ELECTRIC POWER
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National and Regional Summary of Impingement and Entrainment of Fish and Shellfish Based on an Industry Survey of Clean Water Act §316(b) Characterization Studies

2011 TECHNICAL REPORT

National and Regional Summary of Impingement and Entrainment of Fish and Shellfish based on an Industry Survey of Clean Water Act §316(b) Characterization Studies

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NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

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Product Description

In response to the U.S. Environmental Protection Agency's (EPA's) 2004 Phase II §316(b) Rule, many power plants conducted monitoring studies to quantify impingement and entrainment (I&E). Because of the number of studies conducted, the Electric Power Research Institute (EPRI) determined that compilation of this unique data would aid in informing the §316(b) rulemaking and EPRI's Fish Protection Research Program. To collect the data, a web-based questionnaire was developed and implemented. This report reviews the data requested and the database format and summarizes the results of the 240 responses received.

Results and Findings

I&E annual estimates were found to vary widely within and across regions and water body types (for example, the Great Lakes), confirming the importance of site-specific factors on annual values. Gizzard shad and threadfin shad dominated impingement in all freshwater areas, whereas each of the six estuarine/marine areas was dominated by a different species. In freshwater areas, clupeids were again important contributors to entrainment, while bay anchovies were important in several estuarine/marine areas. Annual entrainment generally showed weak to moderate correlations to intake design flow, whereas the correlations between flow and impingement were usually weak.

Challenges and Objectives

The previous round of I&E sampling took place over a roughly 10-year period from the mid-1970s through the mid-1980s, with a few studies done either just prior to or somewhat after this period. Sampling methodologies in the earlier studies were quite variable. In contrast, the most recent round of sampling was conducted during a shorter period, primarily from 2004 through 2007, followed established methodologies for both impingement and entrainment, and followed QA/QC procedures to ensure that samples were collected properly and that specimens were identified accurately. In addition, perhaps because they were collected over such an extended period, the earlier data were never compiled into a single document, making it difficult to evaluate any trends. The more compact nature of the recent studies persuaded EPRI that such a compilation would be both useful and informative. EPRI, therefore, designed a survey that would capture key elements of the various studies and compiled the data into a single database to support current and future I&E analyses.

Applications, Value, and Use

The focus of this effort was to acquire key results from I&E studies that were conducted in response to the 2004 Phase II Rule and compile those data into a single database. Although this report provides an overview of I&E results, the intent was not to conduct an exhaustive analysis of the data. Rather, the intent was to develop a database that can be used by other researchers to address questions and issues that may arise in the future.

Energy producers, federal and state resource agencies and regulators, and the public will find this report a valuable reference for understanding the extent and magnitude of I&E at power plant cooling water intake structures. This report represents the largest I&E database ever compiled and will serve as a valuable resource for future analysis.

Approach

The goal of the survey was to capture key operational and biological data, while minimizing the burden placed on responders. The questionnaire was web-based to further facilitate data entry, delivery, and, more important, eventual data compilation and analysis. Survey completion was estimated to take about 30 minutes if only impingement data were collected and about 60 minutes if both impingement mortality and entrainment data were collected. The website survey was open for about two years to allow maximum participation. All users had unique access to the survey for their plants; however, results presented in this report are not attributed to any particular plant.

Keywords

Clean Water Act §316(b)
Entrainment
Fish protection
Impingement

Abstract

In response to a 2004 regulation for cooling water intake structures at existing steam electric power plants (the "Phase II §316(b) Rule"), which the U.S. Environmental Protection Agency (EPA) promulgated pursuant to §316(b) of the federal Clean Water Act, many of the power plants subject to the Rule conducted monitoring studies to quantify impingement and, in some cases, entrainment (I&E). Because of the number of plants involved, the Electric Power Research Institute (EPRI) determined that compilation of this unique data was important. To capture the data, EPRI developed a web-based questionnaire that asked questions concerning plant characteristics, study design, and biological results.

This report summarizes responses from 240 facilities. Because I&E varied geographically and by water body type, EPRI grouped plants within 12 geographic regions (six freshwater regions and six marine or estuarine regions) as a way to evaluate the existence of regional trends among the plant-specific results. In all six of the freshwater regions, gizzard shad (*Dorosoma cepedianum)* or threadfin shad (*D. petenense)* dominated impingement. There was greater diversity among the marine and estuarine plants. In most of the regions, the mean annual impingement was much higher than the median value, indicating that the means were greatly influenced by one or two very high annual estimates. Nearly half of the plants had annual impingement that was estimated to be 50,000 or fewer fish and shellfish, and 83% of the plants had values estimated to be 500,000 or fewer fish and shellfish. Five percent of the plants had estimated annual values greater than or equal to five million fish and shellfish. Very few state or federal threatened or endangered species were impinged at any of the plants responding to the questionnaire. As was the case for impingement, clupeids were big contributors in the two freshwater regions where entrainment studies were conducted. As was the case for impingement, entrainment composition was more varied among estuarine/marine facilities. Threatened or endangered species were reported in entrainment samples from only two regions. The mean annual entrainment estimate in each region was much higher than its respective median estimate, again reflecting the influence of one or two extremely high estimates on each mean. Overall, 40% of the plants entrained 1 to 50 million organisms, 29% entrained 100 million to one billion organisms, and 20% entrained more than one billion organisms. Based on correlation analysis of

design flow with annual impingement and entrainment, there often was poor correlation between the volume of water pumped and either impingement or entrainment on a national or regional level.

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Section 1: Introduction

In July 2004, the U.S. Environmental Protection Agency (EPA) issued a final rule implementing §316(b) of the Clean Water Act, for existing steam electric power plants with cooling water intake structures designed to withdraw more than 50 MGD from waters of the U.S. (69 Fed. Reg. 41,576 (July 9, 2004). That rule (the "Phase II 316(b) Rule") was challenged by a variety of interest groups, and in January 2007, portions of it were invalidated and remanded to EPA by the U.S. Court of Appeals for the Second Circuit (*Riverkeeper, Inc. v. EPA,* 475 F.3d 83 (2nd Circuit 2007)[1]. The Phase II 316(b) Rule required specific levels of reduction in impingement mortality and entrainment (collectively referred to as I&E) for facilities that used more than 50 MGD of once-through cooling water. These reductions were to be measured against what EPA termed the "calculation baseline," basically the level of I&E that would occur at an individual plant if the plant had a shoreline intake, used 3/8 inch mesh traveling screens, and used no fish protection measures to reduce impingement and entrainment (or losses stemming from impingement and entrainment). Although the Phase II Rule allowed use of historical data to establish the calculation baseline, the majority of the nation's once-through Phase II plants elected to collect new data.

The previous round of I&E sampling took place over a roughly 10-year period from the mid-1970s through the mid-1980s, with a few studies done either just prior to or somewhat after this period. Sampling methodologies in the earlier studies were quite variable. In contrast, the most recent round of sampling was conducted during a shorter period, primarily from 2004 through 2007, followed established methodologies for both impingement and entrainment (e.g., EPRI 2004a, 2005a), and followed QA/QC procedures to ensure that samples were collected properly and that specimens were identified accurately.

The studies prompted by the Phase II 316(b) Rule, however, were conducted over a more compressed period of time, used well-established methodologies, and followed more robust QA/QC procedures. In addition, perhaps because they were collected over such an extended period, the earlier data were never compiled into a single document, making it difficult to evaluate any trends. The more compact nature of the recent studies persuaded EPRI that such a compilation would be both useful and informative.

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[1] On April 20, 2011, EPA released a revised proposal covering all existing facilities with cooling water intake structures. A final rule is scheduled for promulgation by July 27, 2012. As discussed, the study reported on herein was conducted in response to requirements of the remanded 2004 Rule.

EPRI, therefore, designed a survey that would capture key elements of the various studies and compile the data into a single database. Principal objectives of this effort were to:

1. Compile, summarize, and analyze data from the various impingement and entrainment studies conducted in response to the 2004 §316(b) Phase II Rule.
2. Inform the current 316(b) Rulemaking with information on the dominant species impinged and entrained in various waterbody types and regions of the U.S. and their relative abundances in I&E studies.
3. Create a database that could support analyses of the factors that potentially control the extent and character of I&E and also could be used to address questions that may arise in response to EPA's revised rulemaking effort. These factors included:
   - Intake configurations relative to the waterbody shoreline and water withdrawal depth;
   - Methods used in I&E characterization studies;
   - Impingement and entrainment of protected species; and
   - Relationship between I&E and cooling water flow.
4. Estimate national and regional I&E to support benefit analyses; and
5. Use these data to determine whether I&E change greatly from one year to another for those plants that did studies for two or more years.

The focus of this effort was to acquire key results from I&E studies that were conducted in response to the 2004 Phase II Rule and compile those data into a single data base. Although this report provides an overview of I&E results, it was not an intent to conduct an exhaustive analysis of the data. Rather the intent was to develop a database that can be used by other researchers to address questions and issues that may arise in the future.

Section 2: Methods

The goal of the survey was to capture key operational and biological data while minimizing the burden placed on responders. The questionnaire was web-based to further facilitate data entry and delivery and, more importantly, eventual data compilation and analysis. The survey form is presented in Table 2-1. Survey completion was estimated to take about 30 minutes if only impingement data were collected and about 60 minutes if both impingement mortality and entrainment data were collected. If studies were conducted for two or more years, separate questionnaires could be filled out for each study year, which would allow annual comparisons.

EA hosted the website for the survey and kept it open for about two years to allow maximum participation. Each user had unique access to the survey for their plant(s); however, results presented in this report are not ascribed to any particular plant.

The questionnaire requested basic information about each plant including:

- Type of waterbody the intake(s) is located;
- Capacity of the plant in megawatts (MW);
- Pumping capacity of the plant;
- Whether the intake had standard 3/8 inch mesh traveling screens;
- Where in the water column the intake was located;
- If the intake was located along the shore, off-shore, or had an entrance canal; and
- If any fish protection devices in place.

For both entrainment and impingement a series of similar questions concerning the biological results were requested including:

- When did the study start and how long did it last?
- How frequently were samples collected and what was the duration of a typical sampling event?
- How many fish and shellfish were estimated to have been collected?
- Which species or taxa ranked in the top 10 and how many of each was collected?
- Were any state or federally protected species collected?

Table 2-1
Copy of the survey form that was made available to all facilities

Part 1: General Information	
1.1	Person supplying info: Name
1.2	Person supplying info: Phone
1.3	Person supplying info: e-mail
2	Name of Operating Company
3	Type of water body (select one):
4	Name of water body
5	Did you conduct recent (since 2000) studies to comply with the phase II Rule?
5.1	If yes, IM/E/Both?
6	What is MW capacity of your once through cooling units?
7	Is part of your facility closed-cycle (Y/N)?
7.1	If yes, what percentage in terms of MW is closed cycle?
8	Please provide capacity utilization (%) for this facility [when the sampling occurred] (once - through units only):
9	What is the total design pumping capacity (in MGD) for all once – thru units?
10	Does your facility use 3/8″ screens?
11	if not 3/8" screens, please record the mesh size (inches)
12	Were there any fish protective devices in place during the IM &E sampling periods?
12.1	If yes, please provide a brief description of any such devices.
13	Intake location (Surface, Submerged, or both)?
13.1	Depth of submerged intake: (in feet)
14	Intake location: (Shoreline, Offshore, Canal/Forebay, or Multiple)?
14.1	If intake is recessed, how many feet?
15	Briefly describe any "non-standard features" your intake(s) have (e.g. curtain walls, angled bar racks, etc)

Table 2-1 (continued)
Copy of the survey form that was made available to all facilities

Part 2A: Study Design - Impingement	
1.1	When did Impingement sampling begin (mm/dd/yy)?
1.2	When did Impingement sampling end (mm/dd/yy)?
2	How frequently were samples collected? (select one)
2.1	Beginning date when frequency changes occurred:
2.2	End date when frequency changes occurred:
3	What was the duration (in months) of the study?
4	How long (in hours) did a collection period (event) typically last (If duration time varied, insert variable)?
4.1	Other fixed period, please list:
5	Within a given period (event), were subsamples taken?
5.1	If yes, briefly describe (e.g. a sample was collected every 8 hrs during each 24 hr sampling event?).
6	Were impingement survival studies conducted?
7	Were impingement collection efficiencies determined?
Part 2B: Study Design - Entrainment	
1.1	When did the Entrainment Study start (mm/dd/yy)?
1.2	When did the Entrainment Study end (mm/dd/yy)?
2	How were the samples collected? (select all that apply)
2.1	Other types of collection, please list:
3	How frequently were samples collected? (select one)
3.1	Beginning date when frequency changes occurred:
3.2	End date when frequency changes occurred:
4	How long did a collection period typically last? (select one)
4.1	Other fixed period, please list:
5	Within each collection period was a single sample collected? (Y/N)
5.1	If no, how many samples were collected?
6	Did the study encompass one entire spawning season?
6.1	If not, how many subsamples were collected?
Note: if your study lasted for two or more years, please enter the results separately from each of the two most recent years (i.e., prepare a new survey response from the beginning with the appropriate sample dates).	

Table 2-1 (continued)
Copy of the survey form that was made available to all facilities

Part 3A: Results - Impingement	
1	Are additional results available prior to the most recent two years recorded?
2	What was the estimated number of total finfish collected during the study?
3	What was the estimated number of total shell fish collected during the study?
4	Please provide your annual impingement estimate for each of the top 10 fishes/shellfish:
5	Did you collect any state or federally protected T & E species?
5.1	Please list the name and number of each species collected.
6	How was your annual estimate derived?
Part 3B: Results - Entrainment	
1	What was the estimated number of total larval fish collected during the study?
2	What was the estimated number of total shell fish collected during the study?
3	What was the estimated number of fish eggs collected?
4	What was the estimated number of shellfish eggs collected?
5	Please provide your annual entrainment estimate for each of the top 10 larval fishes/shellfish:
6	Did you collect any state or federally protected T & E species?
6.1	Please list the name and number of each species collected.
7	How was your annual estimate derived?
8	Did you do an equivalent adult analysis?
Part 4: Report Request	
1	Are you willing to provide an electronic version of your IM(&E) Characterization Study?
1.1	If yes, please attach or send a disk to: EA Engineering, Science & Technology Attn: Greg Seegert 444 Lake-Cook Rd, Suite 18 Deerfield, IL 60015

Because the number and kinds of organisms impinged and entrained varied depending on waterbody type and location, responses were grouped into 12 categories: West Coast, Northeastern Coastal, Mid-Atlantic Coastal, Southern Coastal and Gulf, Great Lakes, Southeastern Reservoirs, Midwestern Reservoirs, Southwestern Cooling Lakes, Large (freshwater) Rivers, Small (freshwater) Rivers, Hawaii, and Puerto Rico. The geographic boundaries for these areas are described in Table 2-2. Some of these categories (e.g., Large Rivers) were well represented while few plants were studied in other regions (e.g., Hawaii and Puerto Rico). Because of the uniqueness of fauna entrained and impinged at the Hawaii and Puerto Rico plants, those data were kept separate during all analyses. The division between large and small rivers was based on whether the plant conducted only impingement studies (large rivers) or both impingement and entrainment studies (small rivers) because the 2004 Phase II Rule specified that facilities that used more than 5% of the mean annual flow (determined over a 10-year period) were subject to entrainment reduction standards whereas those that used less than 5% were subject only to impingement standards. Regions other than Hawaii and Puerto Rico were sometimes combined into larger groups (e.g., Coastal, Lakes and Reservoirs, and Rivers) to increase sample size for statistical analyses.

Table 2-2
Geographic boundaries for each region (the remaining categories including Great Lakes, Large and Small Rivers, West Coast, Hawaii, and Puerto Rico are self explanatory)

Geographic Region	Area Included
Northeastern Coastal	All coastal facilities from Maine through New Jersey
Mid-Atlantic Coastal	All coastal facilities from Delaware through North Carolina
Southern Coastal and Gulf	All coastal facilities from South Carolina through Texas
Southeastern Reservoirs	Reservoir-sited facilities south of Pennsylvania and the Ohio River and east of the Mississippi River, but also including Arkansas and Louisiana
Midwestern Reservoirs	Reservoir-sited facilities in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota and Wisconsin
Southwestern Cooling Lakes	Facilities in Oklahoma and Texas sited on cooling water lakes

2.1 Qualifications Associated with the Data Summarization

2.1.1 Derivation of Annual Estimates

To standardize results, respondents were asked to estimate their annual I&E. Respondents used three methods to derive these annual estimates. Most respondents (76 percent) used actual flow to derive annual I&E estimates. In this approach, impingement and entrainable organism density were derived from sampling and the results extrapolated based on the volume of water actually used by the plant during the period when the impingement or entrainment was determined. Fourteen percent of the respondents used design flow to estimate annual I&E, where density was multiplied by the maximum pumping rate for the plant that was assumed to be operated on a 24/7 basis. Estimates based on design flows provide a worst case estimate that overestimates the numbers actually entrained or impinged. A smaller group of plants (nine percent) used time extrapolation, which assumed that sampling occurred on representative days and the estimate for each of the days sampled was multiplied by the number of days in each estimating period. For example, if impingement samples were collected weekly, then the estimate for a given week would be the number of organisms impinged on the date sampled times seven, the number of days in a week. The annual estimate would then be the sum of the weekly estimates. This approach also assumes the plant operated on a 24/7 basis, so it too overestimates actual I&E, but probably not as much as the design flow method.

For the purpose of this evaluation, all design flow and time-based estimates were converted to flow-based estimates. Respondents using design or time-based estimating techniques were asked to recalculate their estimates using actual flow or provide the data needed to make those adjustments. Although some respondents provided the needed data, many did not. Representatives of 55 plants (23 percent of respondents) indicated that no flow data were available for their plants during the study period. In some cases, especially for older plants, accurate flow data were not available. This likely contributed to the rather poor response to the request for follow-up data. Ultimately, flow-based estimates were provided or derived for 183 plants; whereas, 33 plants had design flow estimates and 22 plants used time extrapolation. Because annual estimates based on actual flow are more representative, only estimates based on actual flow were used in the analysis of the relationship between plant pumping capacity and I&E losses as subsequently described. Although only flow-based annual estimates were used to determine correlations with pumping capacity, data from all respondents were used to determine operational characteristics and relative abundance.

2.1.2 Shellfish Definition

The suspended 2004 Phase II Rule required data for fish and shellfish; however, it did not provide a definition of shellfish. As a result, a wide variety of organisms were reported as "shellfish". Besides taxa traditionally considered shellfish (i.e., edible crustaceans like shrimp, crabs, and lobsters), many other organisms were reported as "shellfish". These included copepods, amphipods, *Mysis*, plus a number of nuisance species such as *Corbicula*, zebra mussels, and Chinese mystery snails. The decision to include or not include certain organisms appears to vary among regions and states and in some cases decisions appeared to be plant-specific. For example, utilities on the Great Lakes in Wisconsin were asked by the Wisconsin Department of Natural Resources to tally amphipods and *Mysis relicta.* To our knowledge, the inclusion of these taxa as shellfish was unique to Wisconsin. Similarly, a number of plants on the Gulf Coast tallied copepods that were not counted in the other regions. Because of these differences among states and regions, for the purpose of the questionnaire the term "shellfish" was defined to include edible (mostly marine) species (e.g., oysters, marine clams and mussels, lobsters, crayfish, shrimp, and crabs) and species having commercial value (e.g., unionid mussels). The database was queried and included all species as defined above and excluded all species not regularly used for human consumption (e.g., amphipods, *Mysis relicta*, snails, *Corbicula*, copepods, as well as zebra mussels, and other nuisance species).

2.1.3 Quality Control Checks

The size of the database did not allow each and every value to be checked. Nonetheless, it became apparent there were a few data entry errors. Some respondents entered the actual numbers of organisms impinged during the study rather than the annual estimate. A larger number of respondents did not include eggs as part of their annual entrainment totals or as part of their top 10 taxa list. In a few cases, actual totals were used to derive the annual total estimate but extrapolated values were used to derive the annual estimates for the top 10 species or taxa, or vice versa. The last set of data entry errors were easy to spot because in these cases the total annual estimate and the estimate based on the sum of the top 10 species or taxa differed by an order or two in magnitude.

