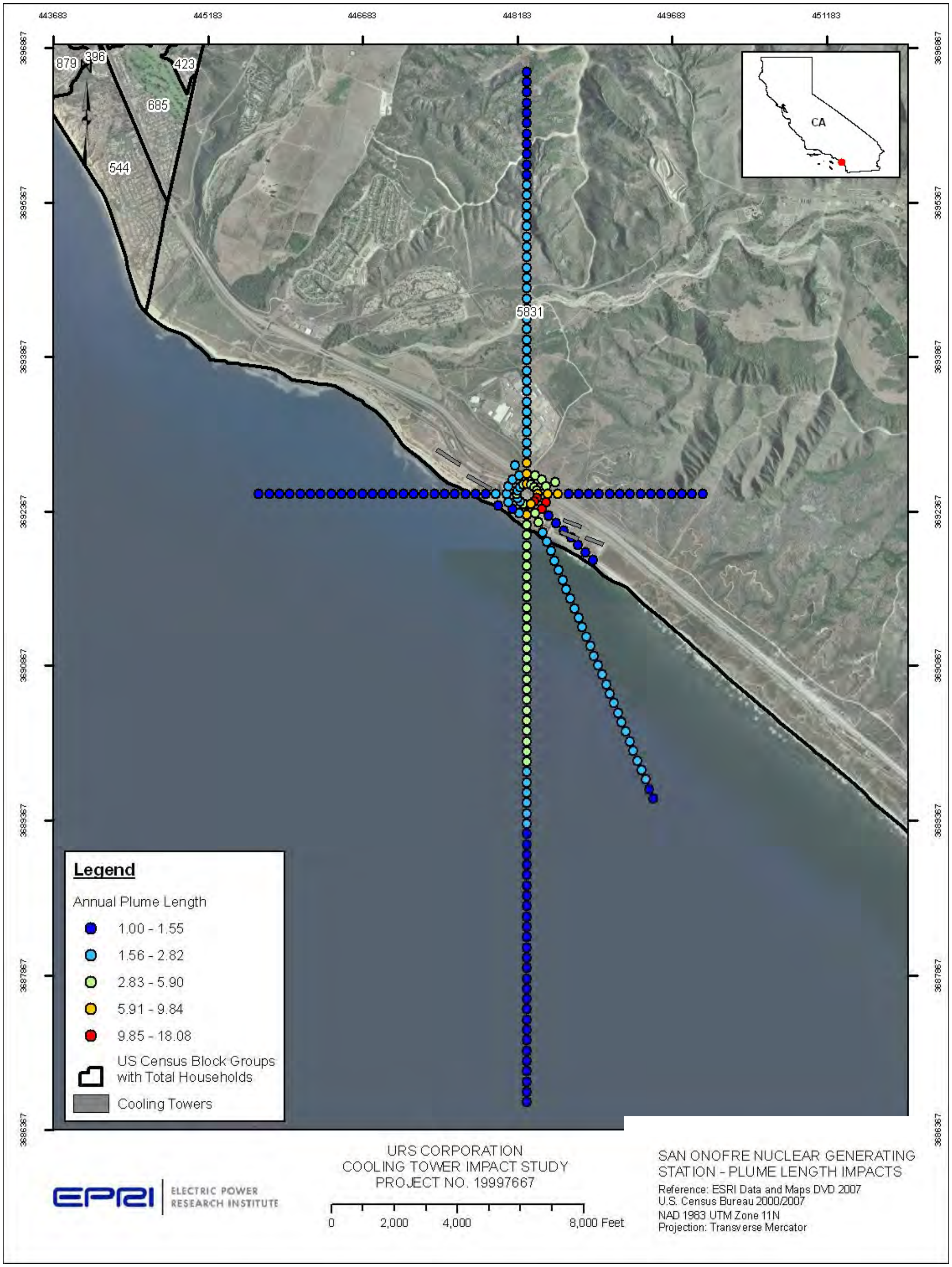


Figure C-41
BTCA2 plume length

C.2.8 RFF

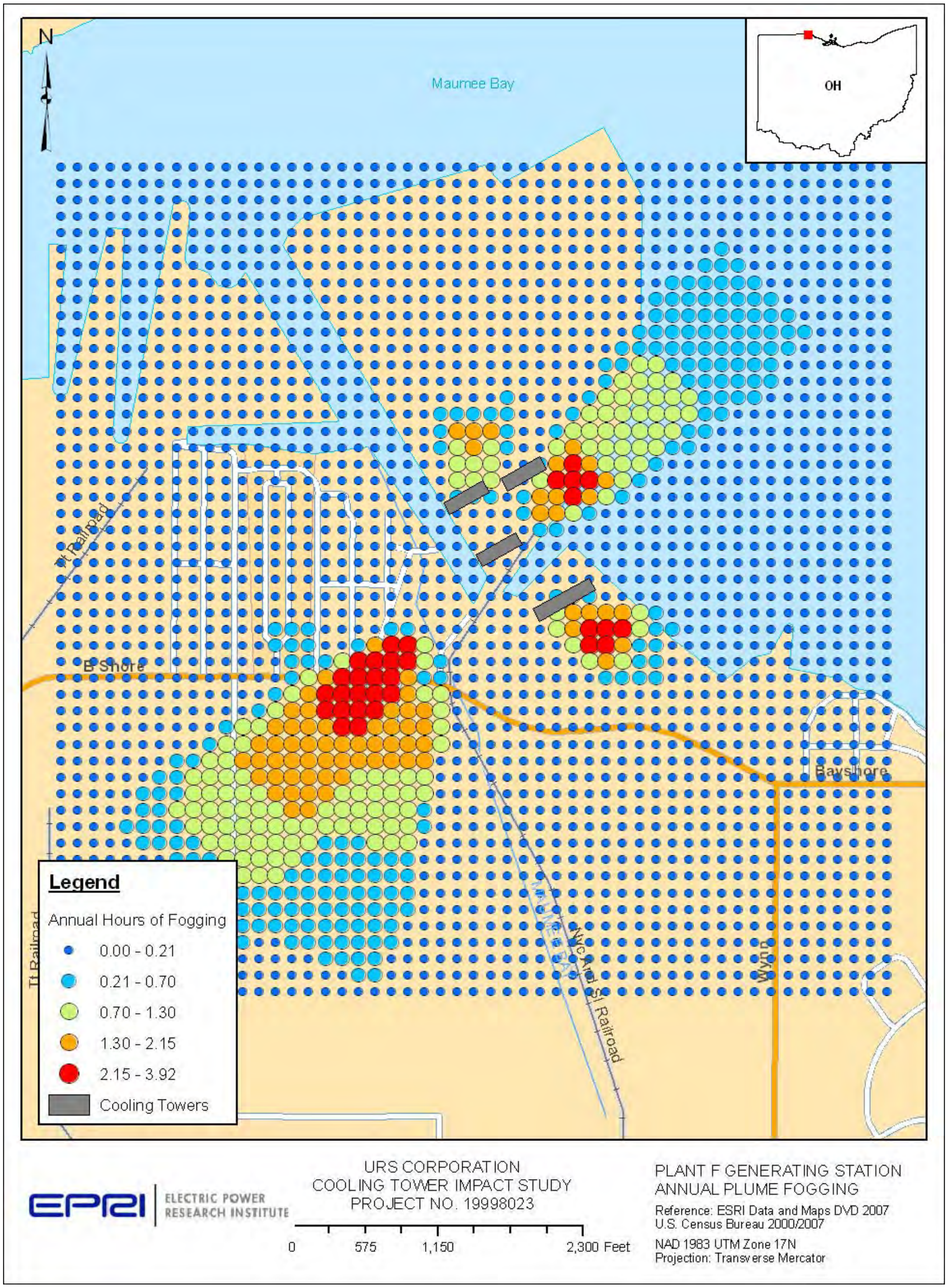


Figure C-42
RFF plume fogging

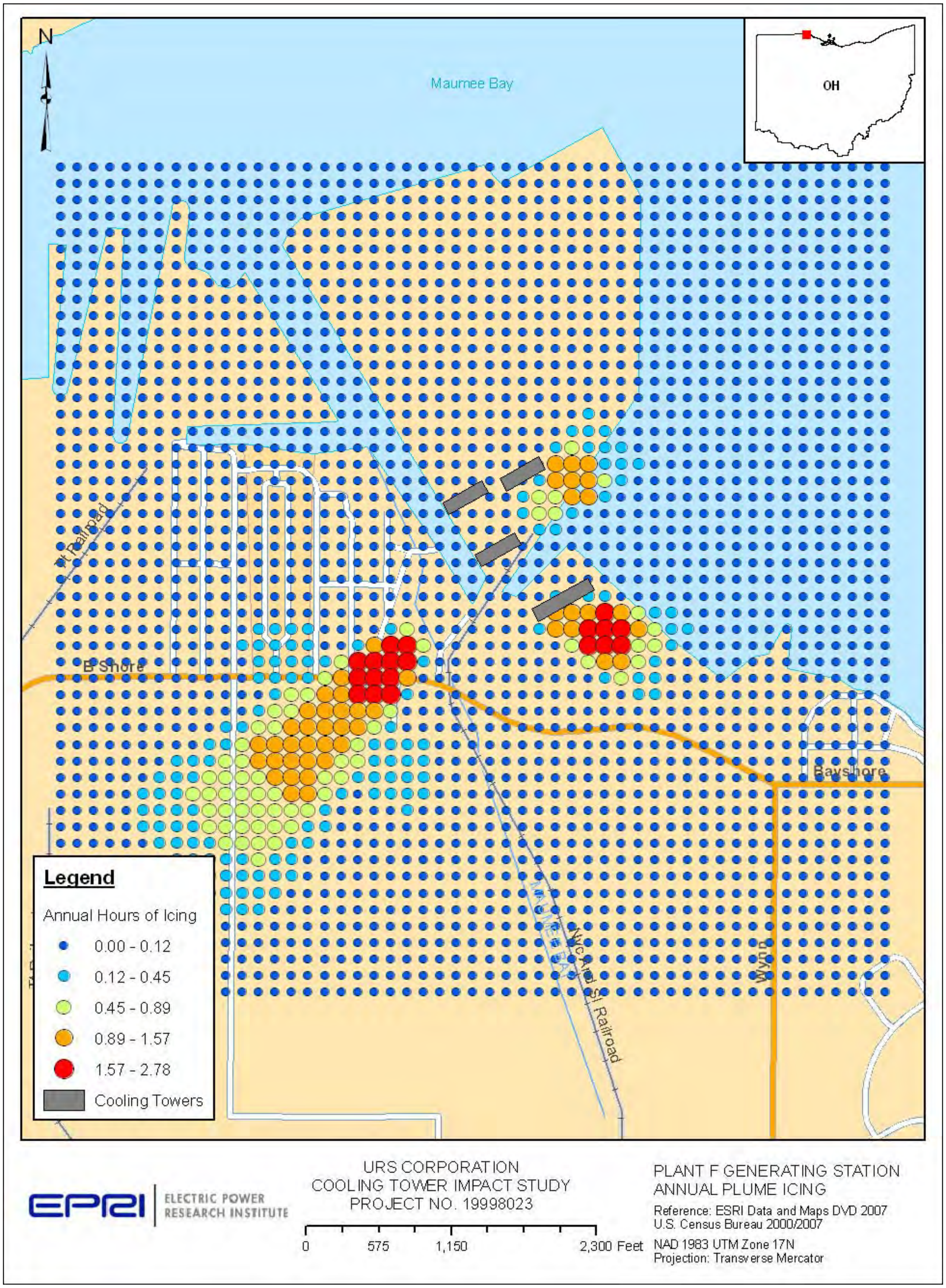


Figure C-43
RFF plume icing

C.2.9 RFG

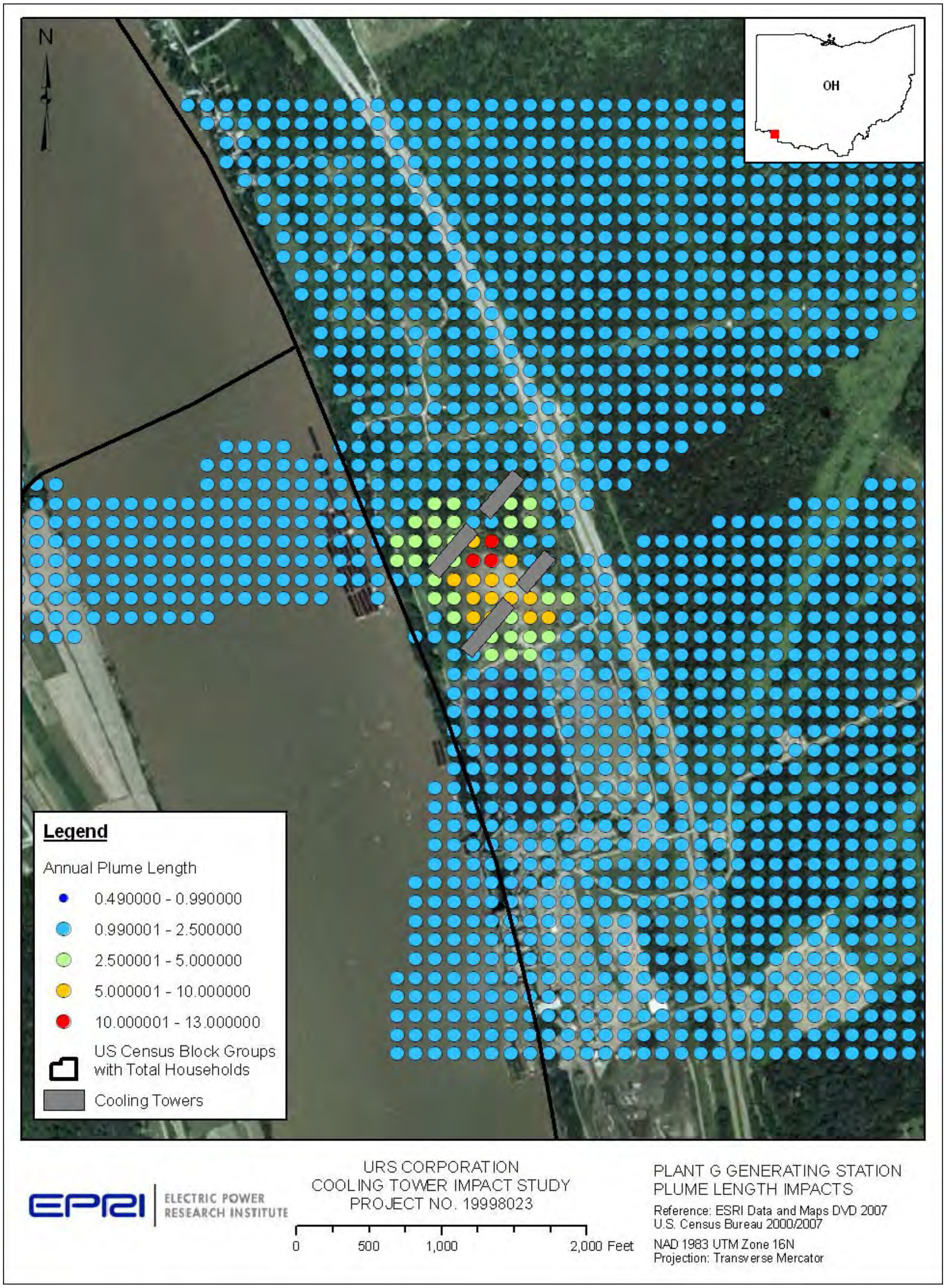


Figure C-44
RFG plume length

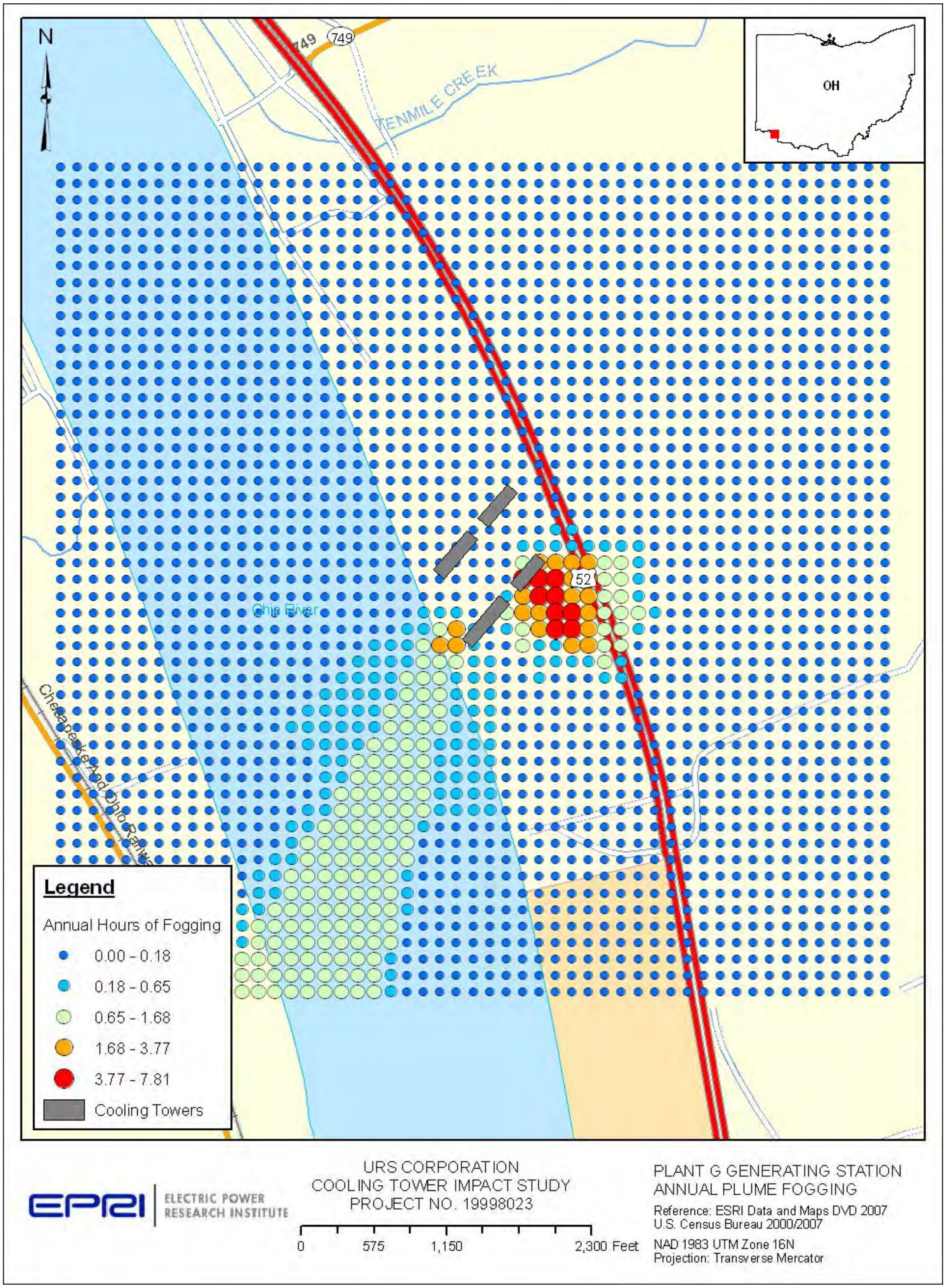


Figure C-45
RFG plume fogging

C.2.10 RFH

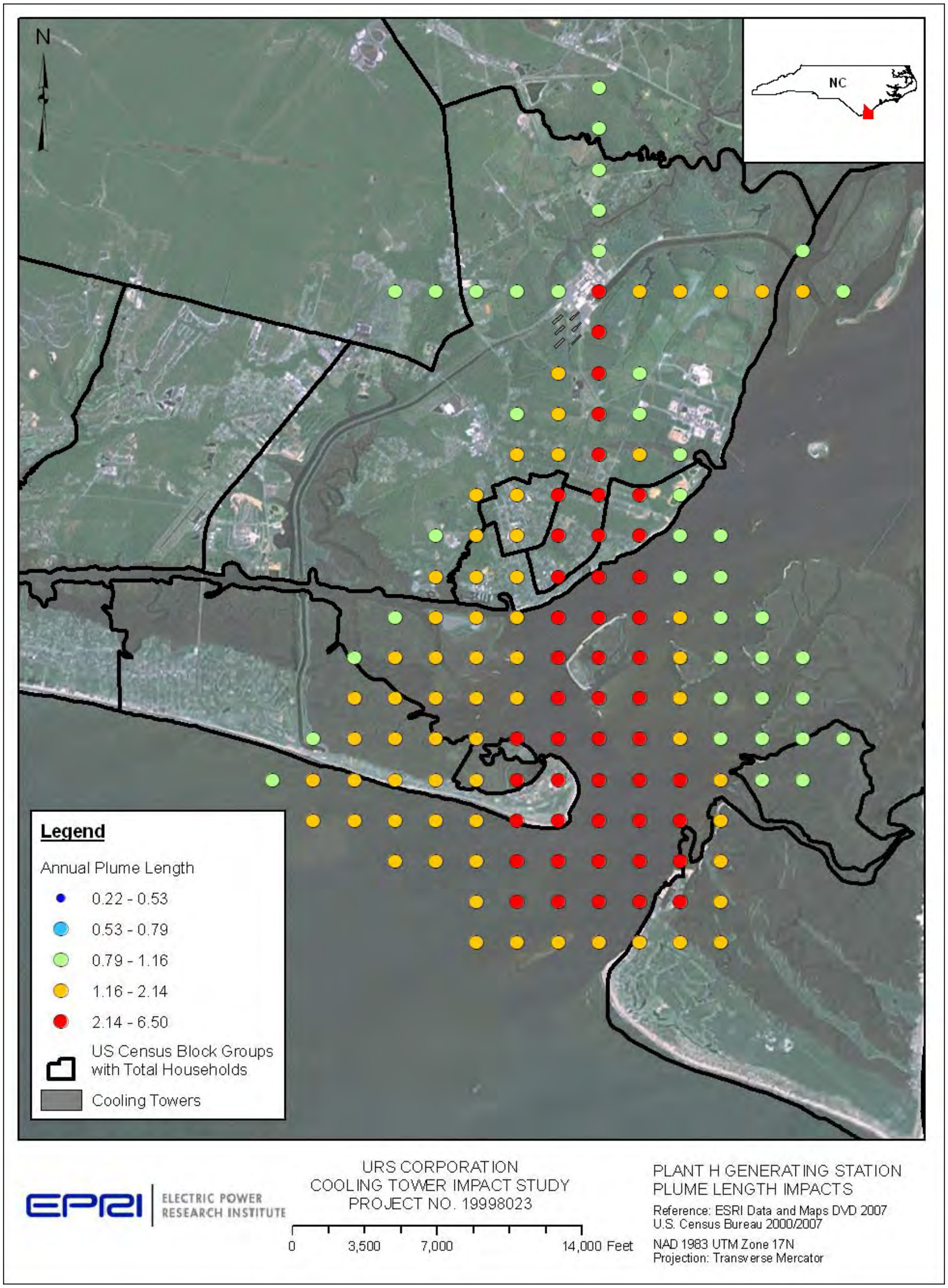


Figure C-46
RFH plume length

C.2.11 RFI

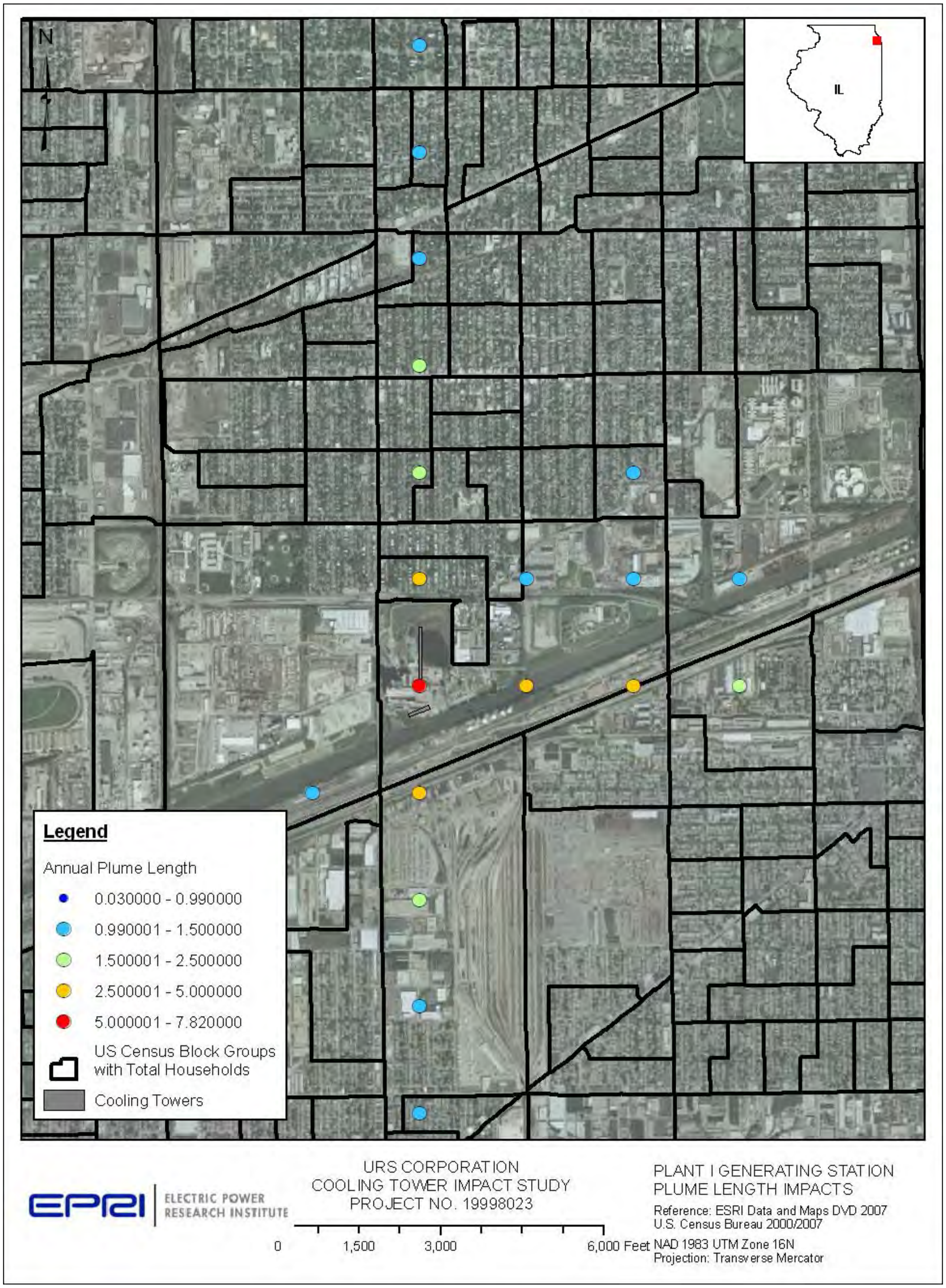


Figure C-47
RFI plume length

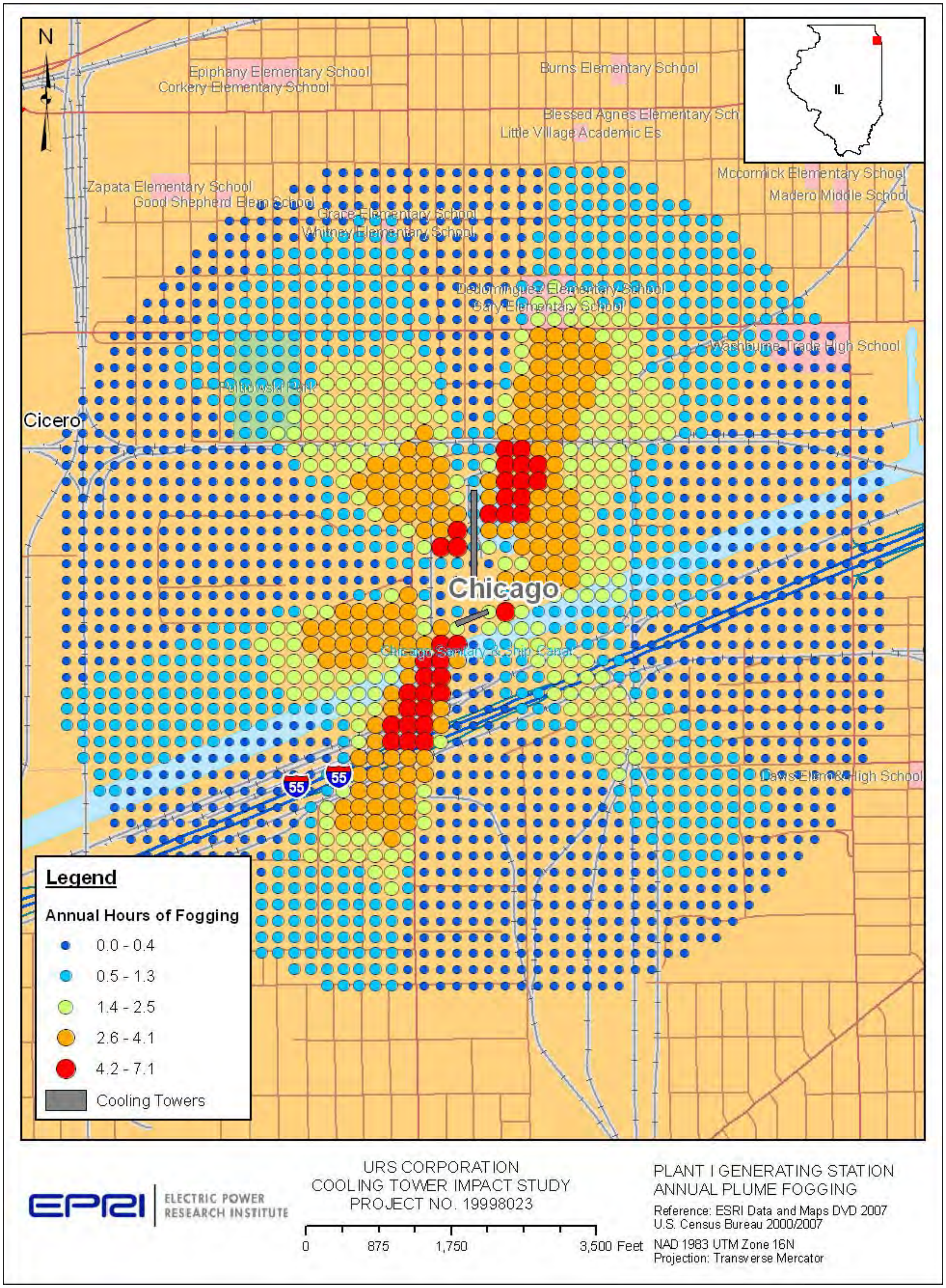


Figure C-48
RFI plume fogging

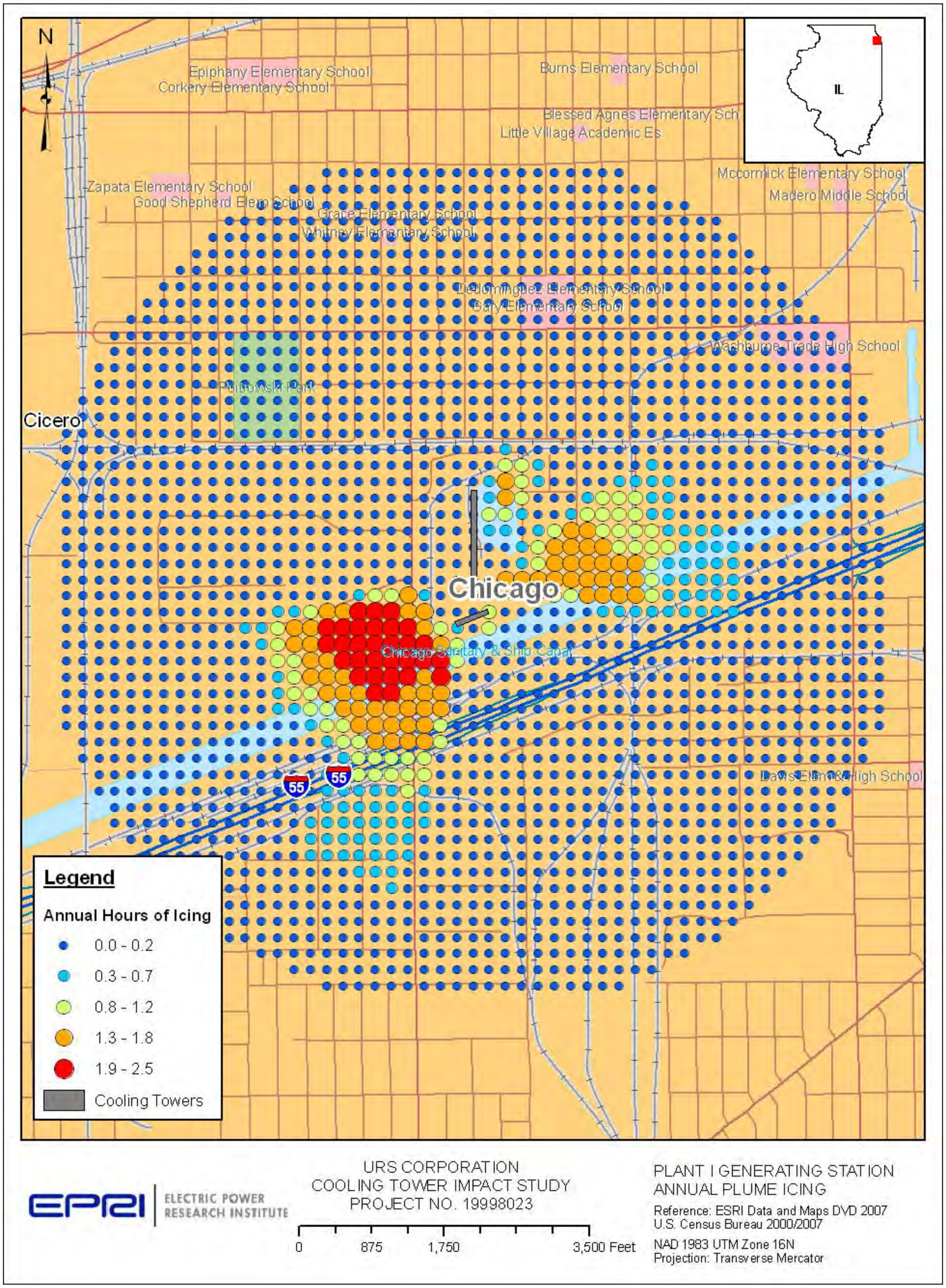


Figure C-49
RFI plume icing

C.2.12 RFJ

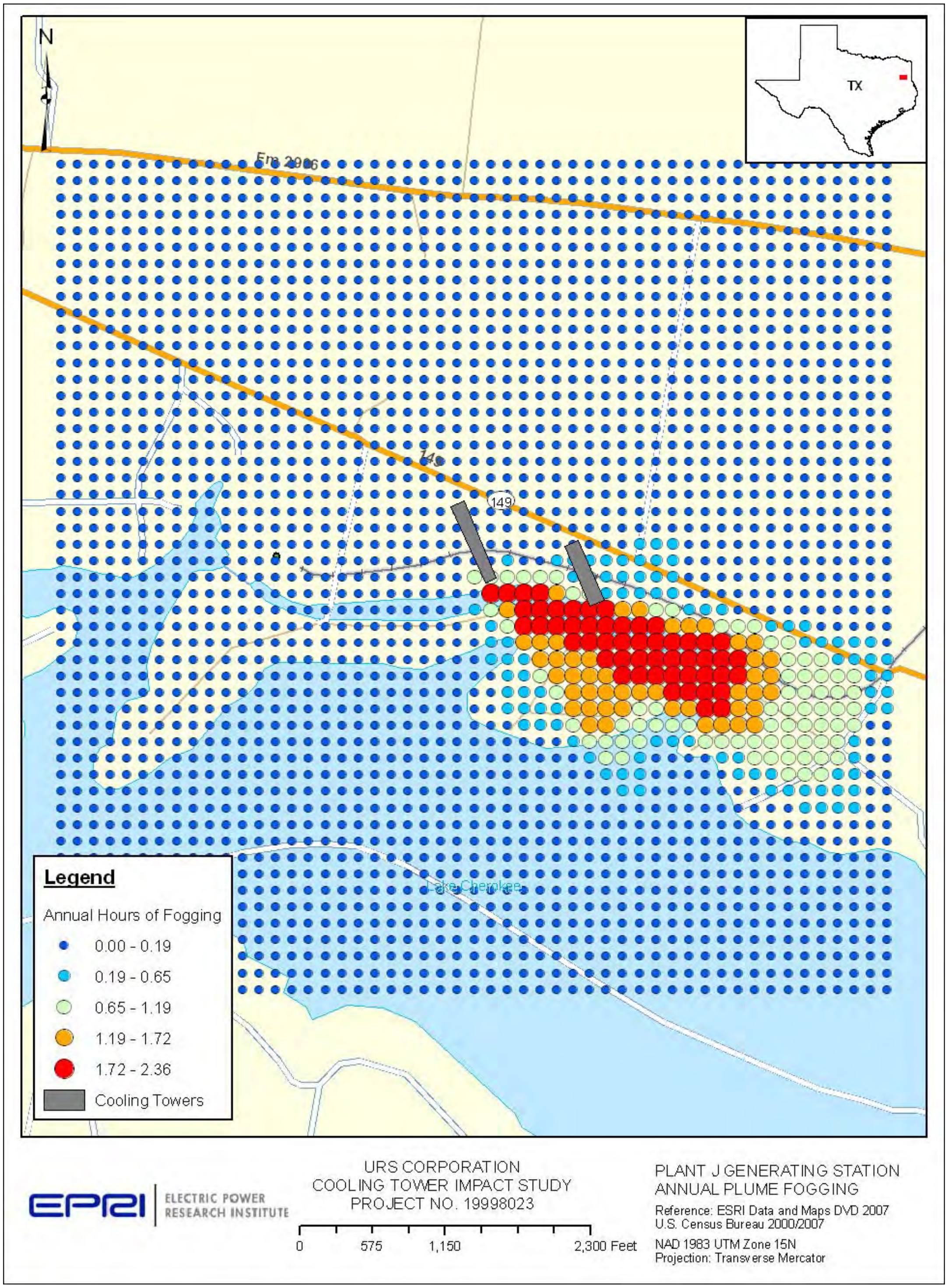


Figure C-50
RFJ plume fogging

C.2.13 RFK

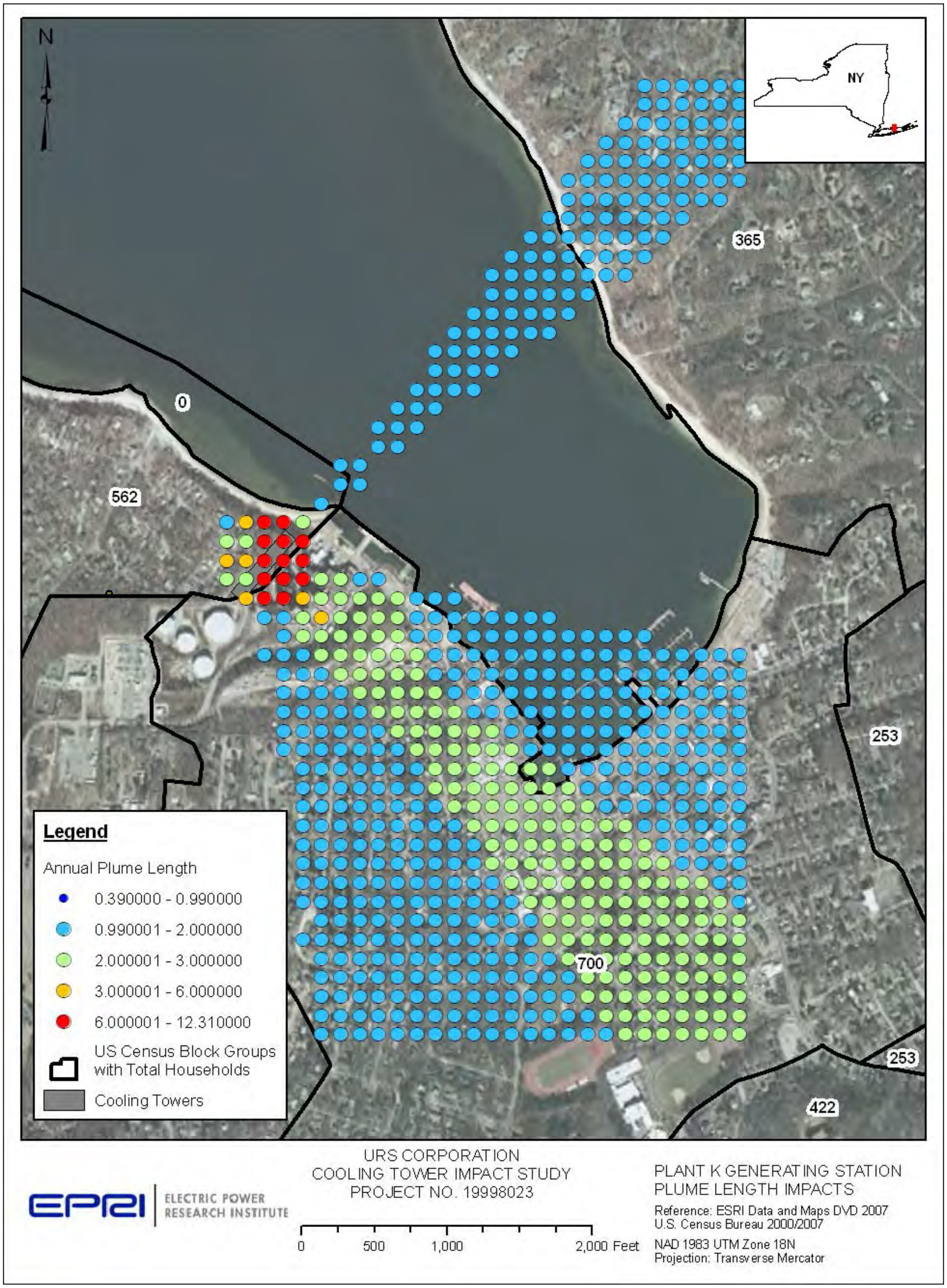


Figure C-51
RFK plume length

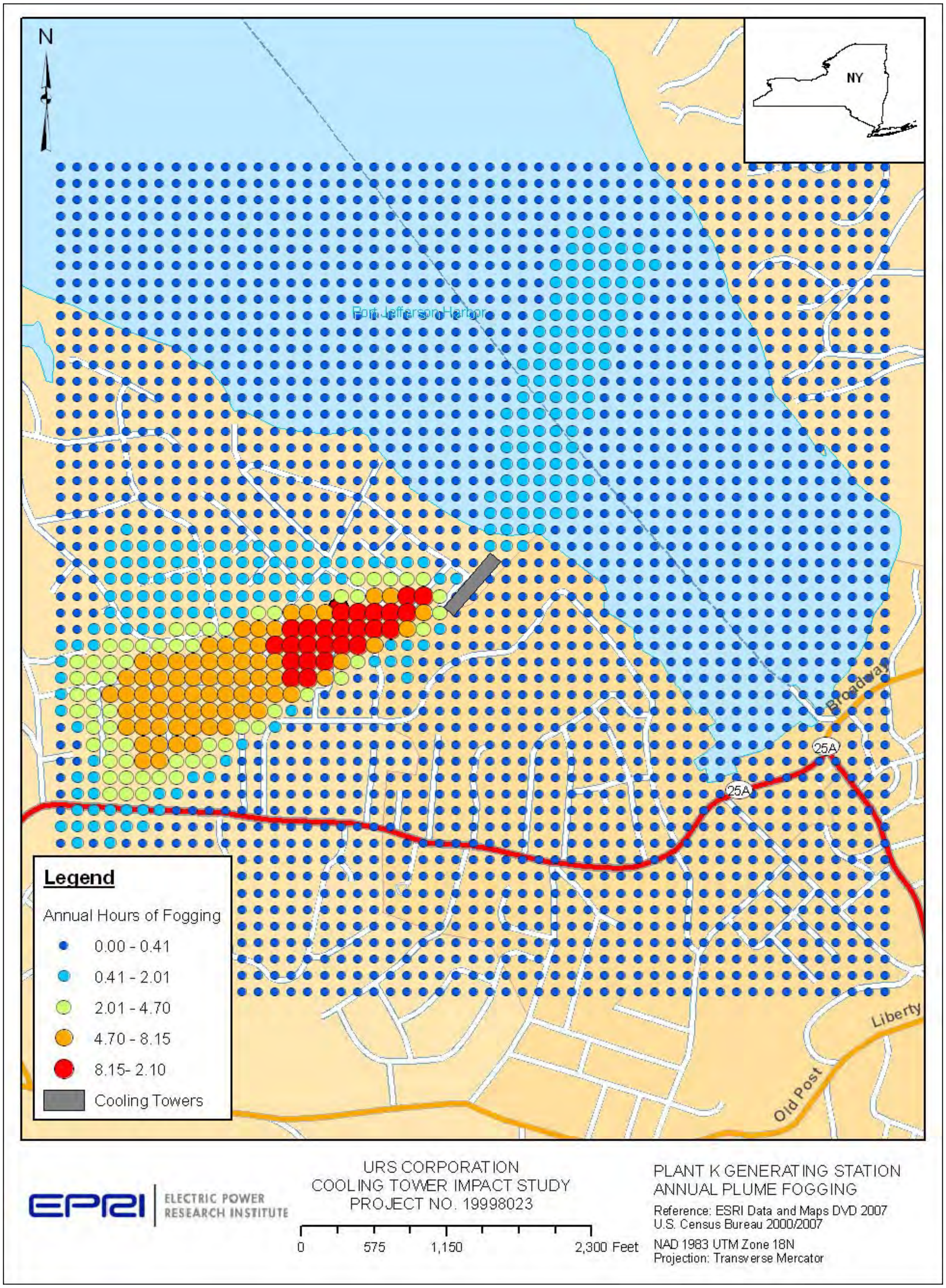


Figure C-52
RFK plume fogging

C.2.14 RFL

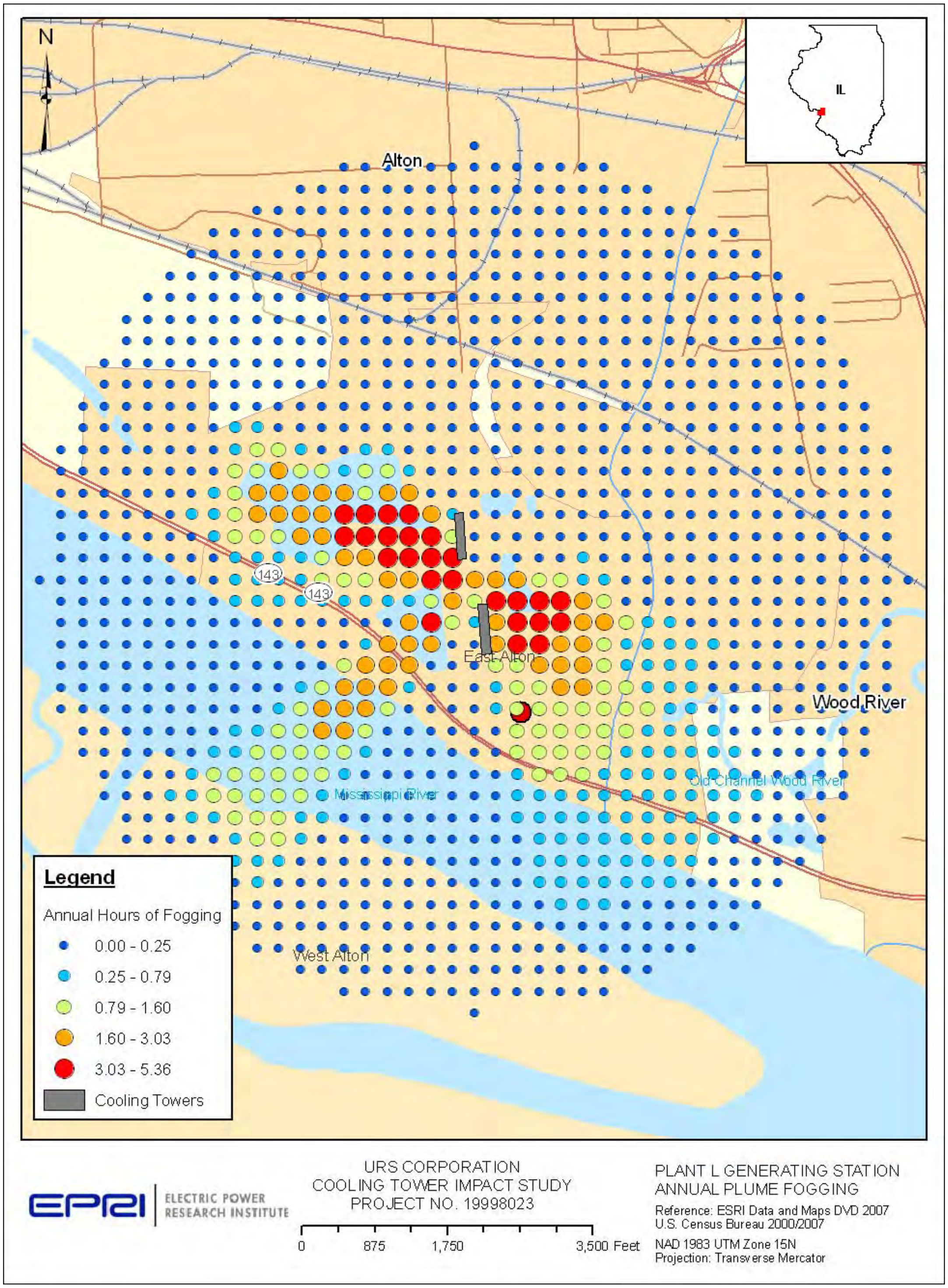


Figure C-53
RFL plume fogging

C.3 Cadna/AR Acoustic Model

Noise associated with the operation of mechanical-draft evaporative cooling towers was estimated using the methods provided in Appendix B. Future noise contours including mechanical-draft evaporative cooling towers are presented in the sections below for each BTP and RF where impacts have been shown to occur. These contours depict the total noise environment including the background noise level, existing plant operations, and predicted mechanical-draft evaporative cooling tower operation.