Based on a review of studies conducted at multiple sites, it is generally the case that a few species/taxa usually dominate I&E and, therefore, the sum of the top 10 species/taxa typically accounts for 90 percent or more of the annual impingement estimate and 90% of the annual entrainment estimate. Thus, all situations where the total for the top ten for either impingement or entrainment was not within 10 percent of the corresponding annual total were flagged (a protocol hereafter referred to as the "10 percent rule"). In these cases, a representative of the plant in question was contacted. In a few cases, the lack of agreement within 10 percent of the two totals (i.e., the total for the top 10 and the total for all species/taxa) was real but in most cases there had been some problem with the data entered. With the help of plant representatives, these errors were corrected. In four cases, the discrepancies could not be resolved due to lack of response by the plant in question. In these cases, the biological data for that plant were removed from the database.

2.1.4 Relationships between Flow and I&E

One of the main tenets of the now-suspended Phase II Rule is that I&E increase as flow increases. To determine the reasonableness of this assumption, I&E were independently compared to plant pumping capacity. Ideally a more robust comparison between I&E and flow would be based on date-specific results; however, those data were not requested. Thus, comparisons between I&E rates and plant pumping capacity were made using simple linear regression techniques where log-transformed I&E annual estimates were regressed against log-transformed design pumping capacity. As indicated above, these regressions only used annual estimates based on actual flows. A few plants submitted I&E results from more than one year. In those cases, the mean of the annual estimates was used in the regressions.

2.1.5 Dominance by a Few Species

One of the questions addressed in this study was which species were most commonly entrained or impinged. A few species tended to overwhelmingly dominate I&E losses and sometimes those species would be incredibly abundant at a few plants, especially in freshwater. For example, threadfin shad (*Dorosoma petenense)* ranked in the top 10 at 24 plants on large rivers. However, one plant accounted for 75 percent of the threadfin shad impinged at all 79 plants in the Large River dataset and 34 percent of all fish collected at those plants. Similarly, gizzard shad (*D. cepedianum)* at two plants accounted for 46 percent of all the fish impinged at the 25 Great Lakes plants. Other species occasionally showing extreme dominance included white perch (*Morone americana*) and bay anchovy (*Anchoa mitchilli*). Using the raw data would skew the results in favor of these few species. Therefore, ranks were used to determine which species were most commonly impinged or entrained. For a given plant, the species and taxa were ranked in order of their numerical abundance. Then those ranks were averaged for the plants in each of the 12 geographic regions. The species or taxon that had the highest average rank was considered to be the species or taxon that was most frequently impinged or entrained.

2.1.6 Relative Abundance

Respondents provided estimates of total I&E (i.e., I&E of all species/taxa) and I&E estimates for the top 10 taxa or species at each plant. A precise estimate of relative abundance by region or waterbody type could not be derived because estimates for all species or taxa impinged or entrained were not requested. An approximation, however, could be derived by calculating the percentage the top 10 taxa or species comprised both overall (i.e., the average of all 12 regions) and in each region. On average, the top 10 comprised 96 percent of the total impingement. In fact, in five regions, the top 10 species and taxa comprised 100 percent of the totals for these regions and in three more regions, the top 10 comprised 96-99 percent of the regional total. Based on the fact that the top 10 taxa comprised such a high percentage of the total, the relative abundance of each top 10 species or taxa was calculated as its percentage relative to the total of all the top 10 species and taxa for that region. This approach is a slight overestimate compared to all the fish and shellfish taxa impinged or entrained in that region, but, as described above, it will be relatively small in all regions and negligible in most regions.

Section 3: Results

A total of 240 of the 428 facilities that use more than 50 MGD responded to the EPRI 316(b) questionnaire, which represents 56 percent of the nation's once-through cooling capacity. The distribution of the 240 facilities by geographic area and waterbody type is provided in Table 3-1. All but 3 of the 240 facilities conducted impingement studies. However, because the Phase II Rule did not require entrainment to be monitored by facilities on reservoirs, cooling lakes, and rivers, so long as the facility did not use more than 5% of the mean annual flow (i.e., Large Rivers), no entrainment data are available for plants located on these waterbody types (Table 3-1). Almost half the studies were conducted on rivers with Large Rivers being the single largest category. Lakes and Reservoirs accounted for 28% of the studies and coastal facilities accounted for 22% of the studies.

Table 3-1
Categories and Distribution of Impingement and Entrainment Results from Facilities in the EPRI 316(b) Database

Region	Number of Respondents (Facilities)	
	Impingement	Entrainment
West Coast	7	6
Northeastern Coastal	20	20
Mid-Atlantic Coastal	11	12
Southern Coastal and Gulf	13	9
Great Lakes	24	24
Southeastern Reservoirs	14	0
Midwestern Reservoirs	13	1
Southwestern Cooling Lakes	16	0
Large Rivers	79	0
Small Rivers	36	36
Hawaii	3	3
Puerto Rico	1	1
Total	237	112

3.1 Intake Characteristics

Facilities using once-through cooling water vary in terms of the cooling water intake structure proximity to the shoreline and depth from which the water is withdrawn. Since these variations have the potential to influence the nature and relative numbers of species impinged and/or entrained and the potential fish protection options, EPRI sought information to characterize the differences. The EPA 2004 Phase II 316(b) Rule made certain assumptions regarding the intake configuration of a "typical" once-through power plant, namely that the intake was located along the shoreline and at the surface of the water column. The survey results suggest that EPA's assumptions are not unreasonable, however, exceptions are common. According to the survey, slightly more than half (54 percent) of the respondents had surface intakes, 30 percent had submerged intakes, and 17 percent had intakes that withdrew from more than one depth in the water column. Also slightly more than half (52 percent) of the respondents have intakes located along the shoreline, with about one third (36 percent) having a canal or forebay, 9 percent having an offshore intake, and a few (3 percent) with intake ports in multiple locations.

3.2 Study Design

EPA did not provide guidance on study methodology so each company proposed a design to its permit authority for approval as part of its Proposal for Information Collection (PIC). Companies were allowed to use historical data, if the company could demonstrate that data remain representative of current conditions. As a result of the time that had elapsed since most historical studies were conducted in the 1970s and 1980s, most companies elected to collect new data. In terms of study duration, almost all (97 percent) were conducted over six to 24 months, with one year (80 percent) being the most frequently selected study duration. Impingement samples were typically collected regularly over the entire duration of the study. Sampling was most frequently conducted every two weeks or twice a month (24 to 26 collections per year, 39 percent of the respondents) or weekly (52 samples per year, 28 percent of the respondents). Other sampling regimes were greater than once per week (11 percent), monthly (4 percent), or "other" (17 percent). The "other" category included studies whose sampling regime changed, often on a seasonal basis, to respond to site-specific changes in the abundance of fish susceptible to impingement. For example, 15 plants on the Ohio River monitored impingement every four weeks when impingement numbers were historically low and every two weeks when impingement was expected to be higher (King et al. 2010).

Even though the Phase II 316(b) Rule as originally proposed dealt with impingement mortality (i.e., IM), very few plants (18 percent) conducted studies to determine what percentage of fish impinged actually survived. Of the few survival studies conducted, at least some reported survival >90 percent using recently developed technologies. For example, Bigbee et al. (2010) reported that several species they tested had survival greater than 90 percent. Nonetheless, survival of certain species (e.g., most clupeids, bay anchovies) is generally considered to be low (< 40 percent) (Fletcher 1990). For purposes of this analysis, unless stated otherwise, the "IM" designation applies to the impingement of all organisms (even though some might survive) as the condition of the organisms is unknown for most facilities.

Most fish impinged end up being tallied during impingement monitoring; however, it is possible that some percentage of impinged fish may not make it to the collection basket for various reasons. Although not all sources of error are accounted for, this percentage can be estimated by determining collection efficiency. Fifteen percent of the plants conducted collection efficiency studies.

Entrainment samples were collected primarily with pumps, plankton nets, or a combination of these two gears. Gears of choice showed some regional differences. Plankton nets were the only gear used in Hawaii, Puerto Rico, and on the West Coast. Overall, plankton nets were used at 38 percent of the responding plants, at 23 percent of the Northeastern Coastal plants, 50 percent of the Mid-Atlantic Coastal plants, 18 percent of the Great Lakes plants, and 41 percent of the Small Rivers plants. Overall, 13 percent of the plants only used pumps. Pumps and nets combined were used at 38 percent of the plants, including 17 percent of the Small Rivers plants, at 41 percent of the Northeastern Coastal plants, at 56 percent at the Southern Coastal and Gulf plants, at 50 percent of the Mid-Atlantic Coastal plants, and at 71 percent of the Great Lakes plants.

Each entrainment sampling period varied from six to 24 hours, with 24 hours being the most common (63 percent) sampling duration. Twenty four hours is a common sampling period because it allows assessment of diel variation in entrainment rates. When sampling is done for 24 hours, a series of subsamples is typically taken so that changes in entrainment rates during each 24-hr period can be assessed. On a regional basis, the percentage of plants using 24-hour sampling periods ranged from 50 to 70 percent in most areas, but was 100 percent at the West Coast plants and the single Puerto Rico plant.

The frequency of entrainment sampling varied considerably. Weekly or every other week sampling was both fairly common (20 and 17 percent, respectively); however, 46 percent of the plants had variable sampling frequencies in response to seasonal changes in larval abundance. Twenty-five percent of the Great Lakes plants sampled twice a week, but this was the only region where this more intense regime was followed.

Ninety-five percent of the plants conducted entrainment studies during the entire fish spawning period. All plants in the West Coast, Mid-Atlantic Coastal, Southern Coastal and Gulf, Hawaii, and Puerto Rico regions sampled throughout the entire spawning period. In the Northeastern Coastal, Great Lakes, and Small Rivers categories, 95, 86, and 98 percent, respectively of the plants sampled during the entire spawning period.

Because natural mortality of eggs and early life stage larvae is greater than 99 percent, some biologists prefer to convert the numbers of these early life history stage individuals into the appropriate number of equivalent Age I individuals. This is typically done using an equivalent adult model (EPRI 2004b). This kind of analysis is more commonly used in estuarine or marine habitats perhaps because there is usually a higher percentage of commercially harvestable fish in these areas than in freshwater systems and, therefore, age-specific mortality estimates needed for equivalent adult models are more available for estuarine and marine species (EPRI 2005b). Equivalent adult models are also available for a number of recreationally important freshwater fishes. Because equivalent adult analysis would be necessary for various follow-up analyses being considered by EPRI, it was useful to determine how many facilities had already completed such studies on their own. It was found that most plants (64 percent) did not convert their entrainment estimates into equivalent adult estimates (Table 3-2). The geographical difference in the use of this methodology was evident in the data. In two freshwater areas, adult equivalent analysis was conducted at 21 percent of the Great Lakes plants and 19 percent of the Small Rivers plants, whereas it was used at up to 90 percent at the coastal facilities (Table 3-2).

Table 3-2
Percentage of Facilities that Applied Equivalent Adult Analysis to Entrainment Results by Region

Region	Applied Equivalent Adult Analysis
West Coast	67%
Northeastern Coastal	90%
Mid-Atlantic Coastal	8%
Southern Coastal and Gulf	56%
Great Lakes	21%
Small Rivers	19%
Hawaii	0%
Puerto Rico	0%
Overall	36%

3.3 Biological Results

3.3.1 Impingement

Table 3-3 lists the most commonly impinged species for each region. Based on ranks, clupeids were the most commonly impinged group at all freshwater facilities with gizzard shad being the most common species impinged at the Great Lakes plants, those on Midwestern Reservoirs, as well as plants on both large and small rivers. Threadfin shad was the most common species impinged at plants in both the Southeastern Reservoirs and Southwestern Cooling Lakes regions. A greater variety of species dominated IM at the estuarine and marine plants. Atlantic menhaden (*Brevoortia tyrannus*), another clupeid, was the most commonly impinged species in the Northeastern Coastal region, white perch was the most commonly impinged species in the Mid-Atlantic Coastal region, and white shrimp (*Litopenaeus setiferus*) ranked first in the Southern Coastal and Gulf region. Along the West Coast, queenfish (*Seriphus politus*) was the most frequently impinged fish. Hawaiian anchovy (*Stolephorus purpureus*) and pink shrimp (*Penaeus duorarum*) were the most frequently impinged organisms in Hawaii and Puerto Rico, respectively.

Table 3-3
Most Commonly Impinged Species by Region Based on Ranks in the EPRI 316(b) Database

Region	Species
West Coast	Queenfish
Northeastern Coastal	Atlantic menhaden
Mid-Atlantic Coastal	White perch
Southern Coastal and Gulf	White shrimp
Great Lakes	Gizzard shad
Southeastern Reservoirs	Threadfin shad
Midwestern Reservoirs	Gizzard shad
Southwestern Cooling Lakes	Threadfin shad
Large Rivers	Gizzard shad
Small Rivers	Gizzard shad
Hawaii	Hawaiian anchovy
Puerto Rico	Pink shrimp

A list of the top five ranked species was prepared for each region for a broader view of the species most frequently impinged (Table 3-4). Examination of this list shows that there was little overlap among the four "coastal" areas. As expected, the top five species along the West Coast did not overlap at all with the other three coastal areas. Blue crab (*Callinectes sapidus*) was a frequently impinged species in all three of the non-western coastal areas, but otherwise there was no overlap among top five species in these areas (Table 3-4).

It was previously mentioned that gizzard shad, threadfin shad, or both species were common in all six freshwater regions. Bluegill (*Lepomis macrochirus*) ranked in the top five in five of the six freshwater regions and channel catfish (*Ictalurus punctatus*) ranked in the top five in four of these regions (Table 3-4). Emerald shiner *(Notropis atherinoides)* ranked in the top five in both Small Rivers and the Great Lakes. Thus, there was considerably more overlap among species impinged at plants in the freshwater areas than in the coastal areas.

Table 3-4
Top 5 Ranked Species by Region in the EPRI 316(b) Database

	Five Most Commonly Collected Taxa	
Region	**Impingement**	**Entrainment**
West Coast	Queenfish	Unidentified fish eggs
	Northern anchovy	unid GOBIIDAE
	Red rock shrimp	Goby complex
	Round stingray	*Hypsoblennius spp.*
	Topsmelt	Anchoa spp.
Northeastern Coastal	Atlantic menhaden	Cunner eggs
	Atlantic silverside	Bay anchovy
	Winter flounder	Bay anchovy eggs
	Blue crab	Atlantic menhaden
	Weakfish	Tautog eggs
Mid-Atlantic Coastal	White perch	White perch
	Blue crab	Bay anchovy eggs
	Bluegill	Naked Goby larvae
	Gizzard shad	Unidentified fish eggs
	Atlantic croaker	unid Shrimp
Southern Coastal and Gulf	White shrimp	Bay anchovy
	Blue crab	Caridean shrimp
	Pink shrimp	unid PENAEIDAE
	Bay anchovy	Cunner eggs
	Hogchoker	Short-tailed crab
Great Lakes	Gizzard shad	Alewife
	Alewife	Unidentified fish eggs
	Yellow perch	unid CYPRINIDAE
	Emerald shiner	Round goby
	Threespine stickleback	Gizzard shad
Southeastern Reservoirs	Threadfin shad	-
	Bluegill	-
	Gizzard shad	-
	Channel catfish	-
	Alewife	-

Table 3-4 (continued)
Top 5 Ranked Species by Region in the EPRI 316(b) Database

	Five Most Commonly Collected Taxa	
Region	**Impingement**	**Entrainment**
Midwestern Reservoirs	Gizzard shad	Unidentified fish eggs
	Bluegill	Yellow perch
	Threadfin shad	*Lepomis* spp.
	White crappie	Alewife
	Channel catfish	Brook silverside
Southwestern Cooling Lakes	Threadfin shad	-
	Bluegill	-
	Gizzard shad	-
	Largemouth bass	-
	Inland silverside	-
Large Rivers	Gizzard shad	-
	Freshwater drum	-
	Threadfin shad	-
	Bluegill	-
	Channel catfish	-
Small Rivers	Gizzard shad	unid CYPRINIDAE
	Bluegill	unid CLUPEIDAE
	Channel catfish	Unidentified fish eggs
	Threadfin shad	unid CATOSTOMIDAE
	Emerald shiner	Gizzard shad
Hawaii	Hawaiian anchovy	*Encrasicholina* spp.
	Iridescent cardinalfish	unid POMACENTRIDAE
	Whitespotted toby	unid PERCIFORMES
	Bay cardinalfish	Unidentified fish eggs
	Unidentified	unid CARANGIDAE
Puerto Rico	Pink shrimp	Caridean shrimp
	Blue crab	Unidentified fish eggs
	Silver jenny	unid SERGESTIDAE
	Blackpoint sculling crab	*Anomura* spp.
	unid Swimming crab	unid PENAEIDAE

3.3.1.1 Composition by Region

Along the West Coast, queenfish was not only the most frequently impinged fish based on rank, it also had the highest relative abundance, accounting for 48 percent of the fish impinged on the West Coast (Figure 3-1). Northern anchovy *(Engraulis mordax)* (28 percent) and Pacific sardine *(Sardinops sagax caerulea)* (8 percent) also had high relative abundance values at plants along the West Coast with all other species or taxa accounting for less than three percent (Figure 3-1).

Along the Mid-Atlantic Coast, white perch accounted for 40 percent of the fish and shellfish impinged (Figure 3-2). Blue crab accounted for 21 percent. All other species each accounted for less than 10 percent of the IM total (Figure 3-2).

Impingement at plants in the Southern Coastal and Gulf region was distributed over a wide diversity of species. The most abundant of these were false arrow crab *(Metoporhaphis calcarata)* (19 percent); pink shrimp (12 percent), bay anchovy (11 percent), Atlantic thread herring *(Opisthonema oglinum)* (11 percent), and hogchocker *(Trinectes maculates)* (8 percent) (Figure 3-3). Collectively, these five species accounted for 61 percent of the fish and shellfish impinged at plants in the Southern Coastal and Gulf region. Eleven other species accounted for one to six percent of the fish and shellfish impinged (Figure 3-3).

In the Northeastern Coastal region, white perch accounted for 40 percent of the organisms impinged (Figure 3-4). Atlantic croaker *(Micropogonias undulates)* (24 percent), weakfish *(Cynoscion regalis)* (11 percent), and blue crab (11 percent) were also commonly impinged in this region.

In Hawaii, Hawaiian anchovy accounted for nearly two-thirds of the fish and shellfish impinged (Figure 3-5). Bay cardinalfish *(Foa brachygramma)* accounted for 11 percent of the organisms impinged, 10 taxa each accounted for one to three percent, and all other taxa combined accounted for about five percent (Figure 3-5).

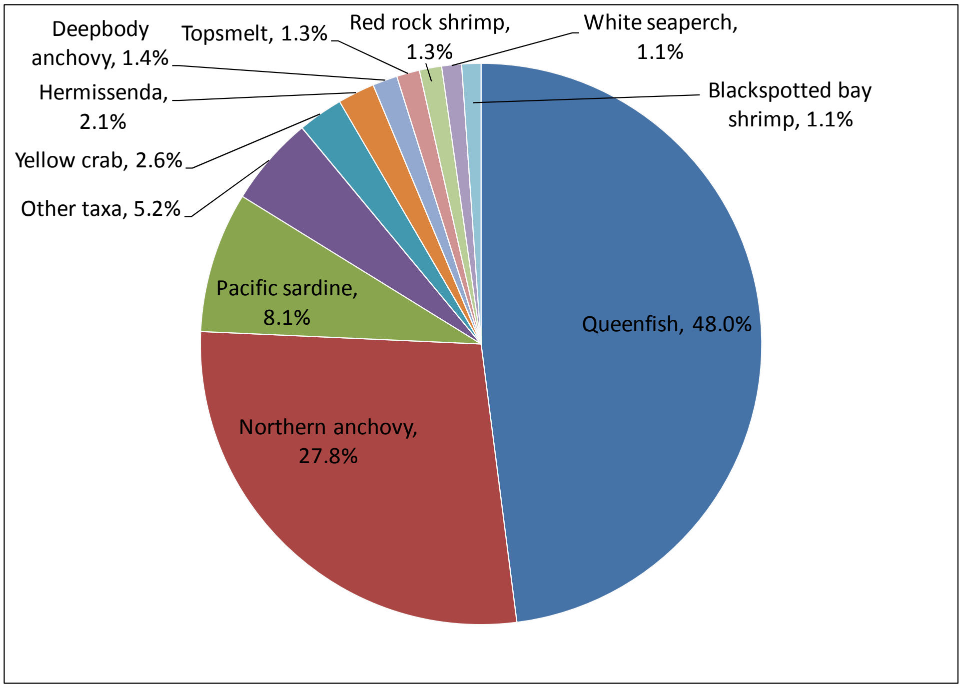

Figure 3-1
Distribution of Common Species Impinged at the West Coast Facilities in the EPRI 316(b) Database

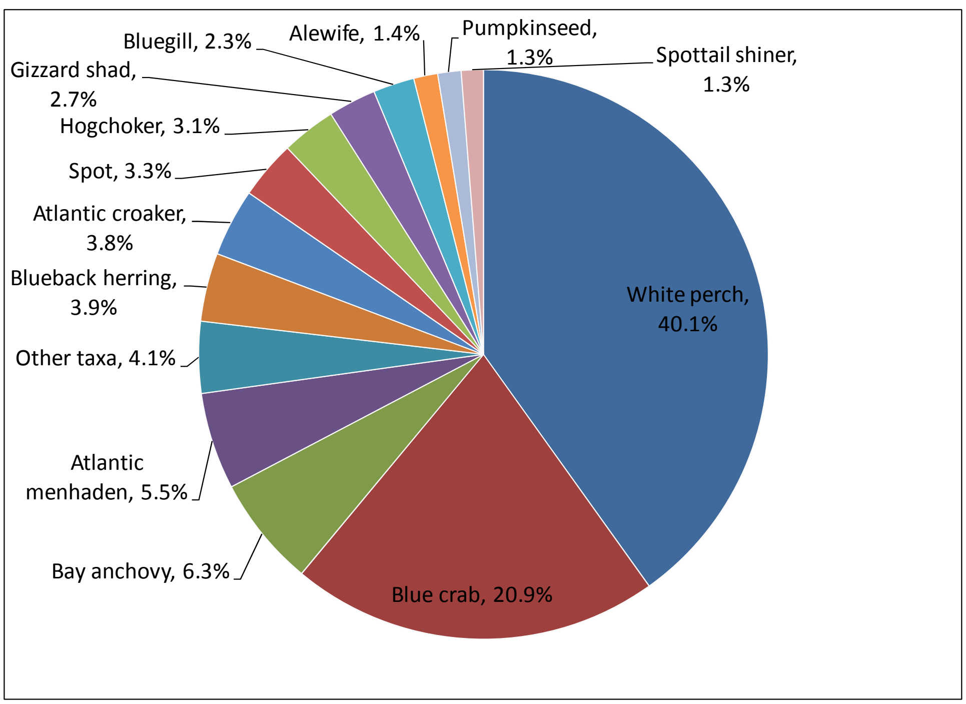

Figure 3-2
Distribution of Common Species Impinged at the Mid-Atlantic Coastal Facilities in the EPRI 316(b) Database

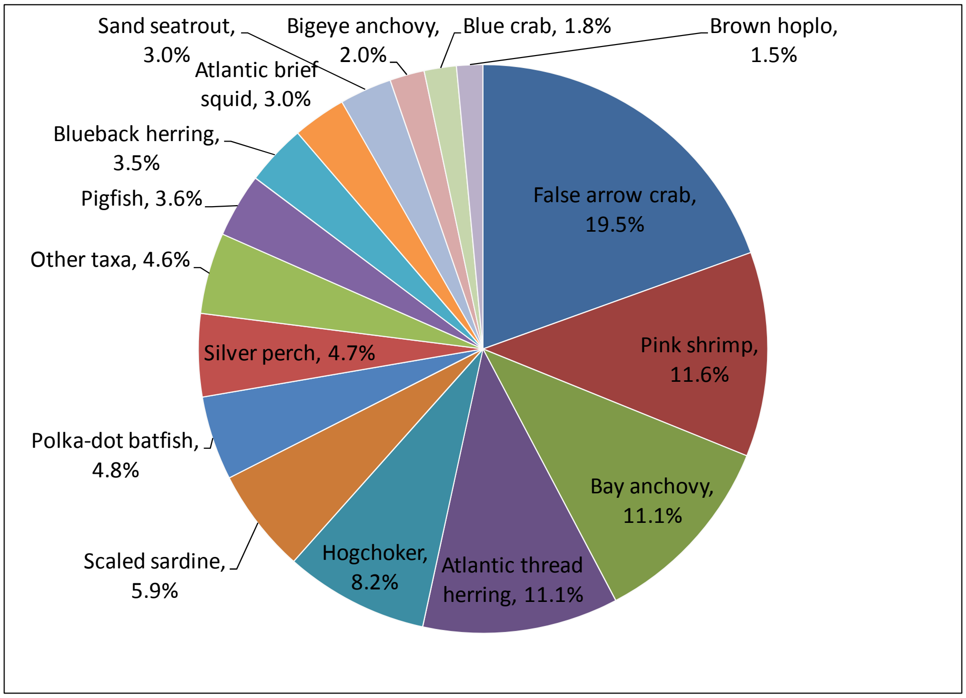

Figure 3-3
Distribution of Common Species Impinged at the Southern Coastal and Gulf Facilities in the EPRI 316(b) Database

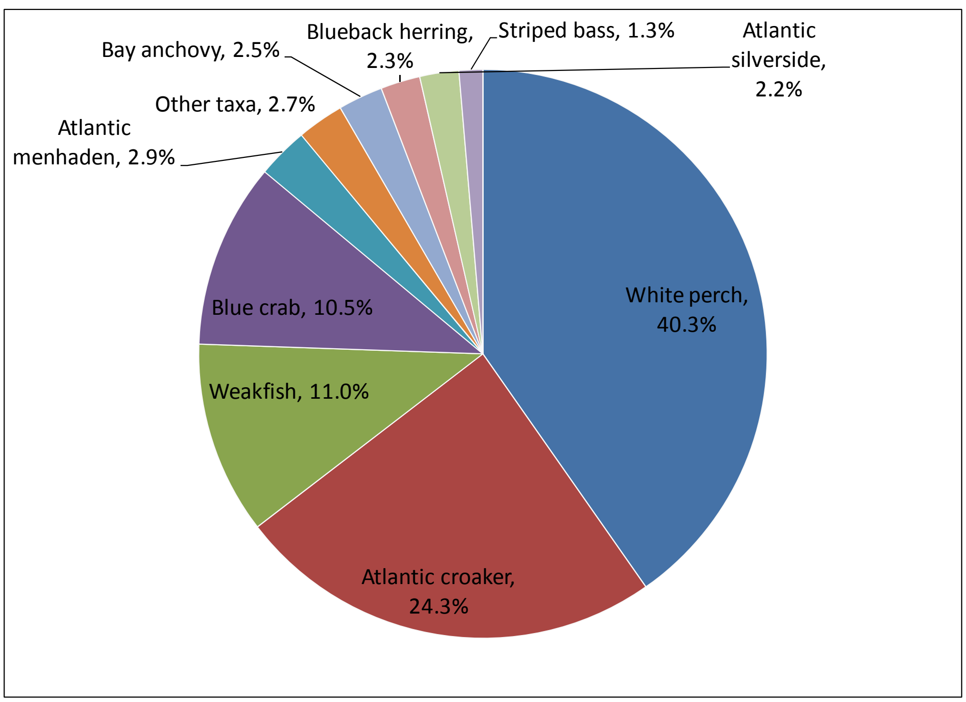

Figure 3-4
Distribution of Common Species Impinged at the Northeast Coastal Facilities in the EPRI 316(b) Database

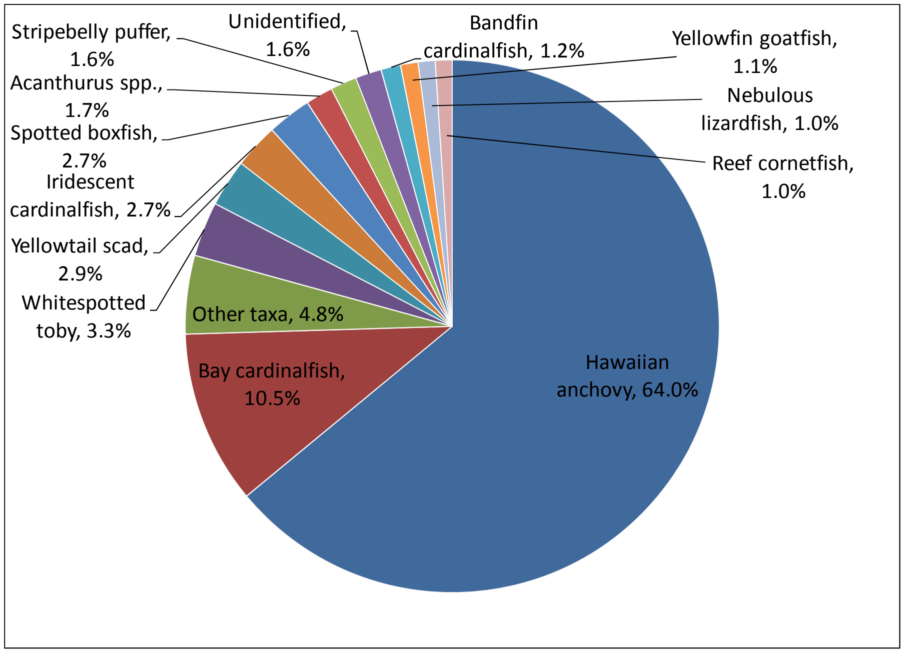

Figure 3-5
Distribution of Common Species Impinged at the Hawaiian Facilities in the EPRI 316(b) Database

Impingement in Puerto Rico was overwhelmingly (83 percent) dominated by pink shrimp. Blue crab (7 percent) and silver jenny *(Eucinostomus gula)* (5 percent) were fairly common but all other species or taxa individually accounted for less than three percent of the impingement (Figure 3-6).

In all freshwater areas, clupeids dominated impingement. In the Great Lakes, gizzard shad accounted for two-thirds of the fish impinged (Figure 3-7). Emerald shiner (18 percent) was common, with white perch, alewife *(Alosa pseudoharengus)*, and white bass *(Morone chrysops)* accounting for seven, four, and one percent of the impingement, respectively (Figure 3-7).

Clupeids strongly dominated impingement at plants in the Southeastern Reservoirs region with threadfin shad, blueback herring *(Alosa aestivalis)*, alewife, and gizzard shad accounting for 52, 6, 4, and 4 percent of impingement, respectively (Figure 3-8). Collectively, these four clupeids accounted for 66 percent of the fish impinged at the Southeastern Reservoirs plants. Bluegill accounted for 25 percent of impingement in Southeastern Reservoirs region (Figure 3-8).

Gizzard shad overwhelmingly dominated (95 percent) impingement at Midwestern Reservoirs (Figure 3-9).

Threadfin shad accounted for 73 percent of the fish impinged at plants in Southwestern Cooling Lakes region (Figure 3-10). Bluegill was next in abundance (18 percent), followed by redear sunfish *(Lepomis microlophus)* and white crappie *(Pomoxis annularis)* (each 2 percent), and yellow bass *(Morone mississippiensis)* (1 percent) (Figure 3-10).

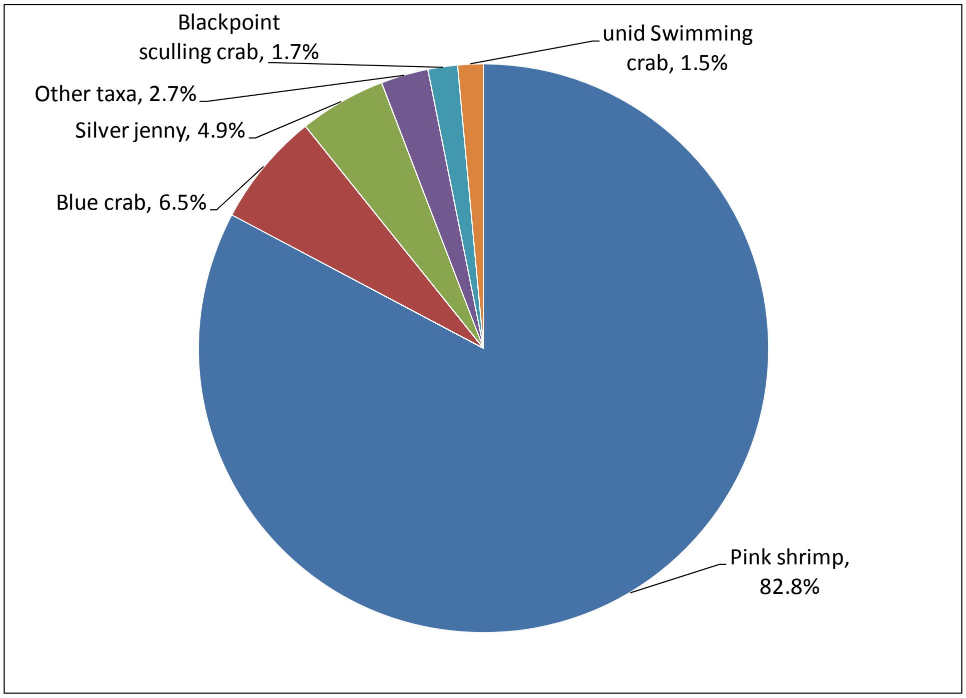

Figure 3-6
Distribution of Common Species Impinged at the Puerto Rican Facility in the EPRI 316(b) Database

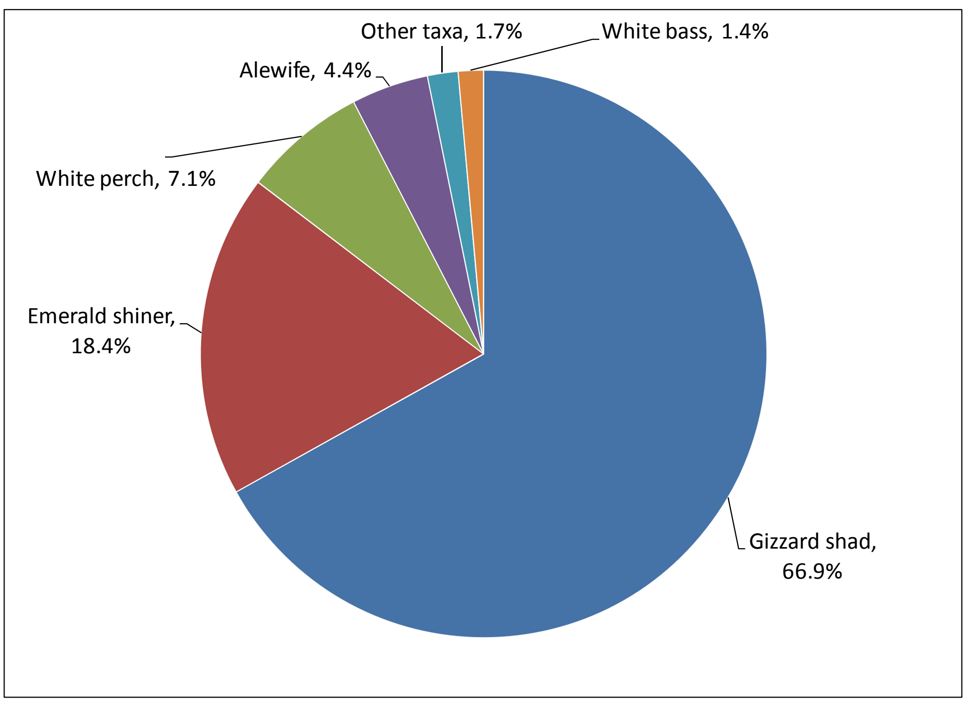

Figure 3-7
Distribution of Common Species Impinged at the Great Lake Facilities in the EPRI 316(b) Database

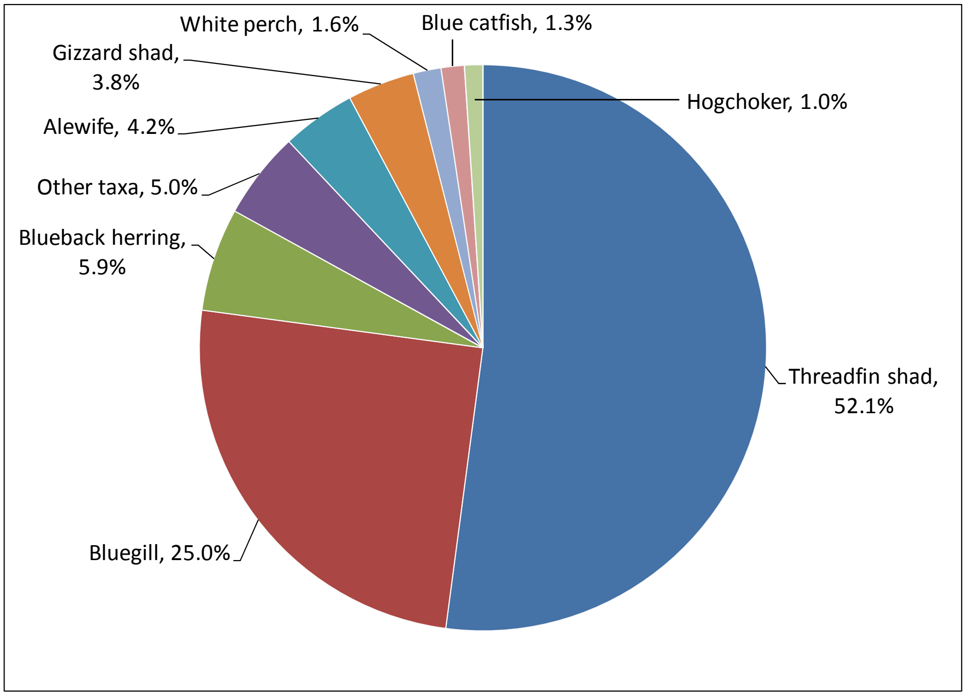

Figure 3-8
Distribution of Common Species Impinged at the Southeastern Reservoir Facilities in the EPRI 316(b) Database

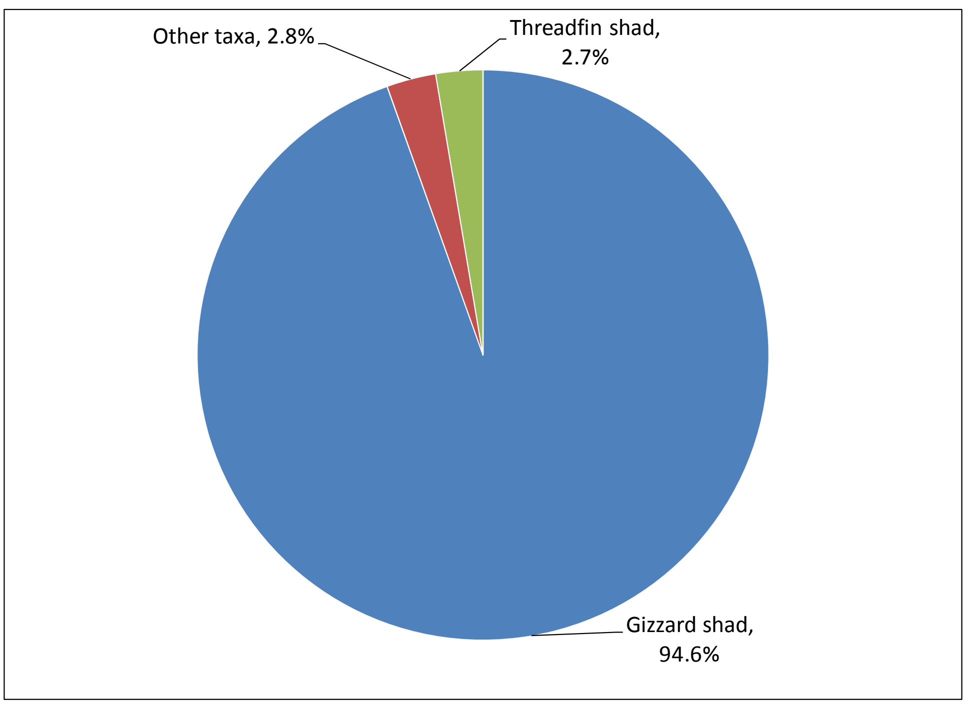

Figure 3-9
Distribution of Common Species Impinged at the Midwestern Reservoir Facilities in the EPRI 316(b) Database