C.3.1 BTCA1

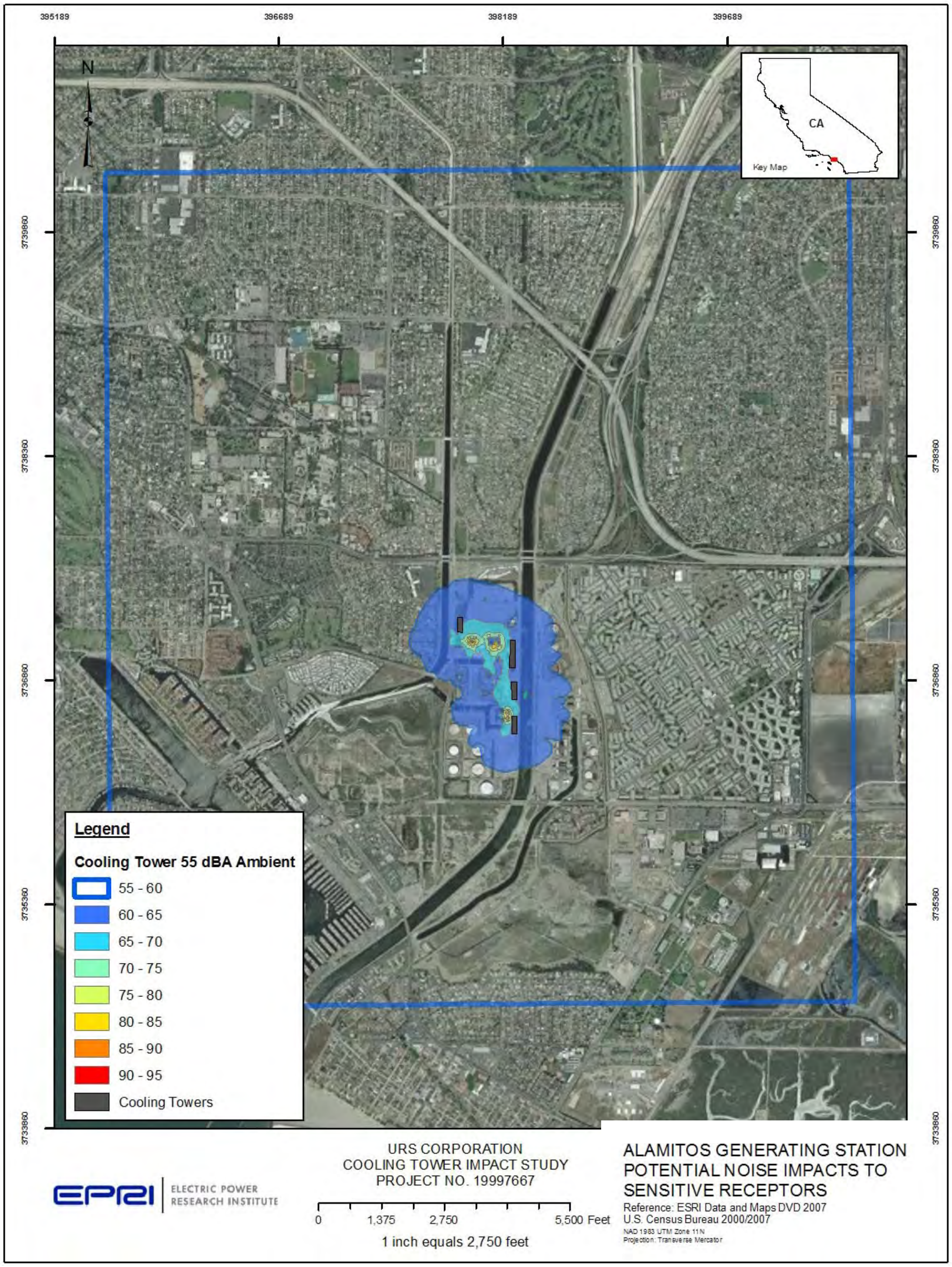


Figure C-54
BTCA1 potential noise impacts to sensitive receptors

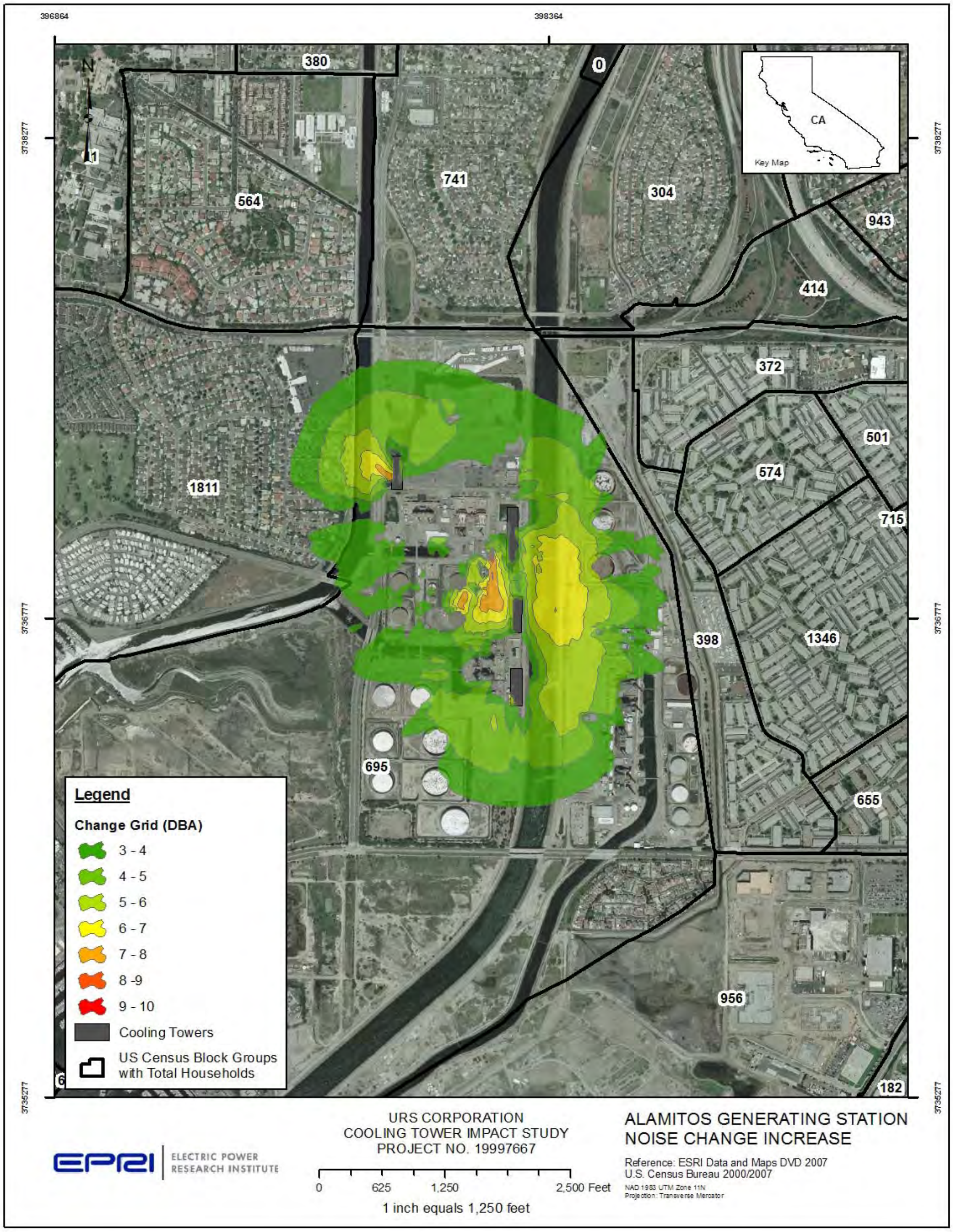


Figure C-55
BTCA1 modeled noise change increase

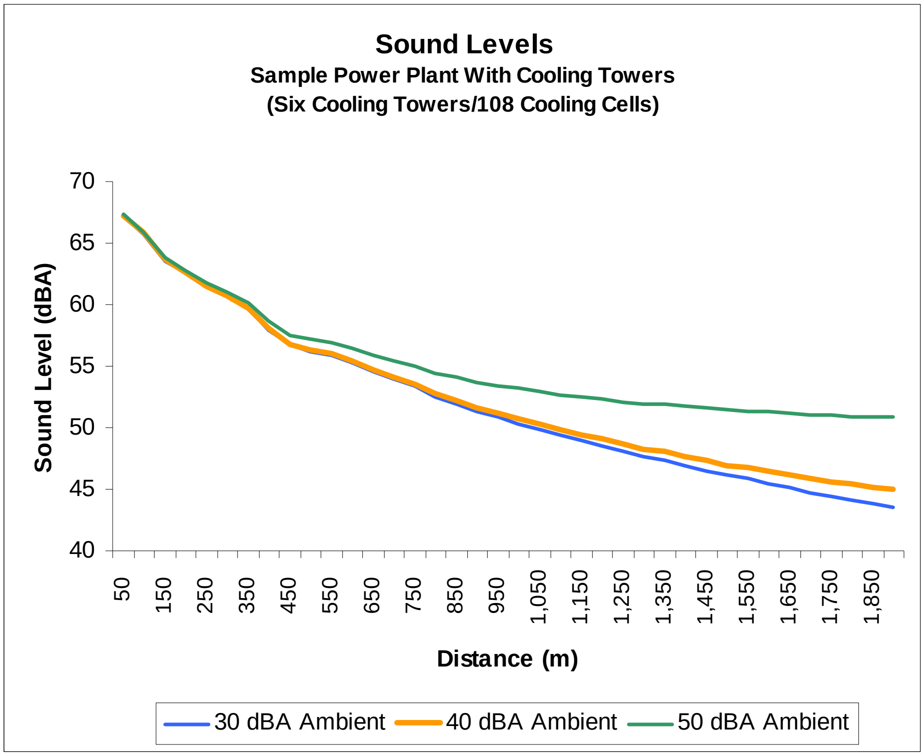


Figure C-56
BTCA1 modeled noise profile

C.3.2 BTPA

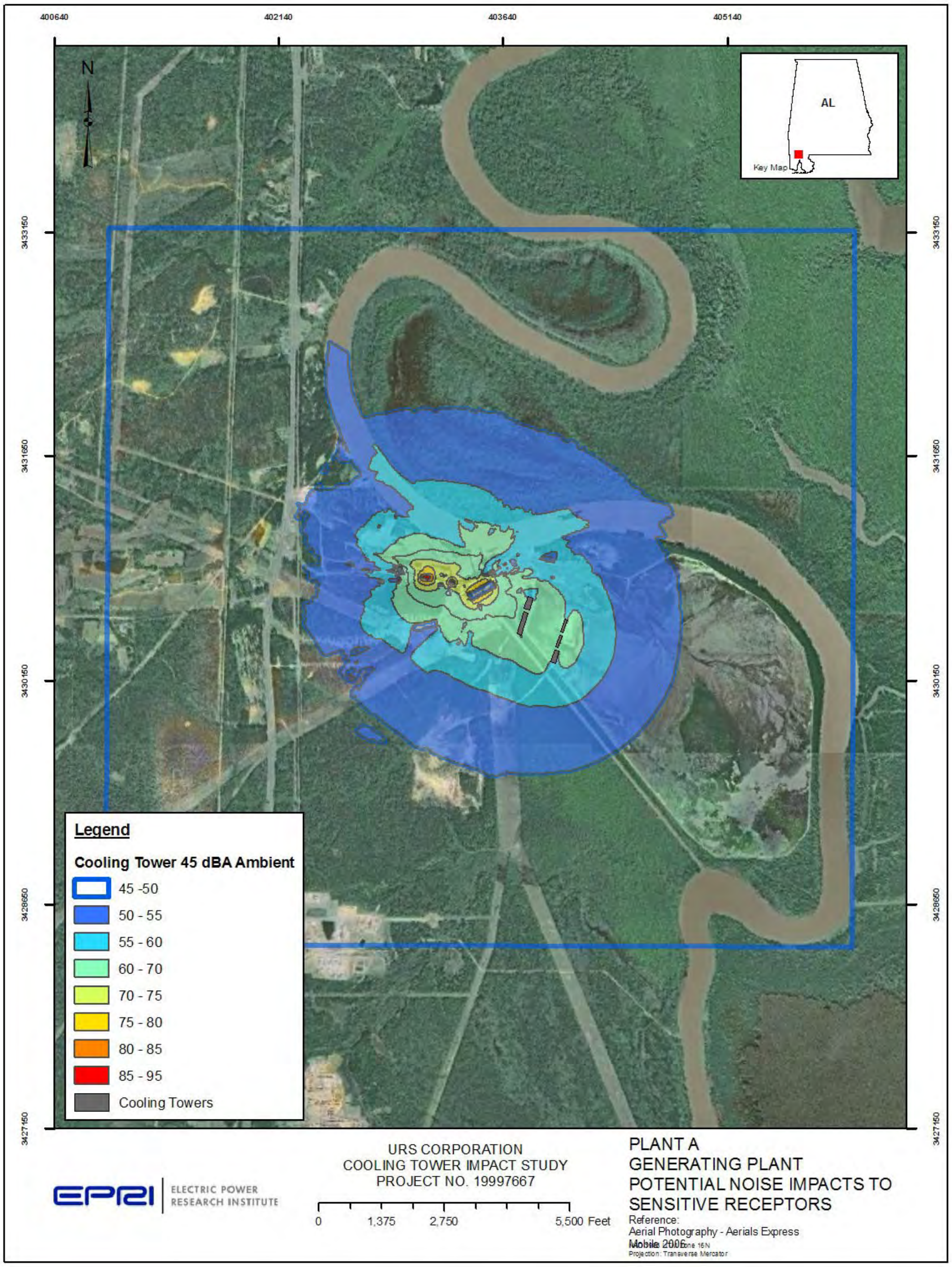


Figure C-57
BTPA potential noise impacts to sensitive receptors

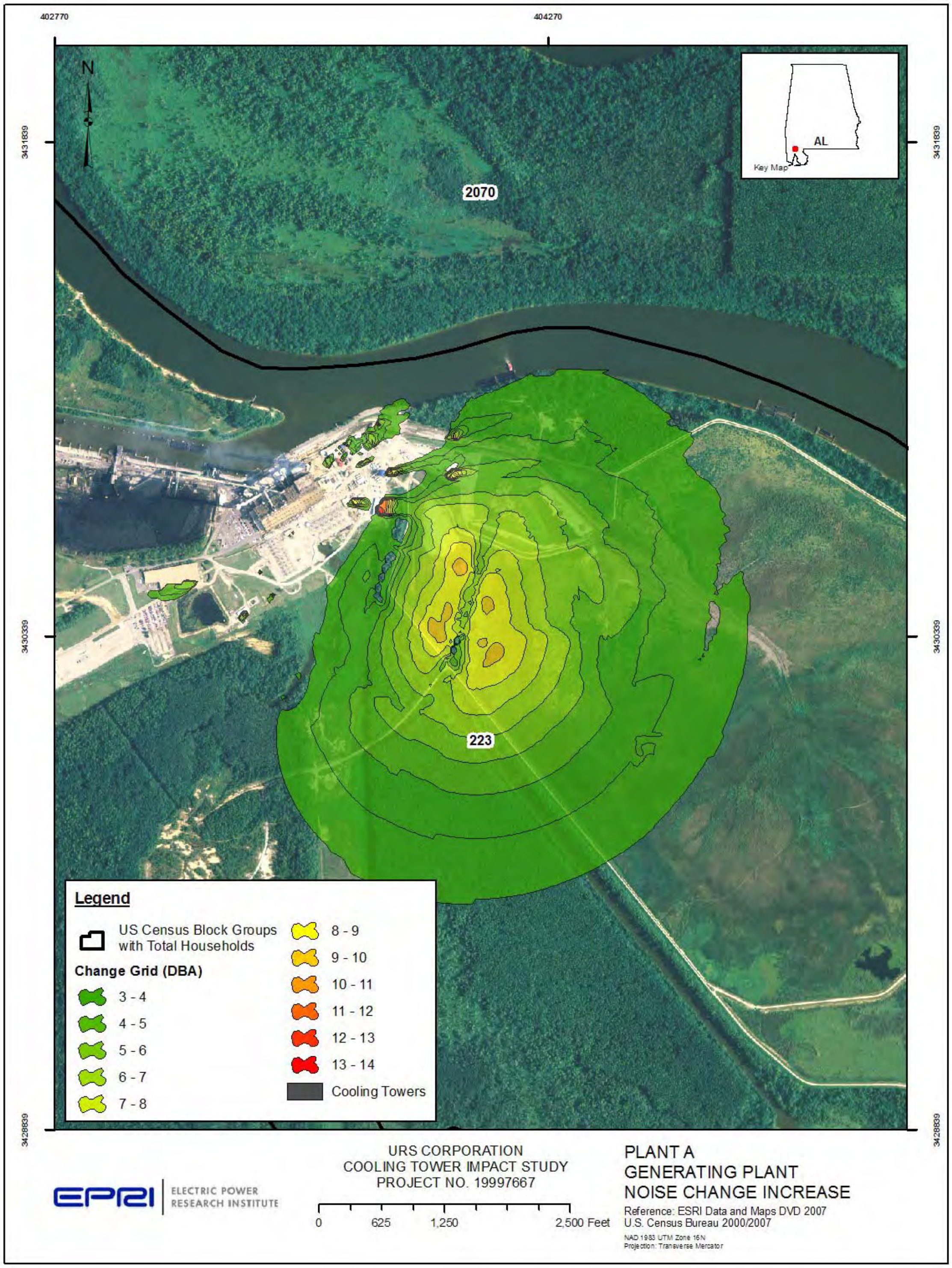


Figure C-58
BTPA modeled noise change increase

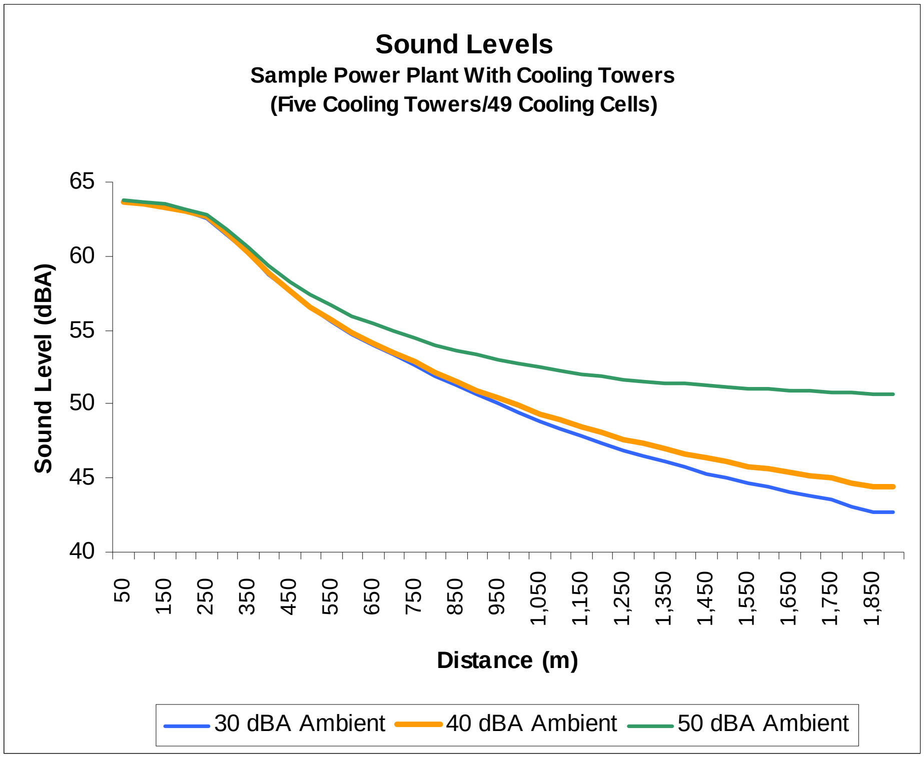


Figure C-59
BTPA modeled noise profile

C.3.3 BTPB

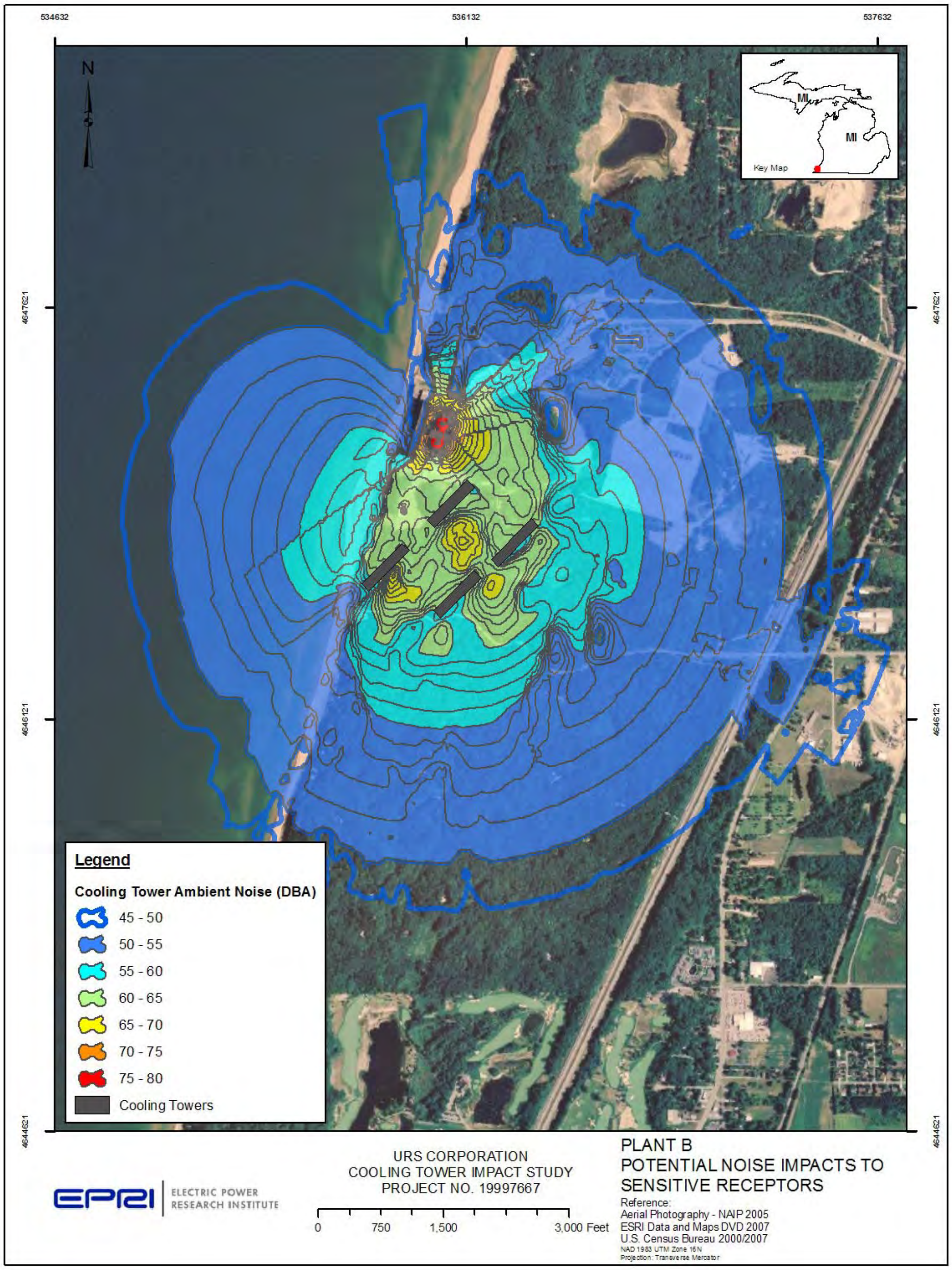


Figure C-60
BTPB potential noise impacts to sensitive receptors

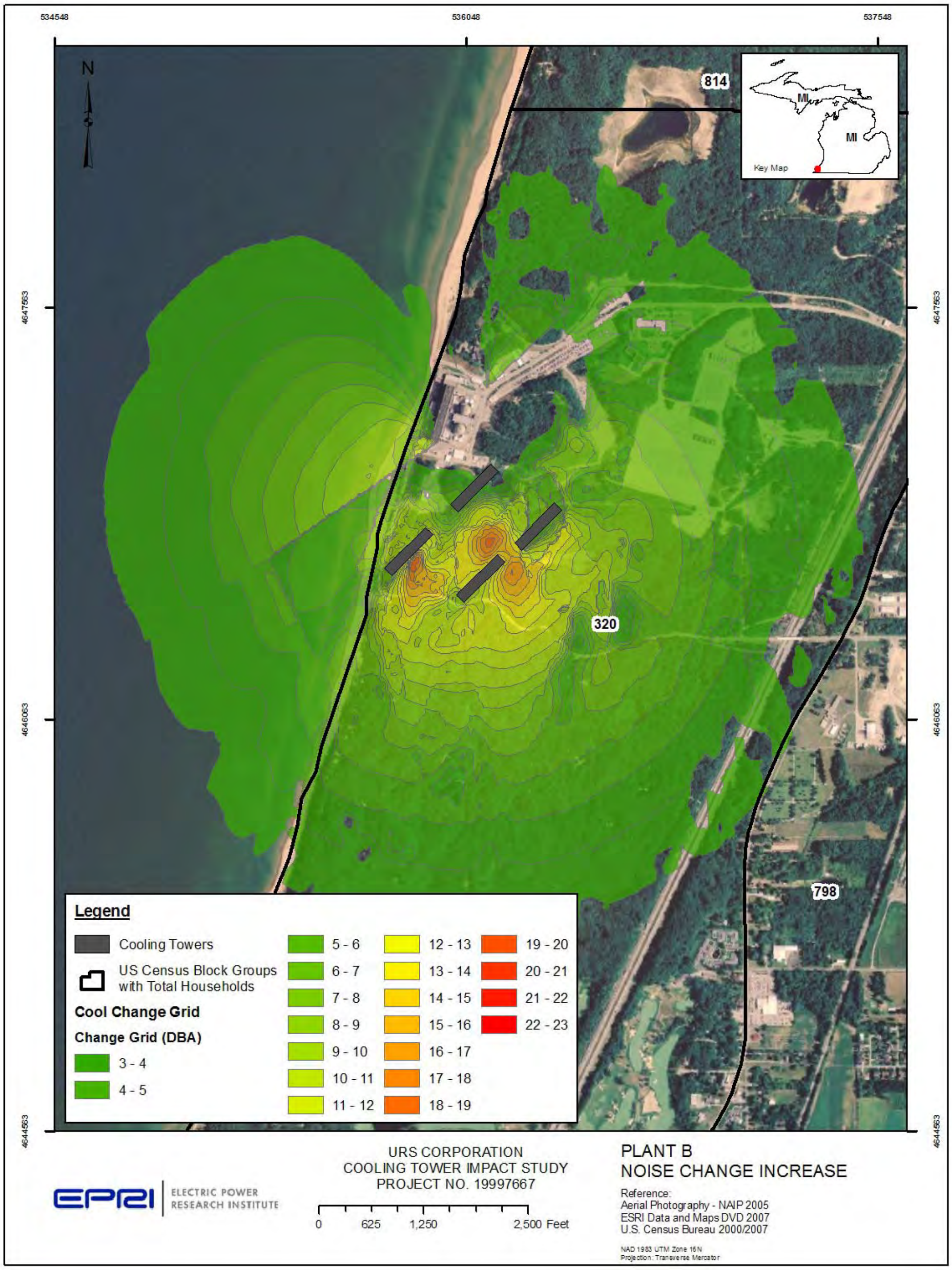


Figure C-61
BTPB modeled noise change increase

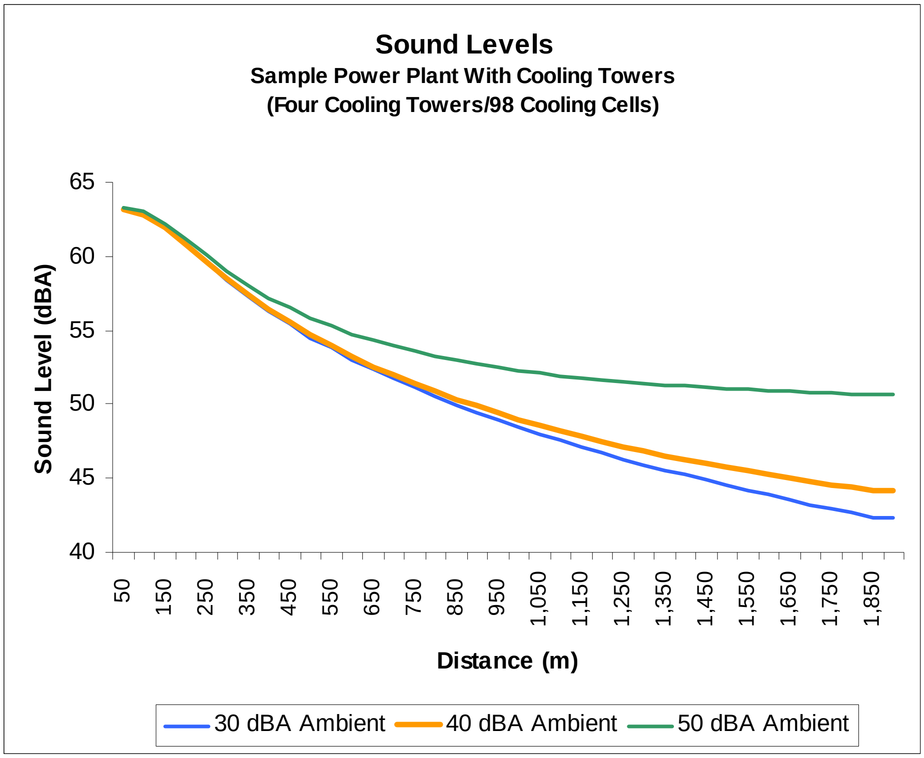


Figure C-62
BTPB modeled noise profile

C.3.4 BTPC

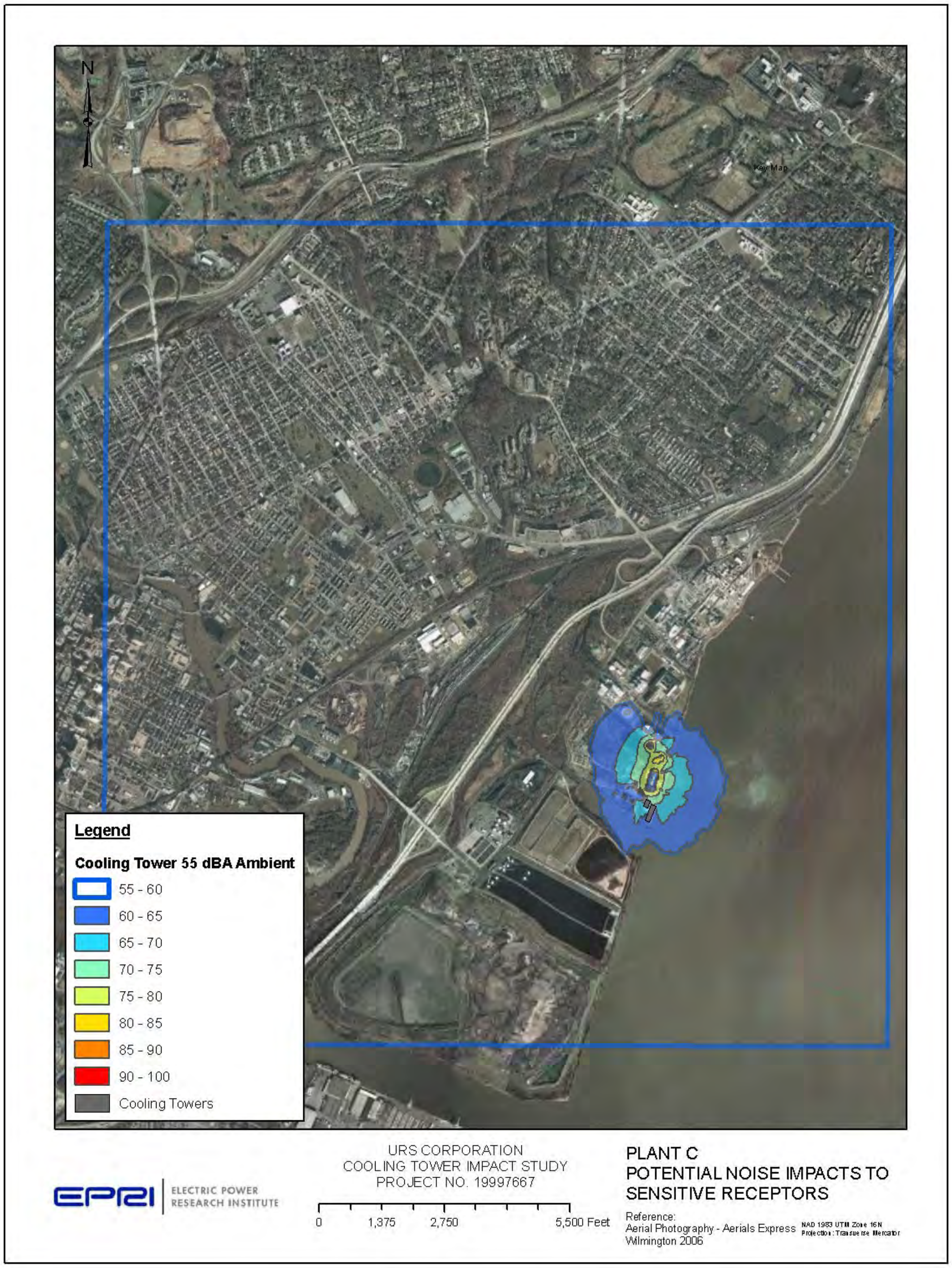


Figure C-63
BTPC potential noise impacts to sensitive receptors

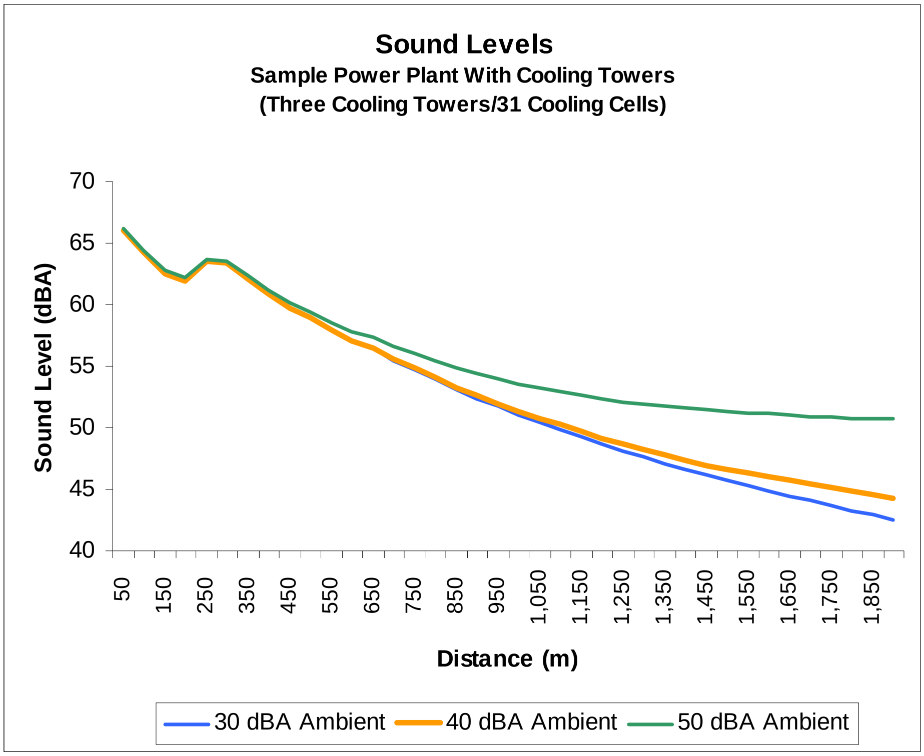


Figure C-64
BTPC modeled noise profile

C.3.5 BTPD

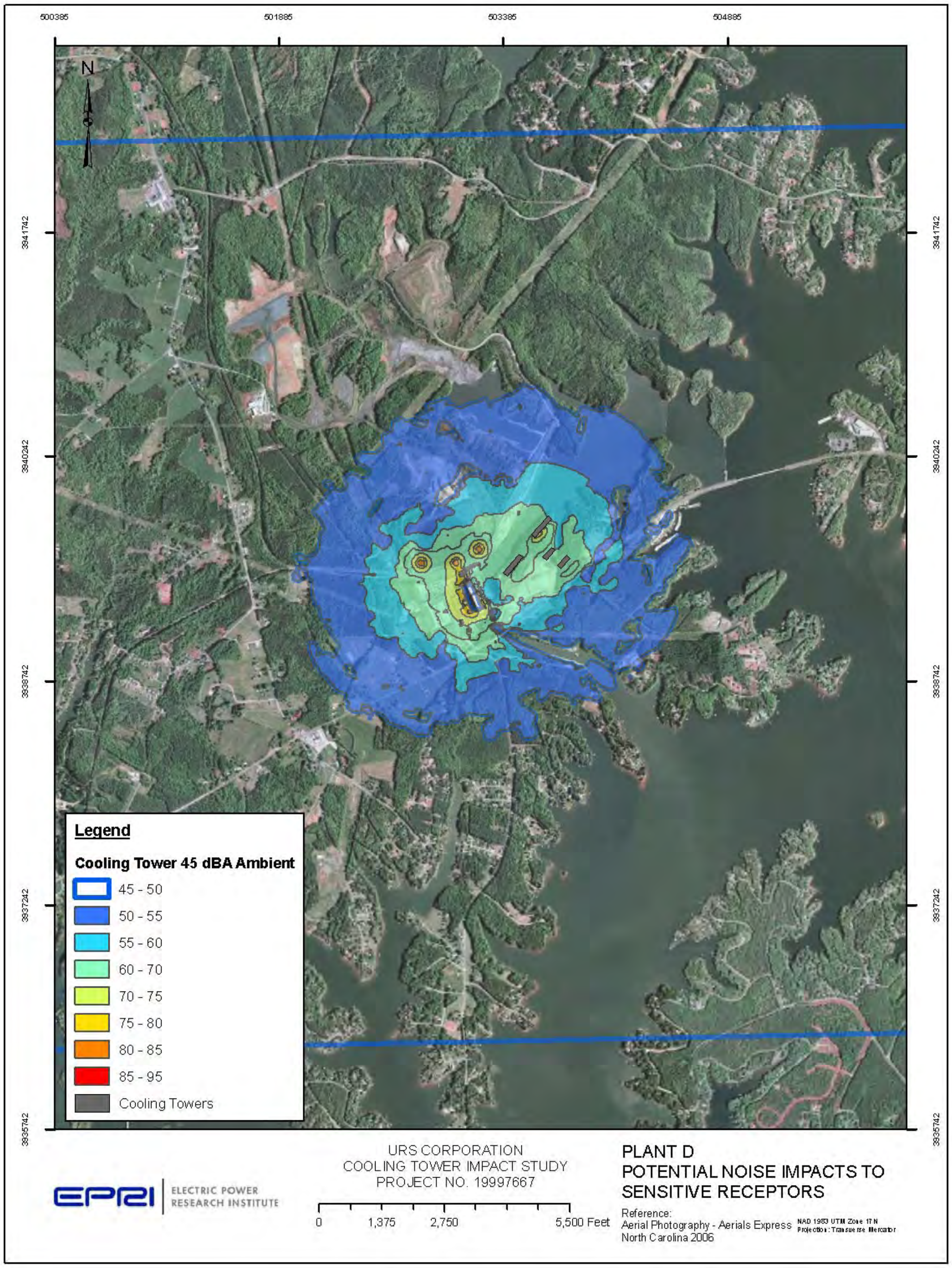


Figure C-65
BTPD potential noise impacts to sensitive receptors

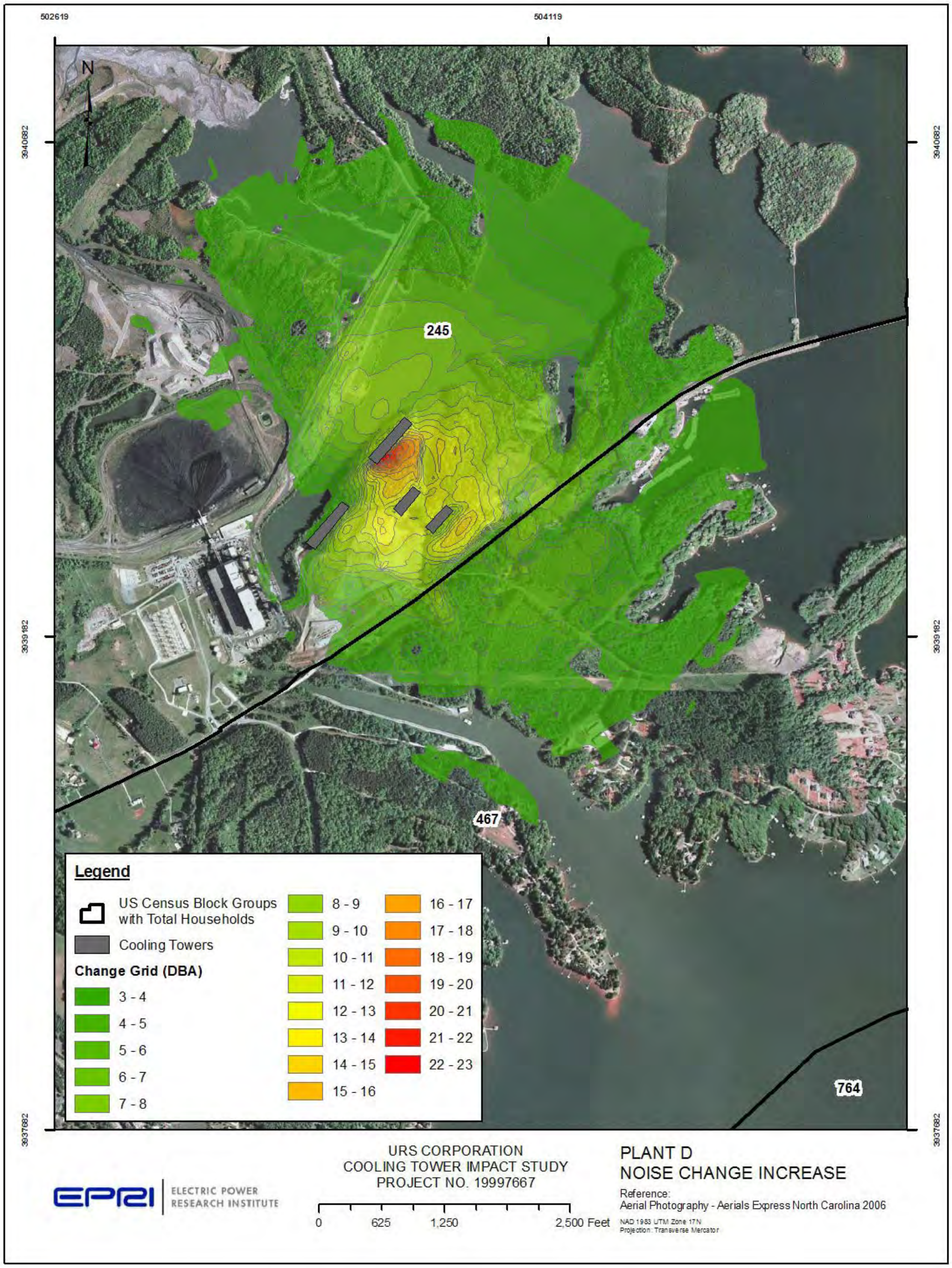


Figure C-66
BTPD modeled noise change increase

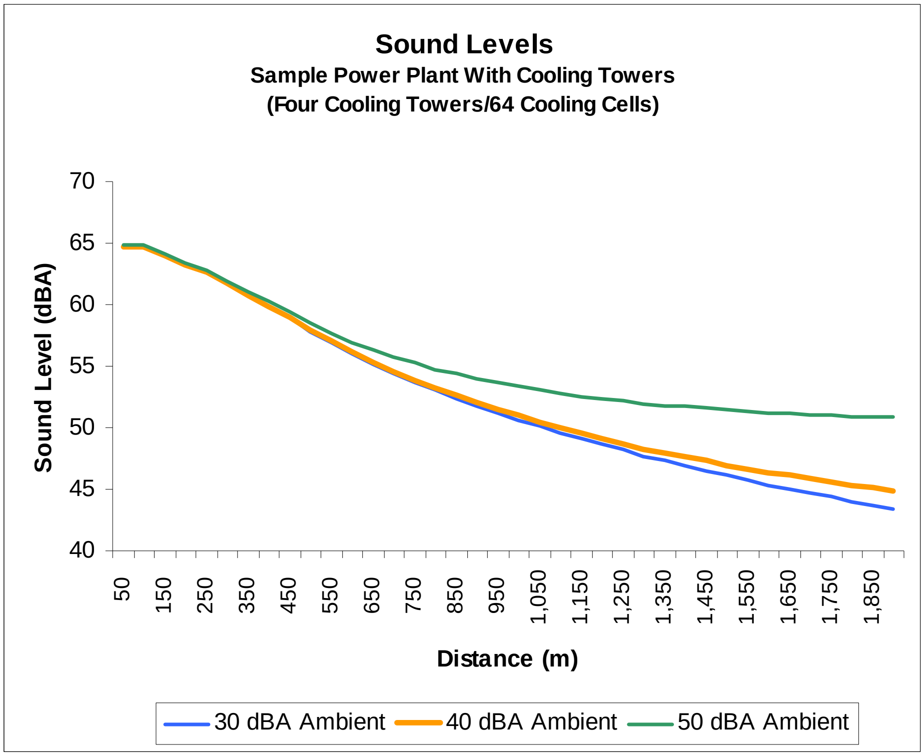


Figure C-67
BTPD modeled noise profile

C.3.6 BTPE

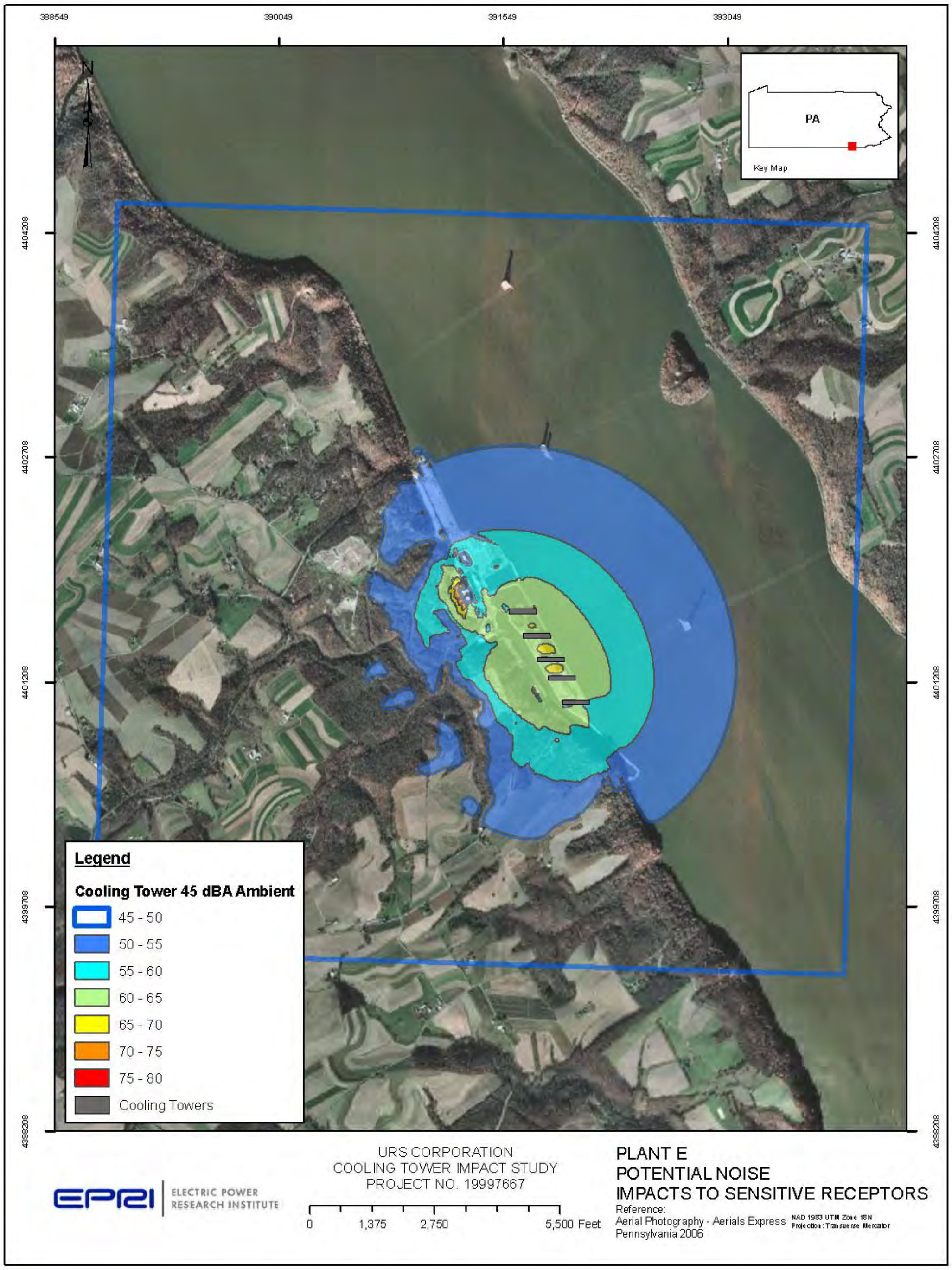


Figure C-68
BTPE potential noise impacts to sensitive receptors

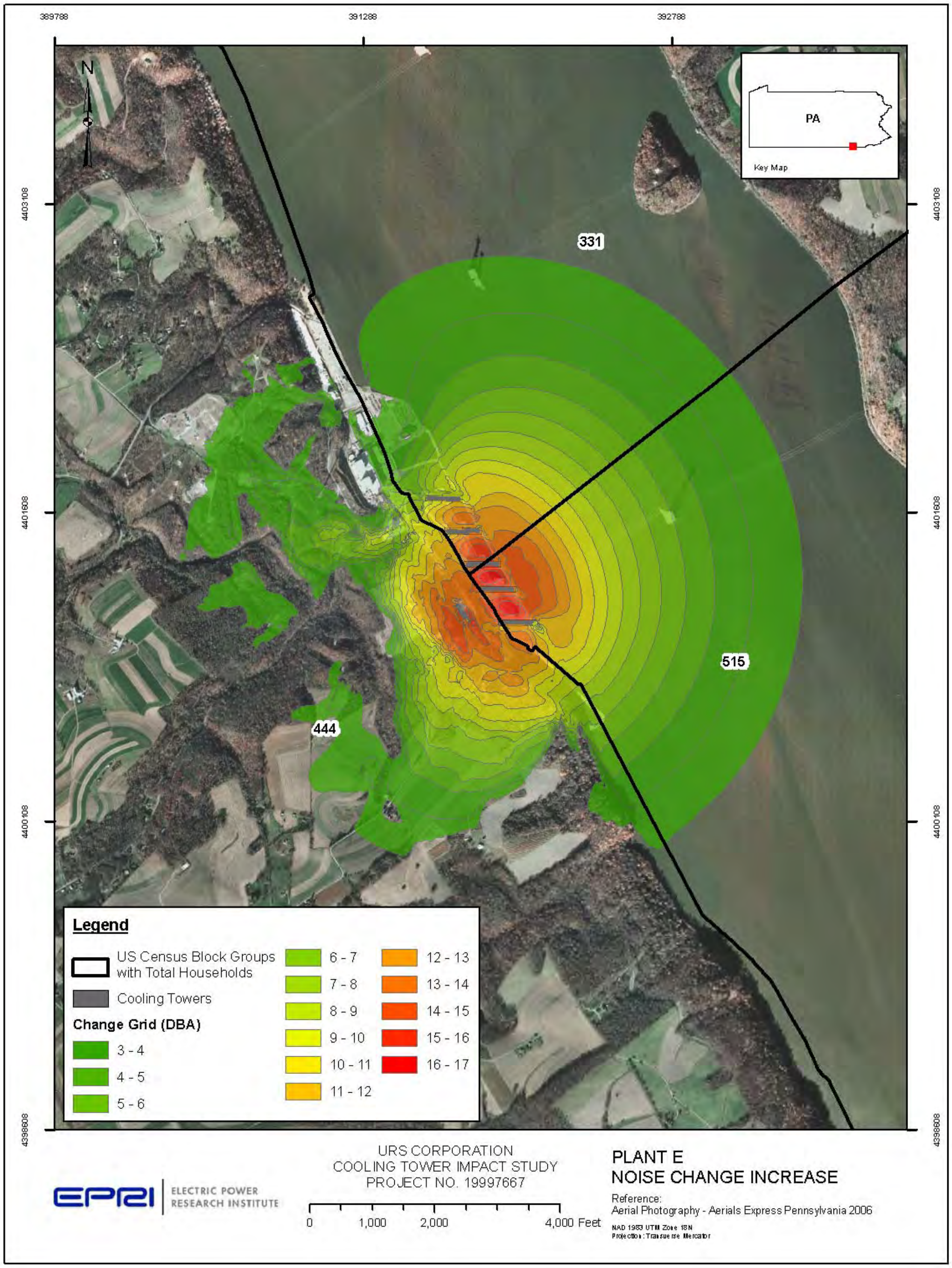


Figure C-69
BTPE modeled noise change increase

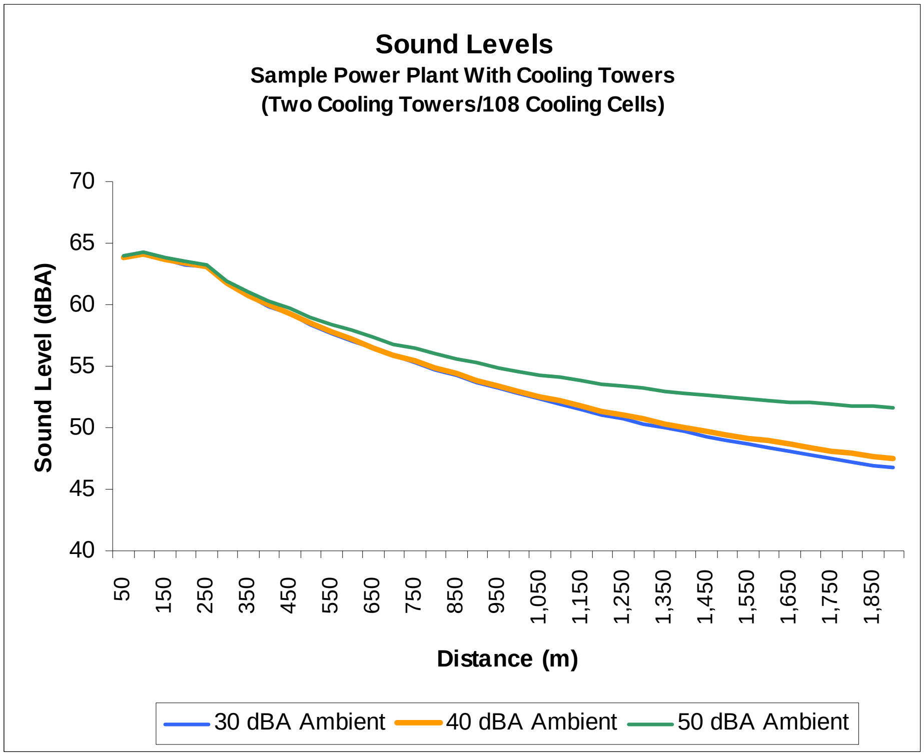


Figure C-70
BTPE modeled noise profile

C.3.7 BTCA2

Figure C-71
BTCA2 potential noise impacts to sensitive receptors

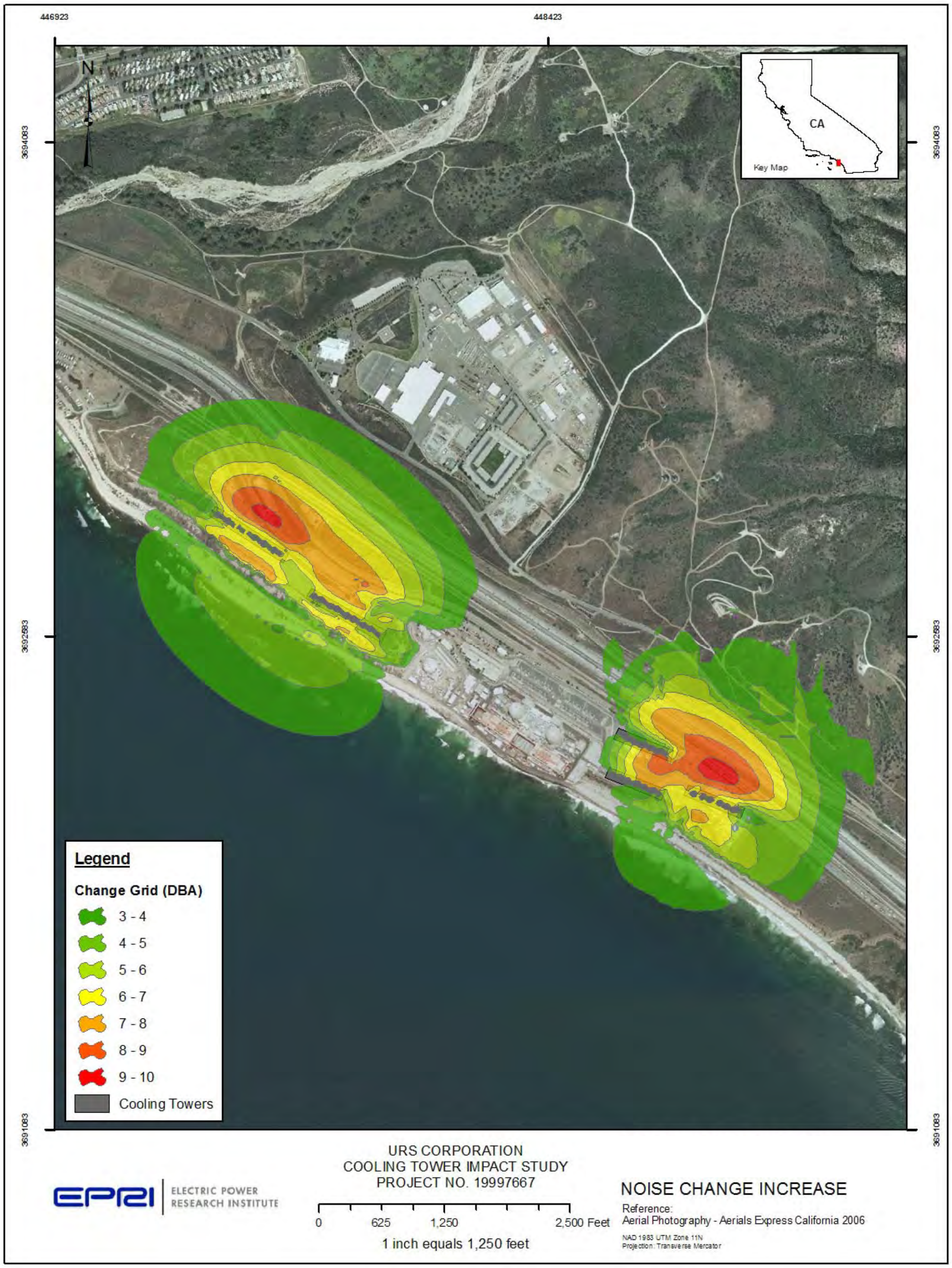


Figure C-72
BTCA2 modeled noise change increase

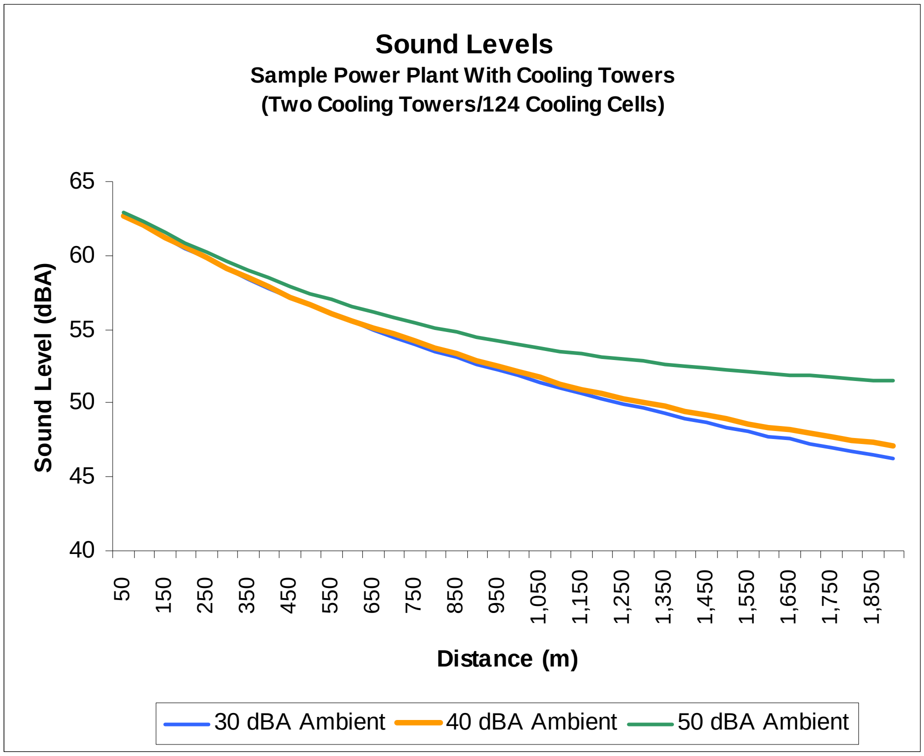


Figure C-73
BTCA2 modeled noise profile

C.3.8 RFG

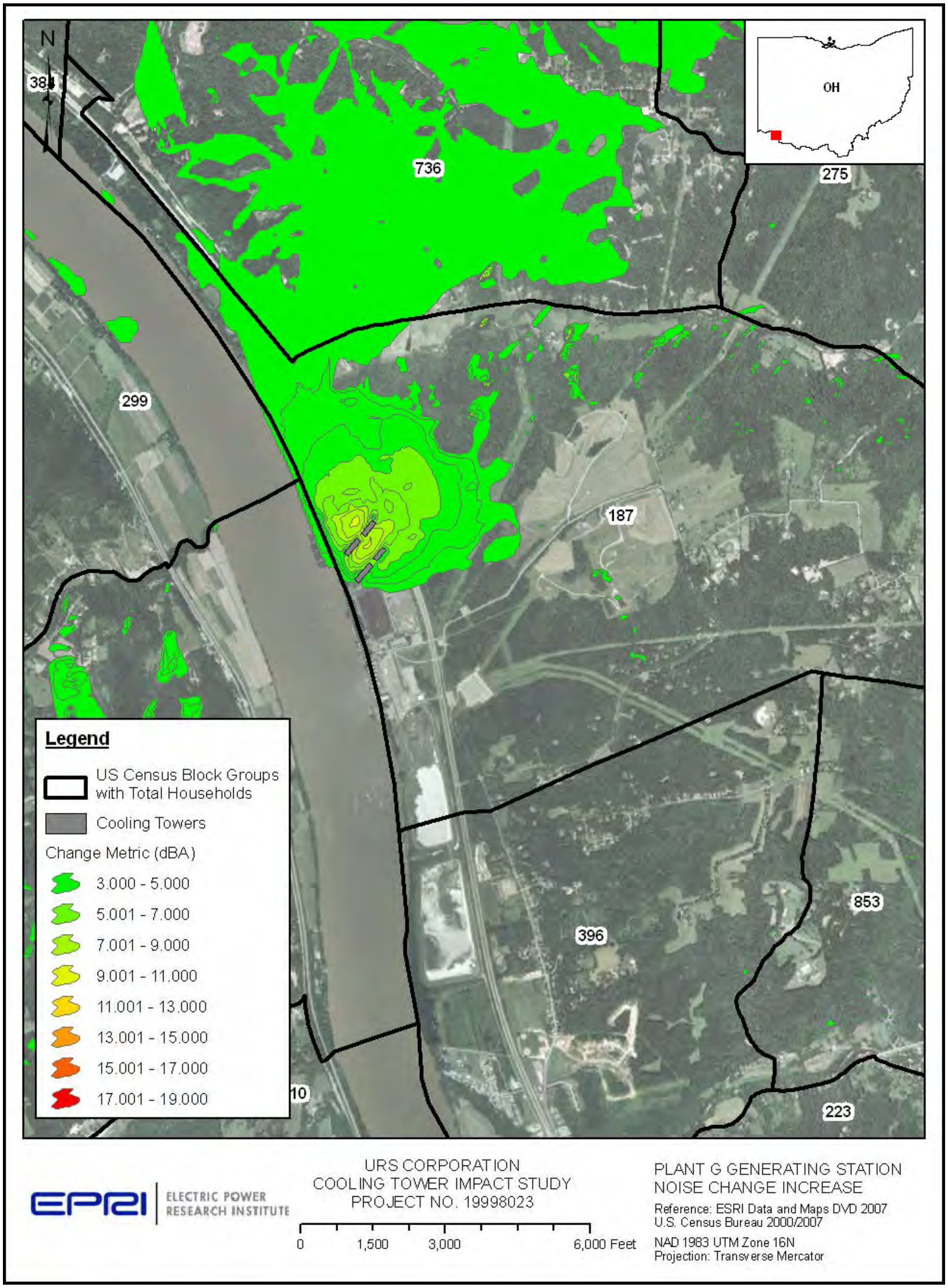


Figure C-74
RFG modeled noise change increase

C.3.9 RFH

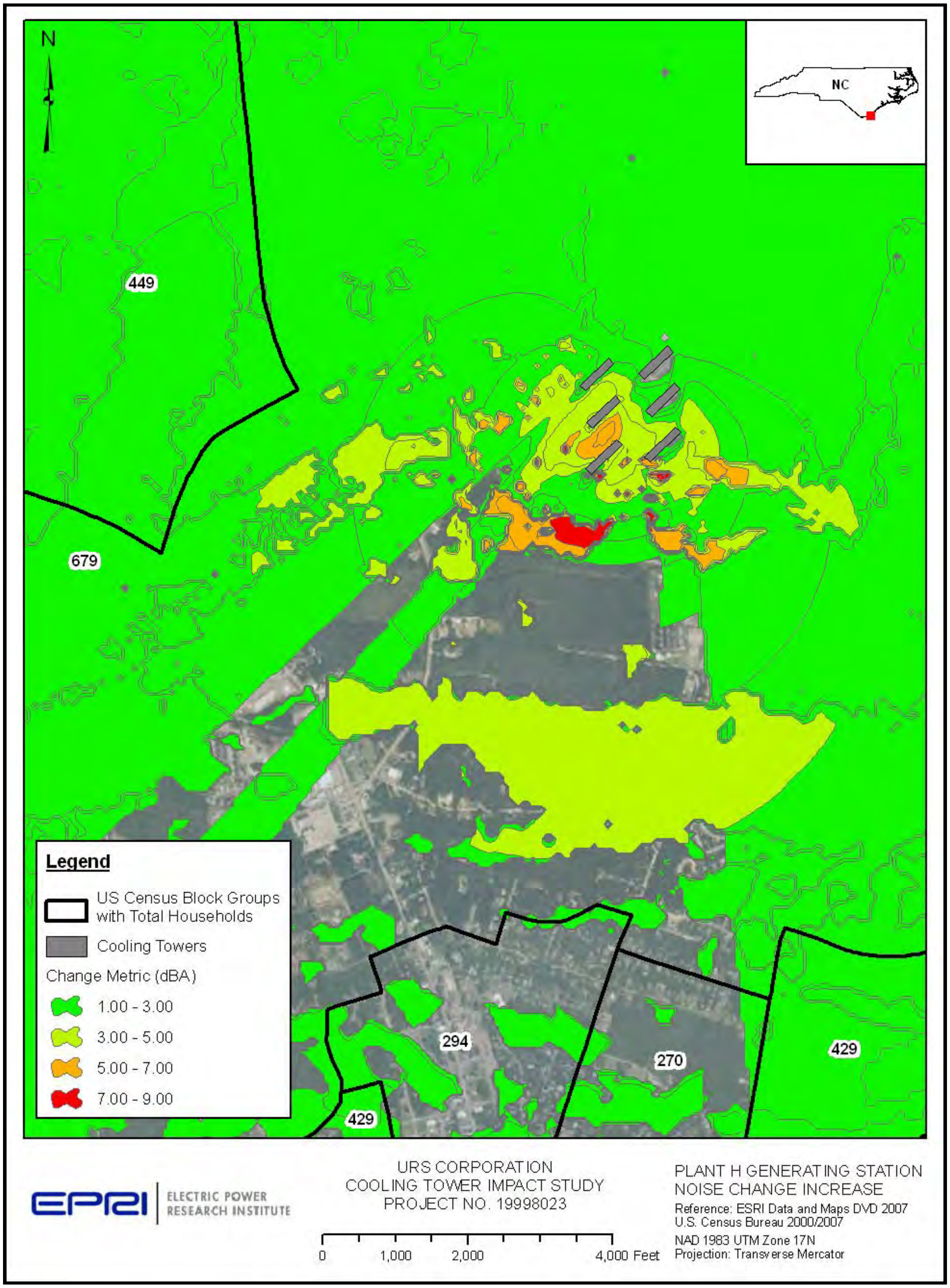


Figure C-75
RFH modeled noise change increase

C.3.10 RFJ

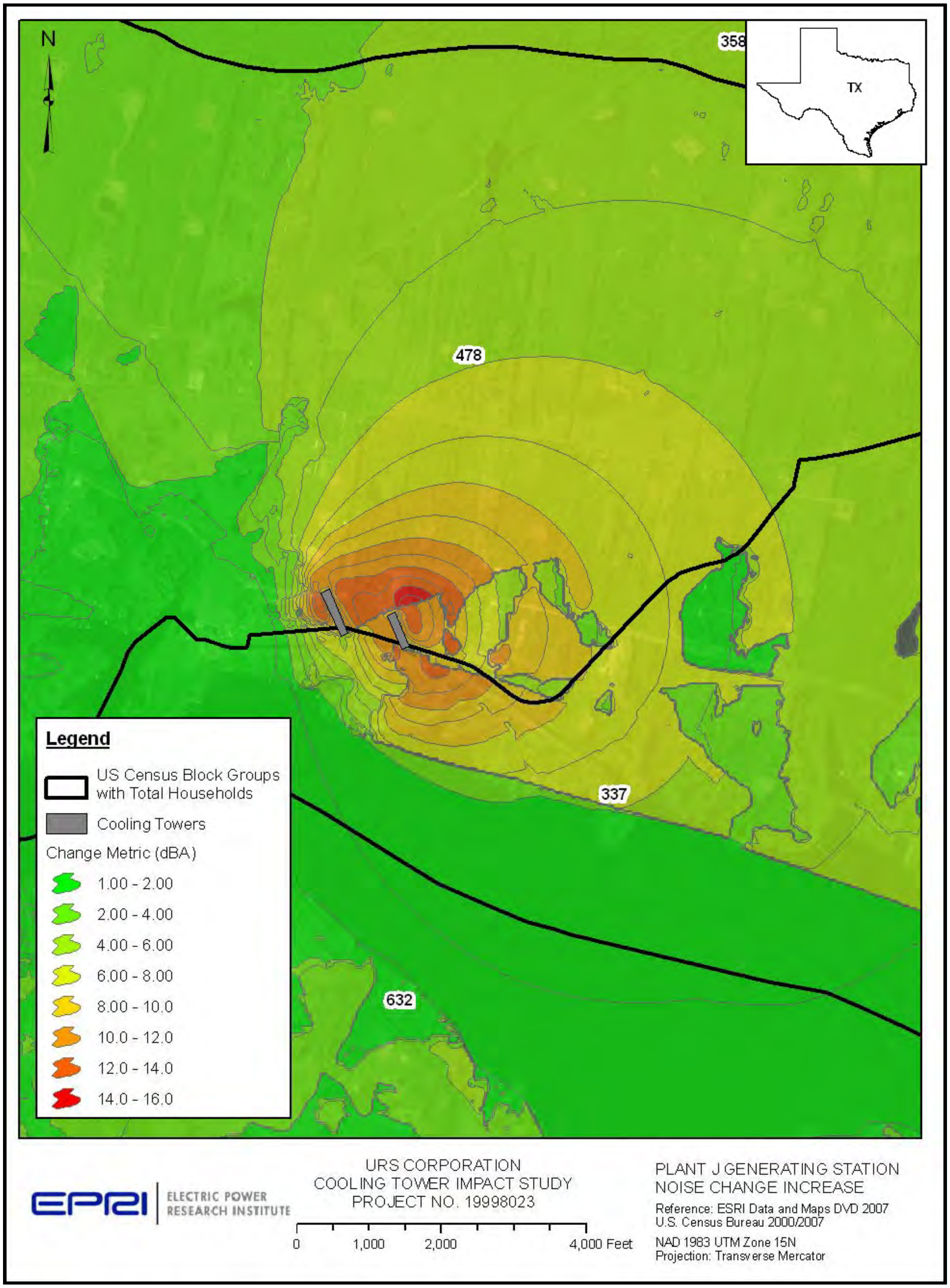


Figure C-76
RFJ modeled noise change increase

C.3.11 RFL

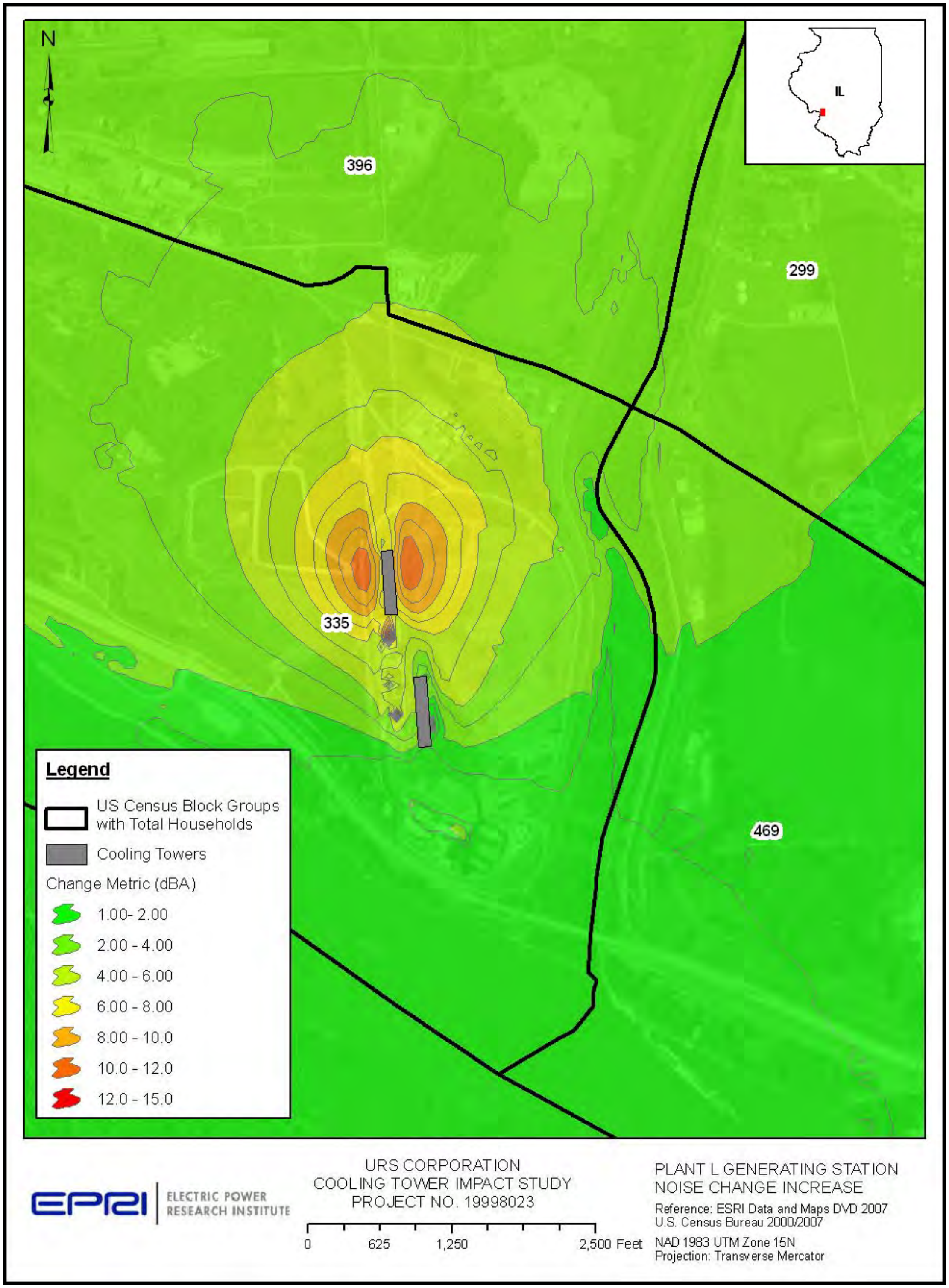
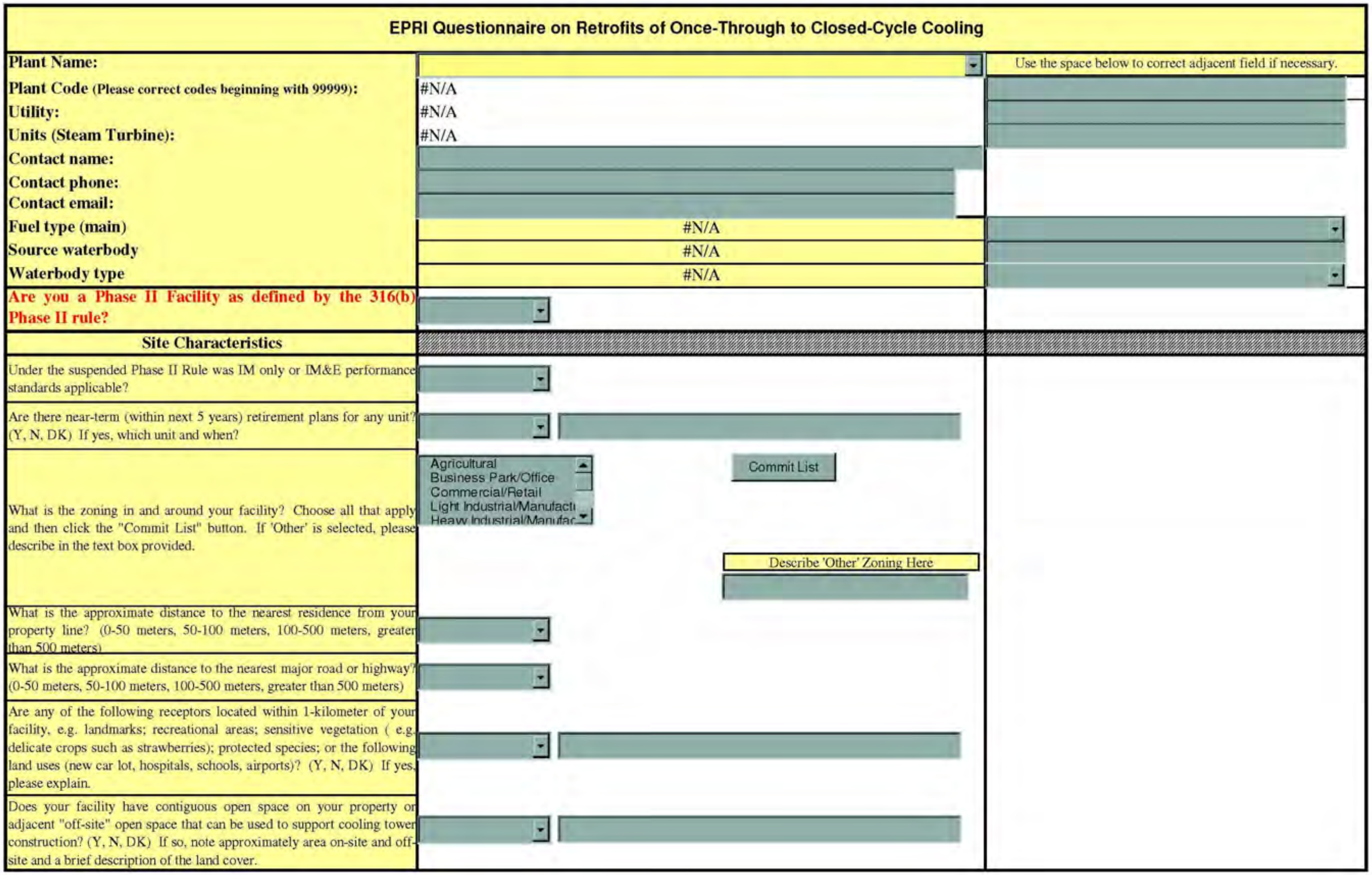
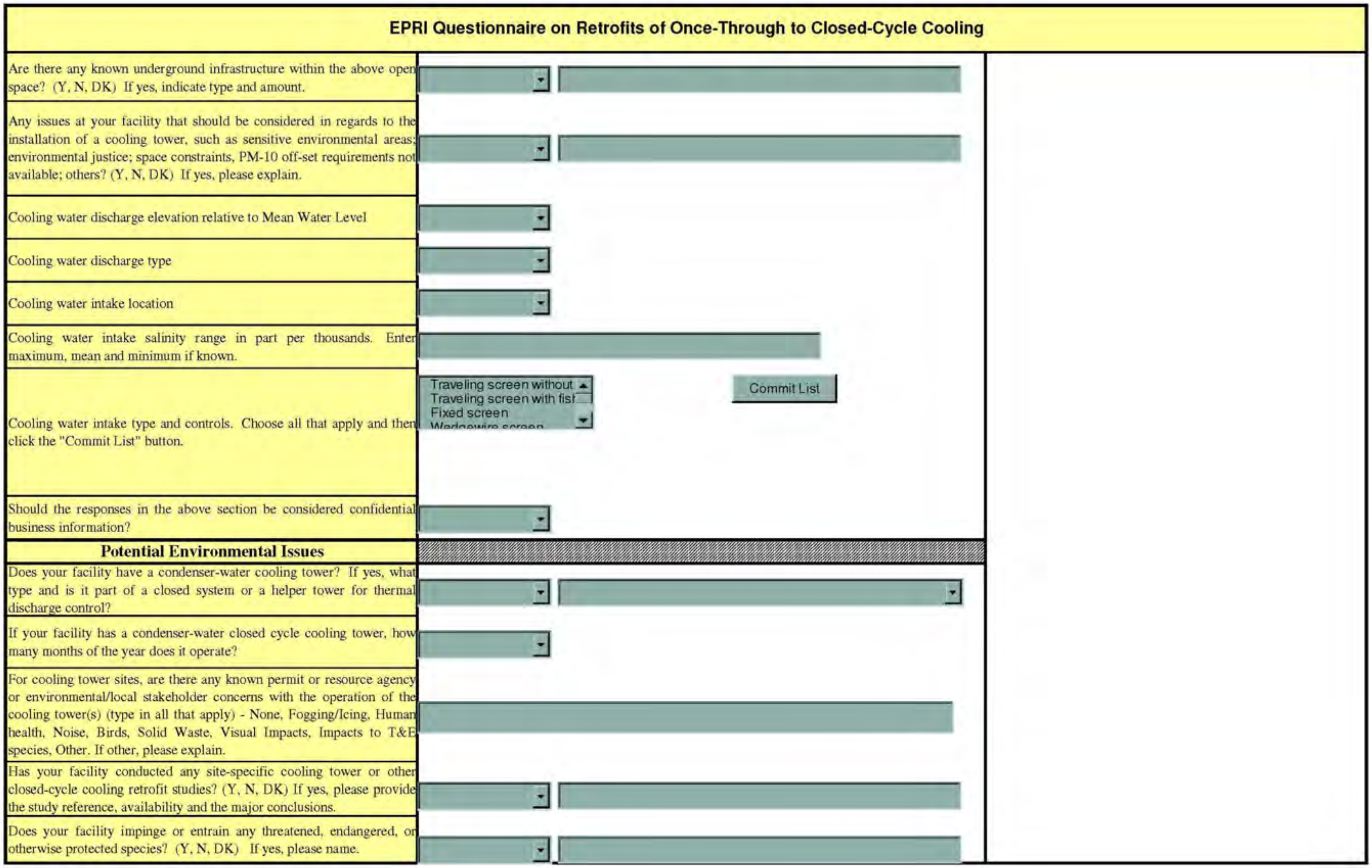


Figure C-77
RFL modeled noise change increase

D
QUESTIONNAIRE

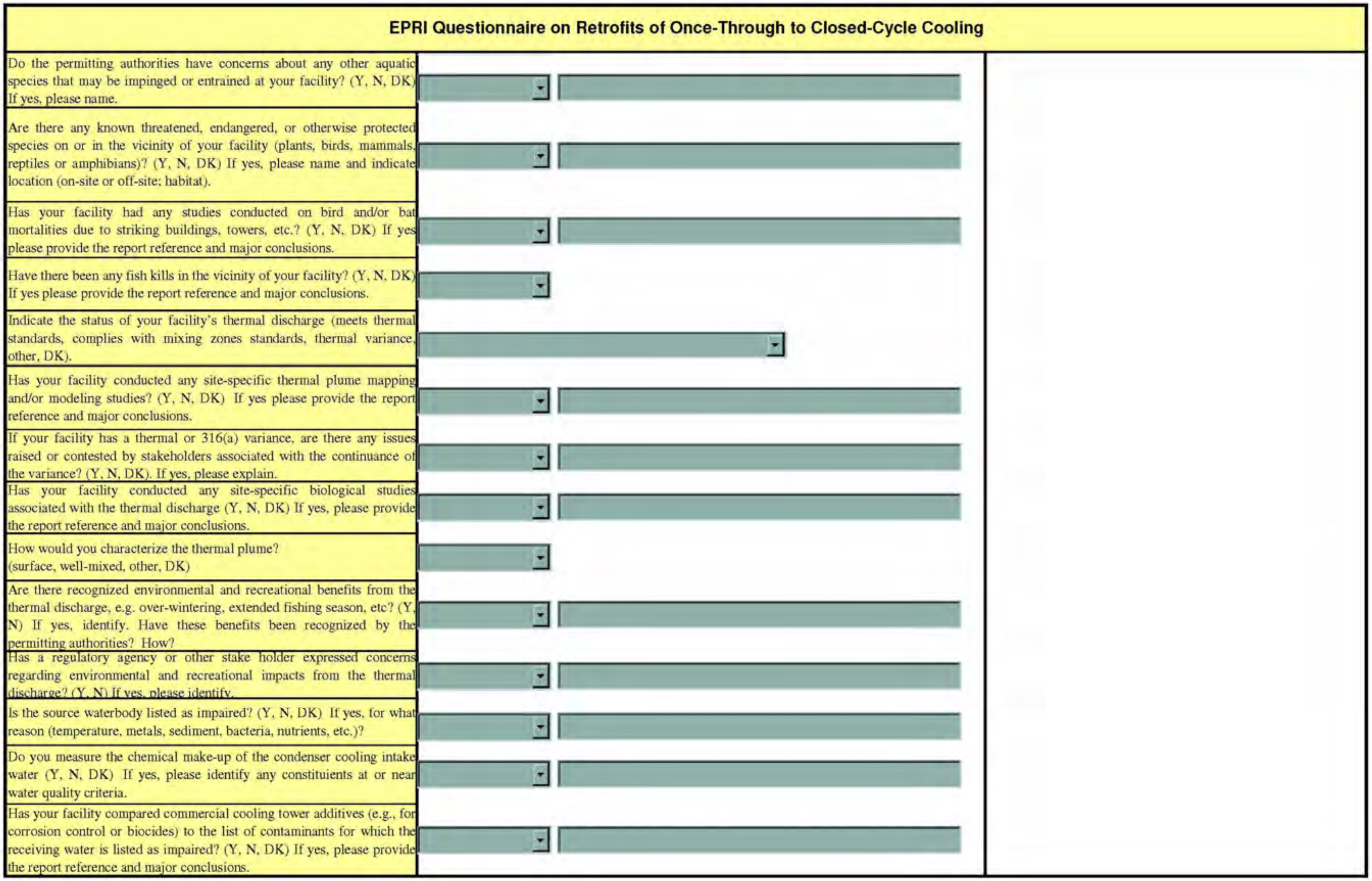


EPRI Questionnaire on Retrofits of Once-Through to Closed-Cycle Cooling		
Plant Name:		Use the space below to correct adjacent field if necessary.
Plant Code (Please correct codes beginning with 99999):	#N/A	
Utility:	#N/A	
Units (Steam Turbine):	#N/A	
Contact name:		
Contact phone:		
Contact email:		
Fuel type (main)	#N/A	
Source waterbody	#N/A	
Waterbody type	#N/A	
Are you a Phase II Facility as defined by the 316(b) Phase II rule?		
Site Characteristics		
Under the suspended Phase II Rule was IM only or IM&E performance standards applicable?		
Are there near-term (within next 5 years) retirement plans for any unit? (Y, N, DK) If yes, which unit and when?		
What is the zoning in and around your facility? Choose all that apply and then click the "Commit List" button. If 'Other' is selected, please describe in the text box provided.	Agricultural Business Park/Office Commercial/Retail Light Industrial/Manufact Heavy Industrial/Manufac Commit List Describe 'Other' Zoning Here	
What is the approximate distance to the nearest residence from your property line? (0-50 meters, 50-100 meters, 100-500 meters, greater than 500 meters)		
What is the approximate distance to the nearest major road or highway? (0-50 meters, 50-100 meters, 100-500 meters, greater than 500 meters)		
Are any of the following receptors located within 1-kilometer of your facility, e.g. landmarks; recreational areas; sensitive vegetation (e.g. delicate crops such as strawberries); protected species; or the following land uses (new car lot, hospitals, schools, airports)? (Y, N, DK) If yes, please explain.		
Does your facility have contiguous open space on your property or adjacent "off-site" open space that can be used to support cooling tower construction? (Y, N, DK) If so, note approximately area on-site and off-site and a brief description of the land cover.		



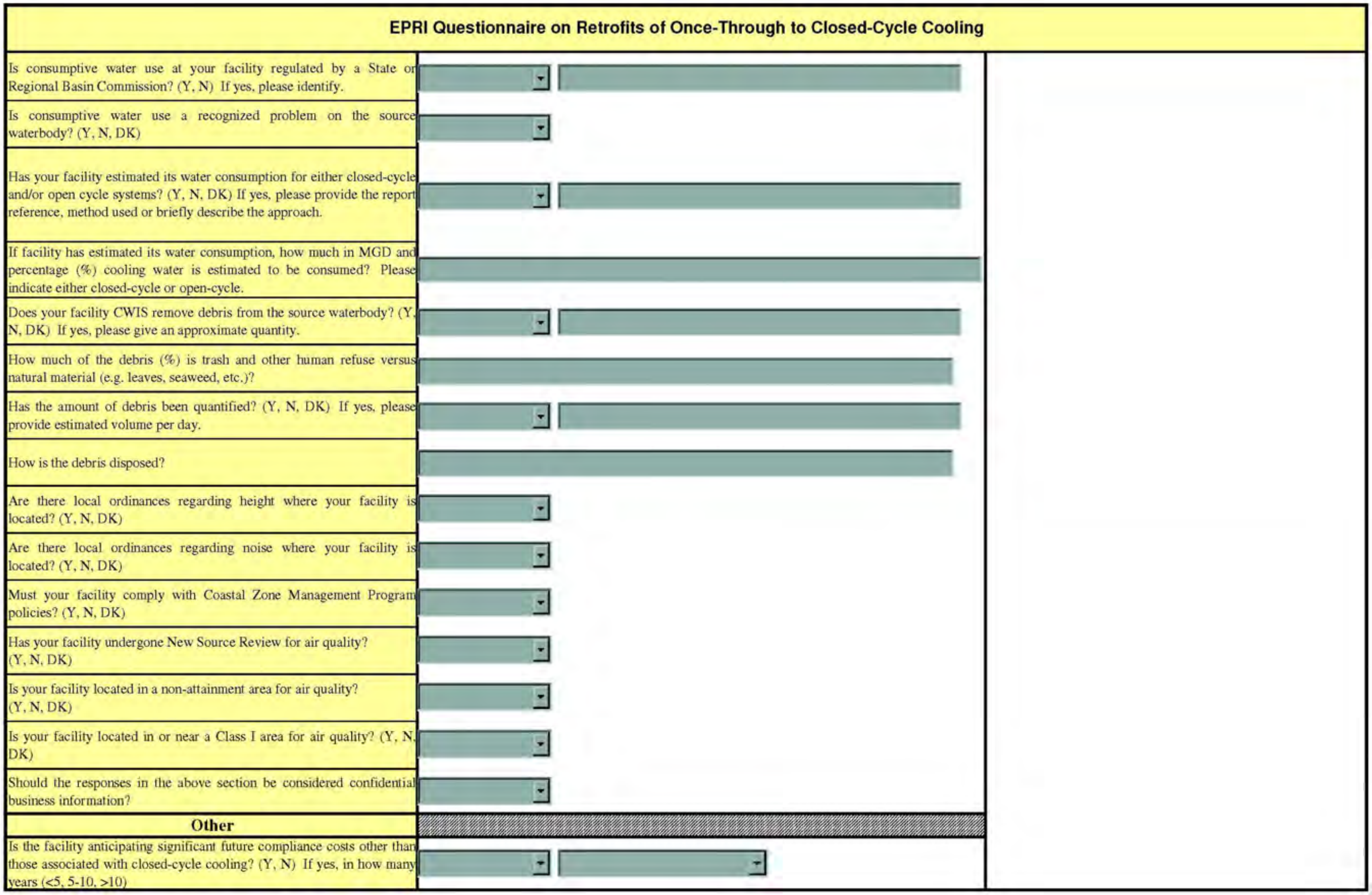
EPRI Questionnaire on Retrofits of Once-Through to Closed-Cycle Cooling

Are there any known underground infrastructure within the above open space? (Y, N, DK) If yes, indicate type and amount.
Any issues at your facility that should be considered in regards to the installation of a cooling tower, such as sensitive environmental areas; environmental justice; space constraints, PM-10 off-set requirements not available; others? (Y, N, DK) If yes, please explain.
Cooling water discharge elevation relative to Mean Water Level
Cooling water discharge type
Cooling water intake location
Cooling water intake salinity range in part per thousands. Enter maximum, mean and minimum if known.
Cooling water intake type and controls. Choose all that apply and then click the "Commit List" button.
Should the responses in the above section be considered confidential business information?
Potential Environmental Issues
Does your facility have a condenser-water cooling tower? If yes, what type and is it part of a closed system or a helper tower for thermal discharge control?
If your facility has a condenser-water closed cycle cooling tower, how many months of the year does it operate?
For cooling tower sites, are there any known permit or resource agency or environmental/local stakeholder concerns with the operation of the cooling tower(s) (type in all that apply) - None, Fogging/Icing, Human health, Noise, Birds, Solid Waste, Visual Impacts, Impacts to T&E species, Other. If other, please explain.
Has your facility conducted any site-specific cooling tower or other closed-cycle cooling retrofit studies? (Y, N, DK) If yes, please provide the study reference, availability and the major conclusions.
Does your facility impinge or entrain any threatened, endangered, or otherwise protected species? (Y, N, DK) If yes, please name.



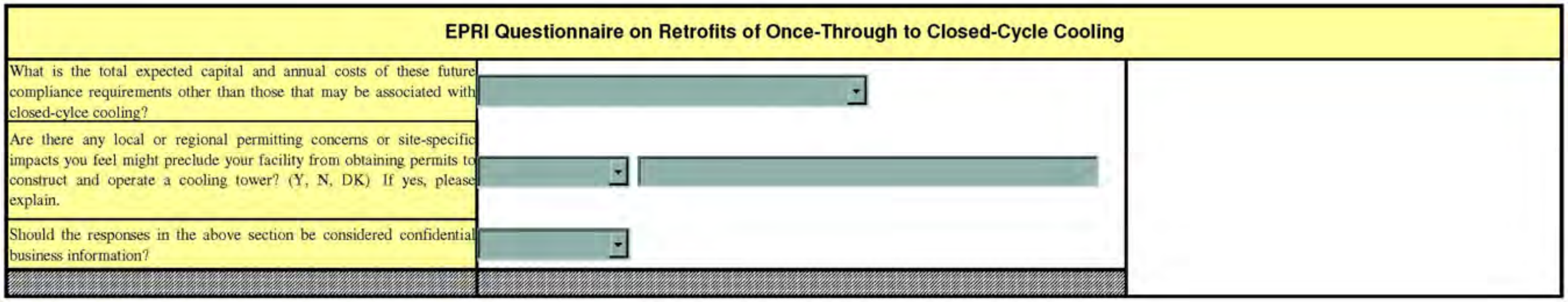
EPRI Questionnaire on Retrofits of Once-Through to Closed-Cycle Cooling

Do the permitting authorities have concerns about any other aquatic species that may be impinged or entrained at your facility? (Y, N, DK) If yes, please name.		
Are there any known threatened, endangered, or otherwise protected species on or in the vicinity of your facility (plants, birds, mammals, reptiles or amphibians)? (Y, N, DK) If yes, please name and indicate location (on-site or off-site; habitat).		