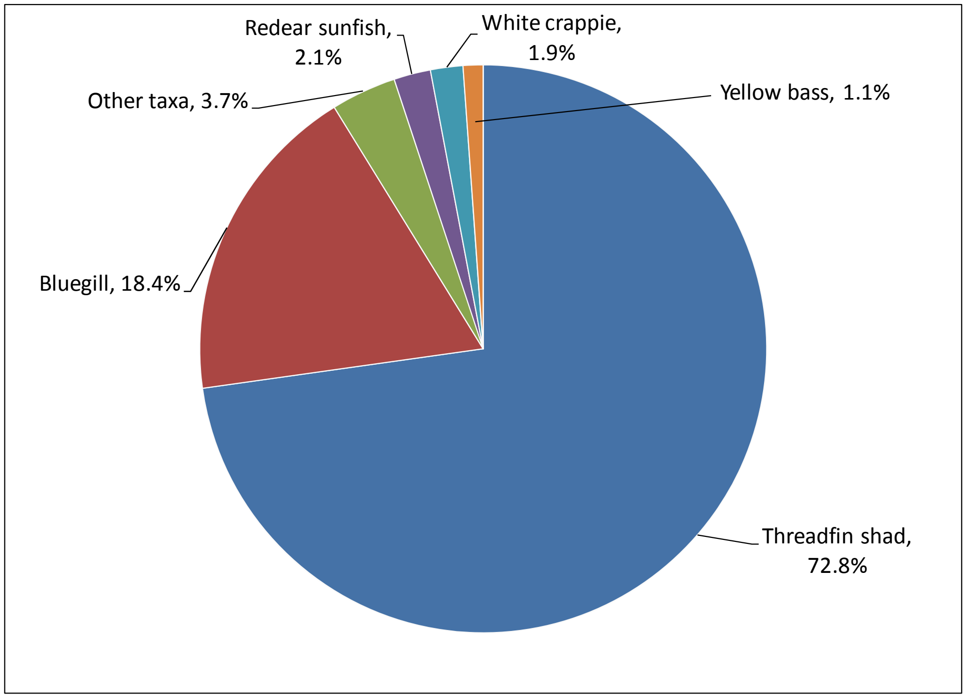

Figure 3-10
Distribution of Common Species Impinged at the Southwestern Cooling Lake Facilities in the EPRI 316(b) Database

Gizzard shad strongly dominated (88 percent) impingement at plants in the Small Rivers region, followed by freshwater drum (*Aplodinotus grunniens*) (3 percent), threadfin shad (2 percent), and channel catfish and emerald shiner (each 1 percent) (Figure 3-11).

Shad also dominated impingement at plants on Large Rivers (Figure 3-12): gizzard shad accounted for 54 percent and threadfin shad accounted for 35 percent. Freshwater drum (7 percent) was the only non-clupeid that accounted for more than one percent of impingement at the Large River plants (Figure 3-12).

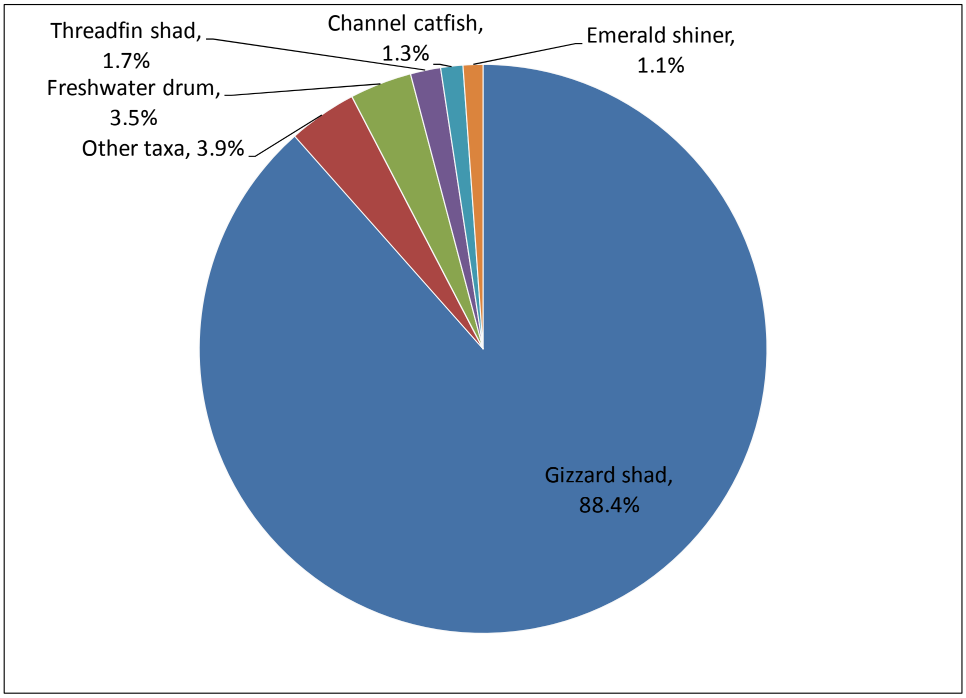

Figure 3-11
Distribution of Common Species Impinged at the Small River Facilities in the EPRI 316(b) Database

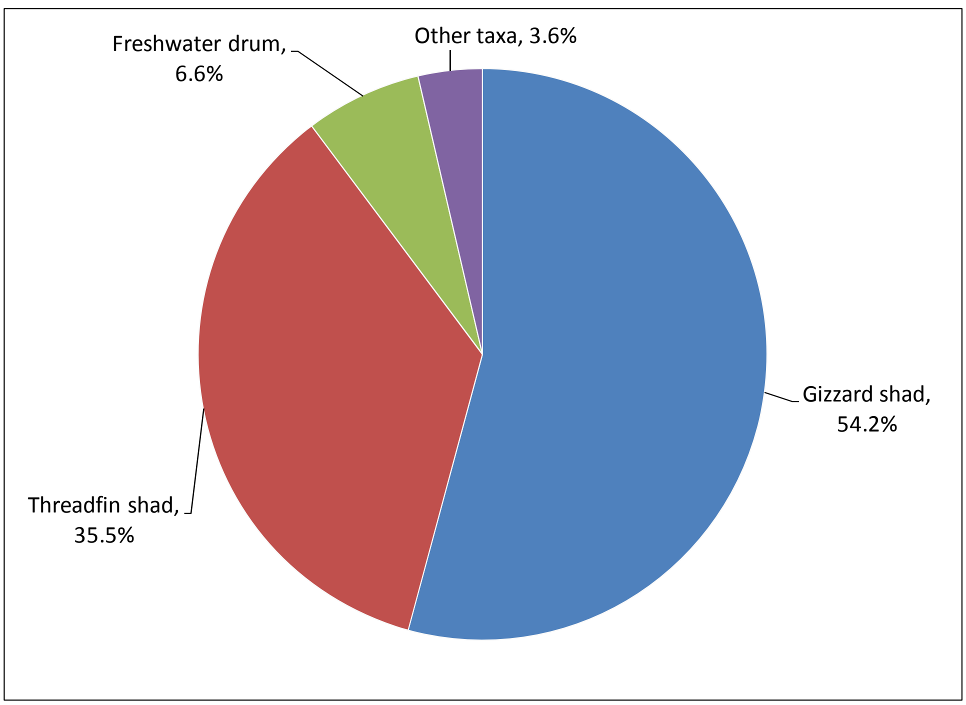

Figure 3-12
Distribution of Common Species Impinged at the Large River Facilities in the EPRI 316(b) Database

3.3.1.2 Abundance by Region

Because they were more representative of actual operating characteristics, only annual estimates based on actual flow are included in the subsequent figures. Thus, it is possible that the number of facilities in a region used in the figures is less than the total number of facilities in that region. Based on extrapolations using only actual intake flows provided by the facilities that participated in the survey, annual impingement estimates were derived for each geographic region (Table 3-5). Except in the Mid-Atlantic Coastal region, median values were lower, often considerably so, than mean values indicating that the means were inflated because of a few very high impingement values. For example, in the Northeastern Coastal region, the mean was 87 times higher than the median, which was due to one plant having an estimated annual impingement total of about 18 million fish and another having a total of about 12 million while all the other plants in this region had totals less than 0.5 million. There was a 23-fold difference between the mean and median at the Great Lakes plants. These plants showed the greatest variation of any region or waterbody type. For example, annual impingement was <5,000 at four plants, while four other plants had totals from 15.3 to 73.7 million. Besides these examples, other regions or waterbody types where the mean estimate was 5 to 10 times higher than the median were Midwestern Reservoirs, Southern Coastal and Gulf, Small Rivers, and Large Rivers (Table 3-5).

The frequency distribution of the annual estimates shows that impingement was relatively low at many plants (Figure 3-13). For example, nearly half (48 percent) of the plants in the database had estimated annual impingement totals of 50,000 or less and 83 percent had impingement totals of 500,000 or less (Figure 3-13). Conversely, only five percent of the plants had totals of five million or greater. On a regional basis, impingement estimates were less than 50,000 at all three Hawaiian plants (Figure 3-14) and less than or equal to 500,000 in the Mid-Atlantic Coastal region and on Southeastern Reservoirs (Figures 3-15 and 3-16). On the West Coast, in Midwestern Reservoirs, at Southwestern Cooling Lakes, and in the Northeast Coastal and Southern Coastal and Gulf regions, impingement was ≤ 500,000 at all but one plant (Figures 3-17 through 3-21). In both river categories, impingement was typically one million or less but in both categories four to five plants had estimated impingement totals of one to five million fish (Figures 3-22 and 3-23). The Great Lakes region showed the widest range of annual estimates as four plants had estimates less than 5,000 fish and five plants had impingement totals of one to five million, with one or two plants in each of the succeeding higher categories (Figure 3-24).

Table 3-5
Impingement Estimates by Region based on Actual Intake Flows for Facilities in the EPRI 316(b) Database

Region	Mean	Median
West Coast	328,311	102,501
Northeastern Coastal	1,823,945	20,796
Mid-Atlantic Coastal	133,225	149,992
Southern Coastal and Gulf	243,727	51,946
Great Lakes	8,095,148	356,051
Southeastern Reservoirs	96,432	53,425
Midwestern Reservoirs	1,000,635	109,479
Southwestern Cooling Lakes	137,168	42,456
Large Rivers	321,052	32,343
Small Rivers	265,540	35,295
Hawaii	9,249	6,077
Puerto Rico	40,983	40,983

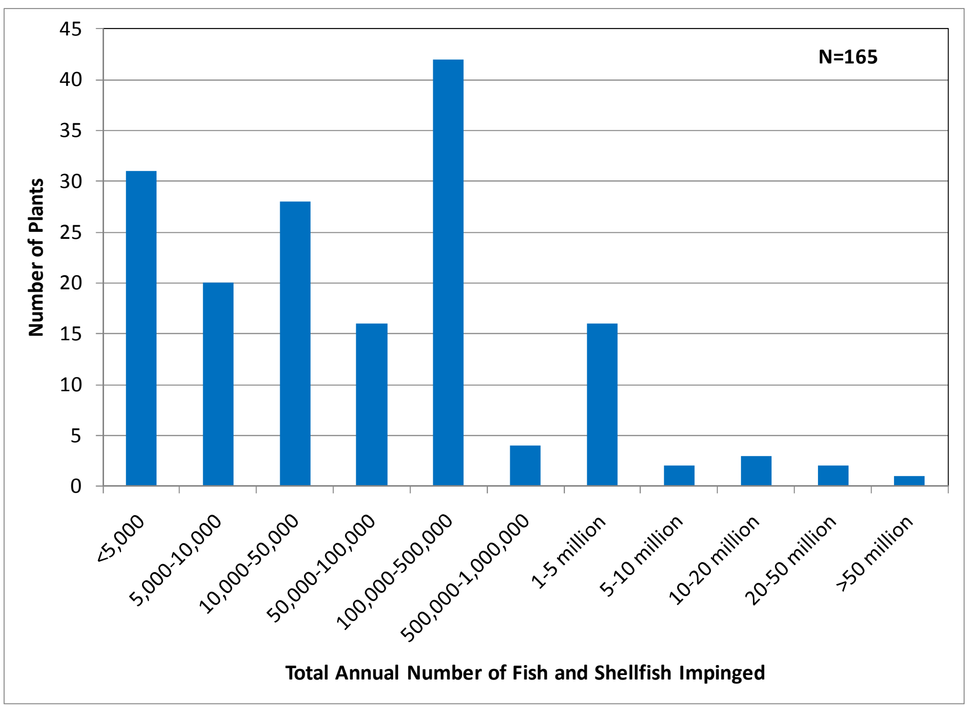

Figure 3-13
Frequency Distribution of the Estimated Number of Fish and Shellfish Impinged at All Power Facilities in the EPRI 316(b) Database that provided Estimates based on Actual Flow

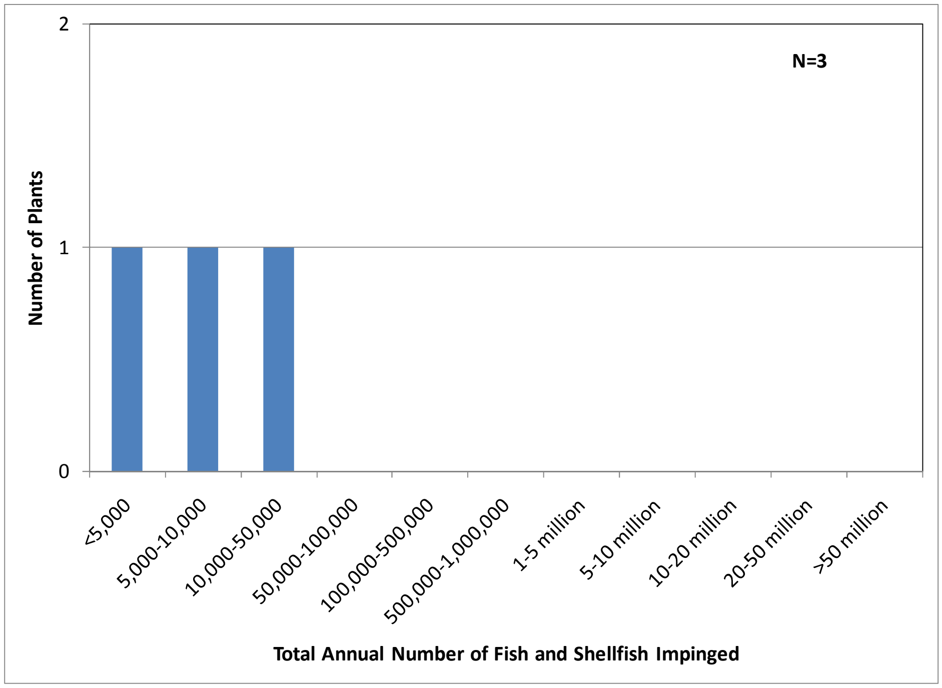

Figure 3-14
Distribution of Annual Impingement Estimates at the Hawaiian Facilities in the EPRI 316(b) Database

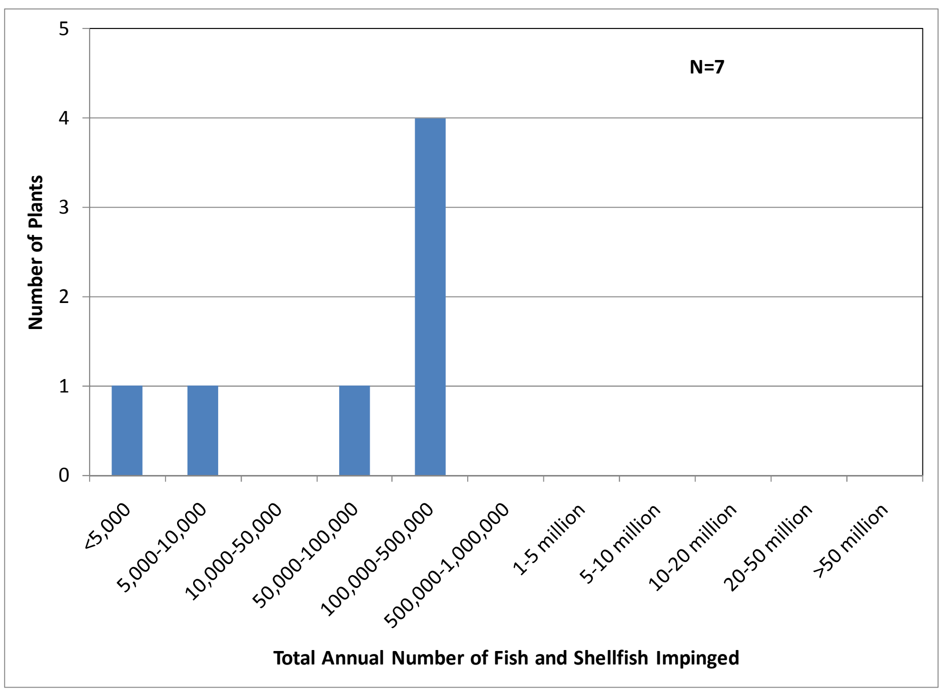

Figure 3-15
Distribution of Annual Impingement Estimates at the Mid-Atlantic Coastal Facilities in the EPRI 316(b) Database

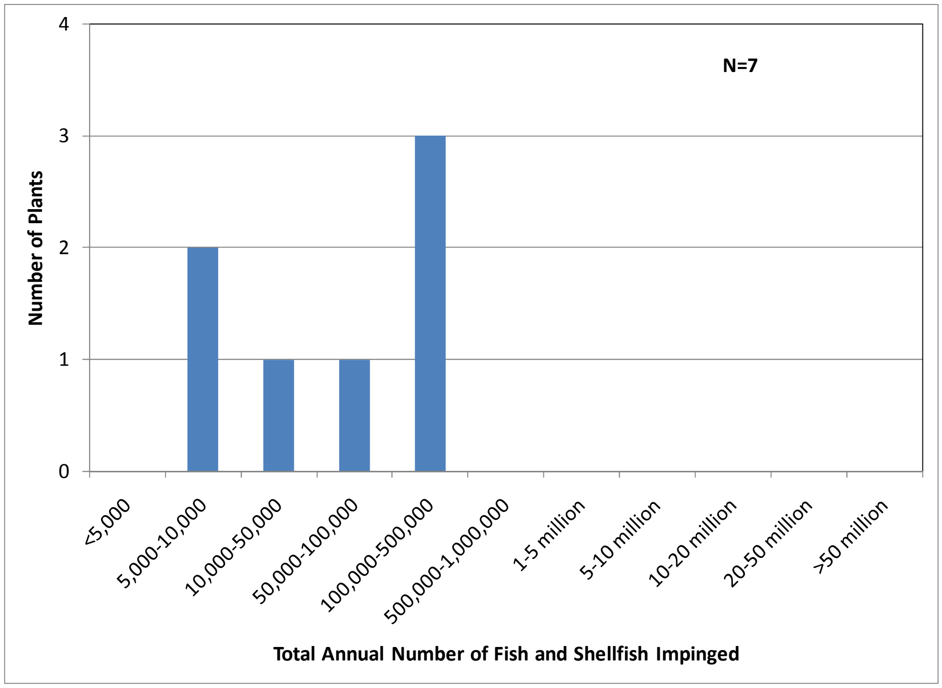

Figure 3-16
Distribution of Annual Impingement Estimates at the Southeastern Reservoir Facilities in the EPRI 316(b) Database

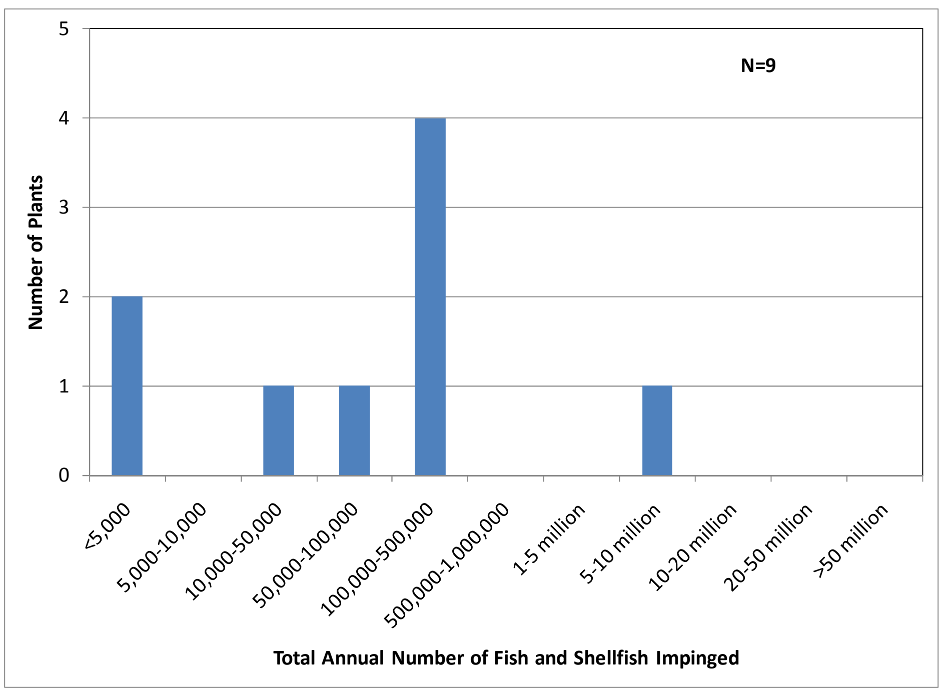

Figure 3-17
Distribution of Annual Impingement Estimates at the Midwestern Reservoir Facilities in the EPRI 316(b) Database

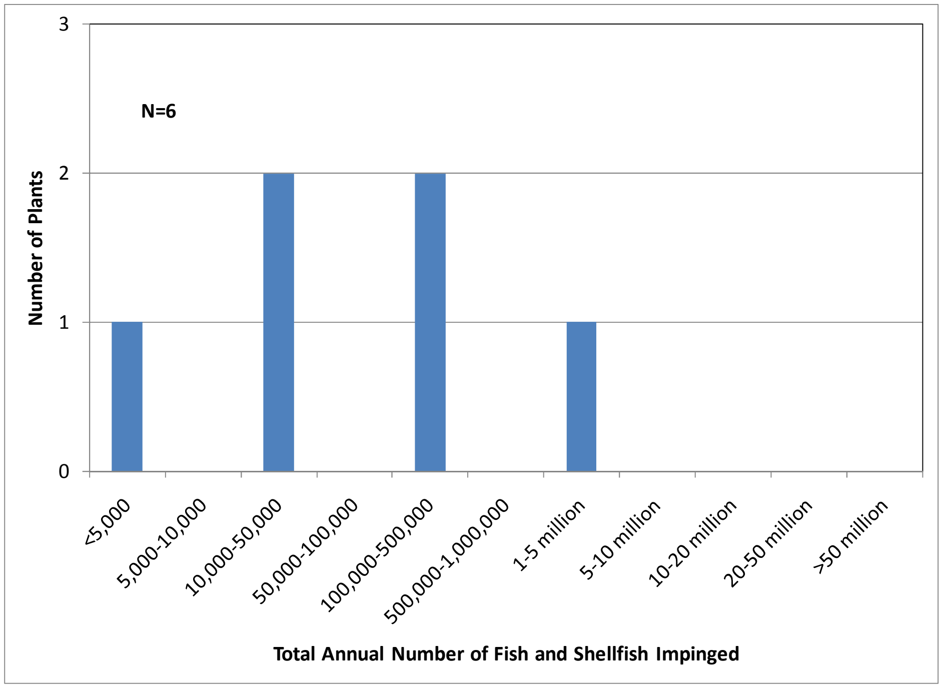

Figure 3-18
Distribution of Annual Impingement Estimates at the West Coast Facilities in the EPRI 316(b) Database

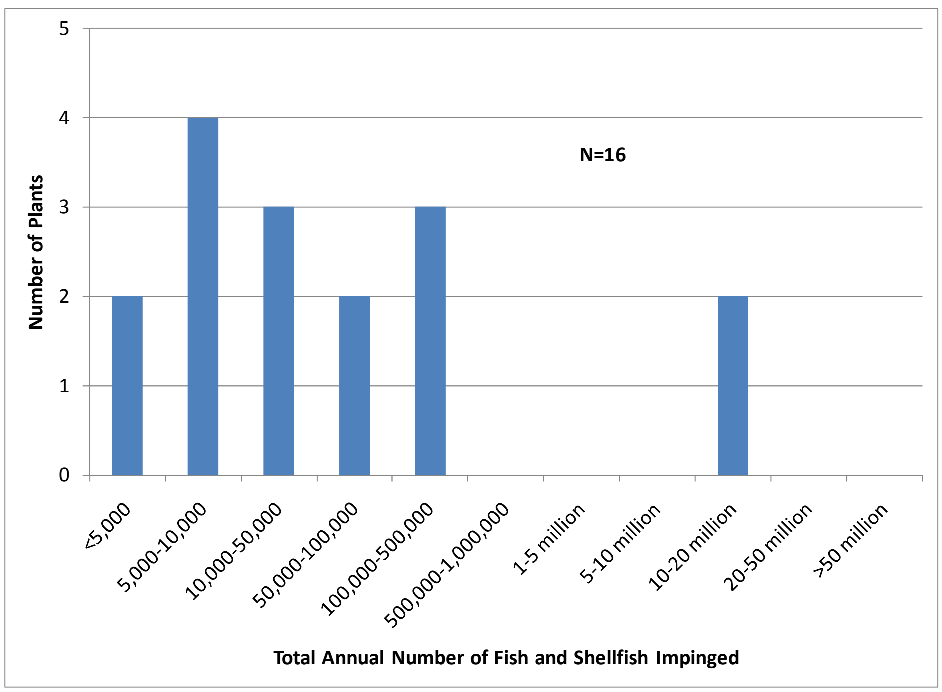

Figure 3-19
Distribution of Annual Impingement Estimates at the Northeastern Coastal Facilities in the EPRI 316(b) Database

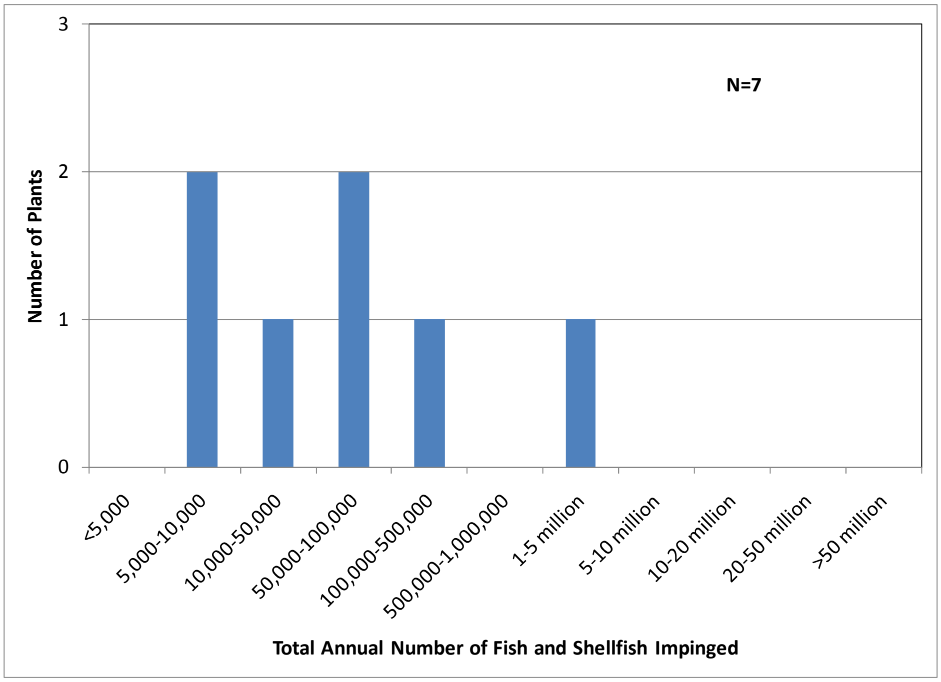

Figure 3-20
Distribution of Annual Impingement Estimates at the Southern Coastal and Gulf Facilities in the EPRI 316(b) Database

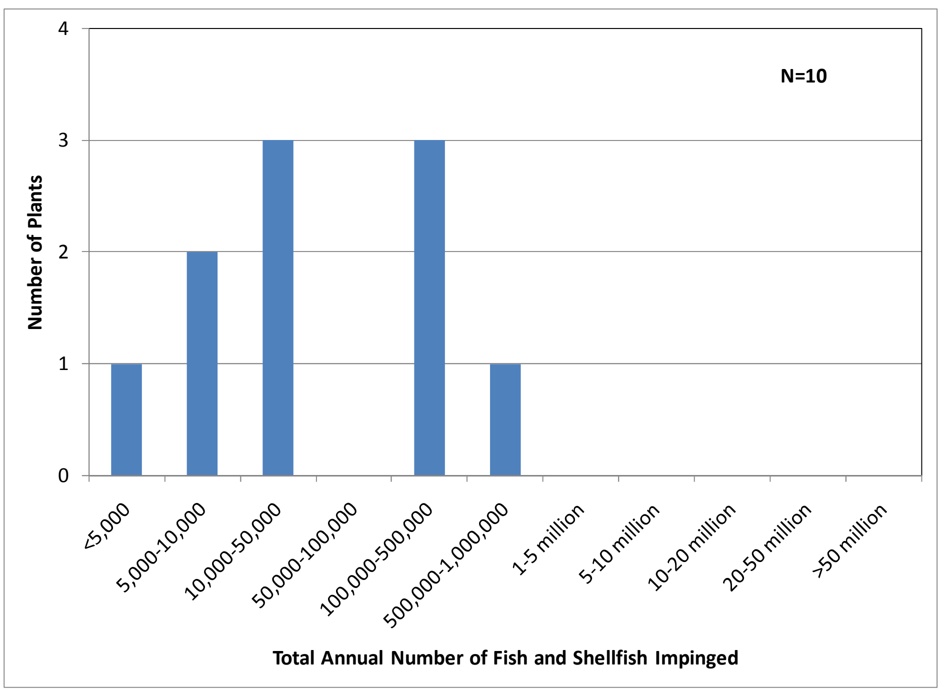

Figure 3-21
Distribution of Annual Impingement Estimates at the Southwestern Cooling Lake Facilities in the EPRI 316(b) Database

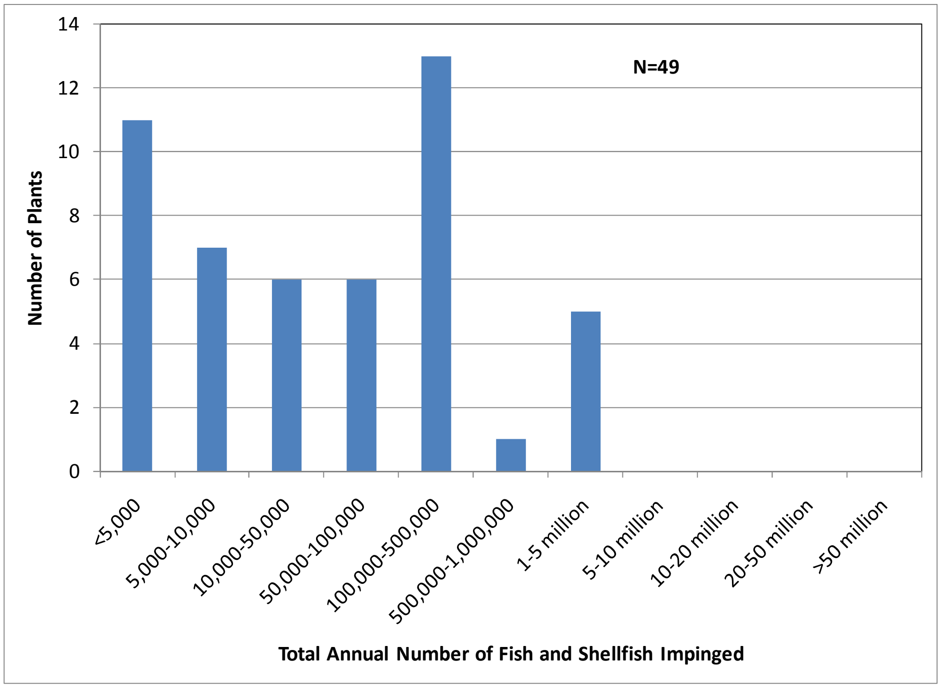

Figure 3-22
Distribution of Annual Impingement Estimates at the Large River Facilities in the EPRI 316(b) Database

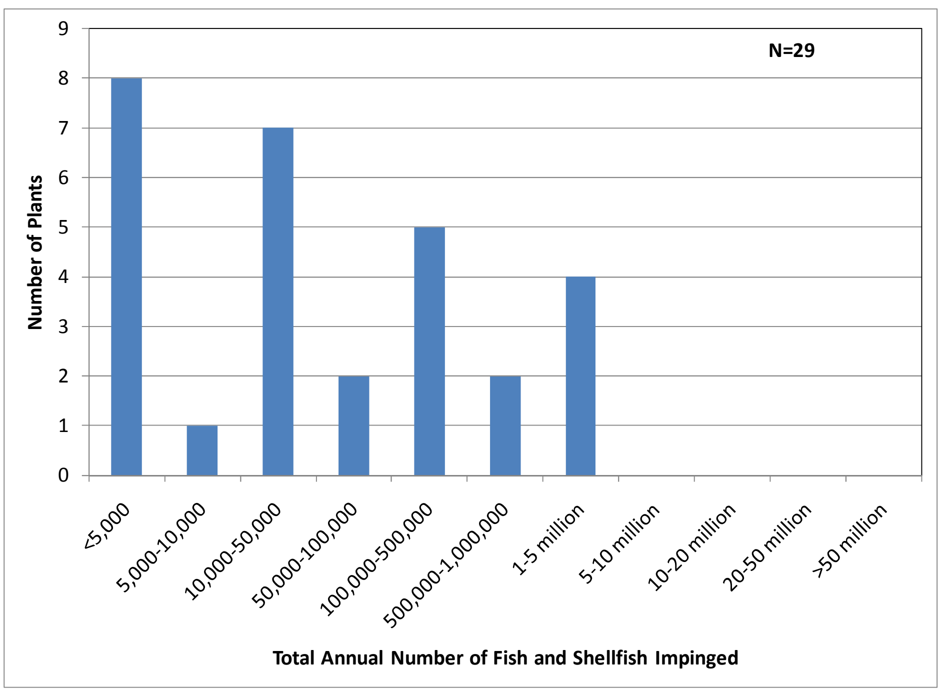

Figure 3-23
Distribution of Annual Impingement Estimates at the Small River Facilities in the EPRI 316(b) Database

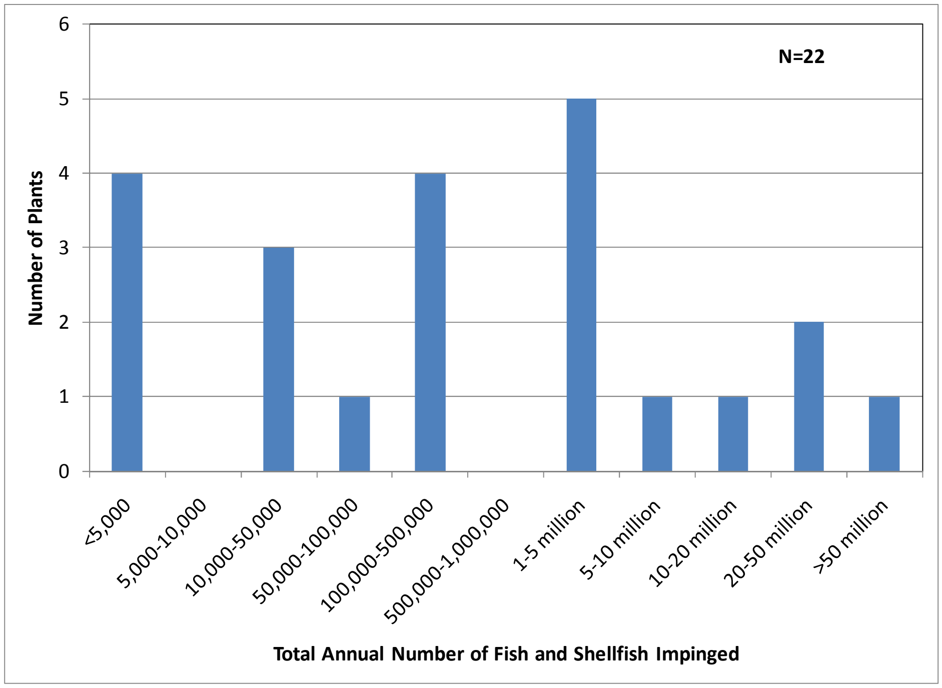

Figure 3-24
Distribution of Annual Impingement Estimates at the Great Lake Facilities in the EPRI 316(b) Database

3.3.2 Entrainment

Each of the seven regions had a different species or taxa ranked number one in the entrainment collections (Table 3-6). As expected, entrainment at the West Coast plants was unlike that in the other three coastal areas but there was some overlap among the three non-western coastal areas (Table 3-4). Bay anchovy larvae ranked first in the Southern Coastal and Gulf region and second in the Northeastern Coastal region with bay anchovy eggs ranking second in the Mid-Atlantic Coastal region and third in the Northeastern Coastal region (Table 3-4). Cunner *(Tautogolabrus adspersus)* eggs ranked first in the Northeastern Coastal region and fourth in the Southern Coastal and Gulf region. Overall, bay anchovy, either as larvae or eggs, was the most commonly entrained species in the various non-western coastal areas.

Table 3-6
Most Commonly Entrained Taxa at Facilities in the EPRI 316(b) Database Based on Ranks

Region	Species/Taxa
West Coast	Unidentified fish eggs
Northeastern Coastal	Cunner eggs
Mid-Atlantic Coastal	White perch
Southern Coastal and Gulf	Bay anchovy
Great Lakes	Alewife
Small Rivers	unid CYPRINIDAE
Hawaii	*Encrasicholina* spp.
Puerto Rico	Caridean shrimp

As was the case for IM, clupeids were big contributors to entrainment at the freshwater plants. In the Great Lakes region, alewife ranked first and gizzard shad ranked fifth (Table 3-4). At the Small Rivers plants, unidentified clupeids ranked second and gizzard shad ranked fifth (Table 3-4). Unidentified cyprinids (minnows) were also important at the freshwater plants, ranking third in the Great Lakes and first in Small Rivers. In the Great Lakes, these cyprinids were probably emerald shiner and spottail shiner *(Notropis hudsonius)*, whereas in Small Rivers several minnow species might be represented.