Has your facility had any studies conducted on bird and/or bat mortalities due to striking buildings, towers, etc.? (Y, N, DK) If yes please provide the report reference and major conclusions.		
Have there been any fish kills in the vicinity of your facility? (Y, N, DK) If yes please provide the report reference and major conclusions.		
Indicate the status of your facility's thermal discharge (meets thermal standards, complies with mixing zones standards, thermal variance, other, DK).		
Has your facility conducted any site-specific thermal plume mapping and/or modeling studies? (Y, N, DK) If yes please provide the report reference and major conclusions.		
If your facility has a thermal or 316(a) variance, are there any issues raised or contested by stakeholders associated with the continuance of the variance? (Y, N, DK). If yes, please explain.		
Has your facility conducted any site-specific biological studies associated with the thermal discharge (Y, N, DK) If yes, please provide the report reference and major conclusions.		
How would you characterize the thermal plume? (surface, well-mixed, other, DK)		
Are there recognized environmental and recreational benefits from the thermal discharge, e.g. over-wintering, extended fishing season, etc? (Y, N) If yes, identify. Have these benefits been recognized by the permitting authorities? How?		
Has a regulatory agency or other stake holder expressed concerns regarding environmental and recreational impacts from the thermal discharge? (Y, N) If yes, please identify.		
Is the source waterbody listed as impaired? (Y, N, DK) If yes, for what reason (temperature, metals, sediment, bacteria, nutrients, etc.)?		
Do you measure the chemical make-up of the condenser cooling intake water (Y, N, DK) If yes, please identify any constituients at or near water quality criteria.		
Has your facility compared commercial cooling tower additives (e.g., for corrosion control or biocides) to the list of contaminants for which the receiving water is listed as impaired? (Y, N, DK) If yes, please provide the report reference and major conclusions.		



EPRI Questionnaire on Retrofits of Once-Through to Closed-Cycle Cooling

Is consumptive water use at your facility regulated by a State or Regional Basin Commission? (Y, N) If yes, please identify.	
Is consumptive water use a recognized problem on the source waterbody? (Y, N, DK)	
Has your facility estimated its water consumption for either closed-cycle and/or open cycle systems? (Y, N, DK) If yes, please provide the report reference, method used or briefly describe the approach.	
If facility has estimated its water consumption, how much in MGD and percentage (%) cooling water is estimated to be consumed? Please indicate either closed-cycle or open-cycle.	
Does your facility CWIS remove debris from the source waterbody? (Y, N, DK) If yes, please give an approximate quantity.	
How much of the debris (%) is trash and other human refuse versus natural material (e.g. leaves, seaweed, etc.)?	
Has the amount of debris been quantified? (Y, N, DK) If yes, please provide estimated volume per day.	
How is the debris disposed?	
Are there local ordinances regarding height where your facility is located? (Y, N, DK)	
Are there local ordinances regarding noise where your facility is located? (Y, N, DK)	
Must your facility comply with Coastal Zone Management Program policies? (Y, N, DK)	
Has your facility undergone New Source Review for air quality? (Y, N, DK)	
Is your facility located in a non-attainment area for air quality? (Y, N, DK)	
Is your facility located in or near a Class I area for air quality? (Y, N, DK)	
Should the responses in the above section be considered confidential business information?	
Other	
Is the facility anticipating significant future compliance costs other than those associated with closed-cycle cooling? (Y, N) If yes, in how many years (<5, 5-10, >10)	



EPRI Questionnaire on Retrofits of Once-Through to Closed-Cycle Cooling

What is the total expected capital and annual costs of these future compliance requirements other than those that may be associated with closed-cylce cooling?		
Are there any local or regional permitting concerns or site-specific impacts you feel might preclude your facility from obtaining permits to construct and operate a cooling tower? (Y, N, DK) If yes, please explain.		
Should the responses in the above section be considered confidential business information?		

E

PHASE II FACILITIES WITH ONCE-THROUGH COOLING SYSTEMS FOR ENVIRONMENTAL IMPACTS ANALYSIS

This appendix provides a list of Phase II facilities that utilize once-through cooling for at least one of their generating units. Efforts were made to include only the units that use once-through cooling when reporting generation and cooling water flow. The list includes baseline information for each facility: identification (facility name), state where located, megawatt (MW) generating capacity, design once-through cooling water (CW) flow rate (million gallons per day [MGD]), fuel classification, and source water body type. This finalized list is considered comprehensive based on EPRI's database of U.S. power plants as of November 9, 2010.

Additional information that was used in the national scaling portion of the study is also provided in this appendix, including:

- The source waterbody type, based on the likely re-write of the currently suspending Phase II Rule:
  - Ocean/Estuary/Tidal Rivers (O/E/TR)
  - Large Rivers/Reservoirs & Lakes (LR/LR)
  - Small Rivers/Great Lakes (SR/GL)
- Region, based on geography and presumed similarities in housing values:
  - California, all facilities in California and Hawaii
  - West, all plants west of the Mississippi River, except those in California
  - Northeast, plants in states east of the Mississippi River and north of the Mason-Dixon Line
  - Southeast, facilities located east of the Mississippi River, but south of the Mason-Dixon Line
- The one facility located in Guam was not assigned to a Region and was not used in national scaling where Region was a factor.
- Population (Pop), based on the census tracts within which the facilities are located and the Year 2000 population expressed in population per square mile (people/mi^2):
  - Low (<100 people/mi2)
  - Medium (Med) (100-1,000 people/mi2)
  - High (>1,000 people/mi2)

- Roadway within 50-meters (50-m), based on results of the EPRI Questionnaire (see Appendix D) and best professional judgment using aerial photography. “Unknown” indicates that the facility is located in a Low or Medium Population area and was not evaluated for proximity to a roadway.
- Generation (megawatt-hour [MW-hr]) for nuclear facilities, calculated from nameplate ratings (MW) obtained from the Nuclear Regulatory Commission’s website and capacity utilization data from the Energy Information Administration’s database.

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Aguirre	Puerto Rico Electric Power	PR	Jobos Bay	Southeast	Non-Nuclear	650.8	900	O/E/TR	Low	Unknown	
Alamitos	AES Alamitos LLC	CA	Cerritos Channel	CA	Non-Nuclear	1181	1950	O/E/TR	High	Yes	
Allen Fossil Plant	Tennessee Valley Authority	TN	Mississippi River	Southeast	Non-Nuclear	549	864	LR/RL	Med	Unknown	
Allen S King	Xcel	MN	Lake St. Croix	Mid/West	Non-Nuclear	467	605	LR/RL	High	Yes	
Allen Steam Plant	Duke Energy Corp	NC	Lake Wylie	Southeast	Non-Nuclear	861	1391	LR/RL	Med	No	
Alma/Madgett	Dairyland Power Coop	WI	Mississippi River	Northeast	Non-Nuclear	540	605	LR/RL	Low	No	
Anclote	Progress Energy Florida	FL	Anclote River	Southeast	Non-Nuclear	1287	1030	O/E/TR	High	Yes	
Arkansas Nuclear 1	Entergy	AR	Dardanelle Reservoir on Arkansas River	Mid/West	Nuclear	1146.2	900	LR/RL	Low	Unknown	6,045,322
Armstrong	Allegheny Energy Supply Co LLC	PA	Allegheny River	Northeast	Non-Nuclear	179	356	LR/RL	Low	Unknown	
Arthur Kill	NRG Arthur Kill Power LLC	NY	Lower New York Bay	Northeast	Non-Nuclear	713	875	O/E/TR	Med	No	
Ashtabula	Cleveland Electric Illuminating Co	OH	Lake Erie	Northeast	Non-Nuclear	252	256	SR/GL	Med	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Ashville	Progress Energy Carolinas	NC	Lake Julian (Powell Creek)	Southeast	Non-Nuclear	316.2	383	LR/RL	Med	No	
Astoria	Astoria Generating Co LP	NY	East River	Northeast	Non-Nuclear	1769	1330	O/E/TR	Med	Unknown	
Avon Lake	RRI	OH	Lake Erie	Northeast	Non-Nuclear	625	766	SR/GL	Med	Unknown	
B C Cobb	Consumers Energy Co	MI	Muskogon Lake	Northeast	Non-Nuclear	583	531	SR/GL	Med	Unknown	
B L England (Beesley's Point)	Rockland Capital	NJ	Great Egg Harbor Bay	Northeast	Non-Nuclear	299	299	O/E/TR	Med	Unknown	
Bailly	Northern Indiana Pub Serv Co	IN	Lake Michigan	Northeast	Non-Nuclear	490	586	SR/GL	Med	Yes	
Barney M Davis	Topaz Power Group LLC	TX	Laguna Madre	Mid/West	Non-Nuclear	467	682	O/E/TR	Low	Unknown	
Barry Steam Electric	Alabama Power Co	AL	Mobile River	Southeast	Non-Nuclear	1119	1837	O/E/TR	Low	Yes	
Bartow	Progress Energy Florida	FL	Tampa Bay	Southeast	Non-Nuclear	562	419	O/E/TR	High	No	
Baxter Wilson	Entergy Mississippi Inc	MS	Mississippi River	Southeast	Non-Nuclear	297	1328	LR/RL	High	No	
Bay Front	Xcel	WI	Lake Superior	Northeast	Non-Nuclear	63.36	76	SR/GL	Med	Unknown	
Bay Shore	First Energy	OH	Lake Erie	Northeast	Non-Nuclear	810	849	SR/GL	Med	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Beaver Valley	AES Beaver Valley	PA	Ohio River	Northeast	Non-Nuclear	145	125	LR/RL	Low	Unknown	
Belews Creek	Duke Energy Corp	NC	Belews Lake	Southeast	Non-Nuclear	1457	2240	LR/RL	Med	Unknown	
Belle River	Detroit Edison Co	MI	St. Clair River	Northeast	Non-Nuclear	950	1270	SR/GL	Low	Yes	
Big Bend	Tampa Electric Co	FL	Hillsborough Bay	Southeast	Non-Nuclear	1396.04	1824	O/E/TR	Med	Unknown	
Big Brown	Luminant Generation Company LLC	TX	Fairfield Reservoir	Mid/West	Non-Nuclear	1015	1150	LR/RL	Low	No	
Big Cajun 2	NRG Louisiana Generating LLC	LA	Mississippi River	Mid/West	Non-Nuclear	380	615	LR/RL	Low	No	
Black Dog	Xcel	MN	Minnesota River	Mid/West	Non-Nuclear	307	401	SR/GL	High	No	
Blount Street	Madison Gas & Electric Co	WI	Lake Monona	Northeast	Non-Nuclear	169.9	194.6	LR/RL	High	Yes	
Bowline Point	Mirant Bowline LLC	NY	Hudson River	Northeast	Non-Nuclear	910.1	1150	O/E/TR	High	No	
Bremo Bluff	Dominion	VA	James River	Southeast	Non-Nuclear	179	250	SR/GL	Low	No	
Bridgeport Harbor	PSEG Power Connecticut LLC	CT	Bridgeport Harbor	Northeast	Non-Nuclear	440	566	O/E/TR	High	No	
Brooklin Navy Yard Cogen	Olympus Power, LLC	NY	East River	Northeast	Non-Nuclear	99	80	O/E/TR	High	Yes	
Browns Ferry	Tennessee Valley Authority	AL	Tennessee River	Southeast	Nuclear	2851.2	3840	LR/RL	Low	Unknown	22,215,744

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Brunner Island	PPL Corp	PA	Susquehanna River	Northeast	Non-Nuclear	795	1483	LR/RL	Med	Unknown	
Brunswick	Progress Energy Carolinas	NC	Cape Fear River	Southeast	Nuclear	1921	2060	O/E/TR	Med	No	14,453,721
Buck	Duke Energy Corp	NC	Yadkin River	Southeast	Non-Nuclear	395	487	SR/GL	Med	Unknown	
Bull Run	Tennessee Valley Authority	TN	Melton Hill Resevoir	Southeast	Non-Nuclear	590	911	LR/RL	Med	Unknown	
Burlington	Interstate Power & Light Co	IA	Mississippi River	Mid/West	Non-Nuclear	116.34	212	LR/RL	Low	No	
Burns Harbor Plant	International Steel Group	IN	Lake Michigan	Northeast	Non-Nuclear	97	176.2	SR/GL	Med	Unknown	
C D McIntosh	Lakeland Electric Utility	FL	Sewer Effluent & Lake Parker	Southeast	Non-Nuclear	212.8	713.3	LR/RL	Med	Unknown	
C P Crane	Constellation Power Source Gen	MD	Seneca Creek	Southeast	Non-Nuclear	446	385	O/E/TR	High	No	
Cabras	Guam Power Authority	Guam	Pacific Ocean	?	Non-Nuclear	238	210	O/E/TR	Low	Unknown	
Calaveris (O.W. Summers/J.T. Deely/J.K. Spruce)	CP San Antonio	TX	San Antonio River	Mid/West	Non-Nuclear	2248.6	3200	LR/RL	Low	Unknown	
Calvert Cliffs	Constellation Energy Group	MD	Chesapeake Bay	Southeast	Nuclear	3628.8	1735	O/E/TR	Med	Unknown	13,997,028

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Canaday	Nebraska Public Power District	NE	Platte River	Mid/West	Non-Nuclear	96.5	125	LR/RL	Low	Unknown	
Canal	Mirant Canal LLC	MA	Cape Cod Canal	Northeast	Non-Nuclear	580	1175	O/E/TR	Med	Unknown	
Cane Run	Louisville Gas & Electric Co	KY	Ohio River	Southeast	Non-Nuclear	370	645	LR/RL	Med	Yes	
Cape Canaveral	Florida Power & Light Co	FL	Indian River	Southeast	Non-Nuclear	792	500	O/E/TR	High	Yes	
Cape Fear	Progress Energy Carolinas	NC	Cape Fear River	Southeast	Non-Nuclear	342	870	SR/GL	Low	No	
Cardinal	Cardinal Operating Co	OH	Ohio River	Northeast	Non-Nuclear	1152	1200	LR/RL	Med	No	
Carl Bailey	Arkansas Electric Coop Corp	AR	White River	Mid/West	Non-Nuclear	97.9	124	LR/RL	Low	Unknown	
Cayuga	AES Cayuga LLC	NY	Cayuga Lake	Northeast	Non-Nuclear	245	306	LR/RL	Low	Unknown	
Cayuga	Duke Energy Corp	IN	Wabash River	Northeast	Non-Nuclear	766	1070	LR/RL	Low	Unknown	
Cedar Bayou - Units 1,2 & 4	NRG Energy, Inc.	TX	Upper Galveston Bay	Mid/West	Non-Nuclear	1132	1740	O/E/TR	Low	No	
Chalk Point LLC	Mirant Mid-Atlantic LLC	MD	Patuxent River	Southeast	Non-Nuclear	720	710	O/E/TR	Low	Unknown	
Chamois	Chamois	MO	Missouri River	Mid/West	Non-Nuclear	71	70	LR/RL	Low	No	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Charles R Lowman	Alabama Electric Coop Inc	AL	Tombigbee River	Southeast	Non-Nuclear	78	86	LR/RL	Low	Unknown	
Chesapeake	Virginia Electric & Power Co	VA	Elizabeth River	Southeast	Non-Nuclear	514	604	O/E/TR	High	No	
Chesterfield	Virginia Electric & Power Co	VA	James River	Southeast	Non-Nuclear	1091.4	1705	O/E/TR	Med	No	
Cheswick	Orion Power Midwest LP	PA	Allegheny River	Northeast	Non-Nuclear	376	637	LR/RL	High	Yes	
Clay Boswell Energy Center	Allete Inc	MN	North Blackwater Lake	Mid/West	Non-Nuclear	156	140	LR/RL	Med	No	
Cliffside	Duke Energy Corp	NC	Broad River	Southeast	Non-Nuclear	269	289	SR/GL	Med	Unknown	
Clifty Creek	Indiana-Kentucky Electric Corp	IN	Ohio River	Northeast	Non-Nuclear	1434	1306	LR/RL	Med	Yes	
Clinton	AmerGen Energy Co LLC	IL	Lake Clinton (dam on Salt Creek)	Northeast	Nuclear	889	1065	LR/RL	Low	No	8,288,461
Coffeen	Ameren Energy Generating Co	IL	Coffeen Lake	Northeast	Non-Nuclear	575	1005	LR/RL	Low	Unknown	
Colbert	Tennessee Valley Authority	AL	Tennessee River	Southeast	Non-Nuclear	1325	1332	LR/RL	Low	Unknown	
Comanche Peak	Luminant	TX	Squaw Creek Reservoir	Mid/West	Nuclear	3168	2300	LR/RL	Low	No	18,517,837

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Conesville	Columbus Southern Power Co	OH	Muskingum River	Northeast	Non-Nuclear	108	165	SR/GL	Low	No	
Conners Creek	Detroit Edison Co	MI	Detroit River	Northeast	Non-Nuclear	213	239	SR/GL	Med	Unknown	
Contra Costa	Mirant Delta LLC	CA	San Joaquin River	CA	Non-Nuclear	440	690	O/E/TR	Med	No	
Cooper	Nebraska Public Power District	NE	Missouri River	Mid/West	Nuclear	983.2	802	LR/RL	Low	Unknown	5,535,894
Costa Sur	Puerto Rico Electric Power	PR	Guayanilla Bay	Southeast	Non-Nuclear	874	1086	O/E/TR	Low	Unknown	
Covanta Mid-Connecticut Inc	Covanta Energy	CT	Connecticut River	Northeast	Non-Nuclear	75	90	LR/RL	Low	Unknown	
Crawford	Midwest Generation EME LLC	IL	Chicago Sanitary and Ship Canal	Northeast	Non-Nuclear	550	584	SR/GL	High	Yes	
Crist	Gulf Power Co	FL	Escambia River	Southeast	Non-Nuclear	156	150	O/E/TR	Med	No	
Cromby	Exelon Generation Co LLC	PA	Schuylkill River	Northeast	Non-Nuclear	359	380	SR/GL	Med	No	
Crystal River 1 and 2	Progress Energy Florida	FL	Gulf of Mexico	Southeast	Non-Nuclear	919	900	O/E/TR	Low	No	
Crystal River 3-nuclear	Progress Energy Florida	FL	Gulf of Mexico	Southeast	Nuclear	979	890	O/E/TR	Low	No	6,699,156
Cumberland	Tennessee Valley Authority	TN	Cumberland	Southeast	Non-Nuclear	2730	2650	LR/RL	Low	Unknown	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Cutler	Florida Power & Light Co	FL	Biscayne Bay	Southeast	Non-Nuclear	213	237	O/E/TR	High	Yes	
Dale	East Kentucky Power Coop Inc	KY	Kentucky River	Southeast	Non-Nuclear	290	176	SR/GL	Low	Unknown	
Dallman	City of Springfield	IL	Lake Springfield	Northeast	Non-Nuclear	353	387.7	LR/RL	Med	Unknown	
Dan E Karn/J.C. Weadock	Consumers Energy Co	MI	Saginaw River	Northeast	Non-Nuclear	432	515	SR/GL	Med	Unknown	
Dan River	Duke Energy Corp	NC	Dan River	Southeast	Non-Nuclear	279.85	361	SR/GL	Med	Unknown	
Danskammer	Dynegy	NY	Hudson River	Northeast	Non-Nuclear	455	493	O/E/TR	Med	Unknown	
Dave Johnston	PacifiCorp	WY	North Platte River	Mid/West	Non-Nuclear	193	454	SR/GL	Low	Unknown	
Decker Creek	City of Austin	TX	Lake Long	Mid/West	Non-Nuclear	695	726	LR/RL	Med	Unknown	
Deepwater	Conectiv Atlantic Generation LLC	NJ	Delaware River	Northeast	Non-Nuclear	221	166	O/E/TR	Low	Unknown	
Diablo Canyon	Pacific Gas & Electric Co	CA	Pacific Ocean	CA	Nuclear	2500	2298	O/E/TR	Low	No	17,252,284
Dickerson	Mirant Mid-Atlantic LLC	MD	Potomac River	Southeast	Non-Nuclear	407	576	SR/GL	Low	Unknown	
Dolphus M Grainger	South Carolina Pub Serv Auth	SC	Waccamaw River	Southeast	Non-Nuclear	116	180	SR/GL	Med	No	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Donald C. Cook Nuclear Plant	Indiana Michigan Power Co	MI	Lake Michigan	Northeast	Nuclear	2369	2161	SR/GL	Med	Yes	15,673,795
Dresden	Exelon Generation Co LLC	IL	Kankakee River	Northeast	Nuclear	1898	1914	SR/GL	Med	No	13,327,733
Dubuque	Alliant Energy	IA	Mississippi River	Mid/West	Non-Nuclear	82	77	LR/RL	Med	Unknown	
Dunkirk	NRG Dunkirk Power LLC	NY	Lake Erie	Northeast	Non-Nuclear	576	586	SR/GL	High	Yes	
E C Gaston	Alabama Power Co	AL	Coosa River	Southeast	Non-Nuclear	832	1000	SR/GL	Low	Yes	
E D Edwards	Ameren Energy Resources Generating	IL	Illinois River	Northeast	Non-Nuclear	579	780.3	SR/GL	Low	Unknown	
E F Barrett	National Grid/KeySpan	NY	Barnum Island Channel	Northeast	Non-Nuclear	294	380	O/E/TR	High	Yes	
E S Joslin	NuCoastal Corporation	TX	Lavaca Bay	Mid/West	Non-Nuclear	370	261	O/E/TR	Low	Unknown	
E.J. Stoneman	Mid-American Power, LLC	WI	Mississippi River	Northeast	Non-Nuclear	53	53	LR/RL	Low	Unknown	
Eagle Valley-HT Pritchard	AES Corporation	IN	White River	Northeast	Non-Nuclear	335	359	SR/GL	Med	Unknown	
East River	Consolidated Edison Co-NY Inc	NY	East River	Northeast	Non-Nuclear	368.4	599	O/E/TR	High	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Eastlake	First Energy	OH	Lake Erie	Northeast	Non-Nuclear	1146	1594	SR/GL	High	No	
Eaton	Southern Co.	MS	Leaf River	Southeast	Non-Nuclear	108	67.5	SR/GL	High	No	
Eddystone	Exelon Generation Co LLC	PA	Delaware River	Northeast	Non-Nuclear	1469	1570	O/E/TR	High	No	
Edge Moor	Conectiv Delmarva Generation Inc	DE	Delaware River	Northeast	Non-Nuclear	837	705	O/E/TR	Low	No	
Edgewater	Wisconsin Power & Light Co (Alliant)	WI	Lake Michigan	Northeast	Non-Nuclear	463	770	SR/GL	High	No	
Edwardsport	Duke Energy Corp	IN	West fork of White River	Northeast	Non-Nuclear	186.79	144.2	SR/GL	Low	Unknown	
El Segundo	NRG - El Segundo Power LLC	CA	Pacific Ocean	CA	Non-Nuclear	381	941	O/E/TR	Low	Yes	
Elk River	GRE	MN	Mississippi River	Mid/West	Non-Nuclear	73	195	LR/RL	Med	No	
Elmer Smith	City of Owensboro	KY	Ohio River	Southeast	Non-Nuclear	265	441	LR/RL	Med	Unknown	
Elrama	Orion Power Midwest LP	PA	Monon-gahela River	Northeast	Non-Nuclear	518	510	LR/RL	Med	Unknown	
Encina	NRG	CA	Agua Hedionda Lagoon	CA	Non-Nuclear	857	964	O/E/TR	High	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
F B Culley	Southern Indiana Gas & Elec Co	IN	Ohio River	Northeast	Non-Nuclear	316.8	389	LR/RL	Low	Unknown	
Fair	Central Iowa Power Coop	IA	Mississippi River	Mid/West	Non-Nuclear	71	62.5	LR/RL	Low	Unknown	
Fairless Hills	Exelon Generation Company, LLC	PA	Delaware River	Northeast	Non-Nuclear	77.8	60	O/E/TR	Low	No	
Far Rockaway	National Grid/KeySpan	NY	Mott Basin	Northeast	Non-Nuclear	87	106	O/E/TR	Low	Unknown	
Fayette/Sam Seymore	LCRA Fayette Power Project	TX	Fayette Power Project Lake	Mid/West	Non-Nuclear	1165	1641	LR/RL	Low	Unknown	
Fisk Street	Midwest Generation EME LLC	IL	Chicago River--South Branch	Northeast	Non-Nuclear	323	348	SR/GL	Low	No	
Flint Creek	Southwestern Electric Co	AR	Flint Creek Reservoir	Mid/West	Non-Nuclear	412	559	LR/RL	Low	No	
Forest Grove	Luminant	TX	Forest Grove Reservoir	Mid/West	Non-Nuclear	1470	1500	LR/RL	Low	Unknown	
Fort Calhoun	Omaha Public Power District	NE	Missouri River	Mid/West	Nuclear	518.4	482	LR/RL	Med	Unknown	3,345,253
Fort Myers	Florida Power & Light Co	FL	Caloo-sahatchee River	Southeast	Non-Nuclear	730	573	O/E/TR	Med	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Fox Lake	Interstate Power & Light Co (Alliant)	MN	Fox Lake	Mid/West	Non-Nuclear	100.83	98	LR/RL	Low	Unknown	
Frank E Ratts	Hoosier Energy R E C Inc	IN	White River	Northeast	Non-Nuclear	102.1	256	LR/RL	Low	Unknown	
G F Weaton	Zinc Corp of America	PA	Ohio River	Northeast	Non-Nuclear	88	120	LR/RL	High	Yes	
Gadsden	Alabama Power Co	AL	Coosa River	Southeast	Non-Nuclear	219	120	SR/GL	High	No	
Gallatin	Tennessee Valley Authority	TN	Cumberland	Southeast	Non-Nuclear	916	1086	LR/RL	Med	Unknown	
Gary Works	United States Steel Corp	IN	Lake Michigan	Northeast	Non-Nuclear	122.15	231	SR/GL	Med	Unknown	
Genoa	Dairyland Power Coop	WI	Mississippi River	Northeast	Non-Nuclear	252	360	LR/RL	Low	Yes	
George Neal North	MidAmerican Energy Co	IA	Missouri River	Mid/West	Non-Nuclear	791	1046	LR/RL	Low	Yes	
George Neal South	MidAmerican Energy Co	IA	Missouri River	Mid/West	Non-Nuclear	468	640	LR/RL	Low	Yes	
Georgia Pacific Cedar Springs	Georgia-Pacific Corp	GA	Chatta-hoochee River	Southeast	Non-Nuclear	85	101.2	SR/GL	Low	Unknown	
Gerald Andrus	Entergy Mississippi Inc	MS	Mississippi River	Southeast	Non-Nuclear	260	750	LR/RL	Low	No	
Gerald Gentleman	Nebraska Public Power District	NE	Sutherland Supply Canal	Mid/West	Non-Nuclear	760.3	1444	LR/RL	Low	Unknown	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
GEUS Steam Plant	Greenville Electric Util Sys	TX	No 4 Resevoir	Mid/West	Non-Nuclear	84	84	LR/RL	Low	Unknown	
Gibbons Creek	Texas Municipal Power Agency	TX	Gibbons Creek Reservoir	Mid/West	Non-Nuclear	418	454	LR/RL	Low	Unknown	
Glen Lyn	Appalachian Power Co	VA	New River	Southeast	Non-Nuclear	373	335	SR/GL	Low	Yes	
Glenwood	National Grid/KeySpan	NY	Hempstead Harbor	Northeast	Non-Nuclear	179	218	O/E/TR	High	Yes	
Gorgas	Alabama Power Co	AL	Warrior River	Southeast	Non-Nuclear	979	1221	SR/GL	Low	No	
Gould Street	Constellation Energy Group	MD	Patapsco River	Southeast	Non-Nuclear	98.6	97	O/E/TR	High	Yes	
Graham	Luminant Generation Company LLC	TX	Graham Reservoir	Mid/West	Non-Nuclear	505	630	LR/RL	Low	No	
Grand Tower	Ameren Energy Generating Co	IL	Mississippi River	Northeast	Non-Nuclear	229	199.3	LR/RL	Low	Unknown	
Grays Ferry	Trigen Phildelphia Energy Corp	PA	Scuylkill River	Northeast	Non-Nuclear	64	57.6	O/E/TR	High	Yes	
Green Bay West Mill	Fort James Operating Co	WI	Lower Fox River	Northeast	Non-Nuclear	120.21	135.8	SR/GL	Med	Unknown	
Green River	Kentucky Utilities Co	KY	Green River	Southeast	Non-Nuclear	177	231	SR/GL	Med	Yes	
Greene County	Alabama Power Co	AL	Black Warrior	Southeast	Non-Nuclear	395.54	500	SR/GL	Low	No	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Greenidge LLC	AES Greenidge LLC	NY	Seneca Lake	Northeast	Non-Nuclear	146.07	107	LR/RL	Low	Unknown	
H L Culbreath Bayside	Tampa Electric Co	FL	Hillsborough Bay	Southeast	Non-Nuclear	2465.3	685.1	O/E/TR	Med	Unknown	
H.A. Wagner	Constellation Power Source Gen	MD	Pataspsco River	Southeast	Non-Nuclear	1060	982	O/E/TR	Med	Unknown	
H.B. Robinson	Progress Energy	SC	Lake Robinson	Southeast	Non-Nuclear	126	185	LR/RL	Low	No	
H.B. Robinson-nuclear	Progress Energy	SC	Lake Robinson	Southeast	Nuclear	740.2	700	LR/RL	Low	No	5,479,054
Hamilton	City of Hamilton	OH	Miami River	Northeast	Non-Nuclear	485	110.6	SR/GL	High	Yes	
Hammond	Georgia Power	GA	Lake Weiss	Southeast	Non-Nuclear	548	800	LR/RL	Low	Yes	
Handley	ExTex LaPorte LP	TX	Lake Arlington	Mid/West	Non-Nuclear	1121	1315	LR/RL	High	No	
Harbor	LADWP	CA	Pacific Ocean	CA	Non-Nuclear	108	75	O/E/TR	Low	Yes	
Harbor Beach	Detroit Edison Co	MI	Lake Huron	Northeast	Non-Nuclear	130	103	SR/GL	Low	Yes	
Harding Street	Indianapolis Power & Light Co	IN	West fork of White River	Northeast	Non-Nuclear	238	360	SR/GL	High	Yes	
Harllee Branch	Georgia Power	GA	Lake Sinclair	Southeast	Non-Nuclear	1139	1735	LR/RL	Low	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Hawthorn	Kansas City Power & Light Co	MO	Missouri River	Mid/West	Non-Nuclear	282.8	693	LR/RL	Med	Unknown	
Haynes	LADWP	CA	Pacific Ocean	CA	Non-Nuclear	1014	1279	O/E/TR	Med	Yes	
Healy	Golden Valley Electric Association	AK	Nenana River	Mid/West	Non-Nuclear	52.9	75	SR/GL	Low	Unknown	
Hennepin	Dynegy	IL	Illinois River	Northeast	Non-Nuclear	230	293	SR/GL	Low	Unknown	
Henry D King	Fort Pierce Utilities Auth	FL	Moore's Creek	Southeast	Non-Nuclear	107.93	113.9	O/E/TR	High	Yes	
Hibbard Energy Center	Minnesota Power Inc	MN	St. Louis River	Mid/West	Non-Nuclear	235.91	124	SR/GL	Med	Yes	
High Bridge	Xcel	MN	Mississippi River	Mid/West	Non-Nuclear	390	510	LR/RL	High	Yes	
Honolulu	Hawaiian Electric Co Inc	HI	Pacific Ocean	CA	Non-Nuclear	184	103	O/E/TR	High	Yes	
Hoot Lake	Otter Tail Power Co	MN	Otter Tail River	Mid/West	Non-Nuclear	116.34	136.9	SR/GL	Med	Unknown	
Horseshoe Lake	Oklahoma Gas & Electric Co	OK	Horseshoe Lake	Mid/West	Non-Nuclear	399.6	395.7	LR/RL	Med	Unknown	
Hudson	PSEG Fossil LLC	NJ	Hackensack River	Northeast	Non-Nuclear	892	983	O/E/TR	Low	No	
Humboldt Bay	PG&E	CA	Pacific Ocean	CA	Non-Nuclear	142	102.4	O/E/TR	Med	Unknown	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Hunlock	UGI	PA	Susquehanna River	Northeast	Non-Nuclear	61	49.9	SR/GL	Med	Unknown	
Huntington Beach LLC	AES Huntington Beach LLC	CA	Pacific Ocean	CA	Non-Nuclear	514	880	O/E/TR	High	Yes	
Huntley Steam	NRG Huntley Power LLC	NY	Niagara River	Northeast	Non-Nuclear	346	816	SR/GL	Med	Unknown	
Hutsonville	Ameren Energy Generating Co	IL	Wabash River	Northeast	Non-Nuclear	173	167	LR/RL	Low	Unknown	
Iatan	Empire District Electric	MO	Missouri River	Mid/West	Non-Nuclear	424.5	706	LR/RL	Low	Unknown	
Indian Point	Entergy Nuclear Indian Point 2, LLC	NY	Hudson River	Northeast	Nuclear	2419.2	2028	O/E/TR	Med	Unknown	16,287,776
Indian River	RRI Energy Florida LLC	FL	Indian River	Southeast	Non-Nuclear	835	609	O/E/TR	Med	Unknown	
Indian River	NRG Indian River Operations Inc	DE	Indian River	Northeast	Non-Nuclear	378	432	O/E/TR	Low	No	
J B Sims	Grand Haven BL&P	MI	Grand River	Northeast	Non-Nuclear	60	75	O/E/TR	High	No	
J E Corette Plant	PPL Montana LLC	MT	Yellowstone River	Mid/West	Non-Nuclear	75	154	SR/GL	Med	Unknown	
J H Campbell	Consumers Energy Co	MI	Lake Michigan	Northeast	Non-Nuclear	936	1440	SR/GL	Med	Unknown	
J M Stuart	Dayton Power & Light Co	OH	Ohio River	Northeast	Non-Nuclear	904	1869	LR/RL	Low	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
J R Whiting	Consumers Energy Co	MI	North Maumee Bay	Northeast	Non-Nuclear	322.6	328	SR/GL	Med	Unknown	
J Sherman Cooper	East Kentucky Power Coop Inc	KY	Cumberland River	Southeast	Non-Nuclear	208.11	341	LR/RL	Med	Unknown	
J.P. Pulliam	Wisconsin Public Service Corp	WI	Green Bay	Northeast	Non-Nuclear	523	373	SR/GL	Med	No	
Jack Watson	Mississippi Power Co	MS	Biloxi River	Southeast	Non-Nuclear	441	512	O/E/TR	Med	No	
James A FitzPatrick	Entergy Nuc FitzPatrick LLC	NY	Lake Ontario	Northeast	Nuclear	518	852	SR/GL	Low	No	6,709,978
James De Young	Holland Board of Public Works	MI	Lake Macatawa	Northeast	Non-Nuclear	102.5	62.8	SR/GL	High	No	
James River	City of Springfield	MO	Lake Springfield	Mid/West	Non-Nuclear	279	253	LR/RL	Med	Unknown	
Jefferies	South Carolina Pub Serv Auth	SC	TL RC CNL	Southeast	Non-Nuclear	357	508	O/E/TR	Low	No	
John Sevier	Tennessee Valley Authority	TN	Holston River	Southeast	Non-Nuclear	714	816	SR/GL	Low	Unknown	
Johnsonville	Tennessee Valley Authority	TN	Tennessee River	Southeast	Non-Nuclear	1601	1408	LR/RL	Low	Unknown	
Joliet 29	Midwest Generation EME LLC	IL	Desplaines River	Northeast	Non-Nuclear	1424	1189	SR/GL	Med	No	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Joliet 9	Midwest Generation EME LLC	IL	Desplaines River	Northeast	Non-Nuclear	438	341	SR/GL	Med	No	
Joppa Steam	Electric Energy Inc	IL	Ohio River	Northeast	Non-Nuclear	589	1100	LR/RL	Low	Unknown	
Kahe	Hawaiian Electric Co Inc	HI	Pacific Ocean	CA	Non-Nuclear	847	650	O/E/TR	Med	Yes	
Kammer	Ohio Power Co	WV	Ohio River	Southeast	Non-Nuclear	713	630	LR/RL	Low	Yes	
Kanawha River	Appalachian Power Co	WV	Kanawha River	Southeast	Non-Nuclear	403	426	LR/RL	Low	Yes	
Kaw	Board of Public Utilities-City of Kansas	KS	Kaw River	Mid/West	Non-Nuclear	120.1	166	SR/GL	High	Yes	
Kendall	Mirant Kendall LLC	MA	Charles River	Northeast	Non-Nuclear	78	67	SR/GL	High	Yes	
Kenneth C Coleman	Western Kentucky Energy Corp	KY	Ohio River	Southeast	Non-Nuclear	335	521.2	LR/RL	Low	Unknown	
Kewaunee	Dominion Energy Kewaunee, Inc.	WI	Lake Michigan	Northeast	Nuclear	582	595	SR/GL	Low	Yes	3,635,334
Kincaid	Dominion Energy	IL	Sangchris Lake	Northeast	Non-Nuclear	461	1182	LR/RL	Low	Yes	
Kingston	Tennessee Valley Authority	TN	Emory River	Southeast	Non-Nuclear	1495	1677	SR/GL	Med	Unknown	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Knox Lee	Southwestern Electric Power Co	TX	Lake Cherokee	Mid/West	Non-Nuclear	639	500	LR/RL	Med	No	
Kraft	Savannah Electric & Power Co	GA	Savannah River	Southeast	Non-Nuclear	259	479	O/E/TR	Low	No	
Kyger Creek	Ohio Valley Electric Corp	OH	Ohio River	Northeast	Non-Nuclear	1166	1085	LR/RL	Low	Yes	
Kyrene	Salt River Proj Ag I & P Dist	AZ	Canal Well	Mid/West	Non-Nuclear	96	96	SR/GL	High	No	
La Cygne	Kansas City Power & Light Co	KS	La Cygne Reservoir	Mid/West	Non-Nuclear	726.1	1418	LR/RL	Low	Unknown	
Labadie	Ameren UE	MO	Missouri River	Mid/West	Non-Nuclear	1232.6	2560	LR/RL	Med	Unknown	
Lake Catherine	Entergy Arkansas Inc	AR	Lake Catherine	Mid/West	Non-Nuclear	564.5	673	LR/RL	Med	Unknown	
Lake Hubbard	Luminant Generation Company LLC	TX	Lake Ray Hubbard Reservoir	Mid/West	Non-Nuclear	870	921	LR/RL	High	No	
Lake Road	Aquila Inc	MO	Missouri River	Mid/West	Non-Nuclear	85.8	99	LR/RL	Low	Unknown	
Lake Shore	Cleveland Electric Illum Co	OH	Lake Erie	Northeast	Non-Nuclear	246	256	SR/GL	High	Yes	
Lansing	Interstate Power & Light Co (Alliant)	IA	Mississippi River	Mid/West	Non-Nuclear	299	317	LR/RL	Low	Unknown	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Lansing Smith	Southern Co.	FL	North Bay	Southeast	Non-Nuclear	260.1	384	O/E/TR	Med	No	
Lauderdale	Florida Power & Light Co	FL	Dania Cut-Off Canal	Southeast	Non-Nuclear	368	312	O/E/TR	High	Yes	
Leland Olds	Basin Electric Power Coop	ND	Missouri River	Mid/West	Non-Nuclear	330	656	LR/RL	Low	Yes	
Lieberman	SWEPCO	LA	Caddo Lake	Mid/West	Non-Nuclear	134	286	LR/RL	Low	No	
Little Gypsy	Entergy Louisiana Inc	LA	Mississippi River	Mid/West	Non-Nuclear	468	1251	LR/RL	Low	Yes	
Lonestar	Southwestern Electric Power Co	TX	Ellison Creek Reservoir	Mid/West	Non-Nuclear	79	40	LR/RL	Low	Unknown	
Maine Energy Recovery Co	Central Maine Power Co	ME	Saco River	Northeast	Non-Nuclear	93.6	22	O/E/TR	High	Yes	
Manchester Street	Narraganset Electric Co	RI	Providence River	Northeast	Non-Nuclear	259	168	O/E/TR	High	Yes	
Mandalay	RRI Energy Mandalay LLC	CA	Pacific Ocean	CA	Non-Nuclear	254	430	O/E/TR	Med	No	
Manitowoc	Manitowoc Public Utilities	WI	Lake Michigan	Northeast	Non-Nuclear	51.8	79	SR/GL	High	No	
Marion	Southern Illinois Power Coop	IL	Lake Egypt	Northeast	Non-Nuclear	225	272	LR/RL	Low	Unknown	
Marshall Steam	Duke Energy Corp	NC	Lake Norman	Southeast	Non-Nuclear	1463	2090	LR/RL	Med	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Martin Lake	Luminant Generation Company LLC	TX	Martin Creek Reservoir	Mid/West	Non-Nuclear	2411	2250	LR/RL	Low	No	
Marysville	Detroit Edison Co	MI	St Clair River	Northeast	Non-Nuclear	368	84	SR/GL	High	Yes	
McClellan	Arkansas Electric Coop Corp	AR	Ouachita River	Mid/West	Non-Nuclear	71	136	SR/GL	Med	Unknown	
McGuire	Duke Energy Corp	NC	Lake Norman	Southeast	Nuclear	2927.6	2240	LR/RL	Med	Unknown	18,007,097
McIntosh	Savannah Electric & Power Co	GA	Savannah River	Southeast	Non-Nuclear	91	167	SR/GL	Med	No	
McManus	Georgia Power	GA	Turtle River	Southeast	Non-Nuclear	166	115	O/E/TR	Med	No	
Meramec	Ameren UE	MO	Mississippi River	Mid/West	Non-Nuclear	675	1035	LR/RL	High	No	
Mercer	PSEG Fossil LLC	NJ	Delaware River	Northeast	Non-Nuclear	691	648	O/E/TR	High	No	
Meredosia	Ameren Energy Generating Co	IL	Illinois River	Northeast	Non-Nuclear	391.7	354.3	LR/RL	Low	Unknown	
Merom	Hoosier Energy R E C Inc	IN	Turtle Creek Reservoir	Northeast	Non-Nuclear	484	1139	LR/RL	Low	No	
Merrimack	Public Service Co of NH	NH	Merrimack River	Northeast	Non-Nuclear	286.9	474	SR/GL	Med	Unknown	
Miami Fort	Duke Energy Corp	OH	Ohio River	Northeast	Non-Nuclear	129.6	163	LR/RL	Med	Unknown	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Michoud	Entergy New Orleans Inc	LA	Miss River Gulf Outlet	Mid/West	Non-Nuclear	763	918	O/E/TR	Low	Unknown	
Mid Connecticut Resource Recovery Facility	Connecticut Resources Recovery Authority	CT	Connecticut River	Northeast	Non-Nuclear	108	90	LR/RL	High	No	
Middletown	NRG Middletown Power LLC	CT	Connecticut River	Northeast	Non-Nuclear	224	353	LR/RL	Med	No	
Mill Creek	Louisville Gas & Electric Co	KY	Ohio River	Southeast	Non-Nuclear	233	419	LR/RL	Med	Yes	
Millstone	Dominion Nuclear Conn Inc	CT	Long Island Sound	Northeast	Nuclear	2190	2205	O/E/TR	Med	Unknown	15,959,448
Milton L Kapp	Interstate Power & Light Co (Alliant)	IA	Mississippi River	Mid/West	Non-Nuclear	197	254.9	LR/RL	Med	Unknown	
Milton R Young	Minnkota Power Coop Inc	ND	Nelson Lake	Mid/West	Non-Nuclear	529.98	700	LR/RL	Low	No	
Missouri City	Independent Blue Valley Power Plant	MO	Missouri River	Mid/West	Non-Nuclear	415.9	46	LR/RL	Low	Unknown	
Mistersky	City of Detroit	MI	Detroit River	Northeast	Non-Nuclear	198.42	189	SR/GL	High	Yes	
Mitchell	Georgia Power	GA	Flint River	Southeast	Non-Nuclear	173	125	SR/GL	Med	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Mitchell	Allegheny Energy Supply Co LLC	PA	Monongahela River	Northeast	Non-Nuclear	255	365	LR/RL	Med	Unknown	
Monroe	Detroit Edison Co	MI	River Raisin and Lake Erie	Northeast	Non-Nuclear	2010	3110	SR/GL	Med	No	
Monticello	Xcel Energy	MN	Mississippi River	Mid/West	Nuclear	444	620	LR/RL	Med	Unknown	4,720,869
Monticello Steam Electric	Luminant Generation Company LLC	TX	Monticello Reservoir	Mid/West	Non-Nuclear	1732	1880	LR/RL	Low	No	
Montrose	Kansas City Power & Light Co	MO	Montrose Reservoir	Mid/West	Non-Nuclear	370.3	510	LR/RL	Low	Unknown	
Montville	NRG Montville Power LLC	CT	Thames River	Northeast	Non-Nuclear	314.76	516	O/E/TR	High	No	
Morgantown	Dominion Energy Services Company, Inc.	WV	Monongahela River	Southeast	Non-Nuclear	80	58	LR/RL	High	Yes	
Morgantown	Mirant Mid-Atlantic LLC	MD	Potomac River	Southeast	Non-Nuclear	1234	1248	O/E/TR	Low	Unknown	
Morro Bay	Dynegy	CA	Morro Bay	CA	Non-Nuclear	453	600	O/E/TR	Med	Yes	
Moss Landing	Dynegy	CA	Moss Landing Harbor	CA	Non-Nuclear	1224	1899	O/E/TR	Low	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Mount Tom	Northeast Generation Services Co	MA	Connecticut River	Northeast	Non-Nuclear	143	144	LR/RL	Med	Unknown	
Mountain Creek	ExTex LaPorte LP	TX	Mountian Creek Lake	Mid/West	Non-Nuclear	722	810	LR/RL	High	Yes	
Mt Storm	Virginia Electric & Power Co	WV	Stony River	Southeast	Non-Nuclear	1184	1693	LR/RL	Low	No	
Muscatine Plant #1	City of Muscatine	IA	Mississippi River	Mid/West	Non-Nuclear	287.61	293.5	LR/RL	Med	Unknown	
Muskingum River	Ohio Power Co	OH	Muskingum River	Northeast	Non-Nuclear	864	840	SR/GL	Low	No	
Muskogee	Oklahoma Gas & Electric Co	OK	Arkansas River	Mid/West	Non-Nuclear	106.6	180	SR/GL	Low	Unknown	
Mystic (Unit 7)	U.S. Power Gen	MA	Mystic River	Northeast	Non-Nuclear	646	560	O/E/TR	High	Yes	
Natrium Plant	PPG Industries Inc	WV	Ohio River	Southeast	Non-Nuclear	65	123	LR/RL	Low	Unknown	
Nebraska City	Omaha Public Power District	NE	Missouri River	Mid/West	Non-Nuclear	432	653	LR/RL	Low	Unknown	
Nelson Dewey	Wisconsin Power & Light Co (Alliant)	WI	Mississippi River	Northeast	Non-Nuclear	167	200	LR/RL	Low	Unknown	
New Castle Plant	RRI Energy	PA	Beaver River	Northeast	Non-Nuclear	253	348	SR/GL	High	No	
New Haven Harbor	PSEG Power Connecticut LLC	CT	New Haven Harbor	Northeast	Non-Nuclear	403.95	466	O/E/TR	High	No	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
New Madrid	Associated Electric Coop Inc	MO	Mississippi River	Mid/West	Non-Nuclear	864	1200	LR/RL	Low	No	
Newington	Public Service Co of NH	NH	Piscataqua River	Northeast	Non-Nuclear	324.8	422	O/E/TR	Med	Unknown	
Newton	Ameren Energy Generating Co	IL	Newton Lake	Northeast	Non-Nuclear	806	1288	LR/RL	Low	Unknown	
Niles	RRI	OH	Mahoning River	Northeast	Non-Nuclear	403	266	SR/GL	Med	Unknown	
Nine Mile Point	Entergy Louisiana Inc	LA	Mississippi River	Mid/West	Non-Nuclear	611.3	1566	LR/RL	Med	Yes	
Nine Mile Point, NY	Constellation Energy Group	NY	Lake Ontario	Northeast	Nuclear	516.9	623	SR/GL	Med	Unknown	13,887,514
Noblesville	Duke Energy Corp	IN	West fork of White River	Northeast	Non-Nuclear	207	100	SR/GL	Med	Unknown	
North Anna	Dominion Resources, Inc.	VA	Lake Anna	Southeast	Nuclear	2707	1956	LR/RL	Low	No	14,383,244
North Omaha	Omaha Public Power District	NE	Missouri River	Mid/West	Non-Nuclear	529	664	LR/RL	Med	Unknown	
North Texas	Brazos Electric Power Coop Inc	TX	Lake Weatherford	Mid/West	Non-Nuclear	95	71	LR/RL	Med	Unknown	
Northport	National Grid/KeySpan	NY	Long Island Sound	Northeast	Non-Nuclear	926	1500	O/E/TR	High	No	
Northside	JEA	FL	St Johns River	Southeast	Non-Nuclear	648	1159	O/E/TR	Med	Unknown	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Norwalk Harbor	NRG Norwalk Harbor Power LLC	CT	Long Island Sound	Northeast	Non-Nuclear	312	330	O/E/TR	High	No	
O H Hutchings	Dayton Power & Light Co	OH	Great Miami River	Northeast	Non-Nuclear	402.5	399	SR/GL	Med	Unknown	
Oak Creek/Elm Road	Wisconsin Electric Power Co	WI	Lake Michigan	Northeast	Non-Nuclear	1180.8	1139	SR/GL	Med	Unknown	
Oak Grove	Luminant Generation Company LLC	TX	Twin Oak Reservoir	Mid/West	Non-Nuclear	1610	1710	LR/RL	Low	No	
Oconee	Duke Energy Corp	SC	Lake Keowee	Southeast	Nuclear	3058	2538	LR/RL	Med	Unknown	19,302,727
Ormond Beach	RRI Energy Ormond Beach, Inc.	CA	Pacific Ocean	CA	Non-Nuclear	685	1516	O/E/TR	Med	No	
Oswego Harbor	NRG Oswego Power LLC	NY	Lake Ontario	Northeast	Non-Nuclear	1132	1740	SR/GL	High	Yes	
Otto E. Eckert	Lansing Board of Water and Light	MI	Grand River	Northeast	Non-Nuclear	233	330	SR/GL	High	No	
Oyster Creek	AmerGen Energy Co LLC	NJ	Barnegat Bay	Northeast	Nuclear	1394.4	630	O/E/TR	High	Yes	4,960,934
P H Robinson	NRG Energy, Inc.	TX	Galveston Bay	Mid/West	Non-Nuclear	1681	2285	O/E/TR	High	Yes	
Palo Seco	Puerto Rico Electric Power	PR	Boca Vieja Cove	Southeast	Non-Nuclear	654	602	O/E/TR	Low	Unknown	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Paradise	Tennessee Valley Authority	KY	Green River	Southeast	Non-Nuclear	608	2427	SR/GL	Low	Unknown	
Peach Bottom Atomic	Exelon Generation Co LLC	PA	Reservoir within Susquehanna River	Northeast	Nuclear	2281	2186	LR/RL	Med	No	18,315,457
Peru	Peru Light & Power Co	IN	Wabash River	Northeast	Non-Nuclear	55.4	34.5	LR/RL	High	Yes	
Petersburg	Indianapolis Power & Light Co	IN	White River	Northeast	Non-Nuclear	428	880	LR/RL	Low	Unknown	
Philip Sporn	Central Operating Co	WV	Ohio River	Southeast	Non-Nuclear	1038	1050	LR/RL	Low	Yes	
Picway	Columbus Southern Power Co	OH	Scioto River	Northeast	Non-Nuclear	101	100	SR/GL	Med	No	
Pilgrim	Entergy Nuclear Generation Co	MA	Cape Cod Bay	Northeast	Nuclear	446.4	706	O/E/TR	Med	No	5,475,467
Pirkey	SWEPCO	TX	Brandy Branch Reservoir	Mid/West	Non-Nuclear	544.3	700	LR/RL	Low	No	
Pittsburg	Mirant Delta LLC	CA	Sacramento/ San Joaquin River	CA	Non-Nuclear	462.2	645	O/E/TR	Med	Yes	
Point Beach	FPL Energy	WI	Lake Michigan	Northeast	Nuclear	1008	1365	SR/GL	Low	No	7,762,897
Port Everglades	Florida Power & Light Co	FL	Intercoastal Waterway	Southeast	Non-Nuclear	1253	1254	O/E/TR	High	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Port Jefferson	National Grid/KeySpan	NY	Long Island Sound	Northeast	Non-Nuclear	294	380	O/E/TR	High	No	
Port Washington	Wisconsin Electric Power Co	WI	Lake Michigan	Northeast	Non-Nuclear	813.6	1206	SR/GL	High	Yes	
Portland	RRI Energy Mid-Atlantic PH	PA	Delaware River	Northeast	Non-Nuclear	314	427	SR/GL	Med	Unknown	
Possum Point	Virginia Electric & Power Co	VA	Potomac River	Southeast	Non-Nuclear	224	313	O/E/TR	Med	No	
Potomac River	Mirant Mid-Atlantic LLC	VA	Potomac River	Southeast	Non-Nuclear	450	510	O/E/TR	High	Yes	
Prairie Creek	Interstate Power & Light Co (Alliant)	IA	Cedar River	Mid/West	Non-Nuclear	205	238	SR/GL	Med	Unknown	
Prairie Island	Xcel Energy	MN	Mississippi River	Mid/West	Nuclear	969	1150	LR/RL	Med	Unknown	8,271,648
Presque Isle	Wisconsin Electric Power Co	MI	Lake Superior	Northeast	Non-Nuclear	350	450	SR/GL	Med	Unknown	
Quad Cities	Exelon Generation Co LLC	IL	Mississippi River	Northeast	Nuclear	1356	1824	LR/RL	Low	No	13,079,844
Quindaro	City of Kansas City	KS	Missouri River	Mid/West	Non-Nuclear	265	239.1	LR/RL	Low	Unknown	
R A Reid	Big River Energy Corp.	KY	Green River	Southeast	Non-Nuclear	130	96	SR/GL	Low	Unknown	
R E Burger	Ohio Edison Co	OH	Ohio River	Northeast	Non-Nuclear	225	415.5	LR/RL	Low	No	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
R Gallagher	Duke Energy Corp	IN	Ohio River	Northeast	Non-Nuclear	436	616	LR/RL	High	No	
R M Heskett	MDU Resources Group Inc	ND	Missouri River	Mid/West	Non-Nuclear	64	115	LR/RL	Med	Unknown	
R Paul Smith	Allegheny Energy Supply Co LLC	MD	Potomac River	Southeast	Non-Nuclear	103.4	116	SR/GL	Med	Unknown	
R W Miller	Brazos Electric Power Coop Inc	TX	Lake Palo Pinto	Mid/West	Non-Nuclear	396	603.6	LR/RL	Low	Unknown	
R. E. Ginna	Constellation Energy Group	NY	Lake Ontario	Northeast	Nuclear	535.7	581	SR/GL	Med	Unknown	4,014,911
Ravenswood	TransCanada	NY	East River	Northeast	Non-Nuclear	1389.6	1752	O/E/TR	High	Yes	
Ray Olinger	City of Garland	TX	Lake Lavon	Mid/West	Non-Nuclear	357	345	LR/RL	Low	Unknown	
Red Wing	Xcel	MN	Mississippi River	Mid/West	Non-Nuclear	50	26	LR/RL	Med	Unknown	
Redondo Beach LLC	AES Redondo Beach LLC	CA	Pacific Ocean	CA	Non-Nuclear	891	1310	O/E/TR	High	Yes	
Richard Gorsuch	American Mun Power-Ohio Inc	OH	Ohio River	Northeast	Non-Nuclear	187	213	LR/RL	Med	Yes	
River Rouge	Detroit Edison Co	MI	Detroit River	Northeast	Non-Nuclear	441	540	SR/GL	Low	Unknown	
Riverbend	Duke Energy Corp	NC	Mt. Island Lake	Southeast	Non-Nuclear	415	470	LR/RL	Med	Unknown	
Riverside	MidAmerican Energy Co	IA	Mississippi River	Mid/West	Non-Nuclear	90	141	LR/RL	Med	No	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Riverside	Xcel	MN	Mississippi River	Mid/West	Non-Nuclear	277	420	LR/RL	High	Yes	
Riverside	Constellation	MD	Patapsco River	Southeast	Non-Nuclear	60.8	78	O/E/TR	High	Yes	
Riverton	Empire District Electric	KS	Spring River	Mid/West	Non-Nuclear	105	87.5	SR/GL	Low	Unknown	
Rivesville	Monongahela Power Co	WV	Monongahela River	Southeast	Non-Nuclear	118.92	137	LR/RL	Med	Unknown	
Riviera	Florida Power & Light Co	FL	Lake Worth	Southeast	Non-Nuclear	564.88	600	O/E/TR	High	Yes	
Robert E Ritchie	Entergy Arkansas Inc	AR	Mississippi River	Mid/West	Non-Nuclear	454	919	LR/RL	Low	No	
Roseton	Dynegy	NY	Hudson River	Northeast	Non-Nuclear	924	1185	O/E/TR	Med	Unknown	
Roxboro	Progress Energy Florida	NC	Hyco Lake	Southeast	Non-Nuclear	1096.1	1775	LR/RL	Low	No	
Rush Island	Ameren UE	MO	Mississippi River	Mid/West	Non-Nuclear	1097	1340	LR/RL	Low	Unknown	
S O Purdom	City of Tallahassee	FL	St Marks River	Southeast	Non-Nuclear	134	137	O/E/TR	Low	Unknown	
Sabine	Entergy Gulf States Inc	TX	Sabine Lake	Mid/West	Non-Nuclear	1275.4	2167	LR/RL	Med	Yes	
Salem	PSEG Nuclear LLC	NJ	Delaware River	Northeast	Nuclear	3168	2540	O/E/TR	Low	No	19,715,637
Salem Harbor	U S Gen New England Inc	MA	Atlantic Ocean	Northeast	Non-Nuclear	692	745	O/E/TR	High	No	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Sam Gideon/Lost Pines 1	LCRA	TX	Lake Bastrop	Mid/West	Non-Nuclear	950	1165	LR/RL	Low	Unknown	
San Juan	Puerto Rico Electric Power	PR	Puerto Nuevo Bay	Southeast	Non-Nuclear	748.8	534	O/E/TR	Low	Unknown	
San Onofre Nuclear	Southern California Edison Co	CA	Pacific Ocean	CA	Nuclear	2335	2150	O/E/TR	Low	No	16,093,656
Sanford	Florida Power & Light Co	FL	St Johns River	Southeast	Non-Nuclear	166.75	156	SR/GL	Med	Yes	
Scattergood	City of Los Angeles	CA	Pacific Ocean	CA	Non-Nuclear	495	838	O/E/TR	Med	Yes	
Schiller	Public Service Co of NH	NH	Piscataqua River	Northeast	Non-Nuclear	153	160	O/E/TR	High	No	
Scholz	Southern Co.	FL	Apalachicola River	Southeast	Non-Nuclear	129.6	80	LR/RL	Low	No	
Schuylkill	Exelon Generation Co LLC	PA	Schuylkill River	Northeast	Non-Nuclear	207	228	O/E/TR	High	No	
Seabrook	FPL Energy Seabrook LLC	NH	Atlantic Ocean	Northeast	Nuclear	447	1296	O/E/TR	Med	Yes	9,439,245
Seminole	Oklahoma Gas & Electric Co	OK	Lake Konawa	Mid/West	Non-Nuclear	1434.2	1500	LR/RL	Low	Unknown	
Sequoyah	Tennessee Valley Authority	TN	Chickamauga Reservoir	Southeast	Nuclear	1616	2442	LR/RL	Med	Unknown	20,043,936

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Sewaren	PSEG Fossil LLC	NJ	Arthur Kill	Northeast	Non-Nuclear	542	428	O/E/TR	High	No	
Shawnee	Tennessee Valley Authority	KY	Ohio River	Southeast	Non-Nuclear	1613	1610	LR/RL	Low	Unknown	
Shawville	RRI Energy Mid-Atlantic PH	PA	Susque-hanna River	Northeast	Non-Nuclear	656	626	LR/RL	Low	Unknown	
Shiras	Marqutte Board of Light and Power	MI	Lake Superior	Northeast	Non-Nuclear	264	77.5	SR/GL	Low	Unknown	
Sibley	Aquila Inc	MO	Missouri River	Mid/West	Non-Nuclear	293	466	LR/RL	Low	Unknown	
Silver Bay	Cleveland Cliffs Inc	MN	Lake Superior	Mid/West	Non-Nuclear	151.3	131.6	SR/GL	Low	Unknown	
Silver Lake	Rochester Public Utilities	MN	Zumbro River	Mid/West	Non-Nuclear	119	105.8	LR/RL	Low	Unknown	
Sioux	Ameren UE	MO	Mississippi River	Mid/West	Non-Nuclear	749	1100	LR/RL	Low	Unknown	
Somerset (Formerly Kintigh)	AES Somerset LLC	NY	Lake Ontario	Northeast	Non-Nuclear	274.04	675	SR/GL	Low	Unknown	
Somerset	NRG Somerset Power LLC	MA	Taunton River	Northeast	Non-Nuclear	274	174	O/E/TR	High	No	
Sooner	Oklahoma Gas & Electric Co	OK	Sooner Lake	Mid/West	Non-Nuclear	789	1096	LR/RL	Low	Unknown	
South Bay	Dynegy	CA	San Diego Bay	CA	Non-Nuclear	517	696	O/E/TR	High	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
SR Bertron	NRG Energy, Inc.	TX	Houston Ship Channel	Mid/West	Non-Nuclear	740	861	O/E/TR	Low	No	
St Clair	Detroit Edison Co	MI	St Clair River	Northeast	Non-Nuclear	1111	1414	SR/GL	Med	Yes	
St Lucie	Florida Power & Light Co	FL	Atlantic Ocean	Southeast	Nuclear	1403	1700	O/E/TR	Med	Yes	12,905,856
Stanton	Great River Energy	ND	Missouri River	Mid/West	Non-Nuclear	144	202	LR/RL	Low	No	
State Line Energy	State Line Energy LLC	IN	Lake Michigan	Northeast	Non-Nuclear	621	1711	SR/GL	Med	No	
Sterlington	Entergy Louisiana Inc	LA	Ouachita River	Mid/West	Non-Nuclear	158.35	224	SR/GL	Low	No	
Stryker Creek	Luminant Generation Company LLC	TX	Stryker Creek Reservoir	Mid/West	Non-Nuclear	527	675	LR/RL	Low	No	
Sunbury Gen	Corona Power LLC	PA	Susquehanna River	Northeast	Non-Nuclear	296	424.7	LR/RL	Med	Unknown	
Surry	Dominion Resources, Inc.	VA	James River	Southeast	Nuclear	2534	1802	O/E/TR	Low	No	12,387,183
Suwannee	Progress Energy Florida	FL	Suwannee River	Southeast	Non-Nuclear	261	217	SR/GL	Low	No	
Syl Laskin Energy Center	Allete Inc	MN	Colby Lake	Mid/West	Non-Nuclear	136	110	LR/RL	Low	No	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Taconite Harbor Energy Center	Allete Inc	MN	Lake Superior	Mid/West	Non-Nuclear	184	225	SR/GL	Low	Yes	
Tanners Creek	Indiana Michigan Power Co	IN	Ohio River	Northeast	Non-Nuclear	1065.77	995	LR/RL	Med	No	
Teche	Cleco Power LLC	LA	Charenton Canal	Mid/West	Non-Nuclear	451	427.8	O/E/TR	High	No	
Tennessee Eastman Operations	Eastman Chemical Co-TN Ops	TN	South Fork - Holston River	Southeast	Non-Nuclear	674.11	194	SR/GL	Med	Unknown	
Thames	AES Thames LLC	CT	Thames River	Northeast	Non-Nuclear	156	181	SR/GL	Med	Unknown	
Thomas B Fitzhugh	Arkansas Electric Cooperative Corp	AR	Arkansas River	Mid/West	Non-Nuclear	60.5	60	SR/GL	Low	Unknown	
Thomas C Ferguson	Lower Colorado River Authority	TX	Lake LBJ	Mid/West	Non-Nuclear	397.485	446	LR/RL	Med	Unknown	
Thomas Hill	Associated Electric Coop Inc	MO	Thomas Hill Lake	Mid/West	Non-Nuclear	1002	1197	LR/RL	Low	No	
Trenton Channel	Detroit Edison Co	MI	Detroit River - Lake Erie	Northeast	Non-Nuclear	516	730	SR/GL	High	Yes	
Trinidad	Luminant Generation Company LLC	TX	Trinidad Reservoir	Mid/West	Non-Nuclear	285	240	LR/RL	Low	No	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Twin Oaks	Sempra	TX	Twin Oak Reservoir	Mid/West	Non-Nuclear	305	330	LR/RL	Low	Unknown	
Tyrone	Kentucky Utilities Co	KY	Kentucky River	Southeast	Non-Nuclear	79	75	SR/GL	Low	Yes	
University of Notre Dame	Indiana Michigan Power Co	IN	St. Joseph Lake	Northeast	Non-Nuclear	113	21.1	LR/RL	High	No	
Urquhart	South Carolina Electric & Gas Co	SC	Savannah River	Southeast	Non-Nuclear	190	243	SR/GL	Med	No	
V C Summer	South Carolina Electric & Gas Co. (1/3 owned by SC Public Service Authority, a.k.a Santee Cooper)	SC	Parr Reservoir	Southeast	Nuclear	720	1100	LR/RL	Low	No	7,537,061
V H Braunig	CP San Antonio	TX	Lake Braunig	Mid/West	Non-Nuclear	1276.6	1401	LR/RL	Med	Unknown	
Valley	Wisconsin Electric Power Co	WI	Menomonee River	Northeast	Non-Nuclear	158.4	280	SR/GL	Low	No	
Valmont	Xcel	CO	Hillcrest Reservoir	Mid/West	Non-Nuclear	194.4	186	LR/RL	Med	Unknown	
Vero Beach Municipal	City of Vero Beach	FL	Indian River	Southeast	Non-Nuclear	144.13	117	O/E/TR	Med	Unknown	
Victoria	Topaz Power Group LLC	TX	Wells and Guadalupe River	Mid/West	Non-Nuclear	557	80	SR/GL	Med	Unknown	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
W H Sammis	Ohio Edison Co	OH	Ohio River	Northeast	Non-Nuclear	1353	2219	LR/RL	Low	Yes	
W S Lee	Duke Energy Corp	SC	Saluda River	Southeast	Non-Nuclear	331	424	SR/GL	Med	Unknown	
Wabash River	Duke Energy Corp	IN	Wabash River	Northeast	Non-Nuclear	747	764	LR/RL	Low	Unknown	
Waiau	Hawaiian Electric Co Inc	HI	Pacific Ocean	CA	Non-Nuclear	430	397	O/E/TR	High	Yes	
Walter C Beckjord	Duke Energy Corp	OH	Ohio River	Northeast	Non-Nuclear	741	1222	LR/RL	Med	Yes	
Walter Scott Jr. (Council Bluffs)	MidAmerican Energy Co	IA	Missouri River	Mid/West	Non-Nuclear	792	821	LR/RL	Low	Unknown	
Warrick	Alcoa Power Generating Inc	IN	Ohio River	Northeast	Non-Nuclear	281	755	LR/RL	Med	Unknown	
Waterford 1 & 2	Entergy Louisiana Inc	LA	Mississippi River	Mid/West	Non-Nuclear	822	912	LR/RL	Med	No	
Waterford 3	Entergy Louisiana Inc	LA	Mississippi River	Mid/West	Nuclear	1555	1165	LR/RL	Med	No	8,692,354
Watts Bar	Tennessee Valley Authority	TN	Watts Bar Reservoir	Southeast	Nuclear	194	1270	LR/RL	Low	Unknown	10,094,976
Waukegan	Midwest Generation EME LLC	IL	Lake Michigan	Northeast	Non-Nuclear	847	976	SR/GL	Med	No	
Welsh	SWEPCO	TX	Swauano Creek Reservoir	Mid/West	Non-Nuclear	1218.2	1674	LR/RL	Low	Yes	

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
West Springfield	North American Energy Alliance	MA	Connecticut River	Northeast	Non-Nuclear	69	214	LR/RL	High	Yes	
Westchester Resco Co	Westchester Resco/Wheelabrator	NY	Hudson River	Northeast	Non-Nuclear	55	74.5	O/E/TR	High	Yes	
Weston	Wisconsin Public Service Corp	WI	Wisconsin River	Northeast	Non-Nuclear	118	135	SR/GL	Low	No	
Westover	AES Westover LLC	NY	Susquehanna River	Northeast	Non-Nuclear	96.95	82	LR/RL	High	No	
Widows Creek	Tennessee Valley Authority	AL	Tennessee River	Southeast	Non-Nuclear	1645	1761	LR/RL	Low	Unknown	
Wilkes	SWEPCO	TX	Johnson Creek Reservoir	Mid/West	Non-Nuclear	539	888	LR/RL	Low	No	
Will County	Midwest Generation EME LLC	IL	Chicago Sanitary and Ship Canal	Northeast	Non-Nuclear	1296	1300	SR/GL	Med	No	
Williams	South Carolina Generating Co Inc	SC	Back River Reservoir	Southeast	Non-Nuclear	534	656	LR/RL	Low	Yes	
Willow Glen	Entergy Gulf States Inc	LA	Mississippi River	Mid/West	Non-Nuclear	1002	2045	LR/RL	Low	Yes	
Willow Island	Monongahela Power Co	WV	Ohio River	Southeast	Non-Nuclear	205	245	LR/RL	Low	Unknown	
Wolf Creek	Westar/KCPL	KS	Wolf Creek Lake	Mid/West	Nuclear	698.4	1220	LR/RL	Low	Unknown	9,164,752

Facility Name	Utility	State	Source Waterbody	Region	Primary Fuel Type	Design CW Flow (MGD)	MW	Water-body Type	Pop	Road-way within 50m?	Generation (MWhr)
Wood River	Dynegy	IL	Mississippi River	Northeast	Non-Nuclear	340	460	LR/RL	High	Yes	
Wyandotte	City of Wyandotte	MI	Detroit River	Northeast	Non-Nuclear	112	73	SR/GL	High	No	
Wyman	FPL Energy	ME	Casco Bay	Northeast	Non-Nuclear	263	837	O/E/TR	Med	Yes	
Yorktown	Virginia Electric & Power Co	VA	York River	Southeast	Non-Nuclear	1382	1230	O/E/TR	Med	No	

F

ONCE-THROUGH COOLED FACILITIES USING > 50 MGD – MASTER LIST FOR CLOSED-CYCLE COOLING RESEARCH PROGRAM

Steam Electric Generating Stations That Would Have Been Designated Phase II Facilities Under the Remanded Phase II Rule (i.e. use >50 MGD of Cooling Water

Notes Regarding the List

1. The list contains a small number of facilities that use once through cooling helper towers during a portion of the year.
2. The list is divided into nuclear and fossil facilities. However, three facilities Crystal River, H.B. Robinson and Waterford have both nuclear and fossil units.
3. For the facility to be on the list it must have an active NPDES permit, although the facility may not have operated in the last year or more. Two facilities have NPDES permits that allow once-through cooling that are still under construction.
4. In terms of Water Body Type: R = River, L/R = Freshwater Lake other than a Great Lake or Freshwater Reservoir, GL = Great Lakes and O/E/TR = Oceans/Estuary/Tidal River. The difference between a "Large" and "Small" River is that the mean annual flow of a large river exceeds 10,000 cfs.
5. It is important to note that some of the listed facilities identified as having once through cooling systems withdrawing cooling water from freshwater lakes and reservoirs may in fact be withdrawing from waterbodies that are considered part of a closed-cycle cooling system.
6. Facilities varied in reporting MW (ex. gross, net, nameplate).
7. Table 1 provides the basis of the flow and MW data shown in columns 7 and 9. The flow basis for each facility is shown in column 6. If the basis of flow and MW data is rated 1 or 2 the facility owner/operator provided Unit specific data, such that the flow and MW data are only for once-through cooling units. If a facility flow basis is rated 3, 4 or 5 it is possible that the flow and MW for the facility include non once-through cooled units.