3.3.2.1 Composition by Region

As expected based on their ranking (Table 3-6), unidentified fish eggs accounted for over two-thirds (69 percent) of the entrained organisms along the West Coast (Figure 3-25). Unidentified Gobidae (6 percent), northern anchovy (5 percent), and unidentified Blennidae (3 percent) were next in terms of relative abundance (Figure 3-25). Seven other taxa each accounted for one to three percent of the total in the West Coast region, with all other taxa accounting for the remaining five percent. In the Northeastern Coastal region, cunner eggs were not only the top ranked taxa (Table 3-6) but also had the highest relative abundance (28 percent) (Figure 3-26). Ten other species or taxa each accounted for four to nine percent of the individuals entrained at plants in this region (Figure 3-26).

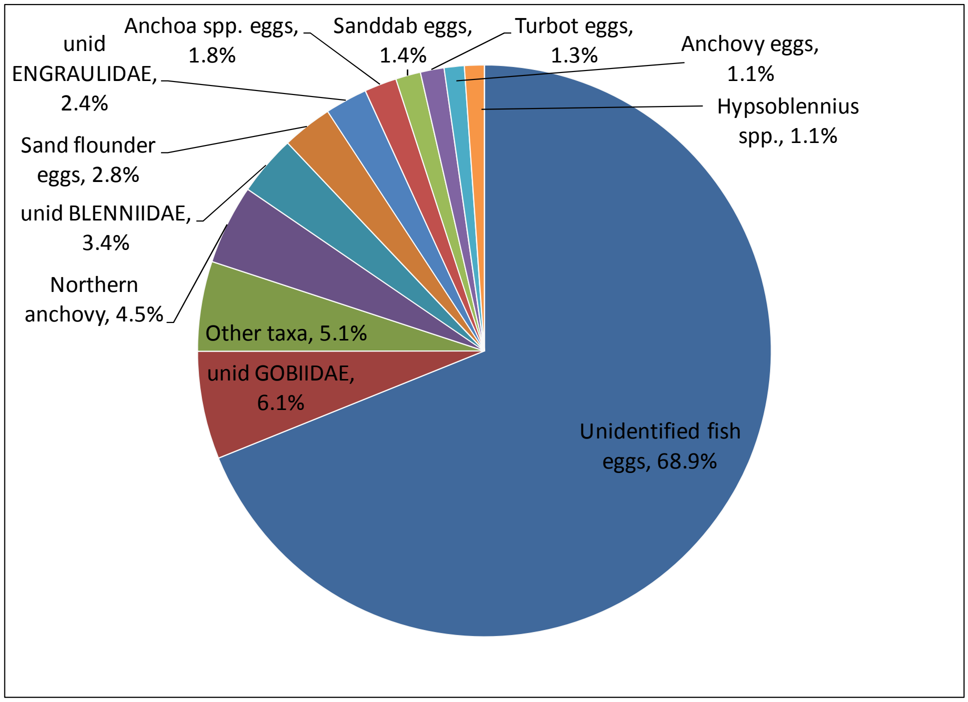

Figure 3-25
Distribution of Common Species Entrained at the West Coast Facilities in the EPRI 316(b) Database

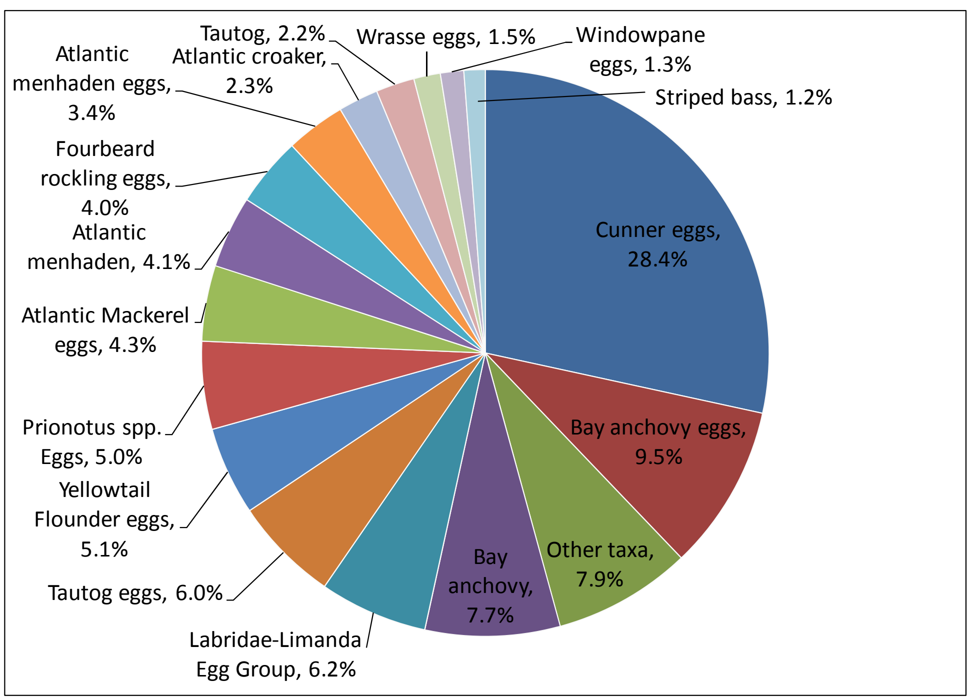

Figure 3-26
Distribution of Common Species Entrained at the Northeast Coastal Facilities in the EPRI 316(b) Database

The Northeastern Coastal region had the most even entrainment distribution of all the regions. Although white perch was ranked highest in the Mid-Atlantic Coastal region (Table 3-6), bay anchovy eggs accounted for 41 percent of the organisms entrained at plants in this region (Figure 3-27), followed by unidentified fish eggs (16 percent), and unidentified gobies (9 percent). Nine other taxa each accounted for one to seven percent of the organisms entrained (Figure 3-27).

Based on relative abundance, three groups dominated entrainment at plants in the Southern Coastal and Gulf region; short-tailed crab *(Potamon fluviatile)* (33 percent), Caridean shrimp *(Periclimenes ornatus)*(27 percent), and "unidentified" (21 percent) (Figure 3-28). *Anomura* spp. accounted for 10 percent of the organisms entrained in the Southern Coastal and Gulf region with three other taxa accounting for one to three percent of the total in this region (Figure 3-28). In Puerto Rico, Caridean shrimp was the top ranked species (Table 3-6) and accounted for 74 percent of the organisms entrained (Figure 3-29). Unidentified fish eggs were the only other taxon that contributed appreciably to entrainment in this region. In Hawaii, *Encrasicholina* spp. was both top ranked (Table 3-6) and the most abundant taxa as measured in terms of relative abundance (Figure 3-30).

In the Great Lakes, alewife was the top ranked species (Table 3-6) but was only fourth (6 percent) in terms of relative abundance behind freshwater drum (36 percent), gizzard shad (20 percent), and unidentified fish eggs (15 percent) (Figure 3-31). *Morone* spp. accounted for 5 percent in this region, with seven other taxa contributing one to three percent (Figure 3-31). The top ranked taxa at plants in the Small Rivers category was unidentified Cyprinidae, which was third in terms of relative abundance behind unidentified Centrarchidae (32 percent) and unidentified Clupeidae (27 percent) (Figure 3-32). In Small Rivers, unidentified Catostomidae and gizzard shad each accounted for six percent in terms of relative abundance, with freshwater drum at five percent (Figure 3-32). Five taxa contributed one to three percent and "other" taxa contributed four percent. The only Midwestern "reservoir" where entrainment samples were collected was a lake connected to Lake Michigan. Because of this connection, the entrainment composition at this site is not representative of a typical Midwestern reservoir. At this atypical site, unidentifiable fish eggs accounted for 61 percent of the organisms entrained, followed by yellow perch *(Perca flavescens)* (18 percent), *Lepomis* spp. (9 percent) and alewife (6 percent) (Figure 3-33).

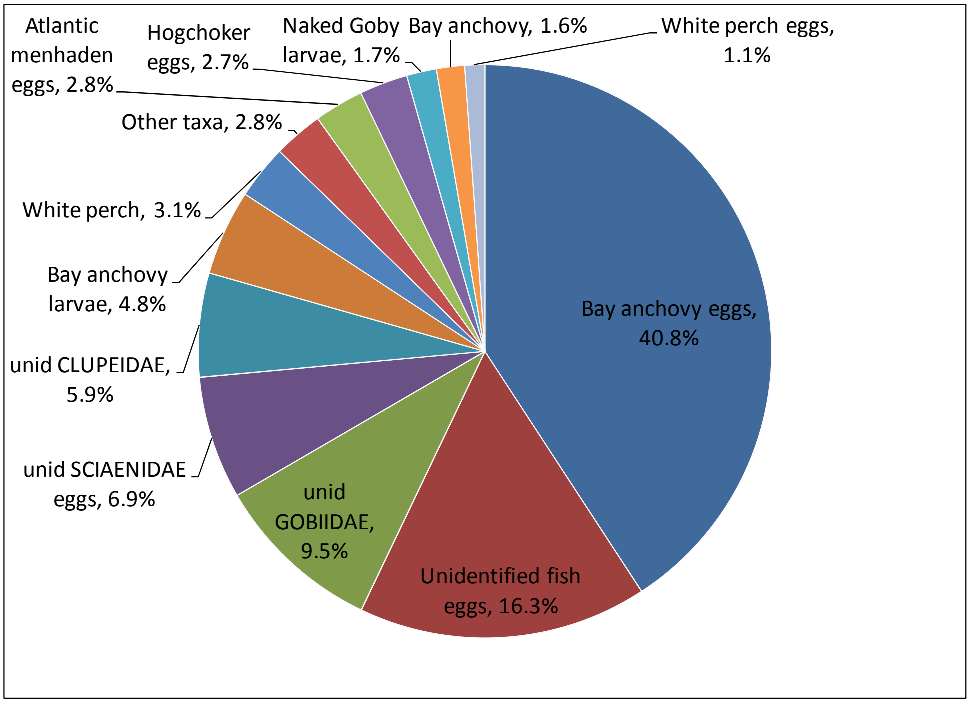

Figure 3-27
Distribution of Common Species Entrained at the Mid-Atlantic Coastal Facilities in the EPRI 316(b) Database

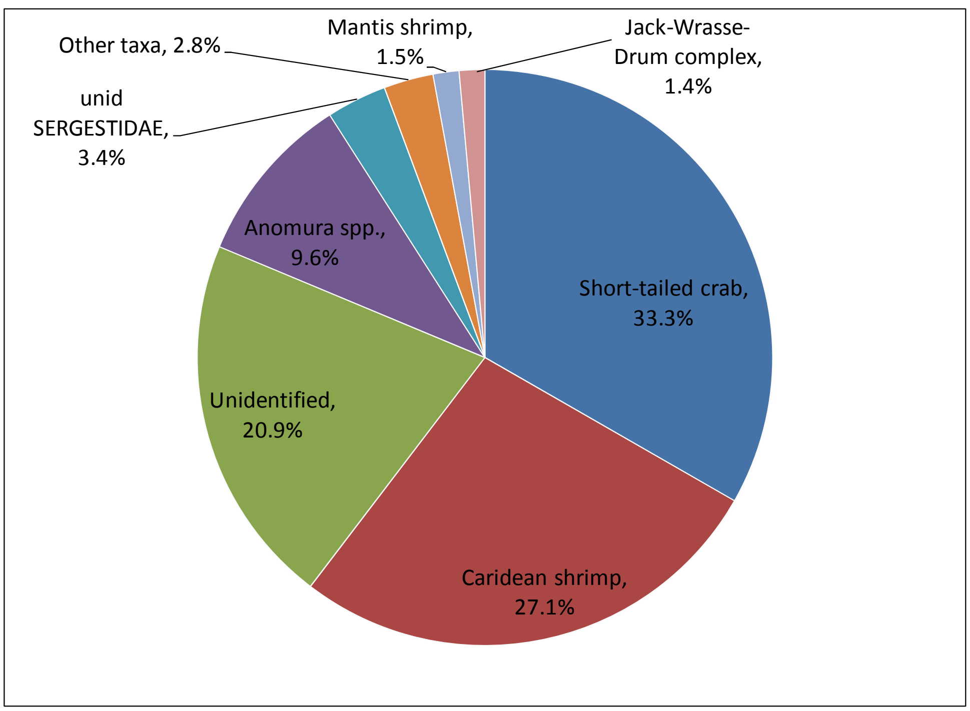

Figure 3-28
Distribution of Common Species Entrained at the Southern Coastal and Gulf Facilities in the EPRI 316(b) Database

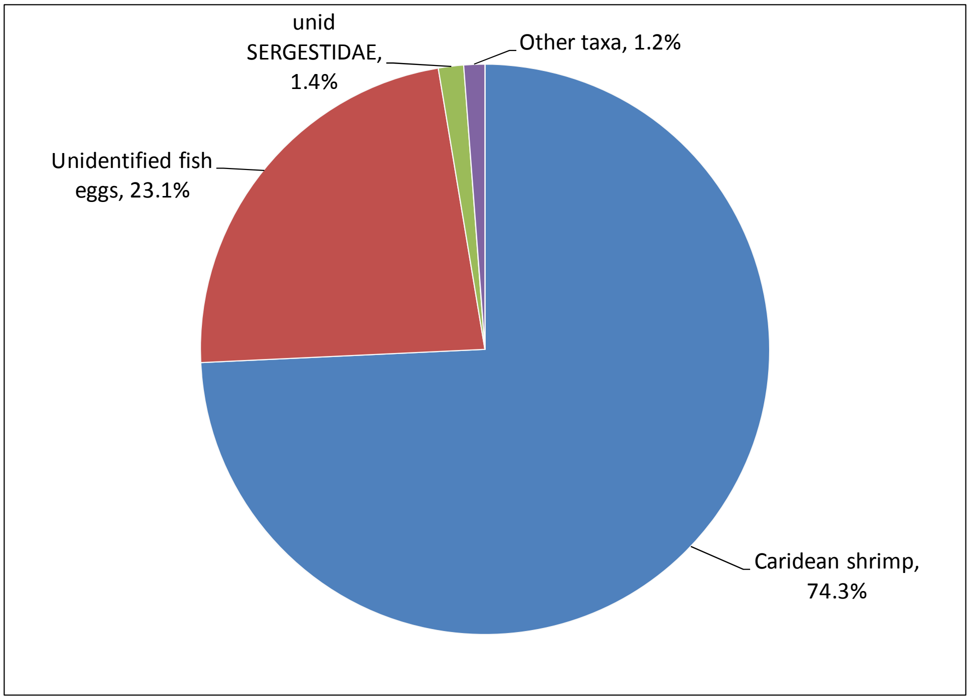

Figure 3-29
Distribution of Common Species Entrained at the Puerto Rican Facility in the EPRI 316(b) Database

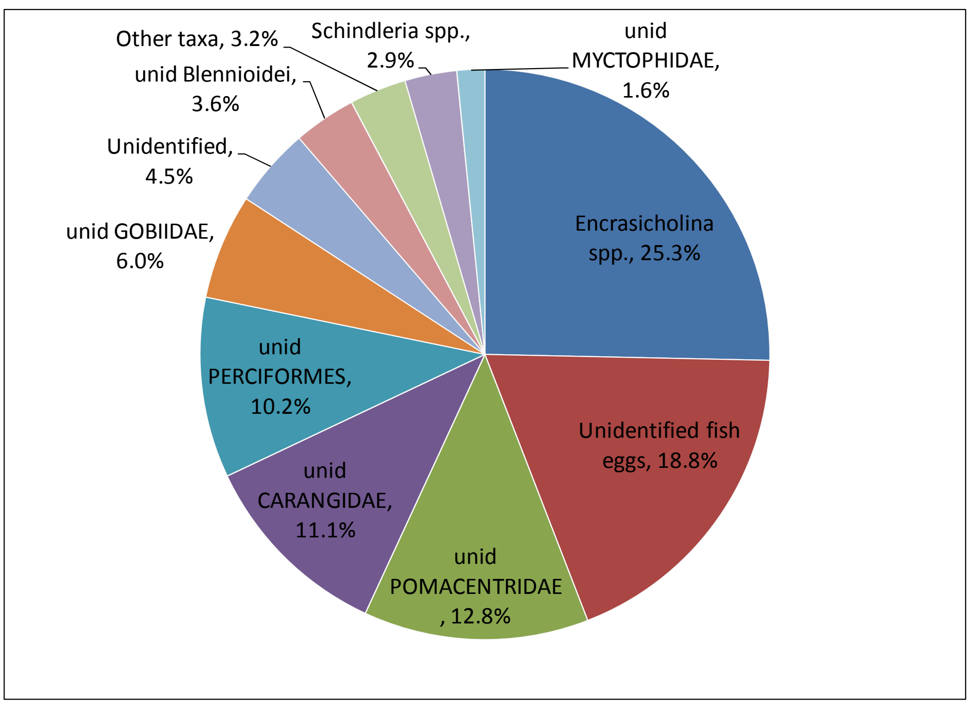

Figure 3-30
Distribution of Common Species Entrained at the Hawaiian Facilities in the EPRI 316(b) Database

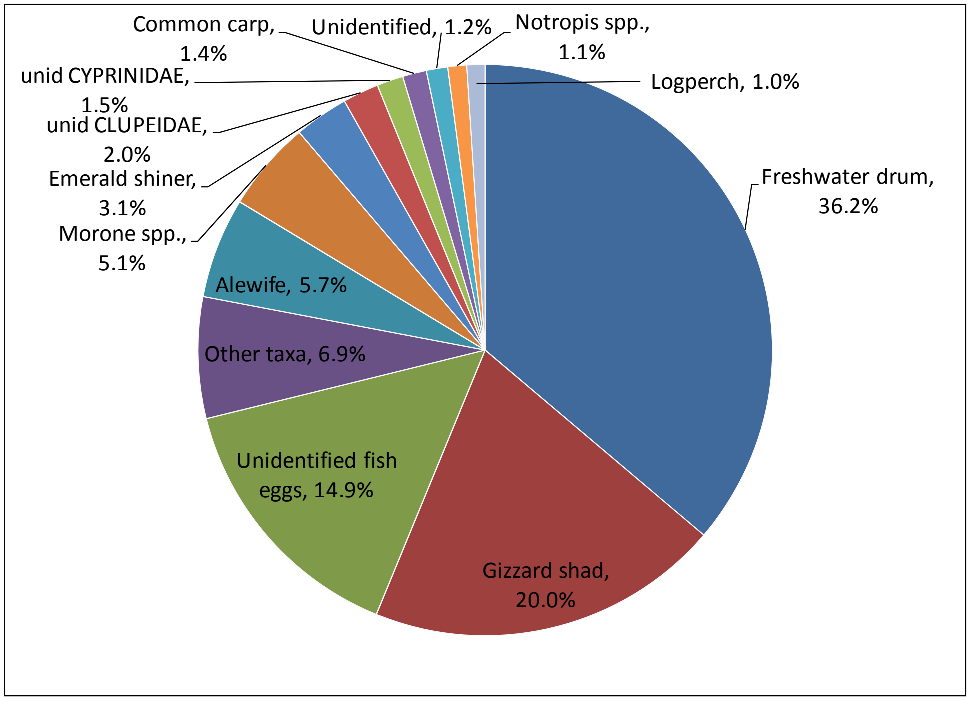

Figure 3-31
Distribution of Common Species Entrained at the Great Lake Facilities in the EPRI 316(b) Database