Table 1 - Priorities for Flow Basis								
1 - Highest priority given to flow information provided in cost estimating worksheets specifically provided to inform the study.								
2 - Second highest priority given to information provided by the Company or Facility based on 316(b) work that includes - PICs, 122.21r information, technology alternative assessments or other direct information on the facility.								
3 - Third highest priority given to flow information provided in Appendix A&B of the Phase II Rule. This information was provided in direct response to a 308 questionnaire.								
4 - DOE or Internet								
[redacted]								
Facility Name	**Utility**	**State**	**Plant Code**	**EPAID**	**Flow Basis**	**Flow (MGD)**	**Water Body Type**	**MW**
Nuclear Facilities								
Arkansas Nuclear 1	Entergy	AR			2	1,146	L/R	900
Browns Ferry	Tennessee Valley Authority	AL	46	DUT1050	2	2,851	R (Large)	3,840
Brunswick	Progress Energy Carolinas	NC	6,014	AUT0419	1	1,921	O/E/TR	2,060
Calvert Cliffs	Constellation Energy Group	MD	6,011	DUT1268	2	3,629	O/E/TR	1,735
Clinton	AmerGen Energy Co LLC	IL	204	AUT0350	1	889	L/R	1,065
Comanche Peak	Luminant Power	TX	6,145	DUT1022	2	3,168	L/R	2,300
Cooper	Nebraska Public Power District	NE	8,036	AUT0255	2	983	R (Large)	802
Crystal River 3	Progress Energy Florida	FL	628	DUT1029	1	979	O/E/TR	890
Diablo Canyon	Pacific Gas & Electric Co	CA	6,099	AUT0012	2	2,500	O/E/TR	2,298

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Donald C. Cook	Indiana Michigan Power Co	MI	6,000	AUT0202	1	2,369	GL	2,161
Dresden	Exelon Generation Co LLC	IL	869	AUT0364	1	1,898	R (Small)	1,914
Fitzpatrick (James A FitzPatrick)	Entergy Nuc FitzPatrick LLC	NY	6,110	AUT0423	2	518	GL	852
Fort Calhoun	Omaha Public Power District	NE	2,289	AUT0173	2	518	R (Large)	482
H.B. Robinson	Progress Energy	SC	3,251		1	740	L/R	700
Indian Point	Entergy Nuclear Indian Point 2, LLC	NY	2,497	AUT0541	2	2,419	O/E/TR	2,028
Kewaunee	Dominion Energy Kewaunee, Inc.	WI	8,024	AUT0114	1	582	GL	595
McGuire	Duke Energy Corp	NC	6,038	AUT0384	2	2,928	L/R	2,240
Millstone	Dominion Nuclear Conn Inc	CT	566	DUT1070	2	2,190	O/E/TR	2,205
Monticello	Xcel Energy	MN	1,922	AUT0588	2	444	R (Large)	620
Nine Mile Point, NY	Constellation Energy Group	NY	2,589	AUT0403	2	517	GL	623
North Anna	Dominion Resources, Inc.	VA	6,168	AUT0187	1	2,707	L/R	1,956
Oconee	Duke Energy Corp	SC	3,265		2	3,058	L/R	2,538
Oyster Creek	AmerGen Energy Co LLC	NJ	2,388	DUT1023	2	1,394	O/E/TR	630
Peach Bottom	Exelon Generation Co LLC	PA	3,166	AUT0570	2	2,281	L/R	2,186
Pilgrim	Entergy Nuclear Generation Co	MA	1,590	AUT0608	2	446	O/E/TR	706
Point Beach	NEXTera Energy	WI	4,046	AUT0085	1	1,008	GL	1,365
Prarie Island	Xcel Energy	MN	1,925	AUT0181	2	969	R (Large)	1,150
Quad Cities	Exelon Generation Co LLC	IL			2	1,356	R (Large)	1,824
R. E. Ginna	Constellation Energy Group	NY	6,122	AUT0190	2	536	GL	581

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Salem	PSEG Nuclear LLC	NJ	2,410	AUT0084	1	3,168	O/E/TR	2,540
San Onofre	Southern California Edison Co	CA	360	AUT0573	2	2,335	O/E/TR	2,150
Seabrook	NEXTera Energy	NH	6,115	AUT0275	1	447	O/E/TR	1,296
Sequoyah	Tennessee Valley Authority	TN			2	1,616	L/R	2,442
St Lucie	NEXTera Energy	FL	6,045		1	1,403	O/E/TR	1,700
Surry	Dominion Resources, Inc.	VA	3,806	DUT1211	1	2,534	O/E/TR	1,802
V C Summer	South Carolina Electric & Gas Co. and SC Public Service Authority	SC	6,127		1	720	L/R	1,100
Waterford 3	Entergy Louisiana Inc	LA	4,270	AUT0513	2	1,555	R (Large)	1,165
Watts Bar	Tennessee Valley Authority	TN			2	194	L/R	1,270
Wolf Creek	Westar /KCPL	KS	210		2	698	L/R	1,220
				Fossil Facilities				
Facility Name	**Utility**	**State**	**Plant Code**	**EPAID**	**Flow Basis**	**Flow (MGD)**	**Water Body Type**	**MW**
Aguirre	Puerto Rico Electric Power	PR	9,999,901		2	651	O/E/TR	900
Alamitos	AES Alamitos LLC	CA	315		2	1,181	O/E/TR	1,950
Allen	Tennessee Valley Authority	TN	2,718	AUT0551	4	549	R (Large)	864
Allen S King	Xcel	MN	1,915	AUT0551	2	467	L/R	605
Allen Steam	Duke Energy Corp	NC	3,393		1	861	L/R	1,391
Alma/Magett	Dairyland Power Coop	WI	4,140	DUT1021	1	540	R (Large)	605

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Anclote	Progress Energy Florida	FL	8,048	DUT1275	1	1,287	O/E/TR	1,030
Armstrong	Allegheny Energy Supply Co LLC	PA	3,178		2	179	R (Large)	356
Arthur Kill	NRG Arthur Kill Power LLC	NY	2,490		2	713	O/E/TR	875
Ashtabula	Cleveland Electric Illum Co	OH	2,835		1	252	GL	256
Ashville	Progress Energy Carolinas	NC	2,706		1	316	L/R	383
Astoria	Astoria Generating Co LP	NY	8,906	AUT0603	3	1,769	O/E/TR	1,330
Avon Lake	RRI	OH	2,836	AUT0245	1	625	GL	766
B C Cobb	Consumers Energy Co	MI	1,695	AUT0021	2	583	GL	531
B L England (Beesley's Point)	Rockland Capital	NJ	2,378	AUT0020	2	299	O/E/TR	299
Bailly	Northern Indiana Pub Serv Co	IN	995	DUT1093	1	490	GL	586
Barney M Davis	Topaz Power Group LLC	TX	4,939	DUT1172	4	467	O/E/TR	682
Barry	Alabama Power Co	AL	3		1	1,119	O/E/TR	1,837
Bartow	Progress Energy Florida	FL	634	DUT1274	1	562	O/E/TR	419
Baxter Wilson	Entergy Mississippi Inc	MS	2,050	AUT0571	1	297	R (Large)	1,328
Bay Front	Xcel	WI	3,982	AUT0499	2	63	GL	76
Bay Shore	First Energy	OH	2,878		1	810	GL	849
Beaver Valley	AES Beaver Valley	PA	10,676	AUT0125	2	145	R (Large)	125
Belews Creek	Duke Energy Corp	NC	8,042		1	1,457	L/R	2,240
Belle River	Detroit Edison Co	MI	6,034	AUT0163	2	950	GL	1,270
Big Bend	Tampa Electric Co	FL	645	DUT1165	4	1,396	O/E/TR	1,824

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Big Brown	Luminant Power	TX	3,497	AUT0449	2	1,015	L/R	1,150
Big Cajun 2	NRG Louisiana Generating LLC	LA	6,055	AUT0500	1	380	R (Large)	615
Black Dog	Xcel	MN	1,904		2	307	R (Small)	401
Blount Street	Madison Gas & Electric Co	WI	3,992	AUT0427	3	170	L/R	195
Bowline Point	Mirant Bowline LLC	NY	2,625		2	910	O/E/TR	1,150
Bremo Bluff	Dominion	VA	3,796	AUT0396	1	179	R (Small)	250
Bridgeport Harbor	PSEG Power Connecticut LLC	CT	568	AUT0601	1	440	O/E/TR	566
Brooklin Navy Yard Cogen	Olympus Power, LLC	NY	54,914	DNU2002	4	99	O/E/TR	80
Brunner Island	PPL Corp	PA	3,140		1	795	R (Large)	1,483
Buck	Duke Energy Corp	NC	2,720	AUT0490	1	395	R (Small)	487
Bull Run	Tennessee Valley Authority	TN	3,396	AUT0024	2	590	L/R	911
Burlington	Interstate Power & Light Co (Alliant Energy)	IA	1,104	AUT0585	1	116	R (Large)	212
Burns Harbor	International Steel Group	IN	10,245		4	97	GL	176
C D McIntosh	Lakeland Electric Utility	FL	676	AUT0590	3	213	L/R	713
C P Crane	Constellation Power Source Gen	MD	1,552	AUT0110	2	446	O/E/TR	385
Cabras	Guam Power Authority	Guam	9,999,904		2	238	O/E/TR	210
Calaveris (O.W. Summers/ J.T. Deely/J.K. Spruce)	CP San Antonio	TX	3,611		2	2,249	L/R	3,200
Canaday	Nebraska Public Power District	NE	2,226	AUT0246	2	97	R	125
Canal	Mirant Canal LLC	MA	1,599		2	580	O/E/TR	1,175

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Cane Run	Louisville Gas & Electric Co	KY	1,363	AUT0001	1	370	R (Large)	645
Cape Canaveral	NEXTera Energy	FL	609		1	792	O/E/TR	500
Cape Fear	Progress Energy Carolinas	NC	2,708	AUT0111	1	342	R (Small)	870
Cardinal	Cardinal Operating Co	OH	2,828		1	1,152	R (Large)	1,200
Carl Bailey	Arkansas Electric Coop Corp	AR	202	DUT1170	2	98	R (Large)	124
Cayuga	AES Cayuga LLC	NY	1,001		2	245	L/R	306
Cayuga	Duke Energy Corp	IN	2,535		2	766	R	1,070
Cedar Bayou	NRG Energy, Inc.	TX	3,460	DUT1238	1	1,132	O/E/TR	1,740
Chalk Point LLC	Mirant Mid-Atlantic LLC	MD	1,571	AUT0049	2	720	O/E/TR	710
Chamois	Chamois	MO	2,169	AUT0254	1	71	R (Large)	70
Charles R Lowman	Powersouth	AL	56	DUT1214	2	78	R	86
Chesapeake	Virginia Electric & Power Co	VA	3,803	AUT0002	1	514	O/E/TR	604
Chesterfield	Virginia Electric & Power Co	VA	3,797	AUT0299	1	1,091	O/E/TR	1,705
Cheswick	Orion Power Midwest LP - RRI Energy	PA	8,226	AUT0106	1	376	R (Large)	637
Clay Boswell	Allete Inc	MN	1,893		1	156	L/R	140
Cliffside	Duke Energy Corp	NC	2,721	AUT0319	1	269	R (Small)	289
Clifty Creek	Indiana-Kentucky Electric Corp	IN	983		1	1,434	R (Large)	1,306
Coffeen	Ameren Energy Generating Co	IL	861	DUT1152	2	575	L/R	1,005
Colbert	Tennessee Valley Authority	AL	47		2	1,325	R (Large)	1,332
Conesville	Columbus Southern Power Co	OH	2,840		1	108	R (Small)	165

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Conners Creek	Detroit Edison Co	MI	1,726	AUT0285	2	213	GL	239
Contra Costa	Mirant Delta LLC	CA	228	AUT0621	2	440	O/E/TR	690
Costa Sur	Puerto Rico Electric Power	PR	9,999,908		2	874	O/E/TR	1,086
Covanta Mid-Connecticut Inc	Covanta Energy	CT	54,945		3	75	L/R	90
Crawford	Midwest Generation EME LLC	IL	867	AUT0507	1	550	R (Small)	584
Crist	Gulf Power Co	FL	641		1	156	O/E/TR	150
Cromby	Exelon Generation Co LLC	PA	3,159	DUT1185	1	359	R (Small)	380
Crystal River 1 and 2	Progress Energy Florida	FL	DUT1029		1	919	O/E/TR	900
Cumberland	Tennessee Valley Authority	TN	3,399	DUT1132	2	2,730	R	2,650
Cutler	NEXTera Energy	FL	610	AUT0268	1	213	O/E/TR	237
Dale	East Kentucky Power Coop Inc	KY	1,385	AUT0261	3	290	R (Small)	176
Dallman	Springfield City of	IL	963	AUT0537	4	353	L/R	388
Dan E Karn/J.C. Weadock	Consumers Energy Co	MI	1,720	DUT1033	1	432	GL	515
Dan River	Duke Energy Corp	NC	2,723		1	280	R (Small)	361
Danskammer	Dynegy	NY	2,480		2	455	O/E/TR	493
Dave Johnston	PacifiCorp	WY	4,158	AUT0583	2	193	R (Small)	454
Decker Creek	Austin Energy	TX	3,548	AUT0151	3	695	L/R	726
Deepwater	Conectiv Atlantic Generation LLC	NJ	3,461	AUT0370	2	221	O/E/TR	166
Dickerson	Mirant Mid-Atlantic LLC	MD	1,572		2	407	R (Small)	576
Dolphus M Grainger	South Carolina Pub Serv Auth	SC	3,317	DUT1014	1	116	R (Small)	180

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Dubuque	Interstate Power and Light (Alliant Energy)	IA	1,046	AUT0277	2	82	R (Large)	77
Dunkirk	NRG Dunkirk Power LLC	NY	2,554	AUT0620	2	576	GL	586
E C Gaston	Alabama Power Co	AL	26		1	832	R (Small)	1,000
E D Edwards	Ameren Energy Resources Generating	IL	856	DUT1111	2	579	R (Small)	780
E F Barrett	National Grid/KeySpan	NY	2,511	AUT0168	2	294	O/E/TR	380
E S Joslin	NuCoastal Corporation	TX	3,436	AUT0493	3	370	O/E/TR	261
E.J. Stoneman	DTE Stoneman, LLC	WI	4,146		2	53	R (Large)	53
Eagle Valley-HT Pritchard	AES Corporation	IN	991	AUT0358	2	335	R (Small)	359
East River	Consolidated Edison Co-NY Inc	NY	2,493	DUT1143	4	368	O/E/TR	599
Eastlake	First Energy	OH	2,837		1	1,146	GL	1,594
Eaton	Southern Co.	MS	2,046	AUT0440	1	108	R (Small)	68
Eddystone	Exelon Generation Co LLC	PA	3,161	AUT0544	1	1,469	O/E/TR	1,570
Edge Moor	Conectiv Delmarva Generation Inc	DE	593	AUT0539	1	837	O/E/TR	705
Edgewater	Wisconsin Power & Light Co (Alliant Energy)	WI	4,050	AUT0036	2	463	GL	770
Edwardsport	Duke Energy Corp	IN	1,004		4	187	R (Small)	144
El Segundo	NRG - El Segundo Power LLC	CA	330	DNU2047	2	381	O/E/TR	941
Elk River	GRE	MN	2,039	AUT0244	1	73	R (Large)	195
Elmer Smith	Owensboro City of	KY	1,374	DUT1041	2	265	R (Large)	441

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Elrama	Orion Power Midwest LP - RRI Energy	PA	3,098	DUT1047	1	518	R (Large)	510
Encina	NRG	CA	302	AUT0625	2	857	O/E/TR	964
F B Culley	Southern Indiana Gas & Elec Co	IN	1,012	AUT0567	3	317	R (Large)	389
Fair Station	Central Iowa Power Coop	IA	1,218	AUT0477	4	71	R (Large)	63
Fairless Hills	Exelon Generation Company, LLC	PA	7,701		1	78	O/E/TR	60
Far Rockaway	National Grid/KeySpan	NY	2,513	DUT1008	2	87	O/E/TR	106
Fayette	LCRA Fayette Power Project	TX	6,179		2	1,165	L/R	1,641
Fisk Street	Midwest Generation EME LLC	IL	886	AUT0405	1	323	R (Small)	348
Flint Creek	Southwestern Electric Co	AR	6,138		1	412	L/R	559
Forest Grove	Luminant Power	TX	9,999,925		2	1,470	L/R	1,500
Fort Myers	Florida Power & Light Co	FL	612	AUT0401	1	730	O/E/TR	573
Fox Lake	Interstate Power & Light Co (Alliant Energy)	MN	1,888	DUT1175	2	101	L/R	98
Frank E Ratts	Hoosier Energy R E C Inc	IN	1,043		2	102	R (Large)	256
G F Weaton	Zinc Corp of America	PA	50,130		4	88	R (Large)	120
Gadsden	Alabama Power Co	AL	7		1	219	R (Small)	120
Gallatin	Tennessee Valley Authority	TN	3,403	AUT0185	2	916	L/R	1,086
Gary Works	United States Steel Corp	IN	50,733		4	122	GL	231
Genoa	Dairyland Power Coop	WI	4,143	AUT0538	1	252	R (Large)	360
George Neal North	MidAmerican Energy Co	IA	1,091	AUT0397	2	791	R (Large)	1,046

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
George Neal South	MidAmerican Energy Co	IA	7,343		2	468	R (Large)	640
Georgia Pacific Cedar Springs	Georgia-Pacific Corp	GA	54,101		4	85	R (Small)	101
Gerald Andrus	Entergy Mississippi Inc	MS	8,054	DUT1194	1	260	R (Large)	750
Gerald Gentleman	Nebraska Public Power District	NE	6,077	AUT0257	2	760	R	1,444
GEUS	Greenville Electric Util Sys	TX	4,195	AUT0481	5	84	L/R	84
Gibbons Creek	Texas Municipal Power Agency	TX	6,136		4	418	L/R	454
Glen Lyn	Appalachian Power Co	VA	3,776		1	373	R (Small)	335
Glenwood	National Grid/KeySpan	NY	2,514	DUT1186	2	179	O/E/TR	218
Gorgas	Alabama Power Co	AL	8		1	979	R	1,221
Gould Street	Constellation Energy Group	MD	1,553	AUT0529	2	99	O/E/TR	97
Graham	Luminant Power	TX	3,490	DUT1072	2	505	L/R	630
Grand Tower	Ameren Energy Generating Co	IL	862	DUT1012	2	229	R (Large)	199
Grays Ferry	Trigen Phildelphia Energy Corp	PA	54,785	DNU2018	3	64	O/E/TR	58
Green Bay West Mill	Fort James Operating Co	WI	10,360		4	120	R (Small)	136
Green River	Kentucky Utilities Co	KY	1,357	DUT1261	1	177	R (Small)	231
Greene County	Alabama Power Co	AL	10		1	396	R (Small)	500
Greenidge	AES Greenidge LLC	NY	2,527		2	146	L/R	107
H.A. Wagner	Constellation Power Source Gen	MD	1,554	AUT0174	2	1,060	O/E/TR	982
H L Culbreath Bayside	Tampa Electric Co	FL	646	DUT1066	3	2,465	O/E/TR	685
H.B. Robinson	Progress Energy	SC	3,251		1	126	L/R	185

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Hamilton	Hamilton City of	OH	2,917	AUT0333	3	485	R (Small)	111
Hammond	Georgia Power	GA	708	AUT0131	1	548	L/R	800
Handley	ExTex LaPorte LP	TX	3,491	AUT0284	1	1,121	L/R	1,315
Harbor	LADWP	CA	399	DUT1068	2	108	O/E/TR	75
Harbor Beach	Detroit Edison Co	MI	1,731	DUT1138	2	130	GL	103
Harding Street	Indianapolis Power & Light Co	IN	990		2	238	R	360
Harllee Branch	Georgia Power	GA	709	AUT0298	1	1,139	L/R	1,735
Hawthorn	Kansas City Power & Light Co	MO	2,079	AUT0361	2	283	R (Largel)	693
Haynes	LADWP	CA	400	AUT0387	2	1,014	O/E/TR	1,279
Healy	Golden Valley Electric Association	AK	6,288	AUT0381	2	53	R (Small)	75
Hennepin	Dynegy Midwest Generation Inc	IL	892	AUT0004	2	230	R (Small)	293
Henry D King	Fort Pierce Utilities Auth	FL	658	AUT0067	4	108	O/E/TR	114
Hibbard	Minnesota Power Inc	MN	1,897		1	236	GL	124
High Bridge	Xcel	MN	1,912	AUT0228	2	390	R	510
Honolulu	Hawaiian Electric Co Inc	HI	764	DUT1145	1	184	O/E/TR	103
Hoot Lake	Otter Tail Power Co	MN	1,943		4	116	R (Small)	137
Horseshoe Lake	Oklahoma Gas & Electric Co	OK	2,951		2	400	L/R	396
Hudson	PSEG Fossil LLC	NJ	2,403	DUT1169	1	892	O/E/TR	983
Hunlock	UGI	PA			2	61	R (Small)	50
Huntington Beach	AES Huntington Beach LLC	CA	335	AUT0612	2	514	O/E/TR	880

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Huntley	NRG Huntley Power LLC	NY	2,549	AUT0604	1	346	GL	816
Hutsonville	Ameren Energy Generating Co	IL	863	AUT0385	2	173	R (Large)	167
Iatan	Kansas City Power & Light Co	MO	6,065	AUT0398	2	425	R (Large)	706
Indian River	RRI Energy Florida LLC	FL	55,318	AUT0496	2	835	R (Small)	609
Indian River	NRG Indian River Operations Inc	DE	594	DUT1206	1	378	O/E/TR	432
J B Sims	Grand Haven BL&P	MI	1,825	AUT0241	4	60	GL (Small)	75
J E Corette	PPL Montana LLC	MT	2,187	AUT0321	1	75	R (Small)	154
J H Campbell	Consumers Energy Co	MI	1,710	AUT0191	1	936	GL	1,440
J M Stuart	Dayton Power & Light Co	OH	2,850	DUT1212	1	904	R (Large)	1,869
J R Whiting	Consumers Energy Co	MI	1,723	DUT1133	2	323	GL	328
J Sherman Cooper	East Kentucky Power Coop Inc	KY	1,384		4	208	R (Large)	341
J.P. Pulliam	Wisconsin Public Service Corp	WI	4,072	AUT0157	2	523	GL	373
Jack Watson	Mississippi Power Co	MS	2,049	AUT0501	1	441	O/E/TR	512
James De Young	Holland Board of Public Works	MI	1,830	DUT1259	3	103	GL	63
James River	Springfield City of	MO	2,161	AUT0518	3	279	L/R	253
Jefferies	South Carolina Pub Serv Auth	SC	3,319	AUT0522	1	357	O/E/TR	508
John Sevier	Tennessee Valley Authority	TN	3,405	DUT1156	2	714	R (Small)	816
Johnsonville	Tennessee Valley Authority	TN	3,406	AUT0337	2	1,601	R (Large)	1,408
Joliet 29	Midwest Generation EME LLC	IL	384	AUT0193	1	1,424	R (Small)	1,189
Joliet 9	Midwest Generation EME LLC	IL	874	AUT0205	1	438	R (Small)	341

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Joppa Steam	Electric Energy Inc	IL	887	DUT1049	4	589	R (Large)	1,100
Kahe	Hawaiian Electric Co Inc	HI	765	AUT0305	1	847	O/E/TR	650
Kammer	Ohio Power Co	WV	3,947		1	713	R (Large)	630
Kanawha River	Appalachian Power Co	WV	3,936		1	403	R (Large)	426
Kaw	Board of Public Utilities-City of Kansas	KS	1,294	AUT0368	3	120	R	166
Kendall	Mirant Kendall LLC	MA	1,595	AUT0623	2	78	R (Small)	67
Kenneth C Coleman	Western Kentucky Energy Corp	KY	1,381		4	335	R (Large)	521
Kincaid	Dominion Energy	IL	876		1	461	L/R	1,182
Kingston	Tennessee Valley Authority	TN	3,407	AUT0552	2	1,495	R (Small)	1,677
Knox Lee	Southwestern Electric Power Co	TX	3,476	DUT1248	1	639	L/R	500
Kraft	Savannah Electric & Power Co	GA	733		1	259	O/E/TR	479
Kyger Creek	Ohio Valley Electric Corp	OH	2,876	AUT0564	1	1,166	R (Large)	1,085
Kyrene	Salt River Proj Ag I & P Dist	AZ	147		2	96	OTHER	96
La Cygne	Kansas City Power & Light Co	KS	1,241		2	726	L/R	1,418
Labadie	Ameren UE	MO	2,103	DUT1046	2	1,233	R (Large)	2,560
Lake Catherine	Entergy Arkansas Inc	AR	170	AUT0073	2	565	L/R	673
Lake Hubbard	Luminant Power	TX	3,452	AUT0027	2	870	L/R	921
Lake Road	Kansas City Power & Light Co	MO	2,098	AUT0127	2	86	R(Large)	99
Lake Shore	Cleveland Electric Illum Co	OH	2,838		1	246	GL	256

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Lansing	Interstate Power & Light Co (Alliant Energy)	IA	1,047	AUT0304	2	299	R (Large)	317
Lansing Smith	Southern Co.	FL	679	AUT0304	1	260	O/E/TR	384
Lauderdale	Florida Power & Light Co	FL	613	AUT0142	1	368	O/E/TR	312
Leland Olds	Basin Electric Power Coop	ND	2,817	DUT0062	1	330	R (Large)	656
Lieberman	SWEPCO	LA	1,417		1	134	L/R	286
Little Gypsy	Entergy Louisiana Inc	LA	1,402	AUT0097	1	468	R (Large)	1,251
Lonestar	Southwestern Electric Power Co	TX	3,477	AUT0080	4	79	L/R	40
Maine Energy Recovery Co	Central Maine Power Co	ME	10,338	DNU2013	3	94	O/E/TR	22
Manchester Street	Narraganset Electric Co	RI	3,236		1	259	O/E/TR	168
Mandalay	RRI Energy Mandalay LLC	CA	345	AUT0638	2	254	O/E/TR	430
Manitowoc	Manitowoc Public Utilities	WI	4,125	DUT1202	3	52	GL	79
Marion	Southern Illinois Power Coop	IL	976	AUT0222	3	225	L/R	272
Marshall	Duke Energy Corp	NC	2,727	AUT0260	2	1,463	L/R	2,090
Martin Lake	Luminant Power	TX	6,146	AUT0176	2	2,411	L/R	2,250
Marysville	Detroit Edison Co	MI	1,732		4	368	GL	84
McClellan	Arkansas Electric Coop Corp	AR	203	DUT1154	2	71	R (Small)	136
McIntosh	Georgia Power	GA	6,124		1	91	R (Small)	167
McManus	Georgia Power	GA	715		1	166	O/E/TR	115
Meramec	Ameren UE	MO	2,104	DUT1192	2	675	R (Large)	1,035
Mercer	PSEG Fossil LLC	NJ	2,408	AUT0058	1	691	O/E/TR	648

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Meredosia	Ameren Energy Generating Co	IL	864	AUT0146	2	392	R (Large)	354
Merom	Hoosier Energy R E C Inc	IN	6,213	AUT0406	1	484	L/R	1,139
Merrimack	Public Service Co of NH	NH	2,364	DUT1031	3	287	R (Small)	474
Miami Fort	Duke Energy Corp	OH	2,832	AUT0472	2	130	R (Large)	163
Michoud	Entergy New Orleans Inc	LA	1,409	AUT0047	2	763	O/E/TR	918
Mid Connecticut Resource Recovery Facility	Connecticut Resources Recovery Authority	CT	9,999,926		4	108	R(Large)	90
Middletown	NRG Middletown Power LLC	CT	562	AUT0577	1	224	R (Large)	353
Mill Creek	Louisville Gas & Electric Co	KY	1,364	DUT1153	1	233	R (Large)	419
Milton L Kapp	Interstate Power & Light Co (Alliant Energy)	IA	1,048	AUT0443	2	197	R (Large)	255
Milton R Young	Minnkota Power Coop Inc	ND	2,823	DUT1103	1	530	L/R	700
Missouri City	Independent Blue Valley Power Plant	MO	2,171	AUT0078	3	416	R (Largel)	46
Mistersky	Detroit City of	MI	1,822	AUT0433	4	198	GL	189
Mitchell	Georgia Power	GA	727	AUT0137	1	173	R (Small)	125
Mitchell	Allegheny Energy Supply Co LLC	PA	3,181	AUT0404	2	255	R (Large)	365
Monroe	Detroit Edison Co	MI	1,448	DUT1002	3	2,010	GL and R	3,110
Monticello	Luminant Power	TX	6,147	DUT1272	2	1,732	L/R	1,880
Montrose	Kansas City Power & Light Co	MO	2,080	AUT0341	2	370	L/R	510
Montville	NRG Montville Power LLC	CT	546	AUT0013	1	315	O/E/TR	516

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Morgantown	Dominion Energy Services Company, Inc.	WV	10,743	AUT0278	1	80	R (Large)	58
Morgantown	Mirant Mid-Atlantic LLC	MD	1,573	DNU2021	2	1,234	O/E/TR	1,248
Morro Bay	Dynegy	CA	259	AUT0613	2	453	O/E/TR	600
Moss Landing	Dynegy	CA	260	AUT0607	1	1,224	O/E/TR	1,899
Mount Tom	Northeast Generation Services Co	MA	1,606	AUT0134	3	143	R (Large)	144
Mountain Creek	ExTex LaPorte LP	TX	3,453	DUT1187	1	722	L/R	810
Mt Storm	Virginia Electric & Power Co	WV	3,954	AUT0178	1	1,184	L/R	1,693
Muscatine Plant #1	Muscatine City of	IA	1,167	AUT0033	4	288	R (Large)	294
Muskingum River	Ohio Power Co	OH	2,872	AUT0547	1	864	R (Small)	840
Muskogee	Oklahoma Gas & Electric Co	OK	2,952	DUT1252	2	107	R (Small)	180
Mystic (Unit 7)	U.S. Power Gen	MA	1,588		4	646	O/E/TR	560
Natrium Plant	PPG Industries Inc	WV	50,491		4	65	R (Large)	123
Nebraska City	Omaha Public Power District	NE	6,096	AUT0394	2	432	R (Large)	653
Nelson Dewey	Wisconsin Power & Light Co (Alliant Energy)	WI	4,054	AUT0053	2	167	R (Large)	200
New Castle Plant	RRI Energy	PA	3,138	AUT0208	1	253	R (Small)	348
New Haven Harbor	PSEG Power Connecticut LLC	CT	6,156	AUT0618	1	404	O/E/TR	466
New Madrid	Associated Electric Coop Inc	MO	2,167	AUT0171	1	864	R (Large)	1,200
Newington	Public Service Co of NH	NH	8,002		4	325	O/E/TR	422
Newton	Ameren Energy Generating Co	IL	6,017		2	806	L/R	1,288

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Niles	RRI	OH	2,861		1	403	R (Small)	266
Nine Mile Point	Entergy Louisiana Inc	LA	1,403	AUT0403	1	611	R (Large)	1,566
Noblesville	Duke Energy Corp	IN	1,007	AUT0416	3	207	R (Small)	100
North Omaha	Omaha Public Power District	NE	2,291	AUT0266	2	529	R (Large)	664
North Texas	Brazos Electric Power Coop Inc	TX	3,627	DUT1038	3	95	L/R	71
Northport	National Grid/KeySpan	NY	2,516	AUT0015	2	926	O/E/TR	1,500
Northside	JEA	FL	667	AUT0568	1	648	O/E/TR	1,159
Norwalk Harbor	NRG Norwalk Harbor Power LLC	CT	548	AUT0120	2	312	O/E/TR	330
O H Hutchings	Dayton Power & Light Co	OH	2,848	DUT1198	3	403	R	399
Oak Creek	Wisconsin Electric Power Co	WI	4,041	DUT1034	1	1,181	GL	1,139
Oak Grove	Luminant Power	TX	9,999,927		2	1,610	L/R	1,710
Ormond Beach	RRI Energy Ormond Beach, Inc.	CA	350	AUT0637	2	685	O/E/TR	1,516
Oswego Harbor	NRG Oswego Power LLC	NY	2,594	AUT0071	1	1,132	GL	1,740
Otto E. Eckert	Lansing Board of Water and Light	MI	1,831	AUT0300	2	233	R (Small)	330
P H Robinson	NRG Energy, Inc.	TX	3,466	DUT1155	1	1,681	O/E/TR	2,285
Palo Seco	Puerto Rico Electric Power	PR	9,999,920		2	654	O/E/TR	602
Paradise	Tennessee Valley Authority	KY			2	608	R(Small)	2,427
Peru	Peru Light & Power Co	IN	1,037	DUT1003	3	55	R (Large)	35
Petersburg	Indianapolis Power & Light Co	IN	994	DUT1085	2	428	R (Large)	880
Philip Sporn	Central Operating Co	WV	3,938	AUT0314	1	1,038	R (Large)	1,050

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Picway	Columbus Southern Power Co	OH	2,843		1	101	R (Small)	100
Pirkey	SWEPCO	TX	7,902		1	544	L/R	700
Pittsburg	Mirant Delta LLC	CA	271	AUT0639	2	462	O/E/TR	645
Port Everglades	Florida Power & Light Co	FL	617		1	1,253	O/E/TR	1,254
Port Jefferson	National Grid/KeySpan	NY	2,517		2	294	O/E/TR	380
Port Washington	Wisconsin Electric Power Co	WI	4,040	DUT1219	1	814	GL	1,206
Portland	RRI Energy Mid-Atlantic PH	PA	3,113	AUT0351	1	314	R (Small)	427
Possum Point	Virginia Electric & Power Co	VA	3,804	AUT0270	1	224	O/E/TR	313
Potomac River	Mirant Mid-Atlantic LLC	VA	3,788	AUT0554	2	450	O/E/TR	510
Prairie Creek	Interstate Power & Light Co (Alliant Energy)	IA	1,073	AUT0181	2	205	R (Small)	238
Presque Isle	Wisconsin Electric Power Co	MI	1,769	DUT1007	1	350	GL	450
Quindaro	Kansas City of	KS	1,295	AUT0297	3	265	R (Large)	239
R A Reid	Big River Energy Corp.	KY	1,383		5	130	R (Small)	96
R E Burger	Ohio Edison Co	OH	2,864	AUT0175	1	225	R (Large)	416
R Gallagher	Duke Energy Corp	IN	1,008		2	436	R (Large)	616
R M Heskett	MDU Resources Group Inc	ND	2,790	DUT1154	4	64	R (Large)	115
R Paul Smith	Allegheny Energy Supply Co LLC	MD	1,570		2	103	R (Small)	116
R W Miller	Brazos Electric Power Coop Inc	TX	3,628	AUT0192	4	396	L/R	604
Ravenswood	TransCanada	NY	2,500	AUT0617	2	1,390	O/E/TR	1,752
Ray Olinger	Garland City of	TX	3,576	DUT1043	2	357	L/R	345

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Red Wing	Xcel	MN	1,926		2	50	R	26
Redondo Beach	AES Redondo Beach LLC	CA	356		1	891	O/E/TR	1,310
Richard Gorsuch	American Mun Power-Ohio Inc	OH	7,286	AUT0446	1	187	R (Large)	213
River Rouge	Detroit Edison Co	MI	1,740	AUT0276	2	441	GL	540
Riverbend	Duke Energy Corp	NC	2,732		1	415	L/R	470
Riverside	Constellation	MD	1,927	AUT0203	2	61	O/E/TR	78
Riverside	MidAmerican Energy Co	IA	1,081	AUT0203	2	90	R	141
Riverside	Xcel	MN	1,559	AUT0203	2	277	R (Large)	420
Riverton	Empire District Electric	KS	1,239	DUT1229	3	105	R	88
Rivesville	Monongahela Power Co	WV	3,945		2	119	R (Large)	137
Riviera	NEXTera Energy	FL	619		1	565	O/E/TR	600
Robert E Ritchie	Entergy Arkansas Inc	AR	173	DUT1161	1	454	R (Large)	919
Roseton	Dynegy	NY	8,006	AUT0411	2	924	O/E/TR	1,185
Roxboro	Progress Energy Carolinas	NC	2,712		1	1,096	L/R	1,775
Rush Island	Ameren UE	MO	6,155	AUT0536	2	1,097	R (Large)	1,340
S O Purdom	Tallahassee City of	FL	689	DUT0576	3	134	O/E/TR	137
Sabine	Entergy Gulf States Inc	TX	3,459	AUT0315	1	1,275	L/R	2,167
Salem Harbor	Dominion	MA	1,626	AUT0631	3	692	O/E/TR	745
Sam Gideon/Lost Pines 1	LCRA	TX	3,601	DUT1273	2	950	L/R	1,165
San Juan	Puerto Rico Electric Power	PR	9,999,924		2	749	O/E/TR	534

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Sanford	Florida Power & Light Co	FL	620		1	167	R (Small)	156
Scattergood	Los Angeles City of	CA	404	AUT0068	2	495	O/E/TR	838
Schiller	Public Service Co of NH	NH	2,367	AUT0083	4	153	O/E/TR	160
Scholz	Southern Co.	FL	642		1	130	R (Large)	80
Schuylkill	Exelon Generation Co LLC	PA	3,169	AUT0183	1	207	O/E/TR	228
Seminole	Oklahoma Gas & Electric Co	OK	2,956		2	1,434	L/R	1,500
Sewaren	PSEG Fossil LLC	NJ	2,411	DUT1100	1	542	O/E/TR	428
Shawnee	Tennessee Valley Authority	KY	1,379	AUT0483	2	1,613	R (Large)	1,610
Shawville	RRI Energy Mid-Atlantic PH	PA	3,131	AUT0011	1	656	R (Large)	626
Shiras	Marqutte Board of Light and Power	MI	1,843	AUT0435	3	264	GL	78
Sibley	Kansas City Power & Light Co	MO	2,094	DUT1227	2	293	R (Large)	466
Silver Bay Power	Cleveland Cliffs Inc	MN	10,849		4	151	GL	132
Silver Lake	Rochester Public Utilities	MN	2,008	AUT0227	3	119	L/R	106
Sioux	Ameren UE	MO	2,107	AUT0072	2	749	R (Large)	1,100
Somerset (Formerly Kintigh)	AES Somerset LLC	NY	6,082		2	274	GL	675
Somerset	NRG Somerset Power LLC	MA	1,613	AUT0384	4	274	O/E/TR	174
Sooner	Oklahoma Gas & Electric Co	OK	6,095		2	789	L/R	1,096
South Bay	Dynegy	CA	310		1	517	O/E/TR	696
SR Bertron	NRG Energy, Inc.	TX	3,468	AUT0248	1	740	O/E/TR	861
St Clair	Detroit Edison Co	MI	1,743	DUT1258	1	1,111	GL	1,414

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Stanton	Great River Energy	ND	2,824	AUT0273	1	144	R (Largel)	202
State Line Energy	State Line Energy LLC	IN	981		1	621	GL	1,711
Sterlington	Entergy Louisiana Inc	LA	1,404	DUT1157	1	158	R (Small)	224
Stryker Creek	Luminant Power	TX	3,504	DUT1011	2	527	L/R	675
Sunbury Gen	Corona Power LLC	PA	3,152		4	296	R (Large)	425
Suwannee	Progress Energy Florida	FL	638	AUT0051	1	261	R (Small)	217
Syl Laskin	Allete Inc	MN	1,891		1	136	L/R	110
Taconite Harbor	Allete Inc	MN	10,075		1	184	GL	225
Tanners Creek	Indiana Michigan Power Co	IN	988	AUT0148	1	1,066	R (Large)	995
Teche	Cleco Power LLC	LA	1,400	AUT0362	3	451	O/E/TR	428
Tennessee Eastman Operations	Eastman Chemical Co-TN Ops	TN	50,481		4	674	R	194
Thames	AES Thames LLC	CT	10,675		2	156	R (Small)	181
Thomas B Fitzhugh	Arkansas Electric Cooperative Corp	AR	201		2	61	R (Small)	60
Thomas C Ferguson	Lower Colorado River Authority	TX	4,937		4	397	L/R	446
Thomas Hill	Associated Electric Coop Inc	MO	2,168	AUT0149	1	1,002	L/R	1,197
Trenton Channel	Detroit Edison Co	MI	1,745	AUT0575	2	516	GL	730
Trinidad	Luminant Power	TX	3,507	AUT0476	2	285	L/R	240
Twin Oaks	Sempra	TX			5	305	L/R	330
Tyrone	Kentucky Utilities Co	KY	1,361	AUT0095	1	79	R (Small)	75
University of Notre Dame	Indiana Michigan Power Co	IN	50,366	DMU3244	3	113	L/R	21

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Urquhart	South Carolina Electric & Gas Co	SC	3,295	AUT0535	1	190	R (Small)	243
V H Braunig	CP San Antonio	TX	3,612		2	1,277	L/R	1,401
Valley	Wisconsin Electric Power Co	WI	3,508	AUT0161	1	158	GL	280
Valmont	Xcel	CO			2	194	L/R	186
Vero Beach	Vero Beach City of	FL	693	AUT0467	4	144	O/E/TR	117
Victoria	Topaz Power Group LLC	TX	3,443	DUT1142	4	557	R	80
W H Sammis	Ohio Edison Co	OH	2,866		1	1,353	R (Large)	2,219
W S Lee	Duke Energy Corp	SC	3,264	AUT0308	1	331	R (Small)	424
Wabash River	Duke Energy Corp	IN	1,010		2	747	R (Large)	764
Waiau	Hawaiian Electric Co Inc	HI	766	DUT1116	1	430	O/E/TR	397
Walter C Beckjord	Duke Energy Corp	OH	2,830	AUT0523	1	741	R (Large)	1,222
Walter Scott Jr. (Council Bluffs)	MidAmerican Energy Co	IA	1,082	DUT1148	2	792	R (Largel)	821
Warrick	Alcoa Power Generating Inc	IN	6,705	AUT0462	4	281	R (Large)	755
Waterford 1 & 2	Entergy Louisiana Inc	LA	8,056	AUT0156	1	822	R (Large)	912
Waukegan	Midwest Generation EME LLC	IL	883	DUT1123	1	731	GL	736
Welsh	SWEPCO	TX	6,139		1	1,218	L/R	1,674
West Springfield	North American Energy Alliance	MA	1,642		4	69	R (Large)	214
Westchester Resco Co	Westchester Resco/Wheelabrator	NY	50,882	DNU2017	3	55	O/E/TR	75
Weston	Wisconsin Public Service Corp	WI	4,078	AUT0344	2	118	R (Small)	135
Westover	AES Westover LLC	NY	2,526		2	97	R (Large)	82

Facility Name	Utility	State	Plant Code	EPAID	Flow Basis	Flow (MGD)	Water Body Type	MW
Widows Creek	Tennessee Valley Authority	AL	50	DUT1209	2	1,645	R (Large)	1,761
Wilkes	SWEPCO	TX	3,478		1	539	L/R	888
Will County	Midwest Generation EME LLC	IL	884	AUT0380	1	1,296	R (Small)	1,300
Williams	South Carolina Genertg Co Inc	SC	3,298	AUT0014	1	534	L/R	656
Willow Glen	Entergy Gulf States Inc	LA	1,394	DUT1228	1	1,002	R (Large)	2,045
Willow Island	Monongahela Power Co	WV	3,946		2	205	R (Large)	245
Wood River	Dynegy Midwest Generation Inc	IL	898	AUT0143	2	340	R (Large)	460
Wyandotte	Wyandotte City of	MI	1,866	AUT0050	4	112	GL	73
Wyman	NEXTera Energy	ME	1,507		1	263	O/E/TR	837
Yorktown	Virginia Electric & Power Co	VA	3,809		1	1,382	O/E/TR	1,230

G
HUMAN HEALTH IMPACTS

G.1 Quantification

Potential upper bounds for possible human health impacts may be estimated through human health risk assessment. The United State Environmental Protection Agency (USEPA) provides risk assessment methodology in its document, “Particulate Matter Health Risk Assessment for Selected Urban Areas,” [1] which relies heavily on the information and conclusions presented in the USEPA’s final assessment of the available particulate matter (PM) health effects literature [2]. PM in urban areas is comprised primarily of sulfate, organic carbon, elemental carbon, crustal materials, nitrate, and in some areas/seasons, biological matter (e.g., pollen). Detailed epidemiological work by Electric Power Research Institute (EPRI) has shown that the health effects attributable to PM are often closely associated with sub-components such as organic carbon and/or co-occurring gases, such as carbon monoxide [3]. Cooling tower drift particles consist mostly of mineral salts, although they likely contain organic matter from spores, pollen, and vegetative or insect fragments entrained into the towers and organic matter in makeup water. Therefore, the uncertainty related to health effects from cooling tower drift particles is very high.

Because EPRI research indicates USEPA’s methods and their application in this closed-cycle cooling retrofit analysis results in very conservative risk estimates at the high end of the upper bound, and due to the lack of impact studies focused on human health effects related to cooling tower fine particulates, human health impacts are not reliably quantifiable. Any such impacts are likely to be extremely variable depending on the nature of the fine particulates in the source waterbody. However, human health risk estimates based on USEPA methodology are provided in this appendix as a highly conservative estimate of the upper bound.

A generalized USEPA concentration-response function [1] was used to estimate the increased incidence of the following endpoints that may occur, over and above possible current baseline effects associated with ambient PM:

- Mortality due to long-term exposure to an increased concentration of PM that measures 2.5 microns or less in diameter ($PM_{2.5}$); and
- Hospital admissions for treatment of morbidity effects such as heart disease, bronchitis, emphysema, and pneumonia due to exposure to increased concentrations of $PM_{2.5}$ and/or PM that measures between 10 and 2.5 microns in diameter ($PM_{10-2.5}$).

Detailed methodology of this quantification is provided in Section G-4.

The estimated increased mortality numbers for the 30 years and older (Age 30+) population due to exposure to increased $PM_{2.5}$ concentration and the increased morbidity numbers for the 65 years and older (Age 65+) population due to increased $PM_{2.5}$ or $PM_{10-2.5}$ concentrations are reported in Table G-1. As with any single point risk estimate, there is considerable uncertainty associated with the values provided in this table and, as discussed above, they are considered to be a conservative representation of the high end of upper bound risk; a low end risk estimate may approach zero. For a more detailed discussion of uncertainties, see Section G.5 below.

Table G-1
Estimated annual risk of increased mortality and morbidity due to cooling tower emissions

[WTP estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.]

	Mortality Results (Age 30+)				Morbidity Results (Age 65+)				
	Exposed Population	**Baseline Annual Death Rate per 100,000 people**[a]	**Baseline Annual Number of Deaths**	**Estimated Annual Increase in Number of Deaths**[b]	**Exposed Population**	**Disease**	**Baseline Annual Hospital Admission Rate per 10,000 People**[c]	**Baseline Annual Number of Cases (Hospital Admissions)**	**Estimated Annual Increase in Number of Cases**[b]
BTCA1 - Los Angeles Co., CA	19,377	936	181	0.05	9,576	CVD	17,421	16,683	12
						COPD	2,099	2,010	0.9
						Pneumonia	3,792	3,632	2
BTPA - Southeast	183	1,520	3	0.0003	41	CVD	4,267	17	0.003
						COPD	456	2	0.0002
						Pneumonia	982	4	0.0005
BTPB - Midwest	6,746	1,481	100	0.005	1,523	CVD	6,048	921	0.08
						COPD	635	97	0.005
						Pneumonia	1,858	283	0.02
BTPC - Northeast	39,290	1,206	474	0.04	8,823	CVD	3,369	2,972	0.7
						COPD	372	328	0.04
						Pneumonia	1,018	898	0.1
BTPD - Southeast	535	1,249	7	0.002	99	CVD	3,369	33	0.009
						COPD	372	4	0.0006
						Pneumonia	1,018	10	0.002
BTPE - Northeast	7,554	1,210	91	0.01	1,282	CVD	4,267	547	0.1
						COPD	456	58	0.007
						Pneumonia	982	126	0.02
BTCA2 - Orange Co., CA	84[d]	902	0.8	0.001	1	CVD	840	0.084	<0.001
						COPD	51	0.0051	<0.0001
						Pneumonia	256	0.026	<0.0001
RFF - Midwest	15,139	1,481	224	0.002	3,498	CVD	4,267	1,493	0.01
						COPD	456	160	0.0009
						Pneumonia	982	343	0.002

Table G-1
Estimated annual risk of increased mortality and morbidity due to cooling tower emissions
[WTP estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.] **(continued)**

	Mortality Results (Age 30+)				**Morbidity Results (Age 65+)**				
	Exposed Population	**Baseline Annual Death Rate per 100,000 people[a]**	**Baseline Annual Number of Deaths**	**Estimated Annual Increase in Number of Deaths[b]**	**Exposed Population**	**Disease**	**Baseline Annual Hospital Admission Rate per 10,000 People[c]**	**Baseline Annual Number of Cases (Hospital Admissions)**	**Estimated Annual Increase in Number of Cases[b]**
RFG - Midwest	1,809	1,136	21	0.0007	288	CVD	3,427	99	0.005
						COPD	120	3	0.0001
						Pneumonia	872	25	0.0008
RFH - Southeast	23,407	1,339	313	0.07	5,397	CVD	3,369	1,818	1
						COPD	372	201	0.1
						Pneumonia	1,018	550	0.3
RFI - Midwest	223,756	1,152	2,579	0.05	38,495	CVD	37,267	143,457	3
						COPD	2,854	10,988	0.2
						Pneumonia	9,735	37,473	0.6
RFJ - South	5,784	1,605	93	0.003	1,206	CVD	3,369	406	0.02
						COPD	372	45	0.001
						Pneumonia	1,018	123	0.004
RFK - Northeast	148,269	1,147	1,701	0.06	25,105	CVD	5,906	14,826	1
						COPD	358	898	0.04
						Pneumonia	1,486	3,729	0.2
RFL - Midwest	20,614	1,492	308	0.007	5,717	CVD	6,048	3,458	0.1
						COPD	635	363	0.007
						Pneumonia	1,858	1,062	0.02
RFS - Midwest	1,651	1,425	24	0.002	400	CVD	4,267	171	0.02
						COPD	456	18	0.001
						Pneumonia	982	39	0.003

[a] Annual death rate per 100,000 (100k) (based on county data) for ages 25+; data were not listed for ages 30+.

[b] Estimates presented here for increases in mortality and morbidity endpoints are based on USEPA methodology and represent the high end of upper bound risk. The low end of the upper bound risk may approach zero.

[c] Hospital Admissions (Number of Cases)-estimates are based on admissions of patients aged 65+ years with cardiovascular disease (CVD), chronic obstructive pulmonary disease (COPD), or pneumonia. Site-specific hospital admissions baseline rates are not available; instead, baseline rates were based on reference cities selected to be representative of the facility locations.

[d] No census data were available for a nearby military base.

G.2 Monetization

Human health monetization methods and values used in this evaluation are consistent with USEPA's methods [4]. USEPA provides the willingness to pay (WTP) value to avoid the risk of mortality (value of a statistical life) and the hospital costs to treat air quality-related diseases (a proxy for WTP) on a per hospital admission basis [4]. Detailed methods are provided in Section G-4, below. The annual average WTP to avoid additional mortality and morbidity associated with cooling towers are reported in Tables G-2 through G-4.

Table G-2
Annual monetized impacts associated with mortality risks

[WTP estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.]

Facility	Total Number of People Exposed (Age 30+)	Annual Mortality (# of Deaths Over Baseline)	Annual WTP to Avoid Mortality (2007$)
BTCA1	19,377	0.05	$327,300
BTPA	183	0.0003	$2,000
BTPB	6,746	0.005	$32,700
BTPC	39,290	0.04	$261,900
BTPD	535	0.002	$13,100
BTPE	7,554	0.01	$65,500
BTCA2[a]	84	0.001	$6,500
RFF	15,139	0.002	$11,000
RFG	1,809	0.0007	$4,700
RFH	23,407	0.07	$483,000
RFI	223,756	0.05	$322,900
RFJ	5,784	0.003	$17,400
RFK	148,269	0.06	$366,200
RFL	20,614	0.007	$44,100
RFS [b]	1,651	0.002	$14,500

[a] Does not include residents of a nearby military base because of a lack of census data.

[b] Impact at this facility was estimated based on modeling from a similar facility.
Totals may not equal due to rounding.

Table G-3
Annual monetized impacts associated with morbidity risks

[WTP estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.]

Facility	Total Number of People Exposed (Age 65+)	Annual Morbidity (# of Hospital Visits Over Baseline)			Annual WTP to Avoid Morbidity (2007$)
		CVD	COPD	Pneumonia	
BTCA1	9,576	12	0.9	2	$355,000
BTPA	41	0.003	0.0002	0.0005	$100
BTPB	1,523	0.08	0.005	0.02	$2,400
BTPC	8,823	0.7	0.04	0.1	$21,300
BTPD	99	0.009	0.0006	0.002	$300
BTPE	1,282	0.1	0.007	0.02	$3,000
BTCA2[a]	1	<0.001	<0.0001	<0.0001	$0
RFF	3,498	0.01	0.0009	0.002	$400
RFG	288	0.005	0.0001	0.0008	$100
RFH	5,397	1	0.1	0.3	$45,700
RFI	38,495	3	0.2	0.6	$102,200
RFJ	1,206	0.02	0.001	0.004	$600
RFK	25,105	1	0.04	0.2	$35,300
RFL	5,717	0.1	0.007	0.02	$3,400
RFS[b]	400	0.02	0.001	0.003	$600

[a] Does not include residents of a nearby military base because of a lack of census data.
[b] Impact at this facility was estimated based on modeling from a similar facility.
Totals may not equal due to rounding.

Table G-4
Total annual monetized impacts associated with health risks

[WTP estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.]

Facility	Annual WTP to Avoid Mortality (2007$)	Annual WTP to Avoid Morbidity (2007$)	Total Annual WTP to Avoid Mortality and Morbidity (2007$)
BTCA1	$327,300	$355,000	$682,400
BTPA	$2,000	$100	$2,100
BTPB	$32,700	$2,400	$35,200
BTPC	$261,900	$21,300	$283,200
BTPD	$13,100	$300	$13,400
BTPE	$65,500	$3,000	$68,400
BTCA2[a]	$6,500	$0	$6,500
RFF	$11,000	$400	$11,400
RFG	$4,700	$100	$4,800
RFH	$483,000	$45,700	$528,600
RFI	$322,900	$102,200	$425,100
RFJ	$17,400	$600	$18,000
RFK	$366,200	$35,300	$401,500
RFL	$44,100	$3,400	$47,500
RFS[b]	$14,500	$600	$15,100

[a] Does not include residents of a nearby military base because of a lack of census data.
[b] Impact at this facility was estimated based on modeling from a similar facility.
Totals may not equal due to rounding.

G.3 National Scaling

The total annual national WTP to avoid additional human health effects associated with PM emissions from cooling towers were scaled from the WTP values shown in Table G-4, above, not from calculations of PM emissions for each Phase II facility.

Potential human health effects are primarily a function of the change in PM_{10} and $PM_{2.5}$ concentrations and the populations exposed. The magnitude of the effect is confounded by other pre-existing variables such as age, annual death rates, and annual hospitalization rates. The PM_{10} and $PM_{2.5}$ concentrations are a function of the cooling tower design related to the concentration of total dissolved solids, cycles of concentration, and flow. Confounding variables include local metrological conditions, topography, and other factors.

During the Beta Test, 15 California facilities were modeled for potential impacts based on the results of the two California Beta Test Plants (BTPs). In that evaluation, the differences in confounding variables for both human health effects and PM_{10} and $PM_{2.5}$ concentrations were assumed to be minor across all California facilities. The population exposed at each California facility was estimated using an area function that adjusts the modeled particulate concentration (PM_{10} and $PM_{2.5}$) at the Beta Test facilities for differences in cooling tower design and hours of operation at each California facility. The population exposed at each California facility was estimated by using the distance function and local population data for each site. The resulting population estimate and average WTP to avoid potential adverse health impacts at the two California BTPs were used to estimate WTP at each location. The results are presented in Table G-5, below.

Table G-5
Scaling impacts to human health for California once through cooled facilities based on wtp to avoid cooling tower related health risks

[WTP estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.]

Facility	Ratio of Population Impacted Relative to BTCA1	Scaled Annual WTP to Avoid Mortality Health Risk (2007$)	Scaled Annual WTP to Avoid Morbidity Health Risk (2007$)	Scaled Total Annual WTP to Avoid Health Risk (2007$)
BTCA1	1	$327,300	$355,000	$682,400
BTCA2	0	$6,500	$0	$6,500
CA1	0.062	$20,400	$22,200	$42,600
CA2	0.026	$8,500	$9,200	$17,800
CA3	0.026	$8,500	$9,200	$17,800
CA4	0.335	$109,800	$119,100	$228,900
CA5	0.006	$1,800	$2,000	$3,800
CA6	0.057	$18,600	$20,200	$38,800
CA7	0.182	$59,500	$64,500	$123,900
CA8	0.0898	$29,400	$31,900	$61,300
CA9	0.085	$27,800	$30,100	$57,800
CA10	0.027	$8,900	$9,600	$18,500
CA11	0.176	$57,600	$62,400	$120,000
CA12	0.125	$40,800	$44,200	$85,000
CA13	0.295	$96,400	$104,600	$201,000
CA14	0.090	$29,500	$32,000	$61,500
CA15	0.167	$54,800	$59,400	$114,300
State-wide Totals		**$906,200**	**$975,700**	**$1,881,900**

WTP rounded to the nearest $100; totals may not equal due to rounding.

Table G-6 reports the estimated impacts to human health for California facilities scaled from the results for BTCA1 and BTCA2 using the same population ratios.

Table G-6
Scaling impacts to human health for California once through cooled facilities

[Estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.]

Facility	Ratio of Population Impacted Relative to BTCA1	Annual Mortality (# of Deaths Over Baseline)	Annual Morbidity (# of Hospital Visits Over Baseline)		
			CVD	**COPD**	**Pneumonia**
BTCA1	1	0.050	12.00	0.90	2.00
BTCA2	0	0.000	0.00	0.00	0.00
CA1	0.062	0.003	0.74	0.06	0.12
CA2	0.026	0.001	0.31	0.02	0.05
CA3	0.026	0.001	0.31	0.02	0.05
CA4	0.335	0.017	4.02	0.30	0.67
CA5	0.006	0.0003	0.07	0.01	0.01
CA6	0.057	0.003	0.68	0.05	0.11
CA7	0.182	0.009	2.18	0.16	0.36
CA8	0.0898	0.004	1.08	0.08	0.18
CA9	0.085	0.004	1.02	0.08	0.17
CA10	0.027	0.001	0.32	0.02	0.05
CA11	0.176	0.009	2.11	0.16	0.35
CA12	0.125	0.006	1.50	0.11	0.25
CA13	0.295	0.015	3.54	0.27	0.59
CA14	0.090	0.005	1.08	0.08	0.18
CA15	0.167	0.008	2.00	0.15	0.33
State-wide Totals		0.137	32.99	2.47	5.50

It was not practical to estimate impacts to all the remaining Phase II facilities using the site-specific methodology in the Beta Test California scale-up. Therefore, impacts to human health for the rest of the Phase II facilities were estimated using the following approach (details of the methodology are provided in Section G.4.3, below). The variables associated with PM_{10} and $PM_{2.5}$ concentrations are accounted for by grouping facilities based on cooling water salinity/waterbody type. To account for the populations exposed, the list of Phase II facilities are categorized into Low (<100 people/mi^2), Medium (100-1,000 people/mi^2) and High (>1,000 people/mi^2) population densities (see Section 2.3 of the main text) resulting in nine subgroups:

- Large Rivers/Reservoirs and Lakes (LR/RL) – High Population;
- LR/RL – Medium Population;
- LR/RL – Low Population;
- Small Rivers/Great Lakes (SR/GL) – High Population;
- SR/GL – Medium Population;
- SR/GL – Low Population;
- Oceans/Estuaries/Tidal Rivers (O/E/TR) – High Population;
- O/E/TR – Medium Population; and
- O/E/TR – Low Population.

The annualized mortality and morbidity statistics for the BTPs and Representative Facilities (RFs), along with the annual WTP to avoid these human health impacts, were grouped into the nine salinity/population subgroups to evaluate the range of potential impacts and WTP. The BTP/RF with the maximum estimated annual WTP to avoid human health impacts was chosen to represent the other facilities in that subgroup as an upper-bound risk estimate. Note that because there were no BTPs/RFs in the SR/GL-Low Population subgroup, the results for RFS, the only freshwater BTP/RF in a Low Population area, were used for estimating the other facilities in that subgroup. Table G-7 presents the results of these calculations.

Table G-7
Estimated national impacts associated with human health risks

[Estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.]

Source Waterbody Type	Population Group	Facilities[a]	Annual Mortality (# of Deaths Over Baseline)	Annual Morbidity (# of Hospital Visits Over Baseline)		
				CVD	COPD	Pneumonia
O/E/TR	Low	CA (5)	0.01	1.0	0.1	0.2
		Other BTPs/RFs (2)	0.04	0.7	0.04	0.1
		Other Phase II (23)	1.1	18.6	1.1	2.7
	Medium	CA (7)	0.04	9.1	0.7	1.5
		Other BTPs/RFs (1)	0.1	1.0	0.1	0.3
		Other Phase II (30)	0.9	13.3	1.3	4.0
	High	CA (4)	0.1	19.3	1.4	3.2
		Other BTPs/RFs (1)	0.1	1.0	0.04	0.2
		Other Phase II (43)	3.8	63.9	2.6	12.8
	O/E/TR subtotal		6.13	128.0	7.3	24.9

Table G-7
Estimated national impacts associated with human health risks

[Estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.] **(continued)**

Source Waterbody Type	Population Group	Facilities[a]	Annual Mortality (# of Deaths Over Baseline)	Annual Morbidity (# of Hospital Visits Over Baseline)		
				CVD	**COPD**	**Pneumonia**
LR/RL	Low	BTPs/RFs (1)	0.002	0.02	0.001	0.003
		Other Phase II (113)	0.1	1.1	0.1	0.2
	Medium	BTPs/RFs (4)	0.02	0.1	0.01	0.03
		Other Phase II (54)	0.3	1.7	0.1	0.3
	High	BTPs/RFs (1)	0.01	0.1	0.01	0.02
		Other Phase II (18)	0.1	1.5	0.1	0.3
	LR/RL subtotal		0.50	4.6	0.3	0.9
SR/GL	Low	BTPs/RFs (0)	0	0	0	0
		Other Phase II (38)	0.02	0.2	0.01	0.03
	Medium	BTPs/RFs (2)	0.01	0.1	0.01	0.02
		Other Phase II (55)	0.1	1.1	0.1	0.3
	High	BTPs/RFs (1)	0.1	3.0	0.2	0.6
		Other Phase II (22)	0.8	48.5	3.2	9.7
	SR/GL subtotal		0.95	52.9	3.5	10.6
National Total			**7.58**	**185.5**	**11.1**	**36.4**

[a] Values in parentheses indicate the number of facilities in the subgroup.

Using the same methodology, the WTP to avoid these human health-related impacts of closed-cycle cooling retrofitting were estimated (Table G-8).

Table G-8
Estimated national monetized impacts associated with health risks

[WTP estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.]

Waterbody Type	Population Group	Facilities	Annual WTP to Avoid Mortality (2007$)	Annual WTP to Avoid Morbidity (2007$)	Annual WTP to Avoid Both Mortality and Morbidity (2007$)
O/E/TR	Low	CA	34,291	30,090	64,381
		BTPs/RFs	263,842	21,417	285,259
		Other Phase II	6,966,623	567,087	7,533,710
	Medium	CA	238,062	258,191	496,253
		BTPs/RFs	482,966	45,661	528,627
		Other Phase II	6,423,096	607,258	7,030,354
	High	CA	593,044	643,189	1,236,233
		BTPs/RFs	366,190	35,330	401,520
		Other Phase II	23,413,703	2,258,953	25,672,656
	O/E/TR subtotal		40,799,000	4,467,200	43,249,000
LR/RL	Low	BTPs/RFs	14,516	608	15,124
		Other Phase II	782,221	32,763	814,984
	Medium	BTPs/RFs	100,691	3,944	104,635
		Other Phase II	1,497,531	49,116	1,546,647
	High	BTPs/RFs	44,110	3,418	47,528
		Other Phase II	678,300	52,560	730,861
	LR/RL subtotal		3,117,400	142,400	3,259,800
SR/GL	Low	BTPs/RFs	0	0	0
		Other Phase II	147,709	6,187	153,896
	Medium	BTPs/RFs	43,732	2,863	46,595
		Other Phase II	446,441	33,195	479,636
	High	BTPs/RFs	322,902	102,209	425,111
		Other Phase II	5,217,245	1,651,428	6,868,673
	SR/GL subtotal		6,178,000	1,795,900	7,973,900
National Total			**48,077,200**	**6,405,500**	**54,482,700**

WTP totals rounded to the nearest $100; totals may not equal due to rounding.

The upper bound total national WTP to avoid human health impacts at all Phase II facilities is over $54 million. However, EPRI research indicates the USEPA methods used to derive these results are very conservative risk estimates. Additionally, no specific human health studies on cooling tower PM impacts were found. For these reasons, human health impacts from cooling tower PM may be negligible.

G.4 Methodology

The risk assessment methodology used here was based on the document entitled "Particulate Matter Health Risk Assessment for Selected Urban Areas" [1]. This document relies heavily on the information and conclusions presented in the USEPA's final assessment of the available PM health effects literature, which was extensively reviewed and commented upon by the Clean Air Scientific Advisory Committee's PM Review Panel and the general public [2].

A generalized concentration-response function was used [1] to estimate the increased incidence of the following endpoints that may occur, over and above current baseline effects associated with ambient PM:

1. Mortality due to long-term exposure to an increased concentration of PM that measures 2.5 microns or less in diameter ($PM_{2.5}$); and
2. Hospital admissions for treatment of morbidity effects such as heart disease, bronchitis, emphysema, and pneumonia due to exposure to increased concentrations of $PM_{2.5}$ and/or PM that measures between 10 and 2.5 microns in diameter ($PM_{10\text{-}2.5}$).

G.4.1 Quantification

G.4.1.1 Overview of Risk Assessment Methods

The generalized concentration-response function given in USEPA [1] was used to estimate the increase in health effects incidence over baseline at ambient PM for both endpoints described above:

$$\Delta y = y(e^{\beta \Delta x} - 1)$$

Where, y = baseline incidence of the health endpoint of interest associated with ambient PM level (x), β = coefficient of ambient PM concentration (PM coefficient), Δx = increase in PM concentration over ambient levels, and Δy = increase in health effects incidence over baseline.

PM coefficients were obtained from relevant studies discussed in USEPA [1]. Baseline incidences used to estimate the mortality endpoints were obtained from online sources. Because morbidity data (i.e., hospital admissions) for specific areas were not readily available, baseline statistics for the morbidity endpoints were based solely on available information [5]. The increase in PM concentrations over ambient levels was obtained through the air dispersion modeling s described in the main text and in Appendix B. Annual increases in PM concentrations (predicted by the air modeling) were applied as an average across each census block exposed.

The data described above were used in the generalized concentration-response function to calculate the estimated increase in mortality and morbidity (i.e., hospital admissions) for each BTP and RF. In each case, the most likely result was estimated based on the USEPA methodology, which is presented here as a high end upper bound estimate of the potential health risk [1]. For the morbidity calculations, the estimates of increased hospital admissions for COPD (i.e., chronic bronchitis and emphysema), CVD, and pneumonia in the Age 65+ age group were summed to get a single estimate for increased morbidity. For each of the three morbidity endpoints, the value entered into the sum was the greater of the results estimated using either the $PM_{2.5}$ or the $PM_{10-2.5}$ concentration.

The resulting value from the concentration-response function, the relative increase in health effects over baseline, was applied to the relevant exposed population in each census block to estimate the number of additional mortalities or morbidities statistically expected due to estimated PM emissions from cooling towers at each site.

G.4.1.2 Selection of Coefficients

A summary of studies reviewed as part of the PM human health risk assessment was presented by USEPA [1]. The studies presented were reviewed by USEPA's Office of Air Quality Planning and Standards staff and were selected for further consideration in their PM risk assessment because:

> "…epidemiological evidence is strong for associations between PM_{10} and $PM_{2.5}$ and mortality, especially for total and cardiovascular mortality. The magnitudes of the associations are relatively small, especially for the multi-city studies. However, there is a pattern of positive and often statistically significant associations across studies for cardiovascular and respiratory health outcomes, including mortality and hospitalization and medical visits for cardiovascular and respiratory diseases, with PM_{10} and $PM_{2.5}$. The few available $PM_{10-2.5}$ studies also provide some evidence for associations between hospitalization for cardiovascular and respiratory diseases with $PM_{10-2.5}$. ... For $PM_{10-2.5}$, the evidence for association with mortality is more limited." [2].

USEPA staff indicated the studies that they believed to be most relevant and reliable for use in their PM risk assessment. The endpoints investigated by USEPA included mortality due to short- and long-term exposure to $PM_{2.5}$, as well as morbidity effects due to short-term exposure to $PM_{2.5}$ and $PM_{10-2.5}$ [1]. From this list of USEPA-identified studies, reports that best estimated the increased health effects due to anticipated exposure to increased PM concentrations above ambient levels were selected. This risk assessment methodology was designed to be applied in the evaluation of hundreds of potential sites located in multiple cities across the United States; therefore, preference was given to studies that were developed to describe the association of ambient PM and mortality across multiple cities, if available. USEPA summarized the PM coefficients and the study details for each [1]. The selected PM coefficients are provided in Table G-9. The studies and USEPA methodology used here and the risk estimates generated from their use represent the high end of upper bound risk.

Table G-9
Summary of PM coefficients selected from USEPA [1]

[The selected studies represent the high end of the upper bound risk; EPRI research indicates the lower end risk may approach zero.]

Endpoint[a]	Cause	PM Coefficient
$PM_{2.5}$ as monitored PM fraction:		
Mortality (Age 30+)	All [6]	0.00583
Morbidity (Age 65+)	CVD (CA sites) [7, 8]	0.00158
	CVD (non-CA sites) [9, 10]	0.00143[b]
		0.00307[c]
		0.00125[d]
	COPD (CA sites) [8, 11]	0.00167
	COPD (non-CA sites) [9, 10]	0.00117
	Pneumonia [9, 10]	0.00398
$PM_{10-2.5}$ as monitored PM fraction:		
Morbidity (Age 65+)	CVD [7, 8]	0.0038954[b]
		0.0017142[c]
		0.0000416[d]
	COPD [9, 10]	0.0033223
	Pneumonia [9, 10]	0.0037814

[a] Mortality endpoint based on population age 30 and older; morbidity endpoint based on population age 65 and older.
[b] ischemic heart disease
[c] congestive heart failure
[d] dysrhythmias

G.4.1.3 Studies Selected for the Mortality Endpoint

Mortality due to long-term exposure to $PM_{2.5}$ was retained as the only concentration-response relationship for modeling the mortality endpoint. Mortality due to long- or short-term exposure to $PM_{10-2.5}$ was not considered because the literature indicates there is not enough evidence to support a significant relationship between mortality and exposure to $PM_{10-2.5}$. Mortality due to short-term exposure to $PM_{2.5}$ was not included as an endpoint in this study due to the lack of reliable data for daily mortality. County-level mortality statistics are reported on an annual basis. Dividing annual statistics by days per year would not yield sensitive enough data to estimate daily mortality. The reverse of this, using the results for short-term exposure to $PM_{2.5}$ to estimate changes in annual mortality rates, is also flawed due to the phenomenon referred to as “harvesting” [1].

Two studies from the USEPA list of relevant studies fit the criteria of long-term exposure to $PM_{2.5}$ and evaluation of total mortality and PM data in multiple cities [1]: the Six Cities analysis by Krewski et al. and the American Cancer Society (ACS) study by Pope et al. (an extension of the Krewski et al. ACS Study) [6, 12]. According to USEPA, the Health Effects Subcommittee of the Science Advisory Board’s Clean Air Act Compliance Council prefers that USEPA use the results from the extended ACS study rather than those from the Six Cities study to represent base case estimates for long-term exposure mortality associated with $PM_{2.5}$ concentrations for the purposes of benefits analyses [1, 13]. Therefore, the extended ACS study was selected to estimate long-term mortality due to increased $PM_{2.5}$ concentrations [6]. That study was conducted based on mortality statistics for ages 30 and above (Age 30+); therefore, the modeling results presented here are relevant only to that age group.

G.4.1.4 Studies Selected for the Morbidity Endpoints

There are only four studies listed by USEPA that report relationships between hospitalization and exposure to $PM_{2.5}$ and/or $PM_{10\text{-}2.5}$ [1]:

- Hospital admissions due to cardiovascular and respiratory symptoms related to ambient $PM_{2.5}$ and $PM_{10\text{-}2.5}$ data in Detroit, MI [9, 10];
- Hospital admissions due to asthma symptoms related to ambient $PM_{2.5}$ and $PM_{10\text{-}2.5}$ data in Seattle, WA [14, 15];
- Hospital admissions for cardiovascular and respiratory symptoms related to ambient $PM_{2.5}$ data in Los Angeles, CA [7, 8, 11]; and
- Lower respiratory symptoms and coughs (not hospital admissions) related to ambient $PM_{2.5}$ and $PM_{10\text{-}2.5}$ data in Boston, MA and St. Louis, MO [16].

Because baseline morbidity data were not readily available for incidence of asthma, lower respiratory symptoms, and coughs, the studies by Sheppard et al. and Schwartz and Neas were not considered further, and those morbidity endpoints were not included in this report [14, 15, 16]. Study results were used to estimate morbidity effects for $PM_{2.5}$ [7, 8, 9, 10, 11]. Since Moolgavkar did not consider morbidity effects due to exposure to $PM_{10\text{-}2.5}$, only the Lippman study was used for that PM component [7, 8, 9, 11]. Both of these studies relied on Medicare hospitalization records for their response data; therefore, the only relevant age group for the morbidity calculations is the Age 65+ portion of the population [7, 8, 9, 10, 11]. No useable data are available for younger age groups; therefore, no modeling calculations could be performed for the portion of the population younger than 65 years.

Three morbidity endpoints were considered in the modeling: (1) Age 65+ hospitalization due to CVD, (2) Age 65+ hospitalization due to COPD (i.e., chronic bronchitis and emphysema), and (3) Age 65+ hospitalization due to pneumonia. For each of these three morbidity endpoints, the response (increased number of Age 65+ hospitalizations) was calculated based on the modeled $PM_{2.5}$ concentration and the modeled $PM_{10\text{-}2.5}$ concentration, and the maximum result from those two estimates was selected as the more conservative result. The sum over these three endpoints was used as the estimated increase in morbidity (measured as hospitalizations in the Age 65+ age group) due to PM exposure.

G.4.1.5 Baseline Health Statistics

County-level mortality statistics were obtained from online sources. The PM coefficient for mortality effects (Table G-10) is based on mortality due to all causes; therefore, the baseline mortality rates for the relevant counties were also selected based on all causes of death. Because morbidity data (i.e., hospital admissions) for specific areas are not readily available, baseline statistics for the morbidity endpoints were based on information provided in Samet et al. [5].

The Samet et al. study [5] summarized hospital admissions data for ages 65+ from Medicare records from 14 cities. General climate information and air-quality data for these 14 reference sites and for 15 of the BTPs and RFs were compiled (listed in the Tables G-11 and G-12) [17]. Reference cities were selected for each of the BTPs and RFs using best professional judgment based on both similarities in climate and air quality days. For the RFs, where good matches for both of these factors were not available, more emphasis was placed on climate than air quality. Baseline morbidity data from one of the 14 reference sites were then applied to each of the individual BTPs and RFs in order to estimate the anticipated increased morbidity effects that might be associated with the modeled increase in PM concentrations.

Table G-10
General climate and percent air quality days for reference sites

Site/Location	General Climate (Koppen-Geiger Climate Classification)[a]	*% Air-Quality Days (2007)*[a]		
		Good	Moderate	Unhealthy [b]
Birmingham, AL	Cfa – Temperate; humid subtropical; mid-latitude; hot summer, mild winter	17%	69%	13%
Boulder, CO	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	73%	24%	2%
Canton, OH	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	66%	26%	8%
Chicago, IL	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	41%	53%	7%
Colorado Springs, CO	BSk – Semi-arid; steppe; cool	77%	23%	0%
Detroit, MI	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	52%	42%	6%
Minneapolis/St Paul, MN	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	62%	35%	3%
Nashville, TN	Cfa – Temperate; humid subtropical; mid-latitude; hot summer, mild winter	50%	40%	10%
New Haven, CT	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	72%	26%	2%
Pittsburgh, PA	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	34%	50%	16%
Provo/Orem, UT	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	42%	45%	13%
Seattle, WA[c]	Csb – Humid subtropical; Mediterranean; dry summer, wet winter	77%	21%	3%

Table G-10
General climate and percent air quality days for reference sites (continued)

Site/Location	General Climate (Koppen-Geiger Climate Classification)[a]	*% Air-Quality Days (2007)*[a]		
		Good	Moderate	Unhealthy [b]
Spokane, WA	Dsb – Moist continental mid-latitude; warm or cool summer, cold winter	81%	19%	0%
Youngstown, OH	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	73%	22%	6%

[a] Climate classifications and air quality data have changed slightly since the Beta Test was conducted.
[b] "Unhealthy" includes days considered to be unhealthy to sensitive individuals.

[c] Seattle, WA climate is sometimes classified as "Cfb" (Temperate oceanic; warm summer, mild winter; no dry season).

Table G-11
General climate and percent air quality days for beta test plants and representative facilities

Site/Location	General Climate (Koppen-Geiger Climate Classification)[a]	*% Air-Quality Days (2007)*[a]			Reference City
		Good	Moderate	Unhealthy[b]	
BTCA1	Csa – Humid subtropical; Mediterranean; hot, dry summer, wet winter	29%	44%	27%	Pittsburgh, PA
BTPA - Southeast	Cfa – Temperate; humid subtropical; mid-latitude; hot summer, mild winter	82%	14%	3%	Youngstown, OH
BTPB - Midwest	Dfb – Humid continental; warm summer, cold winter; year-round precipitation	70%	25%	5%	Minneapolis/St Paul, MN
BTPC - Northeast	Cfa – Temperate; humid subtropical; mid-latitude; hot summer, mild winter	58%	38%	5%	Nashville, TN
BTPD - Southeast	Cfa – Temperate; humid subtropical; mid-latitude; hot summer, mild winter	53%	46%	0%	Nashville, TN
BTPE - Northeast	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	70%	25%	5%	Youngstown, OH
BTCA2	Csb – Humid subtropical; Mediterranean; dry summer, wet winter	67%	28%	5%	Provo/Orem, UT
RFF - Midwest	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	74%	24%	2	Youngstown, OH
RFG - Midwest	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	66%	27%	7%	Canton, OH
RFH - Southeast	Cfa – Temperate; humid subtropical; mid-latitude; hot summer, mild winter	83%	17%	0%	Nashville, TN

Table G-11
General climate and percent air quality days for beta test plants and representative facilities (continued)

Site/Location	General Climate (Koppen-Geiger Climate Classification)[a]	% Air-Quality Days (2007)[a]			Reference City
		Good	Moderate	Unhealthy[b]	
RFI - Midwest	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	41%	53%	7%	Chicago, IL
RFJ - South	Cfa – Temperate; humid subtropical; mid-latitude; hot summer, mild winter	88%	10%	1%	Nashville, TN
RFK - Northeast	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	85%	11%	4%	New Haven, CT
RFL - Midwest	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	63%	32%	5%	Minneapolis/St Paul, MN
RFS - Midwest	Dfa – Humid continental; hot summer, cold winter; year-round precipitation	90%	9%	1%	Youngstown, OH

[a] Climate classifications and air quality data have changed slightly since the Beta Test was conducted.
[b] "Unhealthy" includes days considered to be unhealthy to sensitive individuals.

G.4.1.6 Estimated Increase in PM Emissions from Proposed Cooling Towers

The annual average increase in PM_{10} and $PM_{2.5}$ concentrations (above ambient or baseline concentrations) near each BTP anticipated from the proposed cooling towers at that site were modeled using methods described previously. In the Beta Test, the modeling provided the expected ratio of $PM_{2.5}$-to- PM_{10} emission at each site (a single estimated value for each site), and the $PM_{10-2.5}$ concentration was calculated as the difference in the modeled PM_{10} and $PM_{2.5}$ concentrations. For the other facilities, model results were provided for both PM_{10} and $PM_{2.5}$ concentrations The multiple point estimates of modeled annual average PM_{10} and $PM_{2.5}$ concentrations were overlaid onto a map of the United States Census block groups for the area in order to calculate an average annual increased PM_{10} and $PM_{2.5}$ concentration to which each block group may be exposed.

This PM_{10} and $PM_{2.5}$ concentration information was used with the 2000 Census population and demographics information (including age distribution data) for each block group to estimate the number of individuals exposed to the modeled PM_{10} and $PM_{2.5}$ concentrations. It was assumed in that exposure estimate that the reported 2000 population for each block group was uniformly distributed within the area of that block group.

G.4.2 Monetization

Human health monetization methods are consistent with USEPA, which states, “the appropriate economic measure is WTP” [4]. For changes in mortality risks, estimates are based on WTP to avoid risk increases. The primary literature on this topic is divided into two categories of research: contingent valuation and wage hedonics. Contingent valuation studies are based on reported WTP to avoid risks associated with hypothetical situations. Wage hedonic studies rely on market data that reveal a relationship between wage increments to increased workplace risk. For example, wages for steel workers on the first floor of a skyscraper may be relatively modest. As the height of the skyscraper increases, wages and risk also increase. Wage hedonic studies use these data to estimate WTP to avoid small increases in risk.

For morbidity measures (i.e., hospital admissions), WTP estimates are generally not available. In these cases, WTP is proxied as the cost of treating or mitigating the effect. The cost of illness estimates generally understates the true value of reductions in risk of a health effect.

G.4.2.1 Economics Literature Used in Benefits Transfer

The USEPA provides an estimate for the value of a statistical life based on the advice of the Environmental Economics Advisory Committee of the Science Advisory Board [4, 18]. The USEPA believes $7.56 million (2007$) is the most reasonable single estimate of an individual’s willingness to trade off money for avoiding one statistical death, based on a meta-analysis of 26 studies, 21 of which were hedonic studies. According to the USEPA, this represents an intermediate value from a variety of estimates that appear in economic literature [4, 19, 20].

The $7.56 million value assumes the time of exposure and time of the mortality are very close. However, for many types of exposures, including air pollution, this assumption is not valid. Because future effects are discounted, the existence of a time lag between exposure and mortality is relevant to the estimation of WTP to avoid mortality risks. To capture this effect, USEPA used a 5-year distributed lag structure with 25 percent of premature deaths occurring in the year of exposure, 25 percent in the year after exposure, and 16.7 percent in each of the three years thereafter [4]. Assuming a three percent discount rate and a 30 year cooling tower lifespan, application of this same lag structure reduces average annual WTP to 86.6 percent of the non-lagged average. Therefore, the final value for a statistical life used in this analysis is $6.55 million.

USEPA reports the costs to treat CVD, COPD, and pneumonia for ages 65 and older were $25,214, $16,223, and $21,211 per hospital admission in 2007 dollars [4]. These values do not include pain and suffering and so tend to underestimate the true WTP to avoid a hospital admission.

G.4.2.2 Equations

Annual WTP to avoid an increase in mortality rates is estimated as:

$$AnnualWTP = AnnualIncrementalMortalities \times \$7{,}560{,}000 \times 0.866$$

where *Annual Incremental Mortalities* were from the human health risk assessment, $7,560,000 is USEPA’s value of a statistical life updated to 2007 dollars, and 0.866 is an adjustment factor that incorporates the effect of the lag in mortality rates.

Annual WTP to avoid morbidity is the product of annual incremental morbidities and the appropriate illness treatment cost.

Total annual WTP to avoid human health impacts is the sum of annual WTP to avoid mortality and annual WTP to avoid morbidity.

G.4.3 National Scaling

Potential human health effects are primarily a function of PM_{10} and $PM_{2.5}$ which are a function of the cooling tower design related to concentration of total dissolved solids, cycles of concentration, and flow. The magnitude of the effects is influenced by the size of the population exposed. Therefore, human health effects were scaled to other Phase II facilities by first grouping facilities based on cooling water salinity/source waterbody type. It was assumed that all LR/RL and SR/GL facilities utilize freshwater and all O/E/TR facilities utilize saline or brackish water. Then, to account for the populations exposed, the list of Phase II facilities was categorized into Low (<100 people/mi^2), Medium (100-1,000 people/ mi^2) and High (>1,000 people/ mi^2) population densities (see Section 2.3) resulting in nine subgroups:

- LR/RL – High Population;
- LR/RL – Medium Population;

- LR/RL – Low Population;
- SR/GL – High Population;
- SR/GL – Medium Population;
- SR/GL – Low Population;
- O/E/TR – High Population;
- O/E/TR – Medium Population; and
- O/E/TR – Low Population.

The annualized mortality and morbidity statistics for the BTPs and RFs, along with the annual WTP to avoid these human health impacts, were grouped into the nine salinity/population subgroups to evaluate the range of potential impacts and WTP. The BTP/RF with the maximum estimated annual WTP to avoid human health impacts was chosen to represent the other facilities in that subgroups as an upper-bound risk estimate (Table G-12). Note that because there were no BTPs/RFs in the SR/GL-Low Population subgroup, the results for RFS, the only freshwater BTP/RF in a Low Population area, were used for estimating the other facilities in that subgroup.

Table G-12
Human health subgroups and facilities chosen to represent each

Human Health Subgroups	**Representative Facility**[a]
LR/RL – High Population	RFL
LR/RL – Medium Population	RFJ
LR/RL – Low Population	RFS
SR/GL – High Population	RFI
SR/GL – Medium Population	BTPB
SR/GL – Low Population	RFS
O/E/TR – High Population	RFK
O/E/TR – Medium Population	RFH
O/E/TR – Low Population	BTPC

[a] Representative facilitates for LR/RL and SR/GL waterbody categories are similar due to their status as freshwater source waterbodies and will have similar water quality characteristics.

Human heath effects and WTP to avoid these human health impacts were estimated for the Phase II facilities not already estimated during the BTP/RF or California evaluations by multiplying per MW values (Table G-13) to MW generated by subgroup. Results are presented in Section G.3, above.

Table G-13
Calculated additional morbidity and mortality and wtp to avoid these impacts used for national scaling

Facility	WTP per MW	# Deaths over Baseline per MW	WTP to Avoid Mortality/ MW	Annual Morbidity (# of Hospital Visits Over Baseline)/MW			WTP to Avoid Morbidity/ MW
				CVD/MW	COPD/MW	Pneumonia/ MW	
RFL	$81.10	1.19E-05	$75.27	1.71E-04	1.19E-05	3.41E-05	$5.83
RFJ	$36.02	6.00E-06	$34.88	4.00E-05	2.00E-06	8.00E-06	$1.14
RFS	$8.29	1.10E-06	$7.96	1.10E-05	5.48E-07	1.64E-06	$0.33
RFI	$727.93	8.56E-05	$552.91	5.14E-03	3.42E-04	1.03E-03	$175.02
BTPB	$16.27	2.31E-06	$15.15	3.70E-05	2.31E-06	9.25E-06	$1.13
RFS	$8.29	1.10E-06	$7.96	1.10E-05	5.48E-07	1.64E-06	$0.33
RFK	$1109.17	1.66E-04	$1011.57	2.76E-03	1.10E-04	5.52E-04	$97.60
RFH	$256.62	3.40E-05	$234.45	4.85E-04	4.85E-05	1.46E-04	$22.17
BTPC	$401.70	5.67E-05	$371.46	9.93E-04	5.67E-05	1.42E-04	$30.24

G.5 Uncertainties

G.5.1 Risk Quantification

As with all risk assessments, the point estimates of risk calculated and presented in this appendix are based on a number of assumptions and selected studies, each of which is a source of uncertainty. In general, EPRI research indicates USEPA's methods are very conservative and represents an upper bound estimate of potential impacts [1]. Sources of uncertainty inherent to the USEPA method include:

- Log-linearity for dose-response functions was assumed;
- The conclusions of health studies on risk from PM are not unanimous; selection of different studies for the endpoints evaluated would change the results;
- The generalized concentration-response function used assumes potential health effects are directly correlated to PM concentrations and neglects other potentially co-occurring gaseous pollutants, exposure to other health risks (such as smoking), and other demographic characteristics, such as variations in socioeconomic status or access to health care;
- The PM coefficients for the long-term mortality study were estimated for PM concentrations not less than 7.5 micrograms per cubic meter ($\mu g/m^3$); therefore, the PM coefficients may not be sensitive enough to be used in predicting increases in mortality due to small increases in PM concentrations. There are increasingly wider confidence intervals around estimated relative risks at the lower and upper ends of the range of measured PM concentrations, due to the smaller amount of data available in those ranges [21]; and
- Human activity and exposure patterns can vary geographically, as well as change over time.

USEPA identifies additional sources of uncertainty [1]. Additional sources of uncertainty due to application of the USEPA method to this analysis of cooling tower emissions of the BTPs and RFs include:

- The detailed chemical and particle size composition of the PM was not considered in the modeling. Only the total PM_{10} and $PM_{2.5}$ concentrations were considered in the emissions modeling output. Differences in the composition of PM between the studies used in the USEPA analysis and cooling tower emissions may change the results. PM in urban areas is comprised primarily of sulfate, organic carbon, elemental carbon, crustal materials, nitrate, and in some areas/seasons, biological matter (e.g., pollen). Detailed epidemiological work by EPRI has shown that the health effects attributable to PM are often closely associated with sub-components such as organic carbon and/or co-occurring gases, such as carbon monoxide [3]. Cooling tower drift particles consist mostly of mineral salts although they likely contain organic matter from spores, pollen, and vegetative or insect fragments entrained into the towers and organic matter in makeup water;
- The estimations of annual increase of PM concentrations over the baseline PM concentrations were assumed to be constant over time;
- The PM coefficient for long-term mortality, applied to all BTPs and RFs, was derived from a multi-city study. All of the studies were performed in urban areas and might not correctly represent the concentration-response relationship in rural areas, such as those in which some of the BTPs and RFs are located;
- The study used for the PM coefficient for mortality effects derived PM-related concentration-response mortality statistics only for the population aged 30 years and older, neglecting potential impact to the portion of the population below 30 years of age. Similarly, the studies used for the PM coefficients for likely morbidity effects derived PM-related concentration-response morbidity statistics only for the population aged 65 years and older, neglecting potential impact to the portion of the population below 65 years of age;
- The county-specific mortality rate data for all the test sites were available for the population age group of 25 years and older, but not for the population age group of 30 years and older; therefore, it was assumed that the death rates for the 30+ population are the same as for the 25+ population;
- In many cases, only a portion of a given census block group was predicted to be exposed to increased PM concentrations. In order to estimate the number of the relevant population group exposed to the modeled PM concentration, it was assumed that the census block had uniform density of each population age group across its entire area;
- Countywide mortality statistics from the year 2005 were used. It was assumed that this information is representative of the baseline mortality rate every year and that the information is representative of the mortality rate in the specific area of the county potentially impacted by the cooling towers;
- Since the federal government does not require reports of morbidity statistics, this information is very difficult to obtain, even on a state level. The morbidity risk estimates relied on hospital admissions data from Medicare records for 14 cities across the country [6]. Only one of the RFs was located in a reference city. Each of the BTPs and remaining RFs were matched to one of these 14 reference cities using best professional judgment, based on general climate information and air-quality indices; and

- Morbidity estimates were based on annual average increased PM concentrations and the PM coefficients derived from short-term concentration-response studies, with zero to two day lag time between the concentration measurement and the effect. Results from the short-term concentration-response function were extrapolated to obtain an estimate of increased annual average morbidity rates.

G.5.2 Monetization

There is a moderate degree of uncertainty associated with both the value of a statistical life and the use of that metric rather than the value of a statistical life year to assess incremental mortality risk. It is not clear if this uncertainty biases WTP estimates.

The estimates reported in this section omit WTP to avoid pain and suffering associated with incremental morbidity, WTP to pay to avoid potential morbidity effects among persons under age 35, and WTP to avoid potential mortality impacts to persons under age 65. These omissions bias WTP estimates in a downward direction.

The USEPA method for estimating risk due to PM is very conservative [1]. Since the actual risk could approach zero, WTP could approach zero.

G.5.3 National Scaling

During the Beta Test, 15 California facilities were modeled for potential impacts based on the results of the two California BTPs. In that evaluation, assumptions were made regarding the differences in confounding variables, cooling tower design, and hours of operations between California facilities [22]. The national scaling method used assumptions regarding population, source waterbody type, and the relationship of WTP value with facility generating capacity. A comparison of the results of the two methods is shown in Table G-14.

Table G-14
Comparison of WTP to avoid human health impacts at California facilities using different scaling methods

(WTP estimates are based upon USEPA-calculated human health risk estimates, which represent the high end of risk [1]; however, EPRI research indicates the low end risk estimate could approach zero.)

Facility	California Scaling Method Total Annual WTP to Avoid Health Risk (Mortality + Morbidity) (2007$)	National Scaling Method Total Annual WTP to Avoid Health Risk (Mortality + Morbidity) (2007$)
BTCA1	$682,400	$682,400
BTCA2	$6,500	$6,500
CA1	$42,600	$177,100
CA2	$17,800	$923,100
CA3	$17,800	$378,000
CA4	$228,900	$1,069,200
CA5	$3,800	$30,100
CA6	$38,800	$328,200
CA7	$123,900	$976,100
CA8	$61,300	$110,300
CA9	$57,800	$154,000
CA10	$18,500	$762,800
CA11	$120,000	$389,000
CA12	$85,000	$165,500
CA13	$201,000	$229,600
CA14	$61,500	$1,453,000
CA15	$114,300	$215,000
State-wide Total	**$1,881,900**	**$8,050,100**

WTP rounded to the nearest $100; totals may not equal due to rounding.

The above table clearly shows that the assumptions made for each scaling method had a significant impact on the resulting estimates. Based on the more simplistic national scaling method, estimates are four times greater, resulting in a state-wide estimate over $6 million higher. Therefore, the scaling methodology may overestimate the national impact.

In addition to the scaling methodology, EPRI research indicates the USEPA methodology used to estimate risk at individual facilities results in very conservative risk estimates. Potential upper bounds for possible human health impacts were estimated through a human health risk assessment based on the document entitled “Particulate Matter Health Risk Assessment for Selected Urban Areas” [1]. This document relies heavily on the information and conclusions presented in the USEPA’s final assessment of the available PM health effects literature [2]. Note that while upper bound estimates of exposure and risk are intrinsic to human health risk assessment, EPRI research indicates USEPA’s methods and their application in this analysis results in very conservative risk estimates at the high end of the upper bound. The primary reason the USEPA method is likely too conservative is because it was designed to determine risk from urban air, not cooling towers, and the constituents are very different.

A subset of Phase II facilities utilizes helper towers to reduce the discharge water temperature. Since towers already exist at these facilities, some environmental and social impacts (e.g., drift, fogging and viewshed disruption) currently occur and therefore, impacts of a retrofit to closed-cycle cooling at these power plants would be less than impacts at facilities where no towers are operating. Societal and environmental impacts are overestimated at these facilities.

The overall direction of bias in the analysis is toward overestimating the impact since EPRI is using the USEPA method that is likely to be at the upper end of the range. EPRI research indicates the lower bound could approach zero and the national scaling method appears to overestimate impacts.

G.6 References

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H
IMPINGEMENT MORTALITY AND ENTRAINMENT

Calculations performed for this study were made using spreadsheet software (e.g., Excel), computer models (e.g., AERMOD), or scientific calculators. All digits were retained throughout the multi-step calculations and are often presented in this appendix. However, this implies a level of accuracy not obtainable with the methodology used in the study. Therefore, most values have been rounded for inclusion in the document's text and tables.

H.1 Methodology

H.1.1 Methods for Evaluating Impingement and Entrainment Data

The specific methods described here apply all Beta Test Plants (BTPs) and Representative Facilities (RFs) except for BTPC and BTPD; modeling for these plants was completed independently by the contractor for each facility using similar methods [1, 2, 3].

H.1.1.1 Adult Equivalents (AE1)

For each species, the number of entrained fish at each life stage *j* is field-recorded separately and annualized. The annual numbers of fish lost at each life stage *j* are then translated to annual numbers of equivalent age 1 (*AE*1) fish through multiplication of numbers of fish impinged or entrained by cumulative survival to age 1 (Equation H-5). Life history parameters specific to species and site needed for *AE*1 calculations and are derived from literature sources as needed [4, 5, 6, 7, 8, 9, 10, 11]. The life history parameters used in this analysis are tabulated in Section H.1.1.7.

Survival fraction at life stage *j* is calculated as

$$S_j = e^{(-Z)}$$ **Equation H-1**

where,

$$Z = M + (F*V)$$ **Equation H-2**

and,

Z is total instantaneous mortality

M is the natural instantaneous mortality and

F is the fishing instantaneous mortality

V is the fraction of the life stage vulnerable to fishing mortality

In order to reflect the fact that the fish will have already lived through some portion of the life stage before impingement/entrainment, adjusted survival rates are calculated for the life stage at which loss occurs.

Adjusted survival rate S^*_j is calculated as

$$S^*{}_j = 2S_j e^{-\ln(1+S_j)}$$

Equation H-3

Adjusted survival rates are not used for entrained juveniles because for the majority of species, only very young juveniles are entrained, while older juveniles are either impinged and/or strong enough to overtake the intake current. As such, survival rate S_j applies to the entire juvenile life stage.[1] In order to calculate the age 1 equivalents of actual age 1 losses, the inverse of adjusted survival of age 1 was used.

Cumulative survival to age 1 for fish impinged or entrained younger than age 1 is the product of the adjusted survival rate for the life stage at which loss occurred, and the overall survival rates of each subsequent interval life stage up to but not including age 1.

$$S_{j,1} = S^*{}_j \prod_{i=j+1}^{j_{\max}} S_i$$

Equation H-4

Where,

$S_{j,1}$ is the total cumulative survival rate from stage j to age 1,
S_i is the survival fraction from stage I to stage i+1
S^*_j is the adjusted overall survival rate
j_{max} is the stage immediately prior to age 1

Age 1 equivalents, *AE*1, for life stage *j* are calculated as:

$$AE1_j = L_j S_{j,1}$$

Equation H-5

Where,

Lj is the number of individuals impinged or entrained during life stage j.

The sum of age 1 equivalents representing losses at each life stage reflects the annualized age 1 equivalent losses due to impingement or entrainment for that species.

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[1] Comment 316b EFR.074.101.

$$AE1 = \sum_{j=j_{\min}}^{j_{\max}} AE1_j$$

Equation H-6

H.1.1.2 Forgone Commercial and Recreational Yield

For each species of harvestable fish, the number of impinged or entrained fish at each life stage *j* are field-recorded separately and annualized. Cumulative survival rates are calculated using a methodology similar to that described in the adult equivalent model. However, instead of calculating the cumulative survival rate of each impinged/entrained life stage to age 1, this model calculates the cumulative survival rate of the impinged/entrained life stage *j* to each subsequent life stage *i*. These cumulative survival rates model the theoretical lifespan of the cohort of lost fish, had they never been impinged/entrained. The life history parameters (natural and fishing mortality at each life stage, vulnerability of each life stage to fishery, and starting and average weight for each life stage), specific to the species and the site/region, are tabulated in Section H.1.1.7.

A life-stage specific factor translates the number of fish that would have otherwise survived had they not been lost to impingement/entrainment to a weight of fish that would have otherwise been harvested as commercial catch. (For recreational catch, a similar factor is used, but the weight variable is omitted from the equation in order to calculate number of recreationally caught fish).

This forgone yield factor Y for life stage *i* is calculated as

$$\mathrm{Y_i} = \frac{\mathrm{V_i F_i A_i} \hat{W}_\mathrm{i}}{\mathrm{Z_i}}$$

Equation H-7

Where,

$\mathrm{V_i}$ represents vulnerability of life stage *i* to fishery activity
$\mathrm{F_i}$ is the fishing mortality at life stage *i*
$\mathrm{A_i}$ is an adjustment based on mortality of previous life stage
$\hat{W}$ i represents the average weight of life stage *i*
$\mathrm{Z_i}$ is the total instantaneous mortality at life stage *i*

Note: when $\mathrm{V_i}$ is 0, that is the fish is too young to be fished, $\mathrm{Y}_i = 0$. Thus, no forgone yield is calculated for these stages.

$\mathrm{A_i}$ is included to reflect the fact that forgone fishery yield may only be removed from the portion of the cohort which would not have theoretically survived to the next age, based on total mortality, and is calculated as

$$A_i = 1 - e^{(-Z_i)}$$

Equation H-8

Where,

Z_i is the total mortality for life stage *i*

Forgone fishery yield for life stage *i* lost due do impingement or entrainment on stage *j* ($R_{j,i}$) is calculated as

$$R_{j,i} = S_{j,i} * L_j * Y_i$$

Equation H-9

Where

$S_{j,i}$ is the cumulative survival from stage j to stage *i*
L_j is the number of individuals impinged or entrained during life stage *j*

Note: Cumulative survival from stage *j* to stage *i* is calculated using Equation H-4 and similarly, adjusted survival is not used for entrained juveniles.

When calculating forgone yield for the stage in which impingement or entrainment occurred ($R_{j,j}$) the equation is divided by two, and survival is omitted (Equation H-10). This approximation is needed to account for the fact that the fish were lost during the life stage and losses are assumed to center at the average age at death for that stage.

$$R_{j,j} = \frac{L_j * Y_j}{2}$$

Equation H-10

No forgone yield is calculated for ages prior to the age of impingement because it is presumed that they survived the fishery at the earlier stages.