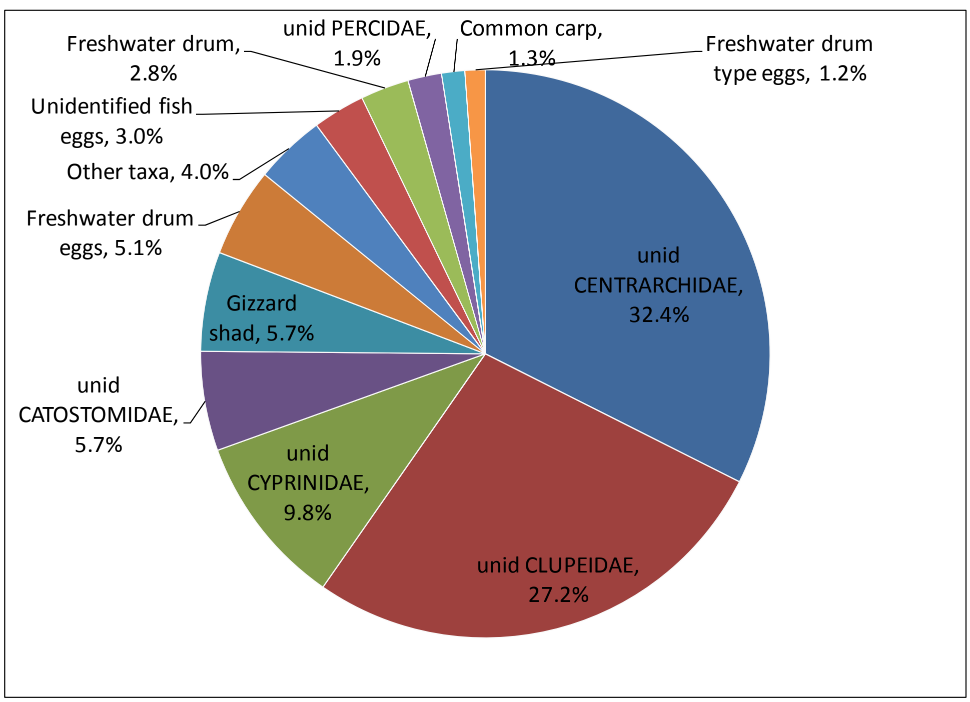

Figure 3-32
Distribution of Common Species Entrained at the Small River Facilities in the EPRI 316(b) Database

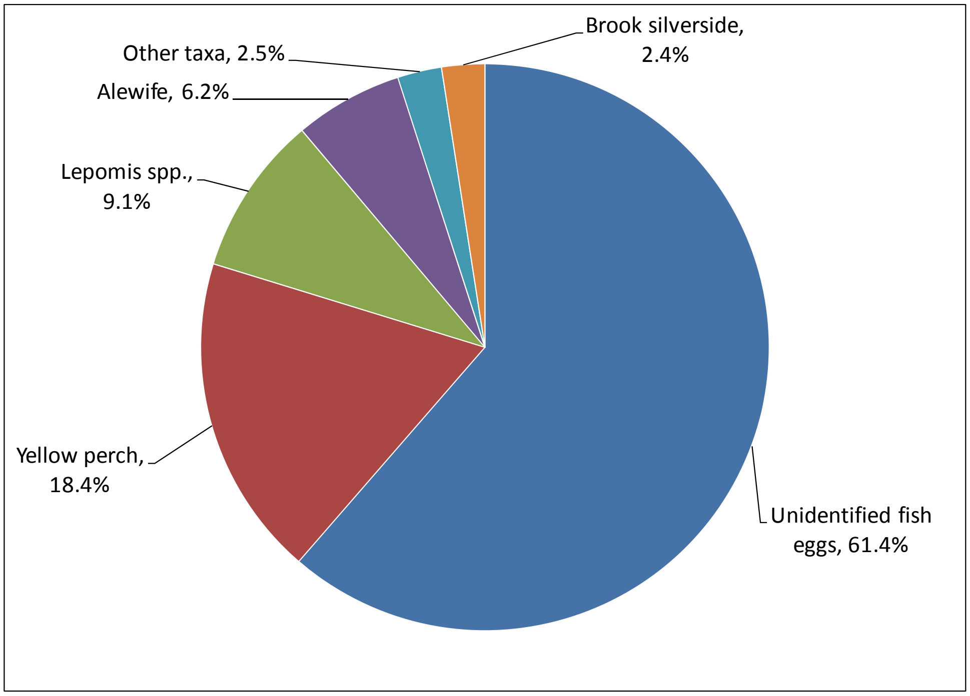

Figure 3-33
Distribution of Common Species Entrained at the one Midwestern Reservoir Facility in the EPRI 316(b) Database

3.3.2.2 Abundance by Region

As was the case for the impingement estimates, mean annual entrainment estimates were considerably higher than median estimates indicating that on a relative basis a few extremely high entrainment estimates increased the mean for each region (Table 3-7). The Southern Coastal and Gulf had the highest mean value (Table 3-7); the relatively high mean was the result of a very high estimate at one plant. The mean was also relatively high (about 8 billion) for plants along the West Coast, in the Northeast Coastal region (about 5 billion), and in Puerto Rico (about 5 billion) (Table 3-7). Means in the Mid-Atlantic Coastal and Hawaii were all around one billion organisms with lower means in the Great Lakes and Small Rivers categories (Table 3-7).

Figures 3-34 through 3-40 show how entrainment estimates were distributed in each region. On the West Coast, estimated entrainment at four of the five plants exceeded one billion (Figure 3-34). In the Northeastern Coastal region, entrainment estimates ranged from less than one hundred thousand to greater than one billion organisms (Figure 3-35). Eleven of the 15 plants in this region had estimates greater than 100 million. In the Southern Coastal and Gulf region, four plants had high to very high entrainment estimates while the fifth plant had a very low entrainment estimate (Figure 3-36). All three Hawaiian plants had entrainment levels similar to other coastal regions (Figure 3-37).

Table 3-7
Annual Entrainment Estimates by Region for Facilities in the EPRI 316(b) Database

	Annual Estimate ($x10^6$)	
Region	**Mean**	**Median**
West Coast	7,987	2,549
Northeastern Coastal	5,368	531
Mid-Atlantic Coastal	1,082	128
Southern Coastal and Gulf	9,020	601
Great Lakes	209	24
Midwestern Reservoirs	74	74
Small Rivers	191	21
Hawaii	1,411	713
Puerto Rico	4,807	4,807

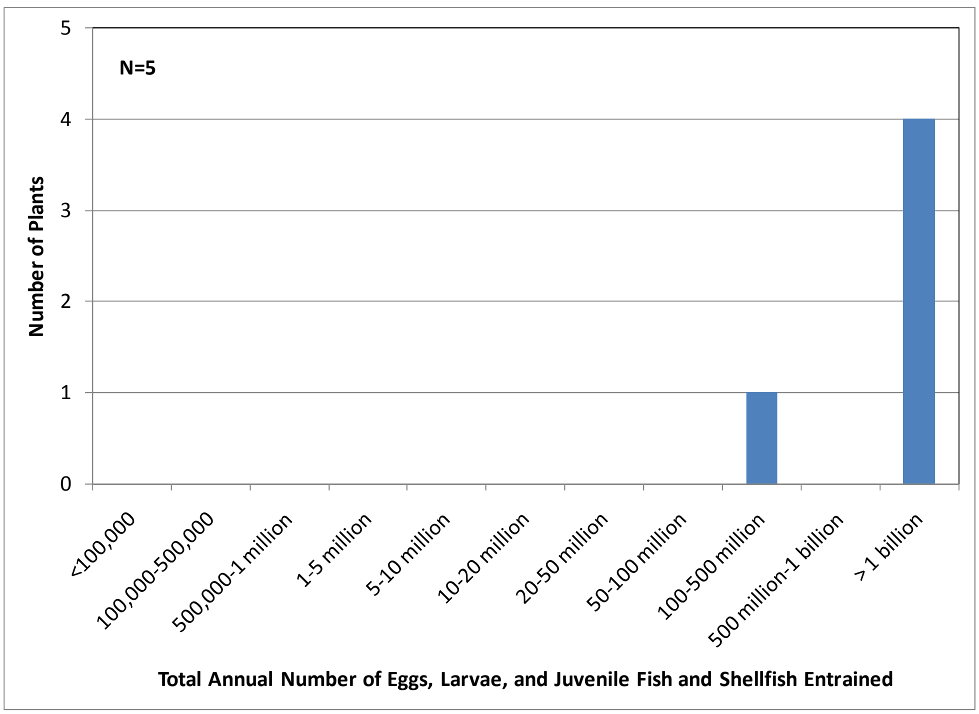

Figure 3-34
Distribution of Annual Entrainment Estimates at the West Coast Facilities in the EPRI 316(b) Database

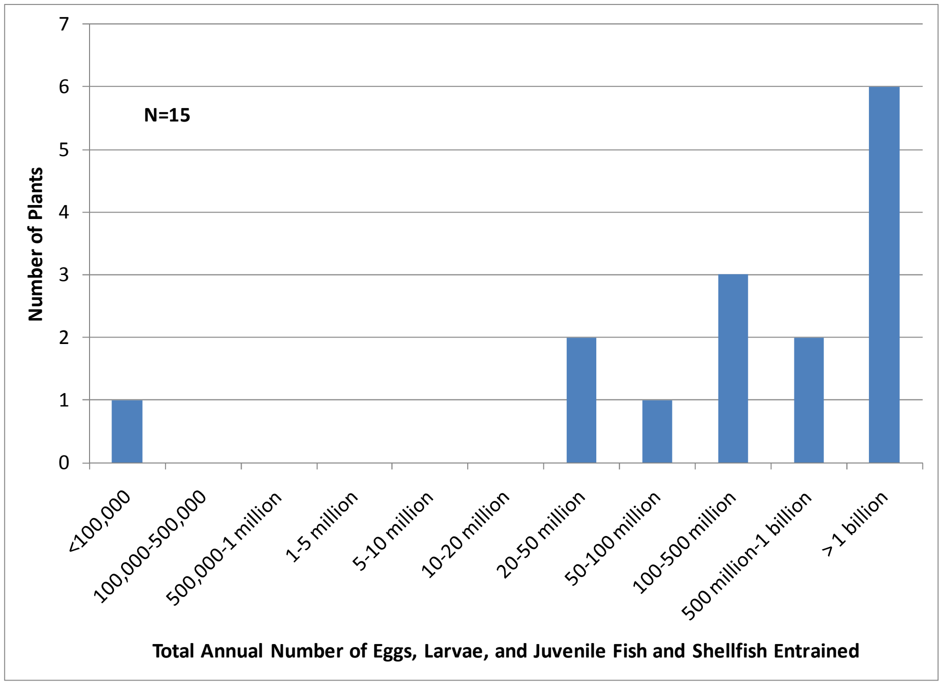

Figure 3-35
Distribution of Annual Entrainment Estimates at the Northeastern Coastal Facilities in the EPRI 316(b) Database

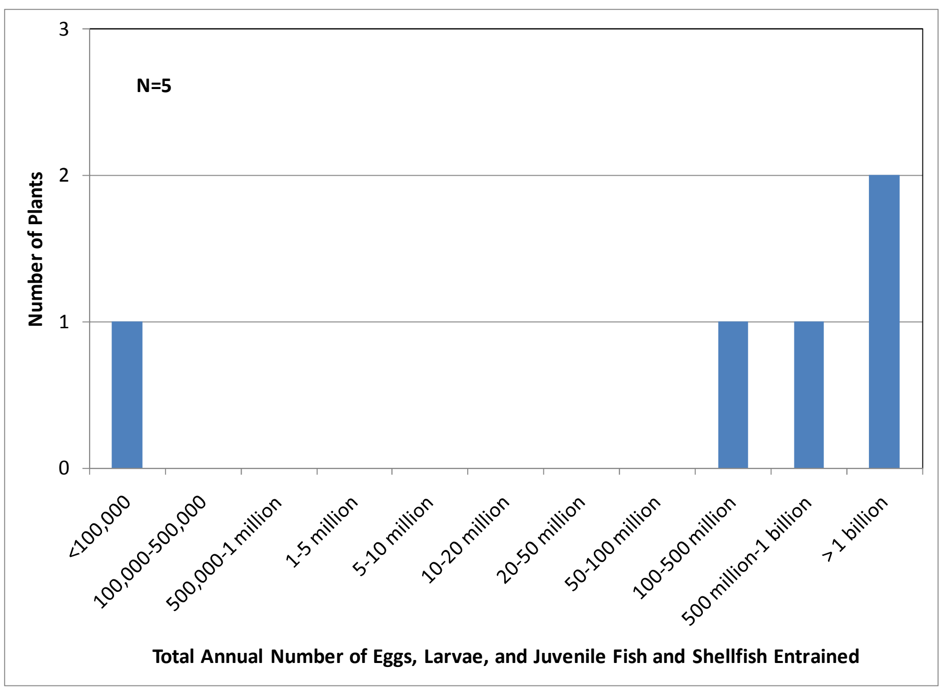

Figure 3-36
Distribution of Annual Entrainment Estimates at the Southern Coastal and Gulf Facilities in the EPRI 316(b) Database

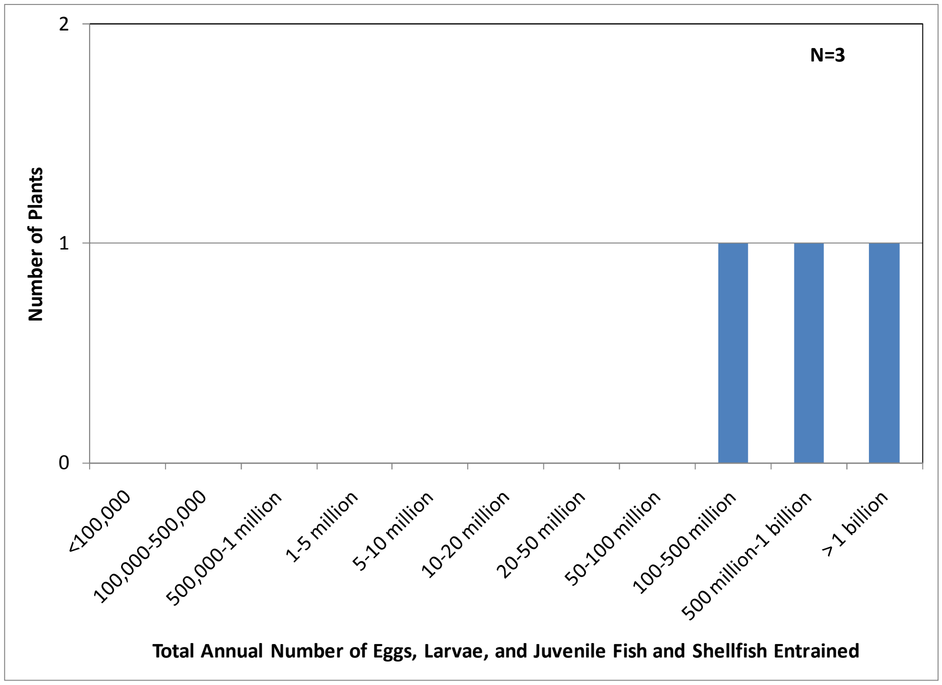

Figure 3-37
Distribution of Annual Entrainment Estimates at the Hawaiian Facilities in the EPRI 316(b) Database

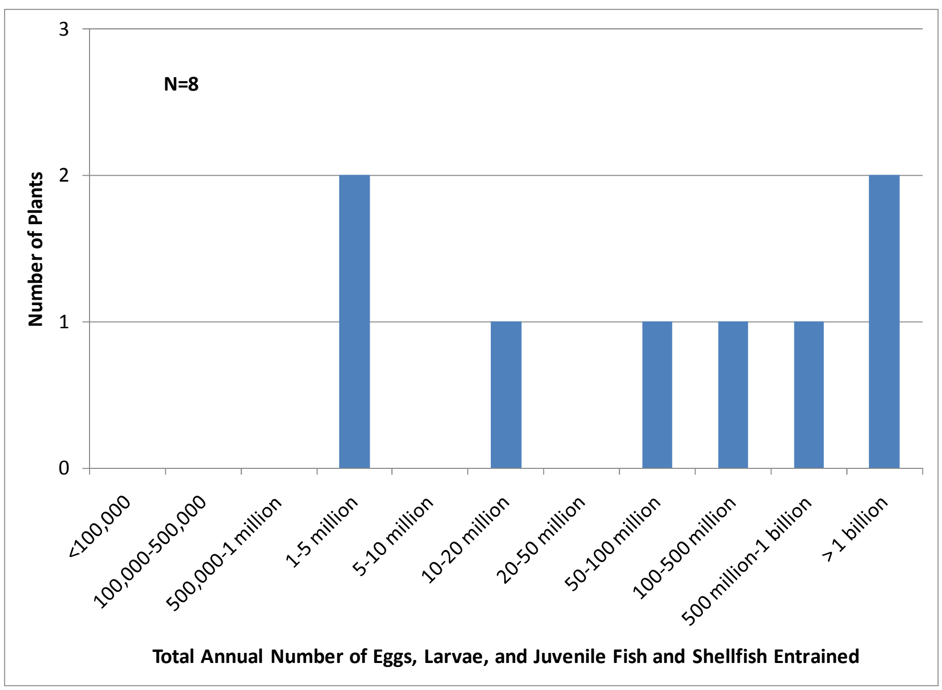

Figure 3-38
Distribution of Annual Entrainment Estimates at the Mid-Atlantic Coastal Facilities in the EPRI 316(b) Database

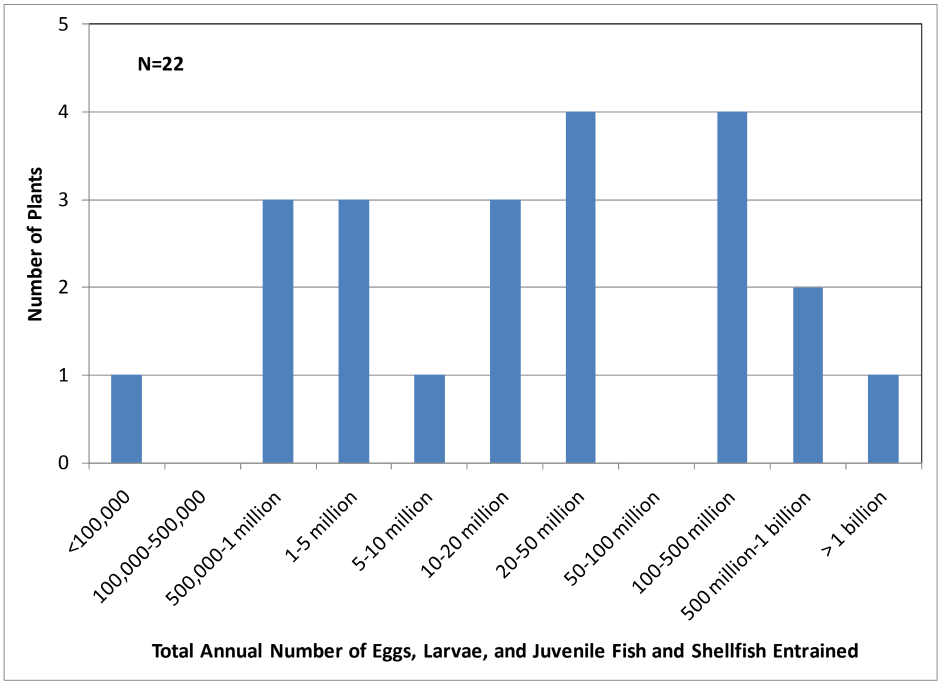

Figure 3-39
Distribution of Annual Entrainment Estimates at the Great Lake Facilities in the EPRI 316(b) Database

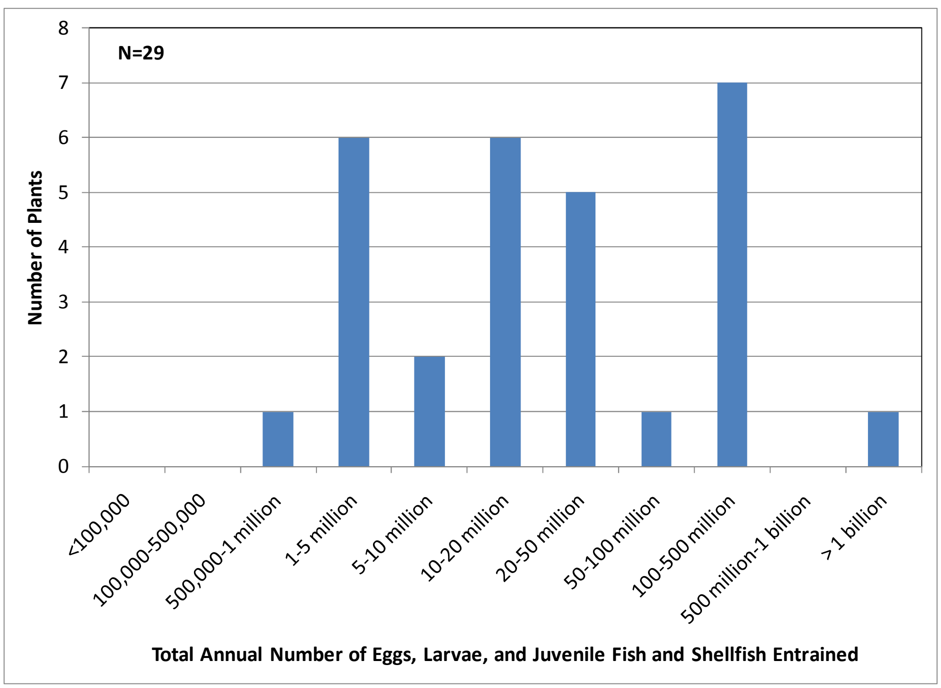

Figure 3-40
Distribution of Annual Entrainment Estimates at the Small River Facilities in the EPRI 316(b) Database

Entrainment estimates at the Mid-Atlantic Coastal plants varied from one to five million to more than one billion (Figure 3-38). Entrainment estimates in the Great Lakes region also ranged on a relative basis from very low (<100,000) to very high (>1 billion) with most of the abundance categories represented (Figure 3-39). Entrainment at Small Rivers plants tended to be moderate (one to 50 million), high (500 million), or in one case very high (greater than one billion) (Figure 3-40). Overall, 40 percent of the plants entrained 1-50 million organisms, 29 percent entrained 100 million to one billion, and 20 percent entrained more than one billion organisms (Figure 3-41). Three plants had relatively low (<100,000 organisms) annual estimates. For these estimates to be biologically meaningful, it would be necessary to convert them to Age 1 equivalents, which was outside the scope of this study.