Cumulative forgone yield for fish impinged/entrained in life stage *j* (CR_j) is calculated as

$$CR_j = \left(\sum_{i=j+1}^{i_{\max}} R_{j,i} \right) + R_{j,j}$$

Equation H-11

Total forgone yield for a species (*FY*) can be calculated by summing the cumulative forgone yield for each life stage the species was lost (Equation H-12).

$$FY = \sum_{j=_{\min}}^{j_{\max}} CR_j$$

Equation H-12

H.1.1.3 Forgone Production (FP)

For each species of forage fish, the number of impinged or entrained fish at each life stage *j* are field-recorded separately and annualized. Using a methodology similar to that described in the forgone fishery yield model, cumulative survival rates to each subsequent life stage *i* are calculated. These cumulative survival rates model the theoretical lifespan of the cohort of lost fish, had they not been impinged/entrained.

A life-stage specific factor translates a number of fish that would have otherwise survived had they not been lost to impingement/entrainment to a weight of fish that would have otherwise been available as prey for harvestable fish.

This forgone production factor *P* for life stage *i* is calculated as

$$P_i = \frac{G_i L_i \overline{W}_i (e^{(G_i - Z_i)} - 1)}{(G_i - Z_i)}$$ **Equation H-13**

Where,

L_i is the number of fish impinged or entrained at life stage *i*
Z_i is the total instantaneous mortality at life stage *i*

Instantaneous growth rate *G* for each life stage *i* is calculated as

$$G_i = \ln\left(\frac{\overline{W}_{(i+1)}}{\overline{W}_i}\right)$$ **Equation H-14**

Where,

$\overline{W}$ i is the average initial weight (pounds) of a fish at life stage *i*

Forgone production for life stage *i* due to impingement or entrainment of stage *j* ($F_{j,i}$) is calculated as

$$F_{j,i} = S_{j,i} * L_j * P_i$$ **Equation H-15**

Where

$S_{j,i}$ is the cumulative survival from stage *j* to stage *i*
L_j is the number of individuals impinged or entrained during life stage *j*

Note: Cumulative survival from stage *j* to stage *i* is calculated using Equation H-4 and similarly, adjusted survival is not used for entrained juveniles.

When calculating forgone production for the stage in which impingement or entrainment occurred ($F_{j,j}$) the equation is modified to include the median age at death expressed as a fraction of the stage (D_i) (Equation H-17). This approximation is needed to account for the fact that the fish were lost during the life stage and only growth that occurs after the median age at death should count as forgone production.

$$F_{j,j} = L_j * \left(\frac{G_i L_i \overline{W_i} (e^{((G_i - Z_i)*D_i)} - 1)}{(G_i - Z_i)} \right)$$

Equation H-16

Median age at death expressed as a fraction of the stage (D_i) can be found by

$$D_i = \frac{\ln 2 - \ln(1 + e^{-Z_i})}{Z_i}$$

Equation H-17

No forgone production is calculated for ages prior to the age of impingement or entrainment since the fish have already made it through those stages.

Cumulative forgone production for fish impinged/entrained in life stage j (CF_j) must include the weight of the organisms originally impinged and is calculated as

$$CF_j = \left(\sum_{i=j+1}^{i_{\max}} F_{j,i} \right) + F_{j,j} + (L_j * \hat{W}_j)$$

Equation H-18

Where

$\hat{W}_j$ is the average weight of a fish in stage j

Note: The actual biomass in lbs for the fish lost at stage j may be substituted for $(L_j * \hat{W}_j)$ if it is known.

Total forgone production for a species (*FP*) expressed in lbs, can be calculated by summing the cumulative forgone yield for each life stage the species was lost (Equation H-19).

$$FP = \sum_{j=_{\min}}^{j_{\max}} CF_j$$

Equation H-19

H.1.1.4 Stage Weights

Life stage weights are presented as initial weights ($\overline{W}$) or average weights ($\hat{W}$) [4]. Average stage weights are needed for the calculation of commercial forgone yield and initial weights are needed for the calculations of forgone production. Average and initial weights are related in the following manner

$$\overline{W}_{i+1} = \hat{W}_i * e^{(G_i*(1-D_i))} \qquad \textbf{Equation H-20}$$

Where

G_i is growth
D_i is median age at death expressed as a fraction of the life stage

If average weights are known, Equation H-20 can be used to find initial weights. Growth (see Equation H-14) is calculated using the average weights but is only used to find initial weights. Calculations of forgone production will use growth calculated from the resulting initial weights.

Average stage weights can be calculated from initial stage weights using the following equation.

$$\hat{W}_i = \frac{\overline{W}_{i+1}}{e^{(G_i*(1-D_i))}} \qquad \textbf{Equation H-21}$$

H.1.1.5 Age Structure of Impinged Fish

The age structure of impinged fish was determined using age length relationships found in the literature and actual length measurements taken during IM&E studies. Length frequency tables for each representative species were used to determine the proportion of the measured fish in each age-length category. These proportions were then applied to the annualized impingement numbers yielding number of fish in each age group impinged per year.

In circumstances where actual length data were not available or when multiple species were grouped together (e.g., non-representative species groupings) it was assumed that impinged fish fell within age classes juvenile through age five according to the survival rates of the surrogate life history table chosen for the group.

H.1.1.6 Distribution of Unidentified Fish and Eggs

In order to evaluate the impact of unidentified organisms they were distributed among identified taxa according to the relative abundance of each taxon with respect to total losses within the age group (i.e., unidentified larvae were distributed to each taxon based on relative abundance of identified larvae). In certain instances organisms were identified to groups (e.g., Paralichthyidae/Labridae/Sciaenidae eggs). These were distributed similarly among taxa within the grouping based on relative abundances of identified organisms.

H.1.1.7 Life History Parameters

Species-specific life history parameters are needed for the calculations in Sections H.1.1.1, H.1.1.2 and H.1.1.3. Literature sources were used to obtain these parameters [4, 5, 6, 7, 8, 9, 10]. Because of the additional analysis presented by EPRI for each species, life history parameters were taken from this source, if available [4]. The species covered by EPRI are limited so USEPA's regional studies were used for any species not covered in the EPRI document [4]. Fishing mortality and vulnerability to fishing mortality are not presented in the EPRI document so these values are taken from USEPA's regional studies [5, 6, 7, 8, 9, 10, 11]. Whenever possible, life history data specific to the species were used in the evaluations; however, when species were grouped (e.g., non-representative species groupings) or when species-specific data were not available surrogate life history data were utilized. Surrogate life history data were chosen based on the similarities in life history characteristics to the species of concern or to the dominant species in the grouping. Sources for the life histories used in the evaluation of impingement and entrainment data can be found in tables H-1 and H-2.

Table H-1
Life history parameter sources used for BTPs separated by facility

Taxon/Taxa	Source	Notes
BTPCA1		
Anchovy	[5]	Used to evaluate northern anchovy, and *Anchoa* spp. (deepbody and slough anchovies).
Combtooth Blenny	[5]	
Commercial Crab	[5]	
Commercial Shrimp	[5]	
Drums and Croakers	[5, 12]	Used to evaluate non-RS recreational species and recreational portion of Non-RS recreational & commercial species.
Flounder	[5]	Used to evaluate non-representative commercial species and commercial portion of non-representative recreational & commercial species.
Forage Shrimp	[5]	
Other Forage Species	[5]	Used to evaluate non-representative forage species.
Other Recreational Species	[5]	Used to evaluate non-representative recreational species.
Pacific Staghorn Sculpin	[5]	
Silversides	[5]	Used to evaluate topsmelt.
BTPCA1		
Surfperch	[5]	Used to evaluate shiner perch. Surfperches are viviparous and give birth to fully developed young.

Table H-1
Life History parameter sources used for BTPs separated by facility (continued)

Taxon/Taxa	Source	Notes
BTCA2		
Anchovies	[5]	Used to evaluate northern anchovy, and *Anchoa* spp. (deepbody and slough anchovies).
Commercial Crab	[5]	
Commercial Shrimp	[5]	
Drum & Croaker	[5, 12]	Used to evaluate white croaker, queenfish, non-representative recreational and commercial species, and recreational portion (entrainment).
Flounders	[5]	Used to evaluate non-representative recreational and commercial species, and commercial portion (impingement and entrainment).
Forage Shrimp	[5]	
Herring	[5]	Used to evaluate Pacific sardine. Since 90% of commercial landings occur in San Francisco Bay it is assumed that the population near BTCA2 is relatively unexploited [13].
Other Commercial Species	[5]	Used to evaluate non-representative recreational species only.
Other Forage Species	[5]	Used to evaluate clinid kelp blennies and forage species.
Other Recreational Species	[5]	Used to evaluate non-representative recreational species only.
Sea Bass	[5]	Used to evaluate kelp bass and barred sand bass. Larval mortality was tuned using survival estimates and total lifetime fecundity (101,810,524 eggs) so that one female surviving to the fecundity weighted average female age of 23 produced two survivors. Batch fecundity was estimated using log regression on total length [14]. Total length by age was estimated using regression on age t (yr) [12].
BTCA2		
Surfperch	[5]	Used to evaluate non-representative recreational and commercial species, and recreational portion (impingement). Note: Surfperches are viviparous and give birth to fully developed young.
BTPA		
Black Crappie	[4, 8]	

Table H-1
Life History parameter sources used for BTPs separated by facility (continued)

Taxon/Taxa	Source	Notes
Blue Crab	[8]	
Bluegill	[8]	Used to evaluate non-representative recreational species.
Catfish	[4, 8]	Used to evaluate blue catfish and channel catfish.
Freshwater Drum	[4]	
Gizzard shad	[4]	
Other Forage	[8]	Used to evaluate non-representative forage species.
Shiner Species	[8]	Used to evaluate silverside shiner.
Sucker (*Ictiobus* spp.)	[8]	Used to evaluate smallmouth buffalo.
Threadfin shad	[4]	
BTPB		
Alewife	[4]	
Lake Whitefish	[9]	
Non-representative Recreational and Commercial Species	[9]	Lake Whitefish
Non-representative Commercial Species Only	[4]	Freshwater Drum
Non-representative Forage Species	[4]	Gizzard Shad
Non-representative Recreational Species Only	[9]	Channel Catfish
Rainbow Smelt	[4, 9]	
Round Goby	[9]	
Spottail Shiner	[4, 9]	
Yellow perch	[4, 9]	
BTPC		
Alewife (River Herring)	[13]	
BTPC		
Atlantic Croaker	[13]	
Bay Anchovy	[13]	
Blue Crab	[15, 16, 17, 18, 19, 20, 21]	
Striped Bass	[13]	
Weakfish	[13]	
White Perch	[13]	

Table H-1
Life History parameter sources used for BTPs separated by facility (continued)

Taxon/Taxa	Source	Notes
BTPE		
American Shad	[4, 10]	
Bluegill	[11]	
Channel Catfish	[4, 11]	
Emerald Shiner	[4]	Used for comely shiner.
Gizzard Shad	[4]	
Largemouth Bass	[10]	
Smallmouth Bass	[11]	
Spottail Shiner	[10]	Used for non-representative forage species.
Walleye	[11]	
White Crappie	[10]	
Yellow perch	[4, 13, 22]	Used for non-representative recreational species.

Table H-2
Life history parameter sources used for RFPs

Taxon/Taxa	Source	Notes
Alewife (Great Lakes)	[4]	
American Eel	[6, 7]	
American Lobster (Gulf of Maine)	[4, 23, 24, 25, 26, 27]	
Anchovies (Gulf of Mexico)	[8]	
Atlantic Cod	[6]	
Atlantic Croaker	[4]	Egg mortality based on two day egg stage.
Atlantic Mackerel	[6]	
Atlantic Menhaden	[4]	
Bay Anchovy	[4, 7]	
Black Crappie	[4, 10]	
Blue Crab	[4, 7, 28]	
Blueback Herring	[4, 7]	
Bluegill	[10]	
Bullhead Catfish	[10]	
Butterfish	[6]	
Channel Catfish	[4, 11]	
Commercial Crabs (North Atlantic)	[6]	

Table H-2
Life history parameter sources used for RFPs (continued)

Taxon/Taxa	Source	Notes
Commercial Shrimp (Gulf of Mexico)	[4, 8, 29]	
Common Carp	[30]	
Crappie	[10]	
Cunner	[6]	
Emerald Shiner	[4]	
Forage (Mid-Atlantic)	[7]	
Forage Fish (Great Lakes)	[9]	
Fourbeard Rockling	[6]	
Freshwater Catfish	[10]	Includes: blue catfish, channel catfish, flathead catfish, and white catfish.
Freshwater Drum	[4, 10]	
Gizzard Shad	[4]	
Grass Shrimp	[31]	
Grubby	[6]	
Inland Forage	[10]	
Inland Recreational Species	[10]	
Jack/Pompano/Lookdown	[8]	
Largemouth Bass	[10]	
Logperch	[9]	
Micropterus Basses (Great Lakes)	[9]	
Minnow Species	[10]	
Naked Goby (Mid-Atlantic)	[7]	
Northern Pipefish	[7]	
Other Commercial (Gulf of Mexico)	[8]	
Other Commercial (North Atlantic)	[6]	
Other Forage (Fish)(Gulf of Mexico)	[8]	
Other Forage (North Atlantic)	[6]	
Other Forage (Shrimp)(Gulf of Mexico)	[8]	
Other Recreational (Gulf of Mexico)	[8]	
Other Recreational (North Atlantic)	[6]	
Pike/Muskellunge	[10]	

Table H-2
Life history parameter sources used for RFPs (continued)

Taxon/Taxa	Source	Notes
Quillback	[10, 32]	
Rainbow Smelt (Inland)	[4, 10]	
Rainbow Smelt (North Atlantic)	[6]	
Recreational/Commercial (Mid-Atlantic)	[7]	
Red Hake	[6]	
Rock Bass	[9]	
Rock Gunnel	[6]	
Round Goby	[9]	
Sculpin (North Atlantic)	[6]	
Searobin	[6]	
Silver perch	[4]	
Skipjack Herring	[10]	
Smallmouth Bass	[10]	
Spot	[4]	
Sticklebacks (North Atlantic)	[6]	
Stone Crab	[4, 33, 34, 35, 36, 37, 38]	
Striped Bass	[4]	
Striped Killifish	[6]	
Summer Flounder	[7]	
Tautog	[6]	
Threadfin Shad	[4]	
Walleye/Sauger	[10, 39, 40]	Natural mortality adjusted from Age 1+ on based on fecundity of 23,000 eggs per lb of female.
Weakfish	[4]	
White Bass (Great Lakes)	[4, 10]	
White Bass (Inland)	[4, 10]	
White Perch (Great Lakes)	[4]	White perch is commercially fished in Lake Erie but not in other Great Lakes, so fishing mortality is not included.
White Perch (Inland)	[10]	
White Sucker (Great Lakes)	[9, 34, 41]	Age 1+ through Age 6+ mortality adjusted from .273 to .73 based on mortality values from: [27]
Windowpane	[6]	
Winter Flounder	[4, 7]	
Yellow Perch	[4, 9]	

H.1.2 Monetization of Aquatic Biota

The methods outlined by USEPA in their 316(b) Phase II and III regional benefits assessment to estimate WTP to avoid the assumed foregone recreational harvest, foregone commercial harvest, and foregone production [2,42].

- WTP for recreationally harvested species is based on per fish consumer surplus.
- WTP for commercially harvested species is based on a per pound producer surplus.
- WTP for forage fish was estimated by converting the foregone prey biomass into potential reductions in the harvest of commercial and recreationally important species.
- If IM&E was judged to alter the viability of a species or materially impair ecosystem functioning, non-use value may exist and some economists believe these non-use values could be large. It is also worth noting that, if IM&E impacts were judged to alter species viability or ecosystem functioning, existing statutes would likely require that facilities address the issue.

H.1.2.1 Monetization Theory

WTP for a reduction in IM&E includes two potential sources: (1) WTP associated with changes to use value and (2) WTP associated with changes to non-use value. Use values arise when a resource is consumed and or experienced. Use values can be associated with directly experiencing a resource (direct use values); use values also arise when indirectly experiencing a good (indirect use values).

In contrast, non-use or passive use values may arise if individuals value environmental resources apart from any personal past, present, or anticipated future use of the resource in question. Non-use values can be associated with use of a resource by others, either now or in the future; however, there may also be non-use values that are not associated with any use of a resource, by anyone, ever. The former, values associated with use by others, are termed altruistic or, in the case of use by future generations, bequest values. The latter, values not associated with any actual use of the resource, have been called intrinsic values, or as in this report, existence values.

Note that non-use values do not reflect value associated with forage fish or with the un-harvested portion of commercial or recreational fish populations. These are indirect use values and are accounted for when one determines the direct use value of commercial and recreational fish. This is because the value of the intermediate goods and processes that go into producing a final good are included in the value of the final good [43]. As the idea relates to fish and fisheries,

- The function of forage fish is reflected in their ability to support commercial and recreational fisheries. The value of that function is reflected in the recreational and commercial value associated with the harvest of non-forage fish.
- Commercial and recreational landings through time are a function of the total population including un-harvested individuals. As such, the value of un-harvested commercial and recreational fish is reflected in commercial and recreational harvest valuation.

In promulgating the Phase II Rule, USEPA noted that if non-use values (existence, bequest, and altruistic) would be altered due to a reduction in IM&E then this benefit category should be considered when estimating the benefits of 316(b) compliance. USEPA also noted that these values are only likely to be altered if IM&E impacts materially alter the probability of survival among listed species or materially degrade the functioning of an ecosystem.

WTP associated with impacts to use values are estimated as consumer surplus (the value of a recreationally harvested organism beyond the costs incurred while harvesting the organism) and producer surplus (the per pound profit associated with the harvest and subsequent dockside sale of commercially harvested species).

WTP associated with potential changes to non-use values (if any) are evaluated on a site-specific basis.

H.1.2.2 Economics Literature Used in Benefits Transfer

Benefits transfer values for recreationally harvested fish are based on a meta-analysis of WTP studies conducted by USEPA and published in their 316(b) Phase III Rule and where appropriate, species-specific values identified in the Phase II Rule [42, 44]. Benefits transfer values for commercially harvested species were based on NOAA dockside values and USEPA producer surplus proportions [44, 45].

Assumptions for the conversion of forage fish to commercially and recreationally harvested fish were taken from USEPA rulemaking documents. The assumed trophic transfer efficiency of 10 percent is taken from the Phase III documents [44]. The assumption that 20 percent of forage biomass is directly consumed by commercial/recreational fish and 80 percent is consumed by an intermediate species before being consumed by a commercial/recreational fish is from the Phase II evaluation methods. Given these two assumptions, the net trophic transfer efficiency is 2.8 percent.

H.1.2.3 Monetization Methods

Annual WTP to avoid a reduction in IM&E of recreationally harvested aquatic organisms is the product of foregone recreational harvest (in numbers of individuals) and the region/species appropriate per-organism consumer surplus.

Annual WTP to avoid a reduction in IM&E of commercially harvested aquatic organisms is the product of foregone commercial harvest (in pounds), the region/species appropriate per pound dock-side value, and an assumed producer surplus (profit) margin. Species specific estimates of consumer surplus from USEPA [44] were used in this analysis.

Annual WTP to avoid a reduction in IM&E of forage fish is estimated as a function of the biomass of commercially and recreationally harvested fish that could have been supported by those forage fish had they not been impinged or entrained. Based on USEPA guidance, a trophic transfer efficiency of 2.8 percent was used to convert the forgone production into forgone commercial and recreational fish [44]. For each facility, the forage biomass was assumed to have been consumed by commercial/recreational fish species in proportions identical to those revealed in the IM&E data. The per pound WTP for forage fish is then based on the consumer and producer surplus associated with those commercial and recreational fish that would have existed had the forage fish not been lost to IM&E.

Per pound WTP to avoid a reduction in IM&E of forage fish is estimated as:

$$PerPoundWTP = 0.028 \times \sum_{f=1}^{F} PR_f \times RWTP_f + PC_f \times CWTP_f \ ,$$

Where 0.028 is a constant reflecting trophic transfer efficiency, *F* indexes the commercially and recreationally harvest species that were entrained and or impinged at the facility, PR_f is the proportion of the recreational and or commercial biomass that is of species *f* and is recreationally harvested, PC_f is the proportion of the recreationally and or commercially harvested biomass that is of species *f* and is commercially harvested, $RMTP_f$ is the per pound recreational WTP associated with species *f*, and $CWTP_f$ is the per pound commercial WTP associated with species *f*.

Annual WTP to avoid a reduction in IM&E of forage fish is the product of per pound WTP and annual pounds of foregone production.

For non-representative species, at each facility, we estimate recreational WTP as the average consumer surplus associated with RS recreation fish at the facility and commercial WTP as the average producer surplus associated with commercial fish at the facility.

Total annual WTP to avoid a reduction in IM&E is the sum of the WTP estimates described above.

For the purposes of this analysis, the reduction in IM&E is assumed to be directly proportional to the calculated reduction in cooling water flow with the installation of a cooling tower.

H.1.2.4 Monetization Data

Recreational values are based on a meta-analysis of recreational fishing studies conducted by USEPA (Table H-3) [44]. The study estimated per fish consumer surplus specific to several regions and species groups. However, USEPA’s Phase III meta-analysis was designed to estimate average WTP for relatively broad groups of fishes. For instance the “other saltwater” estimate might be applied to the very small and common shiner perch to wreckfish which might include grouper and other larger, highly pursued species. The application of an average is appropriate when the suite of fish impacted by IM is wide and fairly evenly represented and or if the primarily impacted species has a value near the group mean. These conditions likely hold for the national analysis.

Table H-3
Marginal recreational value per fish by region in 2007 U.S. dollars[a] [44]

Group	California	North Atlantic	Mid Atlantic	South Atlantic	Gulf of Mexico	Great Lakes	Inland
Small Game	$6.72	$5.50	$5.47	$5.30	$5.21		$4.96
Flatfish	$9.04	$5.52	$5.20	$5.20			
Other Saltwater	$2.74	$2.76	$2.71	$2.64	$2.57		
Salmon						$12.29	
Walleye/Pike						$3.81	$3.80
Bass						$7.93	$8.35
Panfish			$0.98			$1.23	$0.98
Trout						$8.73	$2.62
Unidentified	$2.87	$2.78	$3.00	$2.65	$3.39	$5.76	$2.07

[a] A Consumer Price Index (CPI) of 1.1 was used to convert the recreational values given by USEPA in 2004 U.S. dollars to 2007 U.S. dollars [44, 46].

Monetization data used for each species at each BTP and RF are given in Tables H-4 to H-29.

Table H-4
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at BTCA1

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Anchovy	$0.04		
Northern Anchovy	$0.04		
Pacific Staghorn Sculpin	$0.04	$2.74	
Combtooth Blenny			$0.35
Gobies			$0.35
Topsmelt			$0.35
Shiner Perch	$0.07	$2.74	
Non-representative Forage Species			$0.35
Non-representative Recreational Species		$2.74	
Non-representative Recreational and Commercial Species	$0.55	$2.74	
Commercial Crabs	$1.02		
Commercial Shrimp			
Forage Shrimp			$0.35

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are Pacific staghorn sculpin and shiner perch.

Table H-5
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at BTPA

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	**Consumer Surplus per Fish (2007$)**	**Forgone Value per Pound of Forage (2007$)**[a]
Blue Crab	$0.46	$2.07	
Blue Catfish		$0.98	
Channel Catfish		$0.98	
Silverside Shiner			$0.05
Freshwater Drum		$0.98	
Gizzard Shad			$0.05
Threadfin Shad			$0.05
Smallmouth Buffalo			
Black Crappie		$0.98	
Non-representative Forage Species			$0.05
Non-representative Recreational Species		$1.03	

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are blue catfish, channel catfish, freshwater drum and black crappie.

Table H-6
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at BTPB

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	**Consumer Surplus per Fish (2007$)**	**Forgone Value Pound of Forage (2007$)**[a]
Yellow Perch	$0.61	$1.23	
Spottail Shiner			$0.05
Alewife			$0.05
Round Goby			$0.05
Rainbow Smelt	$0.15	$1.23	
Non-representative Commercial Species Only	$0.61		
Non-representative Recreational Species Only		$1.23	
Non-representative Recreational & Commercial Species	$0.61	$1.23	
Non-representative Forage Species			$0.05

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species is yellow perch.

Table H-7
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at BTPC

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	**Consumer Surplus per Fish (2007$)**	**Forgone Value Pound of Forage (2007$)[a]**
Atlantic Croaker	$0.33	$2.71	
Bay Anchovy			$0.02
Blue Crab	$0.65	$3.00	
River Herring	$0.10		$0.02
Striped Bass	$1.97	$5.47	
Weakfish	$0.85	$5.47	
White Perch	$0.76	$2.71	

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are Atlantic croaker, striped bass, weakfish, and white perch.

Table H-8
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at BTPD

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	**Consumer Surplus per Fish (2007$)**	**Forgone Value per Pound of Forage (2007$)[a]**
Alewife	No Commercial Fishery		$0.04
Blue Catfish		$0.98	
Channel Catfish		$0.98	
Threadfin Shad			$0.04
White Perch		$0.98	

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are blue catfish, channel catfish, and white perch.

Table H-9
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at BTPE

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	**Consumer Surplus per Fish (2007$)**	**Forgone Value per Pound of Forage (2007$)[a]**
Gizzard Shad	No Commercial Fishery		$0.06
Bluegill		$0.98	
Channel Catfish		$0.98	
Walleye		$3.80	
American Shad		$3.80	
White Crappie		$0.98	
Comely Shiner			$0.06
Largemouth Bass		$8.35	
Smallmouth Bass		$8.35	
Non-representative Forage Species			$0.06
Non-representative Recreational Species		$1.46	

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are channel catfish, walleye, largemouth bass, and smallmouth bass.

Table H-10
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at BTCA2

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	**Consumer Surplus per Fish (2007$)**	**Forgone Value per Pound of Forage (2007$)[a]**
Anchovy (*Anchoa* spp.)	$0.04		
Northern Anchovy	$0.04		
Clinid Kelpfishes			$0.09
Kelp/Sand Bass		$2.74	
White Croaker	$0.36	$2.74	
Queenfish	$0.32	$2.74	
Pacific Sardine			$0.09
Non-representative Forage Species			$0.09
Non-representative Recreational Species		$2.74	
Non-representative Commercial Species	$0.32		
Non-representative Recreational & Commercial Species	$0.32	$2.74	
Commercial Crabs/Lobster	$1.31		
Commercial Shrimp			
Forage Shrimp			$0.09

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are kelp, white croaker, and queenfish.

Table H-11
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFF

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Freshwater Drum	$0.04		
Rainbow Smelt	$0.15	$1.23	
White Bass	$0.19	$1.23	
Emerald Shiner			$0.01
Gizzard Shad			$0.01
White Perch			$0.01
Non-representative Recreational & Commercial Species[b]	$0.43	$3.81	
Non-representative Recreational Species[b]		$3.81	
Non-representative Commercial Species[c]	$0.61		
Non-representative Forage Species			$0.01

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are freshwater drum, rainbow smelt, and white bass.

[b] Value based on walleye due to abundance in non-representative species category.

[c] Value based on yellow perch due to abundance in non-representative species category.

Table H-12
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFG

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	**Consumer Surplus per Fish (2007$)**	**Forgone Value per Pound of Forage (2007$)[a]**
Gizzard Shad	$0.04		$0.02
Freshwater Drum	$0.04	$0.98	
Sauger		$3.80	
Skipjack Herring			$0.02
Channel Catfish	$0.16	$0.98	
White Bass		$0.98	
Non-representative Recreational Species		$1.83	
Non-representative Forage Species			$0.02

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are freshwater drum, sauger, channel catfish and white bass.

Table H-13
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFH

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Gobies			$0.07
Bay Anchovy			$0.07
Threadfin Shad			$0.07
Spot	$0.41	$2.64	
Silver Perch			$0.07
Atlantic Croaker	$0.18	$2.64	
Commercial Shrimp	$0.87		
Blue Crab	$0.47		
Lesser Blue Crab			$0.07
Non-representative Recreational & Commercial Species	$0.76	$2.64	
Non-representative Commercial Species	$0.76		
Non-representative Recreational Species		$2.64	
Non-representative Forage Species			$0.07

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are spot and Atlantic croaker.

Table H-14
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFI

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Gizzard Shad	No Commercial Fishery		$0.11
Bluntnose Minnow			$0.11
Spotfin Shiner			$0.11
Round Goby			$0.11
Bluegill		$0.98	
White Perch		$0.98	
Emerald Shiner			$0.11
Common Carp			$0.11
Non-representative Recreational Species		$0.98	
Non-representative Forage species			$0.11

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species is white perch.

Table H-15
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFJ

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Threadfin Shad	No Commercial Fishery		$0.11
Bluegill		$0.98	
Largemouth Bass		$8.35	
White Crappie		$0.98	
Non-representative Recreational Species[b]		$0.98	
Non-representative Forage Species			$0.11

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are largemouth bass and white crappie.

[b] Value based on bluegill due to abundance in non-representative species category.

Table H-16
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFK

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Atlantic Menhaden	$0.05		
Atlantic Silverside			$0.17
Bay Anchovy			$0.17
Butterfish	$0.52		
Cunner		$2.76	
Fourbeard Rockling			$0.17
Red Hake	$0.33		
Striped Killifish			$0.17
Searobins	$0.00	$2.76	
Tautog	$1.08	$2.76	
Non-representative Recreational Species		$2.76	
Non-representative Commercial Species	$0.06		
Non-representative Forage Species			$0.17

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are butterfish, cunner, red hake, searobins, and tautog.

Table H-17
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFL

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Gizzard Shad	No Commercial Fishery		$0.03
Freshwater Drum		$0.98	
Channel Catfish		$0.98	
Bluegill		$0.98	
Blue Catfish		$0.98	
Non-representative Recreational Species		$0.98	
Non-representative Forage Species			$0.03

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are freshwater drum, channel catfish, and blue catfish.

Table H-18
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFM

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Gizzard Shad	No Commercial Fishery		$0.05
Skipjack Herring			$0.05
Threadfin Shad			$0.05
Freshwater Drum		$0.98	$0.05
Silver Carp			$0.05
Blue Catfish		$0.98	
Channel Catfish		$0.98	
Non-representative Recreational Species		$0.98	
Non-representative Forage Species			$0.05

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are blue catfish and channel catfish.

Table H-19
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFN

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Walleye	No Commercial Fishery	$3.80	
Tadpole Madtom			$0.06
Northern Pike		$3.80	
Yellow Perch		$0.98	
Black Bullhead		$0.98	
Black Crappie		$0.98	
Fathead Minnow			$0.06
Rock Bass		$0.98	
Spottail Shiner			$0.06
Non-representative Recreational Species		$1.91	
Non-representative Forage Species			$0.06

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are walleye, northern pike, yellow perch, black bullhead, black crappie, and rock bass.

Table H-20
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFO

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Gizzard Shad	No Commercial Fishery		$0.05
Common Carp			$0.05
Minnows			$0.05
Catfishes		$0.98	
Sunfishes		$0.98	
Black Bass		$8.35	
Darters			$0.05
Yellow Perch		$0.98	
Freshwater Drum		$0.98	
Non-representative Recreational Species		$1.17	
Non-representative Forage Species			$0.05

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are catfishes, black bass, yellow perch, and freshwater drum.

Table H-21
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFP

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Threadfin Shad	No Commercial Fishery		$0.05
Channel Catfish		$0.98	
Bluegill		$0.98	
Inland Silverside			$0.05
Green Sunfish		$0.98	
Common Carp			$0.05
Non-representative Recreational Species		$0.98	
Non-representative Forage Species			$0.05

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species is channel catfish.

Table H-22
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFG

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Sunfish	No Commercial Fishery	$0.98	
Shiner			$0.07
Yellow Perch		$0.98	
Catfish		$0.98	
American Eel			$0.07
White Perch		$0.98	
Non-representative Recreational Species		$0.98	
Non-representative Forage Species			$0.07

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are yellow perch, catfish, and white perch.

Table H-23
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFR

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Forage Shad	No Commercial Fishery		$0.06
Catfish		$0.98	
Sunfish		$0.98	
Largemouth Bass		$8.35	
Weed Shiner			$0.06
Darters			$0.06
Common Carp			$0.06

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are catfish and largemouth bass.

Table H-24
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFS

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Gizzard Shad	No Commercial Fishery		$0.02
Freshwater Drum		$0.98	
Bluegill		$0.98	
Channel Catfish		$0.98	
White Bass		$0.98	
Largemouth Bass		$8.35	
Emerald Shiner			$0.02
Non-representative Recreational Species		$1.02	
Non-representative Forage Species			$0.02

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are freshwater drum, channel catfish, white bass, and largemouth bass.

Table H-25
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFT

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Rainbow Smelt	$0.15	$1.23	
Round Goby			$0.08
Alewife			$0.08
White Sucker			$0.08
Emerald Shiner			$0.08
Gizzard Shad			$0.08
Yellow Perch	$0.61		
Logperch			$0.08
Non-representative Recreational & Commercial Species [b]	$0.19	$1.23	
Non-representative Commercial Species [c]	$0.16		
Non-representative Recreational Species [d]		$7.93	
Non-representative Forage Species			$0.08

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are rainbow smelt and yellow perch.

[b] Value based on white bass due to abundance in non-representative species category.

[c] Value based on channel catfish due to abundance in non-representative species category.

[d] Value based on black basses due to abundance in non-representative species category.

Table H-26
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFU

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Rainbow Smelt	No Commercial Fishery	$0.98	
Gizzard Shad			$0.33
Emerald Shiner			$0.33
Non-representative Recreational Species		$0.98	
Non-representative Forage Species			$0.33

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species is rainbow smelt.

Table H-27
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFV

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Threadfin Shad	No Commercial Fishery		$0.05
Blue Catfish		$0.98	
Channel Catfish		$0.98	
White Perch		$0.98	
Yellow Perch		$0.98	
Gizzard Shad			$0.05
White Catfish		$0.98	
Non-representative Recreational Species		$0.98	

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are blue catfish, channel catfish, white perch, yellow perch, and white catfish.

Table H-28
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFW

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Anchovies			$0.10
Mojarras	$0.83		
Puffers		$2.64	
Commercial Shrimp	$0.87		
Blue Crab	$0.47		
Bonefish		$12.76	
Ladyfish	$0.26		
Tomtate		$2.64	
Lookdown			$0.10
Florida Stone Crab	$2.75		
Non-representative Recreational Species (fish)		$3.29	
Non-representative Forage Species (fish)			$0.10
Non-representative Forage Species (crabs)			$0.10
Non-representative Forage Species (shrimp)			$0.10

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are mojarras, puffers, bonefish, ladyfish, tomtate, and Florida stone crab.

Table H-29
Producer surplus per pound (commercial harvest and forage) or per fish (recreational harvest) at RFX

Taxa	Commercial Value	Recreational Value	Forage Value
	Producer Surplus per Pound (2007$)	Consumer Surplus per Fish (2007$)	Forgone Value per Pound of Forage (2007$)[a]
Cunner		$2.76	
Winter Flounder	$0.96	$5.52	
Northern Pipefish			$0.27
Grubby			$0.27
Commercial Crabs	$0.31		
Sticklebacks			$0.27
American Lobster	$3.49		
Rainbow Smelt			
Rock Gunnel			$0.27
Windowpane		$5.52	
Longhorn Sculpin	$0.03	$2.76	
Atlantic Mackerel	$0.14	$5.52	
Fourbeard Rockling			$0.27
Striped Bass			
Non-representative Recreational & Commercial Species[b]	$0.98	$2.76	
Non-representative Commercial Species	$0.30		
Non-representative Forage Species			$0.27

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are cunner, winter flounder, commercial crabs, American lobster, windowpane, longhorn sculpin, and Atlantic mackerel.

[b] Value based on Atlantic cod due to abundance in non-representative species category.

H.1.3 Monetization Uncertainty and Omissions

There are multiple uncertainties and omissions in this complex analysis.

Timing of benefits delivery-USEPA's methods suggest that annual WTP can be estimated as a linear function of the expected lifetime yield of a cohort of saved fish. This is a reasonable approximation if the fish in question mature quickly and are very short-lived (complete life cycle in one or two years). For long-lived fish that mature slowly, the USEPA methods result in an overestimate of annual benefits [44]. The magnitude of the bias increases as the lag time between saving a fish and the time when it can be harvested increases. For longer lived species the bias can be as high as 10 to 20 percent.

To see this, imagine a harvested fish is valued at $1 and that some technology saves 10 Age-1 equivalent fish each year. If annual mortality is 50 percent and 1/2 of annual mortality is due to fishing, then both the lifetime expected yield of a saved cohort (annual benefits as estimated by USEPA methods) as well as the true average annual benefit can be predicted.

The lifetime expected yield of the cohort saved in Year 1 is estimated as $2.5 + $1.25 + $0.62 + $0.31 = $4.68 (See the diagonal in Table H1-30). USEPA methods approximate the average annual benefits as $4.68. Note that the USEPA methods do not account for the timing of the benefit. In fact only $2.50 is received in Year 1, $3.75 in Year 2, $4.37 in Year 3 and then, it is only in Year 4 that the full $4.68 is received. The average annual value of the actual flow of benefits is only $3.80 (this simple example does not address discounting which exacerbates the difference).

Table H-30
Example of bias created using USEPA methods to estimate WTP for long-lived species [44]

	Number of Saved Age 1 Fish Harvested	Number of Saved Age 2 Fish Harvested	Number of Saved Age 3 Fish Harvested	Number of Saved Age 4 Fish Harvested	Total Benefit in a Given Year
Year 1	2.5	0	0	0	2.5
Year 2	2.5	1.25	0	0	3.75
Year 3	2.5	1.25	0.62	0	4.37
Year 4	2.5	1.25	0.62	0.31	4.7

Timing of benefits delivery was included for striped bass which is long lived, has a high per-fish value, and has a well-identified age class distribution in the harvest data. It was not incorporated for other species.

Additivity of losses associated with forage and recreational fish-USEPA methods suggest that forage fish value is a function of the number of commercial/recreational fish that would have been produced had these forage fish not been removed from the ecosystem by IM&E. This is a reasonable assumption if and only if the number of commercial/recreational fish in the system is limited by forage availability. If some factor other than forage availability limits the number of commercial/recreational fish in a system, then potentially increasing the number of forage fish has no obvious value. This is because the potential increase in forage fish will not translate into any increase in commercial/recreational catch rates.

USEPA methods simultaneously suggest that, if IM&E of commercial/recreational fish are reduced, catch rates among commercial and recreational fishermen will increase. As such, these IM&E reductions are valued based on commercial and or recreational fishermen’s willingness to pay for an increased catch rate. This is a reasonable assumption if and only if the number of sportfish in the system is limited by the balance between the maximum intrinsic growth (in numbers) of commercial/recreational fish populations and the mortality associated with commercial and recreational harvest. If some other factor limits the number of commercial/recreational fish in the system, reducing IM&E of these species has no obvious value. This is because IM&E reductions will not translate into any change in commercial/recreational catch rates.

Because both forage availability and the balance between population growth (in numbers) and harvest cannot simultaneously limit a system, deriving a benefit estimate as the sum of a forage fish component and a commercial/recreational component is theoretically inconsistent. Therefore, this assumption biases the WTP high. An example of this logic is reported in the socioeconomic section of the Final EIS for the Compass Port offshore LNG Project [47]. The impact of failing to incorporate limiting factors is to overstate the WTP to avoid cooling tower reductions in IM&E.

Negative value of invasive/aquatic nuisance species not incorporated-Reductions in IM&E necessarily reduce the number of invasive/nuisance species entrained or impinged. This in turn, may result in more invasive/nuisance species in the waterbody. The increase in these species could have two possible effects, each of which reduces the benefits of IM&E reduction. The two possible effects are:

- The invasive/nuisance species could directly compete with and displace native/desirable fish species; and
- The invasive/nuisance species may alter the probability of invasive/nuisance introductions to other waterbodies that lead to a cascading ecological failure.

Recent entrainment data for BTPD, BTPE, RFG, RFJ, RFL, RFM, RFN, RFO, RFP, RFQ, RFR, RFS, RFU, and RFV are not available-WTP to avoid a reduction in entrainment at BTPD, BTPE, RFG, RFJ, RFL, RFM, RFN, RFO, RFP, RFQ, RFR, RFS, RFU, and RFV has been omitted. This bias WTP estimates toward underestimation at these facilities.

Benefits of other water activities not considered-The only recreational activity we have considered is fishing. While it is difficult to identify recreational activities that would be affected from a reduction of IM&E, to the extent that compliance would alter aquatic populations and that these altered populations would alter the value of, or participation in, other recreational activities, an assessment category have been omitted. This omission could bias benefit calculations towards over or underestimation.

Use of Values Associated with Groups of Fish – WTP to avoid fish mortality is dependant upon the species of fish in question. This report places similar species into groups and assigns a 'per fish' value to all species in the group. The approach is appropriate for estimating national WTP. However, results at any one facility may be biased towards over or under estimation if IM&E at that facility is dominated by only one or two species in a group.

H.1.4 National Scaling

The national benefits of reduced IM&E were to be determined by scaling benefits to cooling water flow. However, preliminary analysis of the Impingement and Entrainment Database by EPRI has determined there is no relationship (with a few exceptions) between flow and IM&E. As a result, this report does not estimate the national benefit of retrofits. EPRI is initiating an independent project to develop a national retrofit benefit estimate. The results of that investigation will be reported separately along with a summary of the EPRI Impingement and Entrainment Database and specific information regarding the impingement and entrainment of protected species.

H.2 Quantification and Monetization Results

Results of the IM&E quantification and monetization process are summarized in Tables H-31 through H-38.

Table H-31
Summary of annual IM and impact assessments at BTCA1

			Commercial Value		Recreational Value			Forage Value	
	Impingement (# of fish)	Adult (Age 1) Equivalents	Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[a]
Anchovy	1,900	1,700	<10	<50	0	0	$0	0	$0
Northern Anchovy	8,000	7,100	<10	<50	0	0	$0	0	$0
Pacific Staghorn Sculpin	18,000	10,300	60	<50	340	3,630	$10,000	0	$0
Combtooth Blenny	200	600	0	$0	0	0	$0	<10	<50
Gobies	2,700	7,000	0	$0	0	0	$0	10	<50
Topsmelt	293,600	540,400	0	$0	0	0	$0	82,250	$29,000
Shiner Perch	64,200	110,100	330	$200	4,370	19,020	$52,100	0	$0
Representative Species Fish Totals	**388,500**	**677,000**	**390**	**$200**	**4,720**	**22,660**	**$62,100**	**82,270**	**$29,000**
Non-Representative Species Forage	5,000	8,900	0	$0	0	0	$0	10	<50
Non-Representative Species Recreation	500	800	0	$0	70	120	$300	0	$0
Non Representative Species Recreational & Commercial	5,100	9,500	260	$100	160	570	$1,600	0	$0
Non-Representative Species Fish Totals	**10,600**	**19,200**	**260**	**$100**	**230**	**680**	**$1,900**	**10**	**<50**
Commercial Crabs	41,000	88,000	<10	<50	0	0	$0	0	$0
Commercial Shrimp	100	100	0	$0	0	0	$0	0	$0
Forage Shrimp	0	0	0	$0	0	0	$0	0	$0
Shellfish Totals	**41,100**	**88,100**	**<10**	**<50**	**0**	**0**	**$0**	**0**	**$0**
Grand Totals	**440,200**	**784,300**	**660**	**$400**	**4,950**	**23,340**	**$64,000**	**82,280**	**$29,000**

[a] Forgone value per pound of forage fish is based on a 0.28 trophic transfer efficiency assuming the predator species are Pacific staghorn sculpin and shiner perch.
Totals may not equal due to rounding.

Table H-32
Summary of annual entrainment and impact assessments at BTCA1

	Entrainment (Thousands of Eggs and Larvae)	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
			Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[a]
Anchovy	66,525	2,100	<10	<50	0	0	$0	0	$0
Northern Anchovy	284,187	8,800	10	<50	0	0	$0	0	$0
Pacific Staghorn Sculpin	238	4,200	20	<50	140	1,490	$4,100	0	$0
Combtooth Blenny	467,721	6,865,500	0	$0	0	0	$0	35,340	$12,500
Gobies	1,088,591	2,834,000	0	$0	0	0	$0	42,650	$15,000
Topsmelt	156,142	40,200	0	$0	0	0	$0	13,860	$4,900
Shiner Perch	0	0	0	$0	0	0	$0	0	$0
Representative Species Fish Totals	**2,063,403**	**9,754,600**	**40**	**<50**	**140**	**1,490**	**$4,100**	**91,840**	**$32,400**
Non-Representative Species Forage	41,980	10,500	0	$0	0	0	$0	160	$100
Non-Representative Species Recreation	391	100	0	$0	30	50	$100	0	$0
Non Representative Species Recreational & Commercial	187,580	95,200	8,000	$4,400	680	2,580	$7,100	0	$0
Non-Representative Species Fish Totals	**229,951**	**105,800**	**8,000**	**$4,400**	**700**	**2,630**	**$7,200**	**160**	**$100**
Commercial Crabs	4,330	300	<10	$0	0	0	$0	0	$0
Commercial Shrimp	0	0	0	$0	0	0	$0	0	$0
Forage Shrimp	0	0	0	$0	0	0	$0	0	$0
Shellfish Totals	**4,330**	**300**	**<10**	**$0**	**0**	**0**	**$0**	**0**	**$0**
Grand Totals	**2,297,684**	**9,860,700**	**8,040**	**$4,400**	**840**	**4,120**	**$11,300**	**92,010**	**$32,400**

[a] Forgone value per pound of forage fish is based on a 0.28 trophic transfer efficiency assuming the predator species are Pacific staghorn sculpin and shiner perch.
Totals may not equal due to rounding.

Table H-33
Summary of annual IM and impact assessments at BTPA

	Impingement (# of fish)	**Adult (Age 1) Equivalents**	**Commercial Value**		**Recreational Value**			**Forage Value**	
			Forgone Commercial Yield (lbs)	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[a]**
Blue Crab	6,000	10,100	30	<50	0	1,170	$2,400	0	$0
Blue Catfish	76,200	32,500	0	$0	6,380	12,970	$12,700	0	$0
Channel Catfish	14,600	17,200	0	$0	2,740	4,440	$4,400	0	$0
Silverside shiner	10,000	36,800	0	$0	0	0	$0	90	<50
Freshwater Drum	37,900	6,900	0	$0	1,050	990	$1,000	0	$0
Gizzard Shad	11,100	10,700	0	$0	0	0	$0	1,610	$100
Threadfin Shad	282,000	101,700	0	$0	0	0	$0	910	<50
Smallmouth Buffalo	500	300	0	$0	0	0	$0	0	$0
Black Crappie	33,700	7,800	0	$0	270	790	$800	0	$0
Representative Species Totals	**472,000**	**224,100**	**30**	**<50**	**10,440**	**20,360**	**$21,200**	**2,610**	**$100**
Non-Representative Species Forage	23,200	41,500	0	$0	0	0	$0	50	<50
Non-Representative Species Recreational	8,500	12,500	0	$0	150	1,650	$1,700	0	$0
Non-Representative Species Totals	**31,700**	**53,900**	**0**	**$0**	**150**	**1,650**	**$1,700**	**50**	**<50**
Grand Totals	**503,600**	**278,000**	**30**	**<50**	**10,590**	**22,020**	**$22,900**	**2,660**	**$100**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are blue catfish, channel catfish, freshwater drum and black crappie.
Totals may not equal due to rounding.

Table H-34
Summary of annual entrainment and impact assessments at BTPA

			Commercial Value		Recreational Value			Forage Value	
	Entrainment (Thousands of Larvae) [a]	Adult (Age 1) Equivalents	Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[a]
Blue Crab	0	0	0	$0	0	0	$0	0	$0
Blue Catfish	79	400	0	$0	80	160	$200	0	$0
Channel Catfish	15	100	0	$0	20	30	<50	0	$0
Silverside Shiner	42,308	383,400	0	$0	0	0	$0	23,460	$1,100
Freshwater Drum	15,424	13,100	0	$0	3,020	3,520	$3,400	0	$0
Gizzard Shad	7,845	2,100	0	$0	0	0	$0	2,150	$100
Threadfin Shad	198,747	329,100	0	$0	0	0	$0	24,500	$1,200
Smallmouth Buffalo	20,913	319,900	0	$0	0	0	$0	0	$0
Black Crappie	12,169	5,300	0	$0	240	800	$800	0	$0
Representative Species Totals	**297,500**	**1,053,400**	**0**	**$0**	**3,360**	**4,520**	**$4,400**	**50,110**	**$2,400**
Non-Representative Species Forage	9,607	2,400	0	$0	0	0	$0	40	<50
Non-Representative Species Recreational	7,533	53,400	0	$0	1,060	12,130	$12,500	0	$0
Non-Representative Species Totals	**17,141**	**55,800**	**0**	**$0**	**1,060**	**12,130**	**$12,500**	**40**	**<50**
Grand Totals	**314,641**	**1,109,200**	**0**	**$0**	**4,410**	**16,650**	**$16,900**	**50,150**	**$2,400**

[a] No eggs reported entrained.

[b] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are blue catfish, channel catfish, freshwater drum and black crappie.
Totals may not equal due to rounding.

Table H-35
Summary of annual IM and impact assessments at BTPB

	Impingement (# of fish)	**Adult (Age 1) Equivalents**	**Commercial Value**		**Recreational Value**			**Forage Value**	
			Forgone Commercial Yield (lbs)	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[a]**
Yellow perch	1,116,300	1,709,900	10,570	$6,500	10,570	26,100	$32,100	0	$0
Spottail shiner	87,300	1,723,900	0	$0	0	0	$0	520	<50
Alewife	82,700	63,600	0	$0	0	0	$0	3,780	$200
Round goby[a]	35,200	57,800	0	$0	0	0	$0	23,060	$1,200
Rainbow smelt	9,000	10,500	<10	<50	<10	30	<50	0	$0
Representative Species Totals	**1,330,500**	**3,565,700**	**10,580**	**$6,500**	**10,580**	**26,130**	**$32,100**	**27,350**	**$1,400**
Non-Representative Species commercial only	100	100	20	<50	0	0	$0	0	$0
Non-Representative Species Recreation only	3,300	6,800	0	$0	750	980	$1,200	0	$0
Non-Representative Species Recreational & Commercial	11,200	28,100	5,000	$3,000	5,000	3,650	$4,500	0	$0
Non-Representative Species Forage	41,000	84,800	0	$0	0	0	$0	8,520	$400
Non-Representative Species Totals	**55,500**	**119,800**	**5,020**	**$3,000**	**5,750**	**4,630**	**$5,700**	**8,520**	**$400**
Grand Totals	**1,386,000**	**3,685,500**	**15,600**	**$9,500**	**16,330**	**30,760**	**$37,800**	**35,870**	**$1,800**

[a] The round goby is an invasive species that is considered to be harmful to Great Lakes fish communities.

[b] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species is yellow perch.
Totals may not equal due to rounding.

Table H-36
Summary of annual entrainment and impact assessments at BTPB

	Entrainment (Thousands of Eggs, Larvae and Juveniles)	**Adult (Age 1) Equivalents**	**Commercial Value**		**Recreational Value**			**Forage Value**	
			Forgone Commercial Yield (lbs)	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[a]**
Yellow perch	1,882	127,200	3,020	$1,800	3,020	7,570	$9,300	0	$0
Spottail shiner	12,457	599,800	0	$0	0	0	$0	8,760	$400
Alewife	22,310	6,500	0	$0	0	0	$0	8,870	$500
Round goby[a]	45,347	79,400	0	$0	0	0	$0	39,290	$2,000
Rainbow smelt	9,818	530,200	140	<50	140	1,940	$2,400	0	$0
Representative Species Totals	**91,813**	**1,343,000**	**3,160**	**$1,900**	**3,160**	**9,520**	**$11,700**	**56,920**	**$2,900**
Non-Representative Species commercial only	141	100	30	<50	0	0	$0	0	$0
Non-Representative Species Recreation only	271	1,300	0	$0	270	560	$700	0	$0
Non-Representative Species Recreational & Commercial	0	0	0	$0	0	0	$0	0	$0
Non-Representative Species Forage	13,494	2,500	0	$0	0	0	$0	3,370	$200
Non-Representative Species Totals	**13,907**	**3,900**	**30**	**<50**	**270**	**560**	**$700**	**3,370**	**$200**
Grand Totals	**105,720**	**1,346,900**	**3,190**	**$1,900**	**3,430**	**10,080**	**$12,400**	**60,290**	**$3,100**

[a] The round goby is an invasive species that is considered to be harmful to Great Lakes fish communities.

[b] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species is yellow perch.
Totals may not equal due to rounding.

Table H-37
Summary of annual IM and impact assessments at BTPC

			Commercial Value		Recreational Value			Forage Value	
	Impingement (# of fish)	**Adult (Age 1) Equivalents**	**Forgone Commercial Yield (lbs)**	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[a]**
Atlantic Croaker	8,737,000	370,000	62,220	$20,500	36,590	31,540	$85,500	0	$0
Bay Anchovy	8,096,400	2,272,100	0	$0	0	0	$0	12,950	$300
Blue Crab	800	1,300	50	<50	20	80	$200	0	$0
River Herring	1,954,300	6,000	60	<50	0	0	$0	7,720	$200
Striped Bass	8,733,300	65,200	3,700	$7,300	98,220	10,380	$56,800	0	$0
Weakfish	21,400	2,300	930	$800	1,270	440	$2,400	0	$0
White Perch	680,200	401,700	100	$100	110	420	$1,100	0	$0
Representative Species Totals	**28,223,300**	**3,118,500**	**67,060**	**$28,700**	**136,200**	**42,860**	**$146,000**	**20,670**	**$500**
Non-Representative Species[a]	817,000	0	0	$0	0	0	$0	0	$0
Unidentifiable Fish[a]	0	0	0	$0	0	0	$0	0	$0
Non-Representative Species Totals[a]	**817,000**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**$0**
Grand Totals[b]	**29,040,300**	**3,118,500**	**67,060**	**$28,700**	**136,200**	**42,860**	**$146,000**	**20,670**	**$500**

[a] Non-RS and unidentifiable fish were not modeled at this facility. Values for losses here are based upon catch ratios from the raw data. In number of organisms, RS species comprise 88.3 percent of the entrainment and 97.2 percent of the impingement.

[b] Losses at this plant are expected losses based on technology currently being installed at the facility. See Appendix A.

[c] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are Atlantic croaker, striped bass, weakfish, and white perch.
Totals may not equal due to rounding.

Table H-38
Summary of annual entrainment and impact assessments at BTPC

			Commercial Value		Recreational Value			Forage Value	
	Entrainment (Thousands of Eggs and Larvae)	**Adult (Age 1) Equivalents**	**Forgone Commercial Yield (lbs)**	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Atlantic Croaker	683	8,000	1,340	$400	790	680	$1,800	0	$0
Bay Anchovy	2,495	97,500	0	$0	0	0	$0	1,870	<50
Blue Crab	0	0	0	$0	0	0	$0	0	$0
River Herring	151,993	92,400	910	$100	0	0	$0	307,890	$6,800
Striped Bass	188,063	60,600	3,440	$6,800	91,280	9,650	$52,800	0	$0
Weakfish	0	0	0	$0	0	0	$0	0	$0
White Perch	5,111	58,500	10	<50	20	60	$200	0	$0
Representative Species Totals	**348,345**	**317,000**	**5,700**	**$7,300**	**92,080**	**10,390**	**$54,800**	**309,760**	**$6,800**
Non-Representative Species[a]	24,689	0	0	$0	0	0	$0	0	$0
Unidentifiable Fish[a]	21,660	0	0	$0	0	0	$0	0	$0
Non-Representative Species Totals[a]	**46,349**	**0**	**0**	**$0**	**0**	**0**	**$0**	**0**	**$0**
Grand Totals[b]	**394,694**	**317,000**	**5,700**	**$7,300**	**92,080**	**10,390**	**$54,800**	**309,760**	**$6,800**

[a] Non-RS and unidentifiable fish were not modeled at this facility. Values for losses here are based upon catch ratios from the raw data. In number of organisms, RS species comprise 88.3 percent of the entrainment and 97.2 percent of the impingement.

[b] Losses at this plant are expected losses based on technology currently being installed at the facility. See Appendix A.

[c] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are Atlantic croaker, striped bass, weakfish, and white perch.
Totals may not equal due to rounding.

Table H-39
Summary of annual IM and impact assessments at BTPD

	Impingement (# of fish)	Entrainment (# of eggs & larvae)[a]	Adult (Age 1) Equivalents [b]	Commercial Value		Recreational Value			Forage Value	
				No Commercial Fishery		Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Alewife	28,200					0	0	$0	1,260	$100
Blue Catfish	8,000					150	150	$100	0	$0
Channel Catfish	2,000					40	40	<$50	0	$0
Threadfin Shad	145,300					0	0	$0	820	<$50
White Perch	3,700					40	150	$200	0	$0
Representative Species Fish Totals	**187,000**	**NA**	**NA**	**NA**	**NA**	**230**	**340**	**$300**	**2,080**	**$100**
Non-Representative Species[c]	1,400					0	0	$0	0	$0
Grand Totals	**188,400**	**NA**	**NA**	**NA**	**NA**	**230**	**340**	**$300**	**2,080**	**$100**

[a] Entrainment was not sampled.

[b] Adult equivalents were not calculated.

[c] Non-RS were not monetized.

[d] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are blue catfish, channel catfish, and white perch.
Totals may not equal due to rounding.

Table H-40
Summary of annual IM and impact assessments at BTPE

	Impingement (# of fish)	Entrainment (# of larvae)	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
				No Commercial Fishery		Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Gizzard Shad	191,200		25,500			0	0	$0	7,400	$500
Bluegill	11,900		1,800			30	320	$300	0	$0
Channel Catfish	14,100		6,300			1,380	3,080	$3,000	0	$0
Walleye	800		1,100			1,010	580	$2,200	0	$0
American Shad	300		200			30	10	<$50	0	$0
White Crappie	300		100			10	20	<$50	0	$0
Comely Shiner	300		35,100			0	0	$0	<100	<$50
Largemouth Bass	100		700			10	10	$100	0	$0
Smallmouth Bass	200		8,600			30	30	$300	0	$0
Representative Species -Totals	219,100	NA	79,300			2,500	4,050	$5,900	7,400	$500
Non-Representative Species Forage	900		1,100			0	0	$0	<100	<$50
Non-Representative Species Recreational	1,400		2,300			10	20	<$50	0	$0
Grand Totals	**221,400**	**NA**	**82,600**			**2,510**	**4,070**	**$6,000**	**7,400**	**$500**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are channel catfish, walleye, largemouth bass, and smallmouth bass.
Totals may not equal due to rounding.

Table H-41
Summary of annual IM and impact assessments at BTCA2

			Commercial Value		Recreational Value			Forage Value	
	Impingement (# of fish)	Adult (Age 1) Equivalents	Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Anchovy (Anchoa spp.)	32,000	13,200	20	<50	0	0	$0	0	$0
Northern anchovy	396,100	414,400	190	<50	0	0	$0	0	$0
Clinid kelpfishes	0	0	0	$0	0	0	$0	0	$0
Kelp/Sand Bass	400	500	0	$0	120	110	$300	0	$0
White croaker	9,600	1,700	70	<50	30	110	$300	0	$0
Queenfish	712,900	704,300	21,380	$6,800	9,560	35,490	$97,200	0	$0
Pacific sardine	107,500	106,500	0	$0	0	0	$0	11,660	$1,100
Representative Species Fish Totals	**1,258,400**	**1,240,500**	**21,650**	**$6,900**	**9,710**	**35,710**	**$97,800**	**11,660**	**$1,100**
Non-Representative Species Forage	42,200	75,600	0	$0	0	0	$0	90	<50
Non-Representative Species Recreational	7,600	10,800	0	$0	1,100	1,760	$4,800	0	$0
Non-Representative Species Commercial	200	200	20	<50	0	0	$0	0	$0
Non Representative Species Recreational & Commercial	44,700	109,500	900	$300	2,600	11,400	$31,200	0	$0
Non-Representative Species Totals	**94,700**	**196,100**	**920**	**$300**	**3,700**	**13,150**	**$36,000**	**90**	**<50**
Commercial Crabs/lobster	68,600	141,100	10	<50	0	0	$0	0	$0
Commercial Shrimp	18,400	21,200	<10	$0	0	0	$0	0	$0
Forage Shrimp	8,100	9,300	0	$0	0	0	$0	<10	<50
Shellfish Totals	**95,000**	**171,700**	**10**	**<50**	**0**	**0**	**$0**	**<10**	**<50**
Grand Totals	**1,448,200**	**1,608,300**	**22,580**	**$7,200**	**13,410**	**48,860**	**$133,900**	**11,750**	**$1,100**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are kelpfish, white croaker, and queenfish.
Totals may not equal due to rounding.

Table H-42
Summary of annual entrainment and impact assessments at BTCA2

			Commercial Value		**Recreational Value**			**Forage Value**	
	Entrainment (Thousands of Eggs and Larvae)	**Adult (Age 1) Equivalents**	**Forgone Commercial Yield (lbs)**	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Anchovy (Anchoa spp.)	4,373	100	<10	$0	0	0	$0	0	$0
Northern anchovy	21,698,847	664,600	1,060	<50	0	0	$0	0	$0
Clinid kelpfishes	146,947	36,600	0	$0	0	0	$0	570	$100
Kelp/Sand Bass	38,891	61,000	0	$0	15,090	13,780	$37,800	0	$0
White croaker	861,403	264,900	10,790	$3,900	4,830	18,470	$50,600	0	$0
Queenfish	1,326,198	407,800	16,610	$5,300	7,430	28,440	$77,900	0	$0
Pacific sardine	8,693	35,700	0	$0	0	0	$0	4,620	$400
Representative Species Fish Totals	**24,085,352**	**1,470,800**	**28,460**	**$9,200**	**27,340**	**60,700**	**$166,300**	**5,180**	**$500**
Non-Representative Species Forage	708,672	133,500	0	$0	0	0	$0	2,080	$200
Non-Representative Species Recreational	235,415	10,600	0	$0	2,080	3,650	$10,000	0	$0
Non-Representative Species Commercial	2,973	1,100	220	$100	0	0	$0	0	$0
Non Representative Species Recreational & Commercial	4,376,933	2,303,100	214,040	$68,800	3,590	13,760	$37,700	0	$0
Non-Representative Species Totals	**5,323,993**	**2,448,300**	**214,260**	**$68,900**	**5,680**	**17,410**	**$47,700**	**2,080**	**$200**
Commercial Crabs/lobster	17,441	1,200	<10	<50	0	0	$0	0	$0
Commercial Shrimp	0	0	0	$0	0	0	$0	0	$0
Forage Shrimp	0	0	0	$0	0	0	$0	0	$0
Shellfish Totals	**17,441**	**1,200**	**<10**	**<50**	**0**	**0**	**$0**	**0**	**$0**
Grand Totals	**29,426,786**	**3,920,200**	**242,730**	**$78,100**	**33,020**	**78,110**	**$214,000**	**7,260**	**$700**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are kelpfish, white croaker, and queenfish.
Totals may not equal due to rounding.

Table H-43
Summary of annual IM and impact assessments at RFF

	Impingement (# of fish)	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
			Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Freshwater drum	225,700	326,800	99,350	$4,000	0	0	$0	0	$0
Rainbow smelt	11,500	28,900	<10	<50	<10	50	$100	0	$0
White bass	1,593,200	2,721,900	189,640	$36,000	189,640	197,890	$243,400	0	$0
Emerald shiner	24,080,900	12,163,000	0	$0	0	0	$0	19,370	$200
Gizzard shad	14,313,100	29,592,700	0	$0	0	0	$0	2,971,600	$29,700
White perch	4,769,200	9,545,500	0	$0	0	0	$0	408,780	$4,100
Representative Species Totals	**44,993,500**	**54,378,700**	**288,990**	**$40,000**	**189,640**	**197,930**	**$243,500**	**3,399,750**	**$34,000**
Non-Representative Species Recreational & Commercial	300	700	60	<50	60	30	$100	0	$0
Non-Representative Species Recreational	116,900	236,000	0	$0	40,520	17,390	$66,300	0	$0
Non-Representative Species Commercial	210,000	323,300	9,650	$5,900	0	0	$0	0	$0
Non-Representative Species Forage	709,200	952,300	0	$0	0	0	$0	12,440	$100
Non-Representative Species Totals	**1,036,500**	**1,512,300**	**9,710**	**$5,900**	**40,580**	**17,420**	**$66,400**	**12,440**	**$100**
Grand Totals	**46,030,000**	**55,891,000**	**298,700**	**$45,900**	**230,230**	**215,350**	**$309,800**	**3,412,190**	**$34,100**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are freshwater drum, rainbow smelt, and white bass.
Totals may not equal due to rounding.

Table H-44
Summary of annual entrainment and impact assessments at RFF

	Entrainment (Thousands of Eggs and Larvae)	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
			Forgone Commercial Yield (lbs)	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Freshwater drum	1,260,489	916,700	306,720	$12,300	0	0	$0	0	$0
Rainbow smelt	435,132	16,821,500	4,350	$700	4,350	61,280	$75,400	0	$0
White bass	156,894	53,500	8,270	$1,600	8,270	9,350	$11,500	0	$0
Emerald shiner	14,616	27,800	0	$0	0	0	$0	3,190	<50
Gizzard shad	0	0	0	$0	0	0	$0	0	$0
White perch	4,739	13,400	0	$0	0	0	$0	1,360	<50
Representative Species Totals	**1,871,870**	**17,832,900**	**319,340**	**$14,500**	**12,620**	**70,630**	**$86,900**	**4,560**	**<50**
Non-Representative Species Recreational & Commercial	713	5,800	830	$400	830	430	$1,600	0	$0
Non-Representative Species Recreational	8,953	141,100	0	$0	40,490	20,970	$79,900	0	$0
Non-Representative Species Commercial	6,009	26,500	1,260	$800	0	0	$0	0	$0
Non-Representative Species Forage	79,040	3,448,200	0	$0	0	0	$0	179,290	$1,800
Non-Representative Species Totals	**94,715**	**3,621,500**	**2,090**	**$1,100**	**41,320**	**21,400**	**$81,500**	**179,290**	**$1,800**
Grand Totals	**1,966,584**	**21,454,400**	**321,430**	**$15,600**	**53,940**	**92,030**	**$168,400**	**183,850**	**$1,800**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are freshwater drum, rainbow smelt, and white bass.
Totals may not equal due to rounding.

Table H-45
Summary of annual IM and impact assessments at RFG

	Impingement (# of fish)	Facility Not Subject to Entrainment Standards	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
				No Commercial Fishery		Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Gizzard Shad	96,100		22,600	500	<$50	0	0	$0	5,500	$100
Freshwater Drum	81,600		12,300	1,400	$100	2,300	1,300	$1,300	0	$0
Sauger	6,200		9,400	0	$0	2,000	900	$3,500	0	$0
Skipjack Herring	3,300		400	0	$0	0	0	$0	400	<$50
Channel Catfish	2,200		1,300	100	<$50	200	400	$400	0	$0
White Bass	1,300		2,200	0	$0	400	400	$400	0	$0
Representative Species Totals	**190,700**	**N/A**	**48,200**	**2,000**	**$100**	**4,900**	**3,000**	**$5,500**	**5,900**	**$100**
Non-Representative Species Recreational	1,500		2,700	0	$0	200	400	$700	0	$0
Non-Representative Species Forage	2,100		3,800	0	$0	0	0	$0	<100	<$50
Non-Representative Species Totals	**3,700**	**N/A**	**6,500**	**0**	**$0**	**200**	**400**	**$700**	**<100**	**<$50**
Grand Totals	**194,300**	**N/A**	**54,800**	**2,000**	**$100**	**5,100**	**3,400**	**$6,200**	**5,900**	**$100**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are freshwater drum, sauger, channel catfish and white bass.
Totals may not equal due to rounding.

Table H-46
Summary of annual IM and impact assessments at RFH

	Impingement (# of fish)	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
			Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Gobies	355,600	1,500	0	$0	0	0	$0	100	<50
Bay Anchovy	2,499,100	2,127,200	0	$0	0	0	$0	1,520	$100
Threadfin Shad	79,700	43,800	0	$0	0	0	$0	300	<50
Spot	826,300	102,700	510	$200	560	1,750	$4,600	0	$0
Silver Perch	117,400	32,200	0	$0	0	0	$0	2,520	$200
Atlantic Croaker	405,900	18,100	1,110	$200	2,190	2,340	$6,200	0	$0
Commercial Shrimp	1,233,200	324,500	8,650	$7,500	0	0	$0	0	$0
Blue Crab	748,200	53,200	580	$300	0	0	$0	0	$0
Lesser Blue Crab	98,300	50,400	0	$0	0	0	$0	11,800	$800
Representative Species Totals	**6,363,600**	**2,753,700**	**10,850**	**$8,200**	**2,750**	**4,090**	**$10,800**	**16,230**	**$1,200**
Non-Representative Species Recreational & Commercial	82,100	47,900	2,140	$1,600	2,140	3,350	$8,800	0	$0
Non-Representative Species Commercial	134,100	114,000	10,200	$7,700	0	0	$0	0	$0
Non-Representative Species Recreational	48,900	33,900	0	$0	3,030	4,740	$12,500	0	$0
Non-Representative Species Forage	168,500	252,000	0	$0	0	0	$0	300	<50
Non-Representative Species Totals	**433,600**	**447,700**	**12,350**	**$9,300**	**5,170**	**8,090**	**$21,400**	**300**	**<50**
Grand Totals	**6,797,200**	**3,201,400**	**23,200**	**$17,600**	**7,920**	**12,180**	**$32,200**	**16,530**	**$1,200**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are spot and Atlantic croaker.
Totals may not equal due to rounding.

Table H-47
Summary of annual entrainment and impact assessments at RFH

			Commercial Value		Recreational Value			Forage Value	
	Entrainment (Thousands of Eggs and Larvae)	Adult (Age 1) Equivalents	Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Gobies	18	100	0	$0	0	0	$0	<10	<50
Bay Anchovy	73	0	0	$0	0	0	$0	<10	<50
Threadfin Shad	0	0	0	$0	0	0	$0	0	$0
Spot	15	0	<10	<50	<10	<10	<50	0	$0
Silver Perch	6	0	0	$0	0	0	$0	<10	<50
Atlantic Croaker	7	0	<10	$0	<10	0	$0	0	$0
Commercial Shrimp	6	0	<10	<50	0	0	$0	0	$0
Blue Crab	3	0	0	$0	0	0	$0	0	$0
Lesser Blue Crab	0	0	0	$0	0	0	$0	0	$0
Representative Species Totals	**128**	**100**	**<10**	**<50**	**<10**	**<10**	**<50**	**<10**	**<50**
Non-Representative Species Recreational & Commercial	2	0	<10	<50	<10	0	$0	0	$0
Non-Representative Species Commercial	2	0	<10	<50	0	0	$0	0	$0
Non-Representative Species Recreational	1	0	0	$0	<10	0	$0	0	$0
Non-Representative Species Forage	26	0	0	$0	0	0	$0	<10	<50
Non-Representative Species Totals	**32**	**0**	**<10**	**<50**	**<10**	**0**	**$0**	**<10**	**<50**
Grand Totals	**160**	**100**	**<10**	**<50**	**<10**	**<10**	**<50**	**<10**	**<50**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are spot and Atlantic croaker.
Totals may not equal due to rounding.

Table H-48
Summary of annual IM and impact assessments at RFI

	Impingement (# of fish)	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
			Forgone Commercial Yield (lbs)	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Gizzard Shad	37,200	30,400	0	$0	0	0	$0	5,700	$600
Bluntnose Minnow	3,700	5,500	0	$0	0	0	$0	30	<50
Spotfin Shiner	2,000	1,000	0	$0	0	0	$0	<10	<50
Round Goby[b]	1,300	1,200	0	$0	0	0	$0	500	$100
Bluegill	900	1,100	0	$0	20	230	$200	0	$0
White Perch	1,800	4,600	0	$0	<10	<10	<50	0	$0
Emerald Shiner	900	500	0	$0	0	0	$0	<10	<50
Common Carp	0	0	0	$0	0	0	$0	0	$0
Representative Species Totals	**47,800**	**44,200**	**0**	**$0**	**20**	**240**	**$200**	**6,230**	**$700**
Non-Representative Species Recreational	3,200	5,600	0	$0	510	790	$800	0	$0
Non-Representative Species Forage	1,800	3,200	0	$0	0	0	$0	<10	<50
Non-Representative Species Totals	**5,000**	**8,800**	**0**	**$0**	**510**	**790**	**$800**	**<10**	**<50**
Grand Totals	**52,800**	**53,000**	**0**	**$0**	**530**	**1,040**	**$1,000**	**6,230**	**$700**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species is white perch.

[b] The round goby is an invasive species that is considered to be harmful to the fish communities of the source waterbody.
Totals may not equal due to rounding.

Table H-49
Summary of annual entrainment and impact assessments at RFI

	Entrainment (Thousands of Eggs and Larvae)	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
			Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Gizzard Shad	14,372	4,300	0	$0	0	0	$0	5,810	$600
Bluntnose Minnow	1,960	12,200	0	$0	0	0	$0	410	<50
Spotfin Shiner	0	0	0	$0	0	0	$0	0	$0
Round Goby[b]	0	0	0	$0	0	0	$0	0	$0
Bluegill	1,254	8,900	0	$0	180	2,010	$2,000	0	$0
White Perch	0	0	0	$0	0	0	$0	0	$0
Emerald Shiner	0	0	0	$0	0	0	$0	0	$0
Common Carp	25,790	26,100	0	$0	0	0	$0	32,830	$3,600
Representative Species Totals	**43,375**	**51,500**	**0**	**$0**	**180**	**2,010**	**$2,000**	**39,050**	**$4,300**
Non-Representative Species Recreational	299	1,100	0	$0	210	370	$400	0	$0
Non-Representative Species Forage	3,143	800	0	$0	0	0	$0	10	<50
Non-Representative Species Totals	**3,441**	**1,800**	**0**	**$0**	**210**	**370**	**$400**	**10**	**<50**
Grand Totals	**46,816**	**53,300**	**0**	**$0**	**390**	**2,380**	**$2,300**	**39,060**	**$4,300**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species is white perch.

[b] The round goby is an invasive species that is considered to be harmful to the fish communities of the source waterbody.
Totals may not equal due to rounding.

Table H-50
Summary of annual IM and impact assessments at RFJ

				Commercial Value		**Recreational Value**			**Forage Value**	
	Impingement (# of fish)	**Facility Not Subject to Entrainment Standards**	**Adult (Age 1) Equivalents**	**No Commercial Fishery**		**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Threadfin Shad	2,400		100			0	0	$0	5	<$50
Bluegill	2,000		5,900			50	430	$400	0	$0
Largemouth Bass	1,000		1,400			30	50	$400	0	$0
White Crappie	700		1,100			130	200	$200	0	$0
Representative Species Totals	**6,100**	**N/A**	**8,600**	**N/A**	**N/A**	**210**	**690**	**$1,000**	**5**	**<$50**
Non-Representative Species Recreational	300		400			10	50	$100	0	$0
Non-Representative Species Forage	300		500			0	0	$0	1	<$50
Non-Representative Species Totals	**600**	**N/A**	**900**	**N/A**	**N/A**	**10**	**50**	**$100**	**1**	**<$50**
Grand Totals	**6,700**	**N/A**	**9,600**	**N/A**	**N/A**	**210**	**740**	**$1,100**	**6**	**<$50**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are largemouth bass and white crappie.
Totals may not equal due to rounding.

Table H-51
Summary of annual IM and impact assessments at RFK

			Commercial Value		**Recreational Value**			**Forage Value**	
	Impingement (# of fish)	**Adult (Age 1) Equivalents**	**Forgone Commercial Yield (lbs)**	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Atlantic menhaden	55,700	3,100	430	<50	0	0	$0	0	$0
Atlantic silveRepresentative Specieside	2,100	400,800	0	$0	0	0	$0	20	<50
Bay anchovy	0	0	0	$0	0	0	$0	<10	$0
Butterfish	2,600	1,600	50	<50	0	0	$0	0	$0
Cunner	1,700	2,700	0	$0	10	100	$300	0	$0
Fourbeard rockling	0	0	0	$0	0	0	$0	0	$0
Red hake	1,100	2,100	260	$100	0	0	$0	0	$0
Striped killifish	4,100	4,100	0	$0	0	0	$0	90	<50
Searobins	2,700	1,600	10	$0	50	210	$600	0	$0
Tautog	600	900	40	<50	480	120	$300	0	$0
Representative Species Totals	**70,700**	**416,900**	**790**	**$200**	**550**	**430**	**$1,200**	**110**	**<50**
Non-Representative Species Recreational	2,100	12,500	0	$0	670	980	$2,700	0	$0
Non-Representative Species Commercial	1,800	10,900	580	<50	0	0	$0	0	$0
Non-Representative Species Forage	1,400	2,600	0	$0	0	0	$0	<10	$0
Non-Representative Species Totals	**5,400**	**25,900**	**580**	**<50**	**670**	**980**	**$2,700**	**<10**	**$0**
Grand Totals	**76,100**	**442,900**	**1,370**	**$200**	**1,220**	**1,410**	**$3,900**	**120**	**<50**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are butterfish, cunner, red hake, searobins, and tautog.
Totals may not equal due to rounding.

Table H-52
Summary of annual entrainment and impact assessments at RFK

	Entrainment (Thousands of Eggs and Larvae)	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
			Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Atlantic menhaden	325,356	1,015,400	79,250	$4,000	0	0	$0	0	$0
Atlantic silveRepresentative Specieside	874	2,200	0	$0	0	0	$0	340	$100
Bay anchovy	92,188	188,100	0	$0	0	0	$0	810	$100
Butterfish	1,937	1,100	30	<50	0	0	$0	0	$0
Cunner	198,370	97,100	0	$0	530	4,560	$12,600	0	$0
Fourbeard rockling	48,382	65,500	0	$0	0	0	$0	3,200	$500
Red hake	0	0	0	$0	0	0	$0	0	$0
Striped killifish	0	0	0	$0	0	0	$0	0	$0
Searobins	40,491	153,000	1,020	$0	5,300	20,150	$55,600	0	$0
Tautog	215,834	7,400	320	$300	3,810	970	$2,700	0	$0
Representative Species Totals	**923,432**	**1,529,800**	**80,620**	**$4,300**	**9,640**	**25,680**	**$70,900**	**4,350**	**$700**
Non-Representative Species Recreational	42,734	17,100	0	$0	3,360	5,890	$16,300	0	$0
Non-Representative Species Commercial	19,901	30,600	6,030	$300	0	0	$0	0	$0
Non-Representative Species Forage	28,851	19,900	0	$0	0	0	$0	180	<50
Non-Representative Species Totals	**91,486**	**67,600**	**6,030**	**$300**	**3,360**	**5,890**	**$16,300**	**180**	**<50**
Grand Totals	**1,014,917**	**1,597,300**	**86,650**	**$4,700**	**13,000**	**31,570**	**$87,100**	**4,530**	**$800**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are butterfish, cunner, red hake, searobins, and tautog.
Totals may not equal due to rounding.

Table H-53
Summary of annual IM and impact assessments at RFL

				Commercial Value		Recreational Value			Forage Value	
	Impingement (# of fish)	**Facility Not Subject to Entrainment Standards**	**Adult (Age 1) Equivalents**	**No commercial fishery**		**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Gizzard Shad	33,000		51,100			0	0	$0	8,000	$200
Freshwater Drum	25,700		2,600			800	700	$700	0	$0
Channel Catfish	1,300		600			100	300	$300	0	$0
Bluegill	900		800			<100	200	$200	0	$0
Blue Catfish	400		300			100	100	$100	0	$0
Representative Species Totals	**61,400**	**N/A**	**55,400**	**N/A**	**N/A**	**1,000**	**1,200**	**$1,200**	**8,000**	**$200**
Non-Representative Species Recreational	700		1,200			100	200	$200	0	$0
Non-Representative Species Forage	800		1,500			0	0	$0	<100	<$50
Non-Representative Species Totals	**1,500**	**N/A**	**2,600**	**N/A**	**N/A**	**100**	**200**	**$200**	**<100**	**<$50**
Grand Totals	**62,800**	**N/A**	**58,000**	**N/A**	**N/A**	**1,200**	**1,400**	**$1,400**	**8,000**	**$200**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are freshwater drum, channel catfish, and blue catfish.
Totals may not equal due to rounding.

Table H-54
Summary of annual IM and impact assessments at RFM

				Commercial Value		Recreational Value			Forage Value	
	Impingement (# of fish)	**Facility Not Subject to Entrainment Standards**	**Adult (Age 1) Equivalents**	**No Commercial Fishery**		**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Gizzard Shad	84,000		25,000			0	0	$0	6,100	$300
Skipjack Herring	56,000		13,000			0	0	$0	9,500	$600
Threadfin Shad	30,000		65,000			0	0	$0	200	<$50
Freshwater Drum	25,000		3,000			900	600	$600	0	$0
Silver Carp[b]	20,000		35,000			0	0	$0	30,500	$1,500
Blue Catfish	3,000		3,000			500	800	$800	0	$0
Channel Catfish	3,000		1,000			300	600	$600	0	$0
Representative Species Totals	**220,000**	**N/A**	**145,000**	**N/A**	**N/A**	**1,600**	**2,000**	**$2,000**	**46,200**	**$2,300**
Non-Representative Species Recreational	4,000		7,000			600	900	$900	0	$0
Non-Representative Species Forage	1,000		2,000			0	0	$0	<100	<$50
Non-Representative Species Totals	**5,000**	**N/A**	**9,000**	**N/A**	**N/A**	**600**	**900**	**$900**	**<100**	**<$50**
Grand totals	**225,000**	**N/A**	**154,000**	**N/A**	**N/A**	**2,200**	**2,900**	**$2,900**	**46,200**	**$2,300**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are blue catfish and channel catfish.

[b] The silver carp is an invasive species that is considered to be harmful to the fish communities of the source waterbody.
Totals may not equal due to rounding.

Table H-55
Summary of annual IM and impact assessments at RFN

				Commercial Value		Recreational Value			Forage Value	
	Impingement (# of fish)	**Facility Not Subject to Entrainment Standards**	**Adult (Age 1) Equivalents**	**No Commercial Fishery**		**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Walleye	1,800		500			130	70	$300	0	$0
Tadpole Madtom	900		1,700			0	0	$0	5	<$50
Northern Pike	900		<100			30	<10	<$50	0	$0
Yellow Perch	600		300			10	30	<$50	0	$0
Black Bullhead	400		300			20	60	$100	0	$0
Black Crappie	300		<100			<10	<10	<$50	0	$0
Fathead Minnow	300		500			0	0	$0	1	<$50
Rock Bass	300		300			10	50	<$50	0	$0
Spottail Shiner	<100		<100			0	0	$0	<1	<$50
Representative Species Totals	**5,500**	**N/A**	**3,600**	**N/A**	**N/A**	**200**	**210**	**$400**	**6**	**<$50**
Non-Representative Species Recreational	200		400			40	60	$100	0	$0
Non-Representative Species Forage	400		800			0	0	$0	1	<$50
Non-Representative Species Totals	**600**	**N/A**	**1,200**	**N/A**	**N/A**	**40**	**60**	**$100**	**1**	**<$50**
Grand Totals	**6,200**	**N/A**	**4,800**	**N/A**	**N/A**	**240**	**270**	**$500**	**7**	**<$50**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are walleye, northern pike, yellow perch, black bullhead, black crappie, and rock bass.
Totals may not equal due to rounding.

Table H-56
Summary of annual IM and impact assessments at RFO

	Impingement (# of fish)	Facility Not Subject to Entrainment Standards	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
				No Commercial Fishery		Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Gizzard Shad	4,200		2,100			0	0	$0	460	<$50
Common Carp	800		300			0	0	$0	310	<$50
Minnows	1,700		2,200			0	0	$0	10	<$50
Catfishes	900		700			100	200	$200	0	$0
Sunfishes	29,700		15,500			300	3,300	$3,200	0	$0
Black Bass	1,300		2,300			100	100	$900	0	$0
Darters	200		1,400			0	0	$0	<10	<$50
Yellow Perch	200		200			<100	<100	<$50	0	$0
Freshwater Drum	9,400		3,000			1,000	800	$800	0	$0
Representative Species Totals	**48,500**	**N/A**	**27,700**	**N/A**	**N/A**	**1,500**	**4,400**	**$5,200**	**780**	**<$50**
Non-Representative Species Recreational	1,300		1,700			200	300	$400	0	$0
Non-Representative Species Forage	2,600		4,600			0	0	$0	10	<$50
Non-Representative Species Totals	**3,900**	**N/A**	**6,300**	**N/A**	**N/A**	**200**	**300**	**$400**	**10**	**<$50**
Grand Totals	**52,400**	**N/A**	**34,000**	**N/A**	**N/A**	**1,700**	**4,800**	**$5,600**	**790**	**<$50**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are catfishes, black bass, yellow perch, and freshwater drum.
Totals may not equal due to rounding.

Table H-57
Summary of annual IM and impact assessments at RFP

	Impingement (# of fish)	Facility Not Subject to Entrainment Standards	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
				No Commercial Fishery		Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Threadfin Shad	264,700		523,800			0	0	$0	2,100	$100
Channel Catfish	3,400		3,200			640	1,200	$1,200	0	$0
Bluegill	2,900		1,600			30	400	$400	0	$0
Inland Silverside	600		<100			0	0	$0	<100	<$50
Green Sunfish	400		600			10	100	$100	0	$0
Common Carp	400		800			0	0	$0	400	<$50
Representative Species Totals	**272,400**	**N/A**	**530,000**	**N/A**	**N/A**	**670**	**1,700**	**$1,600**	**2,500**	**$100**
Non-Representative Species Recreational	500		800			70	100	$100	0	$0
Non-Representative Species Forage	500		800			0	0	$0	<100	<$50
Non-Representative Species Totals	**900**	**N/A**	**1,600**	**N/A**	**N/A**	**70**	**100**	**$100**	**<100**	**<$50**
Grand Totals	**273,300**	**N/A**	**531,600**	**N/A**	**N/A**	**750**	**1,800**	**$1,700**	**2,500**	**$100**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species is channel catfish.
Totals may not equal due to rounding.

Table H-58
Summary of annual IM and impact assessments at RFQ

	Impingement (# of fish)	Facility Not Subject to Entrainment Standards at Current Capacity Utilization	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
				No Commercial Fishery		Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Sunfish	800		1,900			20	300	$200	0	$0
Shiner	600		7,700			0	0	$0	10	<$50
Yellow Perch	500		700			20	100	$100	0	$0
Catfish	200		200			10	<100	<$50	0	$0
American Eel	100		500			0	0	$0	20	<$50
White Perch	<100		<100			<10	0	$0	0	$0
Representative Species Totals	**2,200**	**N/A**	**11,000**	**N/A**	**N/A**	**60**	**300**	**$300**	**20**	**<$50**
Non-Representative Species Recreational	100		100			10	<100	<$50	0	$0
Non-Representative Species Forage	200		300			0	0	$0	<10	<$50
Non-Representative Species Totals	**300**	**N/A**	**400**	**N/A**	**N/A**	**10**	**<100**	**<$50**	**<10**	<$50
Grand Totals	**2,400**	**N/A**	**11,400**	**N/A**	**N/A**	**70**	**400**	**$400**	**20**	**<$50**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are yellow perch, catfish, and white perch.
Totals may not equal due to rounding.

Table H-59
Summary of annual IM and impact assessments at RFR

				Commercial Value		Recreational Value			Forage Value	
	Impingement (# of fish)	Facility Not Subject to Entrainment Standards	Adult (Age 1) Equivalents	No Commercial Fishery		Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Forage Shad	380		1,200			0	0	$0	4	<$50
Catfish	290		200			40	80	$100	0	$0
Sunfish	90		100			<10	10	<$50	0	$0
Largemouth Bass	50		100			<10	<10	<$50	0	$0
Weed Shiner	30		300			0	0	$0	<1	<$50
Darters	20		100			0	0	$0	<1	<$50
Common Carp	10		<100			0	0	$0	4	<$50
Grand Totals	**880**	**N/A**	**1,800**	**N/A**	**N/A**	**40**	**90**	**$100**	**8**	**<$50**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are catfish and largemouth bass.

Totals may not equal due to rounding.

Table H-60
Summary of annual IM and impact assessments at RFS

	Impingement (thousands of fish)	Facility Not Subject to Entrainment Standards	Adult (Age 1) Equivalents (thousands)	Commercial Value		Recreational Value			Forage Value	
				No Commercial Fishery		Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Gizzard Shad	767		1,585			0	0	$0	159,200	$3,200
Freshwater Drum	62		90			27,400	15,800	$15,500	0	$0
Bluegill	60		88			1,100	11,600	$11,400	0	$0
Channel Catfish	19		38			5,800	7,900	$7,700	0	$0
White Bass	3		6			500	800	$800	0	$0
Largemouth Bass	3		7			100	200	$1,600	0	$0
Emerald Shiner	2		1			0	0	$0	<100	<$50
Representative Species Totals	**916**	**N/A**	**1,815**	**N/A**	**N/A**	**34,900**	**36,400**	**$37,100**	**159,200**	**$3,200**
Non-Representative Species Recreation	4		8			700	1,100	$1,100	0	$0
Non-Representative Species Forage	7		12			0	0	$0	<100	<$50
Non-Representative Species Totals	**11**	**N/A**	**20**	**N/A**	**N/A**	**700**	**1,100**	**$1,100**	**<100**	**<$50**
Grand Totals	**927**	**N/A**	**1,835**	**N/A**	**N/A**	**35,600**	**37,400**	**$38,200**	**159,200**	**$3,200**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are freshwater drum, channel catfish, white bass, and largemouth bass.
Totals may not equal due to rounding.

Table H-61
Summary of annual IM and impact assessments at RFT

			Commercial Value		**Recreational Value**			**Forage Value**	
	Impingement (# of fish)	**Adult (Age 1) Equivalents**	**Forgone Commercial Yield (lbs)**	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Rainbow smelt	7,000	4,300	<10	<50	<10	20	<50	0	$0
Round goby[b]	800	1,300	0	$0	0	0	$0	430	<50
Alewife	0	0	0	$0	0	0	$0	<10	<50
White sucker	300	500	0	$0	0	0	$0	60	<50
Emerald shiner	2,800	29,600	0	$0	0	0	$0	30	<50
Gizzard shad	138,700	170,600	0	$0	0	0	$0	31,440	$2,500
Yellow perch	3,700	6,000	90	$100	90	230	$300	0	$0
Logperch	4,000	6,800	0	$0	0	0	$0	90	<50
Representative Species Totals	**157,300**	**219,100**	**100**	**$100**	**100**	**240**	**$300**	**32,050**	**$2,600**
Non-Representative Species Recreational & Commercial	200	300	30	<50	30	30	<50	0	$0
Non-Representative Species Commercial	200	400	70	<50	0	0	$0	0	$0
Non-Representative Species Recreational	3,100	8,000	0	$0	160	220	$1,700	0	$0
Non-Representative Species Forage	2,700	4,900	0	$0	0	0	$0	<10	<50
Non-Representative Species Totals	**6,300**	**13,700**	**90**	**<50**	**190**	**250**	**$1,800**	**<10**	**<50**
Grand Totals	**163,600**	**232,900**	**190**	**$100**	**280**	**490**	**$2,100**	**32,060**	**$2,600**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are rainbow smelt and yellow perch.

[b] The round goby is an invasive species that is considered to be harmful to the fish communities of the source waterbody.
Totals may not equal due to rounding.

Table H-62
Summary of annual entrainment and impact assessments at RFT

			Commercial Value		**Recreational Value**			**Forage Value**	
	Entrainment (Thousands of Eggs and Larvae)	**Adult (Age 1) Equivalents**	**Forgone Commercial Yield (lbs)**	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Rainbow smelt	6,079	213,500	60	<50	60	780	$1,000	0	$0
Round goby	3,190	1,200	0	$0	0	0	$0	680	$100
Alewife	2,203	700	0	$0	0	0	$0	220	<50
White sucker	1,299	18,600	0	$0	0	0	$0	4,550	$400
Emerald shiner	868	1,400	0	$0	0	0	$0	150	<50
Gizzard shad	546	100	0	$0	0	0	$0	170	<50
Yellow perch	376	1,600	40	<50	40	100	$100	0	$0
Logperch	43	1,700	0	$0	0	0	$0	90	<50
Representative Species Totals	**14,605**	**238,800**	**90**	**<50**	**90**	**870**	**$1,100**	**5,860**	**$500**
Non-Representative Species Recreational & Commercial	8	0	<10	<50	<10	<10	<50	0	$0
Non-Representative Species Commercial	22	0	10	<50	0	0	$0	0	$0
Non-Representative Species Recreational	182	14,100	0	$0	590	870	$6,900	0	$0
Non-Representative Species Forage	1,034	300	0	$0	0	0	$0	<10	<50
Non-Representative Species Totals	**1,245**	**14,400**	**20**	**<50**	**590**	**870**	**$6,900**	**<10**	**<50**
Grand Totals	**15,850**	**253,200**	**110**	**<50**	**690**	**1,750**	**$8,000**	**5,860**	**$500**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are rainbow smelt and yellow perch.

[b] The round goby is an invasive species that is considered to be harmful to the fish communities of the source waterbody.
Totals may not equal due to rounding.

Table H-63
Summary of annual IM and impact assessments at RFU

	Impingement (# of fish)	Facility Not Subject to Entrainment Standards	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
				No Commercial Fishery		Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Rainbow Smelt	3,100		7,700			<10	20	$20	0	$0
Gizzard Shad	1,800		3,700			0	0	$0	400	$100
Emerald Shiner	1,200		600			0	0	$0	<100	<$50
Representative Species Totals	**6,100**	**N/A**	**12,000**	**N/A**	**N/A**	**<10**	**20**	**$20**	**400**	**$100**
Non-Representative Species Recreational	300		500			50	80	$80	0	$0
Non-Representative Species Forage	200		300			0	0	$0	<100	<$50
Non-Representative Species Totals	**500**	**N/A**	**900**	**N/A**	**N/A**	**50**	**80**	**$80**	**<100**	**<$50**
Grand Totals	**6,600**	**N/A**	**12,900**	**N/A**	**N/A**	**50**	**100**	**$100**	**400**	**$100**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species is rainbow smelt.
Totals may not equal due to rounding.

Table H-64
Summary of annual IM and impact assessments at RFV

				Commercial Value		Recreational Value			Forage Value	
	Impingement (# of fish)	Facility Not Subject to Entrainment Standards	Adult (Age 1) Equivalents	No Commercial Fishery		Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Threadfin Shad	4,000		600			0	0	$0	<100	<$50
Blue Catfish	1,000		1,000			200	200	$200	0	$0
Channel Catfish	900		1,000			200	400	$400	0	$0
White Perch	800		3,200			<100	<100	<$50	0	$0
Yellow Perch	500		600			<100	100	$100	0	$0
Gizzard Shad	300		200			0	0	$0	<100	<$50
White Catfish	200		500			100	100	$100	0	$0
Representative Species Totals	**7,700**	**N/A**	**7,100**	**N/A**	**N/A**	**500**	**800**	**$800**	**<100**	**<$50**
Non-Representative Species Recreational	200		400			<100	<100	<$50	0	$0
Non-Representative Species Totals	**200**	**N/A**	**400**	**N/A**	**N/A**	**<100**	**<100**	**<$50**	**0**	**$0**
Grand Totals	**7,900**	**N/A**	**7,500**	**N/A**	**N/A**	**500**	**800**	**$800**	**<100**	**<$50**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are blue catfish, channel catfish, white perch, yellow perch, and white catfish.
Totals may not equal due to rounding.

Table H-65
Summary of annual IM and impact assessments at RFW

			Commercial Value		Recreational Value			Forage Value	
	Impingement (# of fish)	Adult (Age 1) Equivalents	Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Anchovies	44,400	79,500	0	$0	0	0	$0	80	<50
Mojarras	4,100	7,200	650	$500	0	0	$0	0	$0
PuffeRepresentative Species	7,600	13,400	0	$0	1,200	1,880	$5,000	0	$0
Commercial Shrimp	5,800	277,000	90	$100	0	0	$0	0	$0
Blue crab	800	400	<10	<50	0	0	$0	0	$0
Bonefish	600	1,100	0	$0	100	150	$1,900	0	$0
Ladyfish	300	500	50	<50	0	0	$0	0	$0
Tomtate	1,200	2,200	0	$0	200	310	$800	0	$0
Lookdown	600	1,000	0	$0	0	0	$0	210	<50
Florida stone crab[b]	1,100	400	30	$100	0	0	$0	0	$0
Representative Species Totals	**66,400**	**382,800**	**820**	**$700**	**1,490**	**2,330**	**$7,700**	**290**	**<50**
Non-Representative Species Recreational (fish)	400	700	0	$0	70	110	$300	0	$0
Non-Representative Species Forage (fish)	6,000	10,800	0	$0	0	0	$0	10	<50
Non-Representative Species Forage (crabs)	3,000	2,200	0	$0	0	0	$0	180	<50
Non-Representative Species Forage (shrimp)	3,000	3,500	0	$0	0	0	$0	<10	<50
Non-Representative Species Totals	**12,500**	**17,300**	**0**	**$0**	**70**	**110**	**$300**	**190**	**<50**
Grand Totals	**78,900**	**400,000**	**820**	**$700**	**1,560**	**2,440**	**$8,000**	**480**	**<50**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are mojarras, puffers, bonefish, ladyfish, tomtate, and Florida stone crab.

[b] Forgone commercial yield for this species was reduced by half due to the fact that only the claws are consumed (prices are in value per pound of claws) and approximately half of the crab's weight is contained in the claw.
Totals may not equal due to rounding.

Table H-66
Summary of Annual Entrainment and Impact Assessments at RFW

	Entrainment (Thousands of Eggs and Larvae)	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
			Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Anchovies	5,858,257	183,300	0	$0	0	0	$0	2,700	$300
Mojarras	537,581	22,900	4,500	$3,700	0	0	$0	0	$0
PuffeRepresentative Species	997,083	42,400	0	$0	8,350	14,640	$38,700	0	$0
Commercial Shrimp	0	0	0	$0	0	0	$0	0	$0
Blue crab	2,125,848	2,400	140	$100	0	0	$0	0	$0
Bonefish	79,793	3,400	0	$0	670	1,170	$15,000	0	$0
Ladyfish	39,962	1,700	340	$100	0	0	$0	0	$0
Tomtate	163,015	6,900	0	$0	1,370	2,390	$6,300	0	$0
Lookdown	77,815	3,500	0	$0	0	0	$0	2,000	$200
Florida stone crab[b]	3,060,963	127,100	11,720	$32,200	0	0	$0	0	$0
Representative Species Totals	**12,940,316**	**393,600**	**16,690**	**$36,100**	**10,380**	**18,210**	**$59,900**	**4,700**	**$500**
Non-Representative Species Recreational (fish)	1,124,119	385,000	0	$0	75,760	132,840	$437,200	0	$0
Non-Representative Species Forage (fish)	1,378,862	205,200	0	$0	0	0	$0	3,210	$300
Non-Representative Species Forage (crabs)	9,547,646	10,900	0	$0	0	0	$0	174,110	$17,400
Non-Representative Species Forage (shrimp)	13,697,736	117,560,500	0	$0	0	0	$0	105,580	$10,600
Non-Representative Species Totals	**25,748,363**	**118,161,600**	**0**	**$0**	**75,760**	**132,840**	**$437,200**	**282,900**	**$28,300**
Grand Totals	**38,688,679**	**118,555,200**	**16,690**	**$36,100**	**86,150**	**151,050**	**$497,200**	**287,600**	**$28,800**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are mojarras, puffers, bonefish, ladyfish, tomtate, and Florida stone crab.

[b] Forgone commercial yield for this species was reduced by half due to the fact that only the claws are consumed (prices are in value per pound of claws) and approximately half of the crab's weight is contained in the claw.
Totals may not equal due to rounding.

Table H-67
Summary of annual IM and impact assessments at RFX

			Commercial Value		Recreational Value			Forage Value	
	Impingement (# of fish)	**Adult (Age 1) Equivalents**	**Forgone Commercial Yield (lbs)**	**Commercial Loss (2007$)**	**Forgone Recreational Yield (lbs of fish)**	**Forgone Recreational Yield (# of fish)**	**Recreational Loss (2007$)**	**Forgone Production (lbs of fish)**	**Commercial/ Recreational Forgone Value (2007$)[c]**
Cunner	900	900	0	$0	<10	30	$100	0	$0
Winter flounder	400	0	<10	<50	<10	<10	<50	0	$0
Northern pipefish	900	400	0	$0	0	0	$0	<10	<50
Grubby	400	700	0	$0	0	0	$0	10	<50
Commercial Crabs	300	400	<10	<50	0	0	$0	0	$0
Sticklebacks	300	400	0	$0	0	0	$0	<10	<50
American lobster	100	200	10	<50	0	0	$0	0	$0
Rainbow smelt	0	100	0	$0	0	0	$0	0	$0
Rock gunnel	0	0	0	$0	0	0	$0	<10	<50
Windowpane	0	0	0	$0	<10	<10	<50	0	$0
Longhorn sculpin	0	0	<10	$0	<10	<10	<50	0	$0
Atlantic mackerel	0	0	0	$0	0	0	$0	0	$0
Fourbeard rockling	0	0	0	$0	0	0	$0	0	$0
Striped bass[b]	0	0	0	$0	0	0	$0	0	$0
Representative Species Totals	**3,300**	**3,200**	**20**	**<50**	**<10**	**30**	**$100**	**10**	**<50**
Non-Representative Species Recreational & Commercial	0	0	<10	<50	<10	<10	<50	0	$0
Non-Representative Species Commercial	300	600	50	<50	0	0	$0	0	$0
Non-Representative Species Forage	200	300	0	$0	0	0	$0	<10	$0
Non-Representative Species Totals	**600**	**1,000**	**60**	**<50**	**<10**	**<10**	**<50**	**<10**	**$0**
Grand Totals	**3,900**	**4,200**	**80**	**$100**	**10**	**40**	**$100**	**10**	**<50**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are cunner, winter flounder, commercial crabs, American lobster, windowpane, longhorn sculpin, and Atlantic mackerel.

[b] Modeling results showed no fish surviving to be caught by recreational fishermen; therefore the forgone recreational yield is $0.
Totals may not equal due to rounding.

Table H-68
Summary of annual entrainment and impact assessments at RFX

	Entrainment (Thousands of Eggs and Larvae)	Adult (Age 1) Equivalents	Commercial Value		Recreational Value			Forage Value	
			Forgone Commercial Yield (lbs)	Commercial Loss (2007$)	Forgone Recreational Yield (lbs of fish)	Forgone Recreational Yield (# of fish)	Recreational Loss (2007$)	Forgone Production (lbs of fish)	Commercial/ Recreational Forgone Value (2007$)[c]
Cunner	117,801	608,800	0	$0	3,330	28,600	$78,900	0	$0
Winter flounder	1,469	100	<10	<50	<10	<10	<50	0	$0
Northern pipefish	308	0	0	$0	0	0	$0	<10	$0
Grubby	12,878	21,200	0	$0	0	0	$0	500	$100
Commercial Crabs	10,982	135,100	6,020	$1,900	0	0	$0	0	$0
Sticklebacks	0	0	0	$0	0	0	$0	0	$0
American lobster	69	100	<10	<50	0	0	$0	0	$0
Rainbow smelt	2,033	500	0	$0	0	0	$0	0	$0
Rock gunnel	29,434	408,100	0	$0	0	0	$0	8,210	$2,200
Windowpane	3,467	300	0	$0	<10	<10	<50	0	$0
Longhorn sculpin	13,572	22,400	280	<50	1,060	7,680	$21,200	0	$0
Atlantic mackerel	3,842	200	20	<50	<10	<10	<50	0	$0
Fourbeard rockling	19,205	213,500	0	$0	0	0	$0	9,890	$2,600
Striped bass[b]	34	0	0	$0	<10	0	$0	0	$0
Representative Species Totals	**215,093**	**1,410,300**	**6,330**	**$1,900**	**4,400**	**36,300**	**$100,200**	**18,600**	**$5,000**
Non-Representative Species Recreational & Commercial	302	400	70	$100	70	70	$200	0	$0
Non-Representative Species Commercial	3,131	700	150	<50	0	0	$0	0	$0
Non-Representative Species Forage	3,980	900	0	$0	0	0	$0	10	<50
Non-Representative Species Totals	**7,413**	**2,100**	**220**	**$100**	**70**	**70**	**$200**	**10**	**<50**
Grand Totals	**222,506**	**1,412,300**	**6,550**	**$2,000**	**4,470**	**36,370**	**$100,400**	**18,610**	**$5,000**

[a] Forgone value per pound of forage fish is based on a 0.028 trophic transfer efficiency assuming the predator species are cunner, winter flounder, commercial crabs, American lobster, windowpane, longhorn sculpin, and Atlantic mackerel.
[b] Modeling results showed no fish surviving to be caught by recreational fishermen; therefore the forgone recreational yield is $0.

Totals may not equal due to rounding.

Table H-69
Summary of annual monetized losses due to IM&E at BTPs and RFs

Facility	Commercial Loss (2007$)	Recreational Loss (2007$)	Forage Loss (2007$)	Total Loss (2007$)	Reduction in Circulating Water Intake (%)[a]	WTP for Potential Reduction in IM&E (2007$) [b]
BTCA1	$4,700	$75,200	$61,500	$141,500	94	$133,000
BTPA	<$50	$39,900	$2,500	$42,300	96	$40,600
BTPB	$11,400	$50,200	$4,900	$66,500	98	$65,200
BTPC [c]	$36,000	$200,800	$7,300	$244,100	99	$241,700
BTPD	$0	$300	$100	$400	98	$400
BTPE	$0	$6,000	$500	$6,400	98	$6,300
BTCA2	$85,300	$347,900	$1,700	$435,000	94	$408,900
RFF	$61,500	$478,200	$36,000	$575,600	99	$569,800
RFG	$100	$6,200	$100	$6,400	97	$6,200
RFH	$17,600	$32,200	$1,200	$51,000	93	$47,400
RFI	$0	$3,300	$5,000	$8,300	98	$8,100
RFJ	$0	$1,100	<$50	$1,100	98	$1,100
RFK	$4,900	$91,000	$800	$96,700	95	$91,900
RFL	$0	$1,400	$200	$1,600	98	$1,600
RFM	$0	$2,900	$2,300	$5,200	98	$5,100
RFN	$0	$500	<$50	$500	98	$500
RFO	$0	$5,600	<$50	$5,600	97	$5,400
RFP	$0	$1,700	$100	$1,900	97	$1,800
RFQ	$0	$400	<$50	$400	98	$400
RFR	$0	$100	<$50	$100	98	$100
RFS	$0	$38,200	$3,200	$41,400	97	$40,200
RFT	$200	$9,600	$3,000	$13,300	98	$13,000
RFU	$0	$100	$100	$200	98	$200
RFV	$0	$800	<$50	$800	97	$800
RFW	$36,800	$505,200	$28,900	$570,800	95	$542,300
RFX	$2,100	$100,500	$5,000	$107,400	95	$102,000

[a] Does not include service water; therefore the percent reduction is overestimated.

[b] The WTP for the potential reduction in IM&E is a benefit for closed-cycle cooling. This benefit is in opposition to the WTP to avoid the adverse affects of closed-cycle cooling. Therefore, these values are presented in Table 6-6 of the main text as negative numbers.

[c] Losses at BTPC are expected losses based on technology currently being installed at the facility. See Appendix A.

Totals may not equal due to rounding.

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