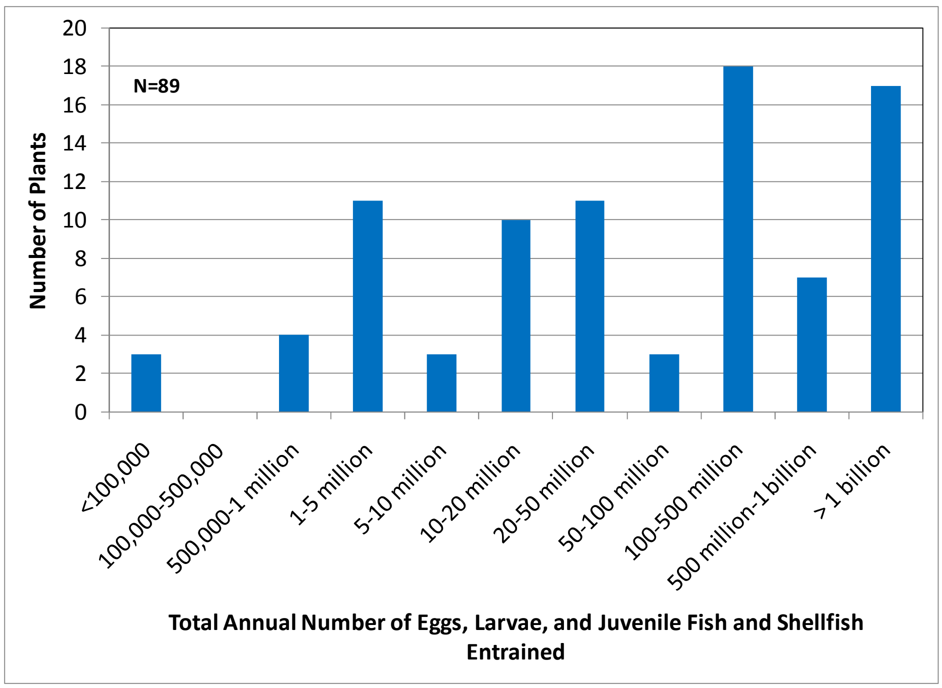

Figure 3-41
Frequency Distribution of the Estimated Number of Fish and Shellfish Entrained at Power Facilities in the EPRI 316(b) Database

3.3.3 Relationship between Design Pumping Capacity and I&E

The suspended 2004 EPA Phase II Rule assumed that there was a direct and positive relationship between the volume of water pumped and I&E. To examine the reasonableness of this assumption, log-transformed I&E annual estimates were regressed against the log-transformed design pumping capacity (in MGD) of each plant. This was done by region and for several combined categories: rivers (combination of the Small Rivers and Large Rivers categories), coastal (all coastal plants regardless of geographic area), lakes and reservoirs (all reservoirs, cooling lakes, natural lakes, and the Great Lakes) and all plants combined. Ideally, these comparisons would have been based on actual volume pumped at each facility.

However, those data were not available for this study. Nonetheless, one would expect that plants with a large design capacity would pump more water than plants with lower design capacity, so if there is a positive relationship between the volume pumped and the number of organisms impinged or entrained it should be revealed by the analysis conducted herein. However, examination of the various graphs shows that the relationships between design pumping capacity and I&E in most regions were often weak. R-square values ≥0.7 were considered to be high, those from 0.35 to 0.69 were considered to be moderate, while those <0.35 were considered to be low.

West Coast

The r-square value was high (0.80) for entrainment and low (0.15) for impingement (Figure 3-42).

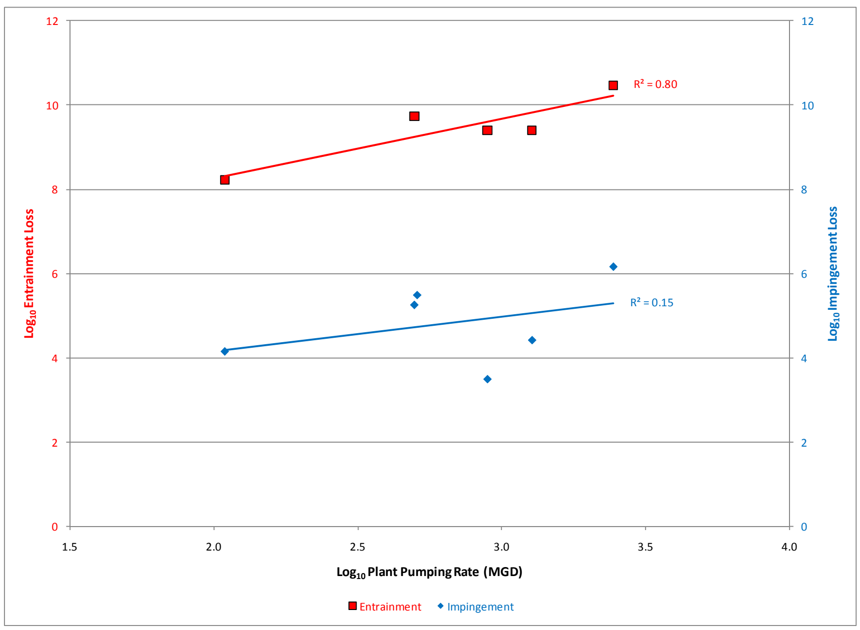

Figure 3-42
Regression of I&E Annual Estimates against Design Pumping Capacity for the West Coast Facilities (I=6, E=5) in the EPRI 316(b) Database

Mid-Atlantic Coastal

Both impingement (0.49) and entrainment (0.46) had moderate r-square values for this region (Figure 3-43).

Southern Coast and Gulf

The impingement (0.35) r-square in this region was moderate and the entrainment r-square was very low (<0.01) (Figure 3-44). The low r-square for entrainment was the result of a single low datum point at one of the larger facilities in the region (Figure 3-44). If this datum point is excluded, the entrainment r-square value increases from <0.01 (Figure 3-44) to 0.91 (Figure 3-45).

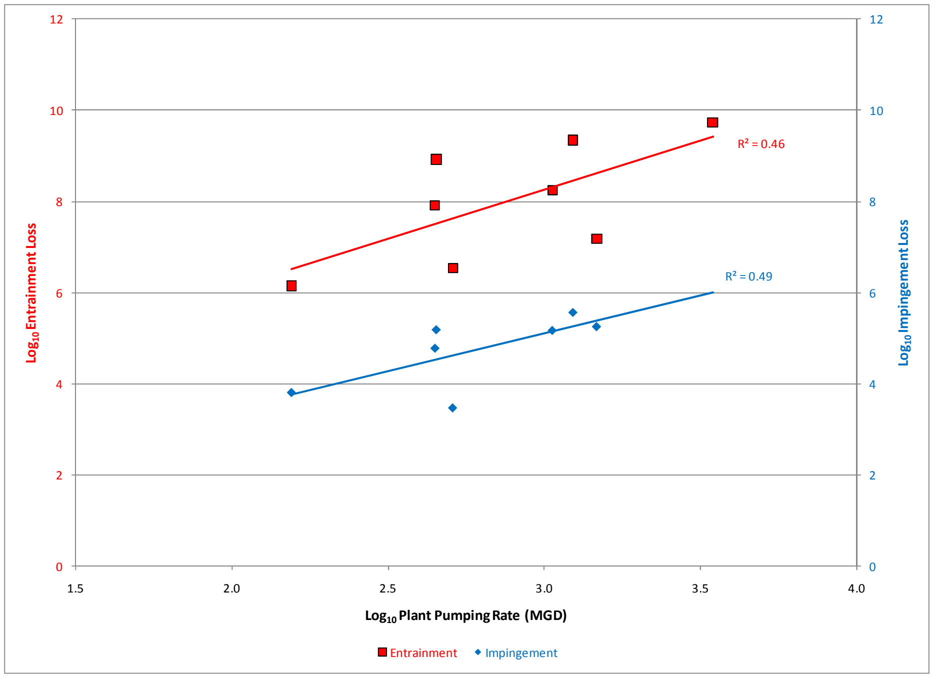

Figure 3-43
Regression of I&E Annual Estimates against Design Pumping Capacity for the Mid-Atlantic Coastal Facilities (I=7, E=8) in the EPRI 316(b) Database

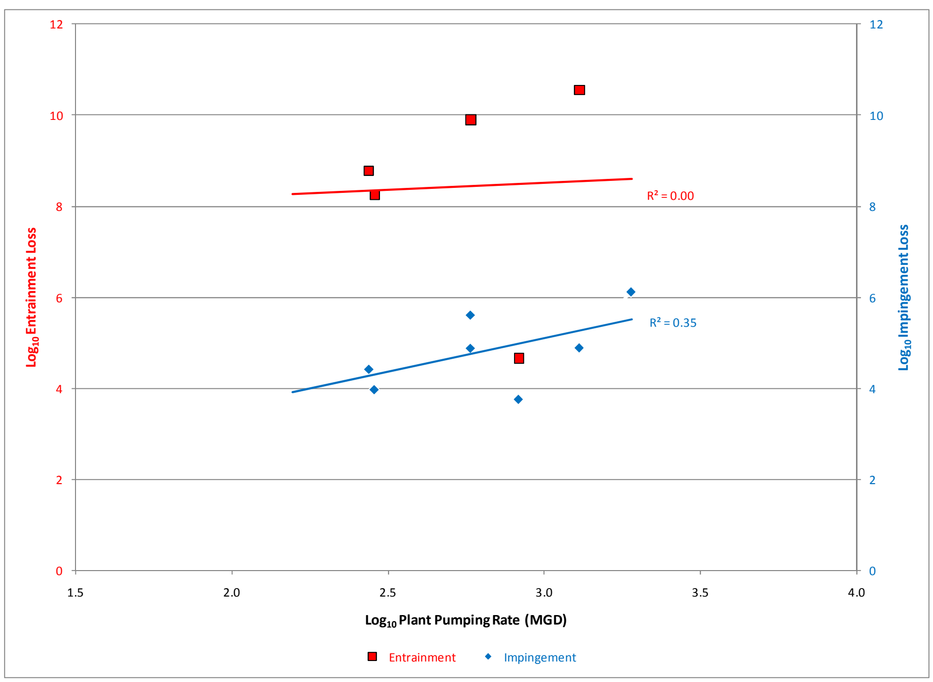

Figure 3-44
Regression of I&E Annual Estimates Against Design Pumping Capacity for the Southern Coastal and Gulf Facilities (I=8, E=5) in the EPRI 316(b) Database

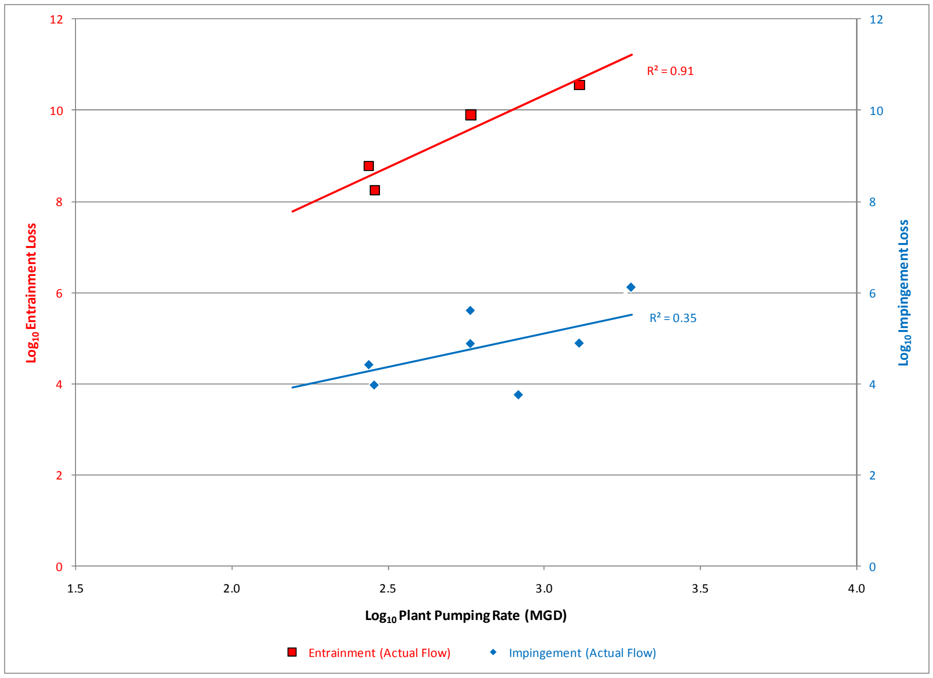

Figure 3-45
Regression of I&E Annual Estimates Against Design Pumping Capacity for the Southern Coastal and Gulf Facilities (I=8, E=4) in the EPRI 316(b) Database excluding the Facility with the Lowest Entrainment Estimate

Midwestern Reservoirs

Except for one entrainment study, plants in this category only conducted impingement studies. The regression based on the impingement data resulted in a low r-square of 0.14 (Figure 3-46). Examination of Figure 3-46 indicates that the largest plant in this region had an impingement total that was lower than the totals at most of the other plants. Removal of this point increased the r-square value from 0.14 to 0.47 (Figure 3-47). Although this point appeared to be a statistical outlier, the impingement total at this plant may have been the result of site-specific factors that resulted in a lower than expected impingement total.

Northeastern Coastal

The r-square for entrainment in the Northeastern coastal region was low (0.23) and the r-square for impingement was only slightly higher (0.33) (Figure 3-48). The entrainment r-square was strongly influenced by one low datum point. If that point is removed, the entrainment r-square increases to 0.39 (Figure 3-49).

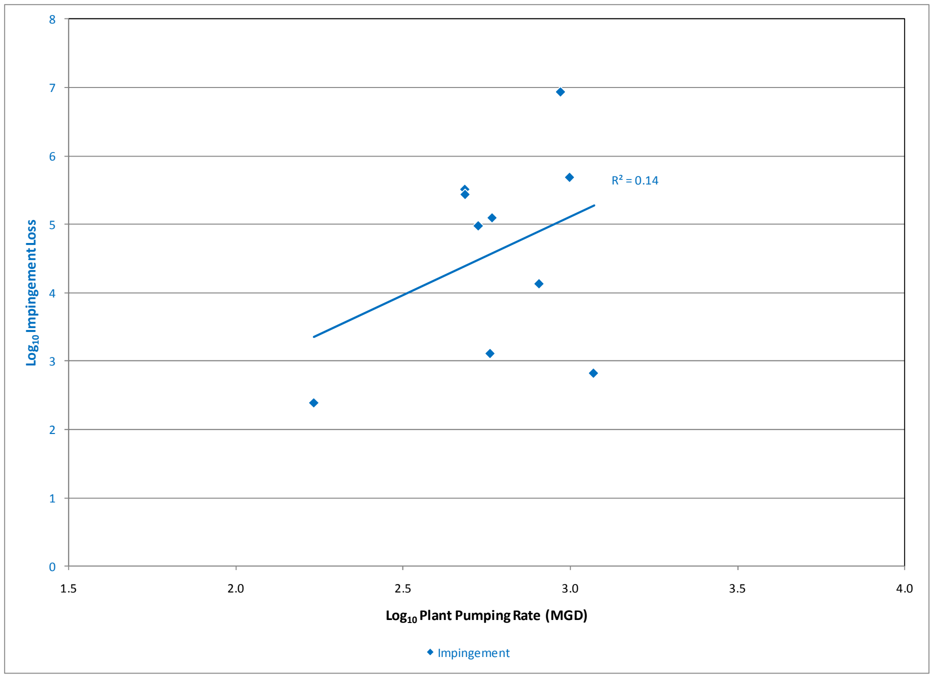

Figure 3-46
Regression of the Impingement Annual Estimates against Design Pumping Capacity for the Midwestern Reservoir Facilities (N=10) in the EPRI 316(b) Database

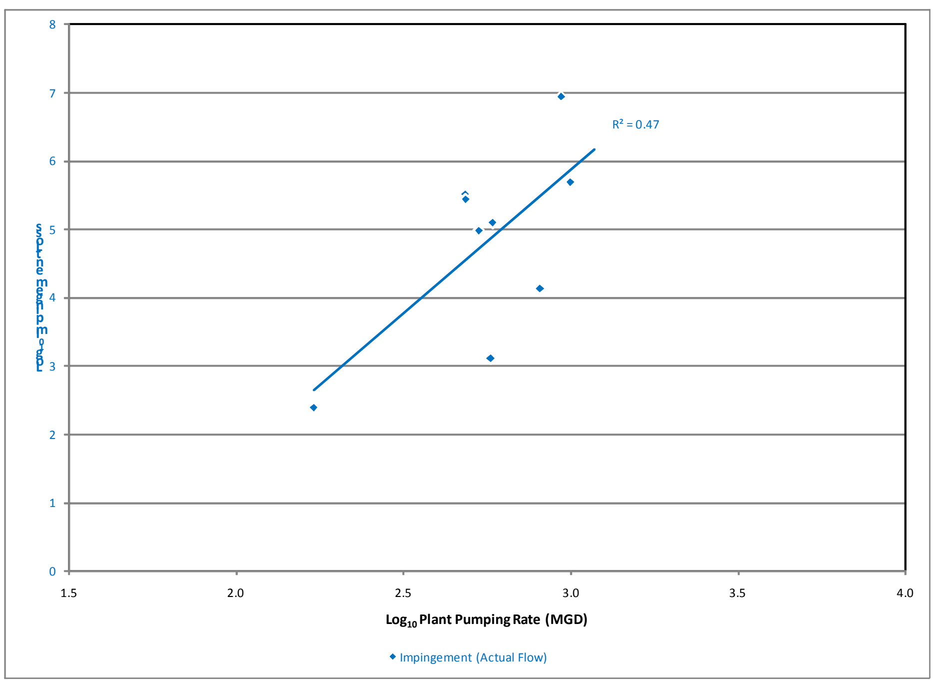

Figure 3-47
Regression of the Impingement Annual Estimates against Design Pumping Capacity for the Midwestern Reservoir Facilities (N=9) in the EPRI 316(b) Database excluding the Facility with the Lowest Estimate

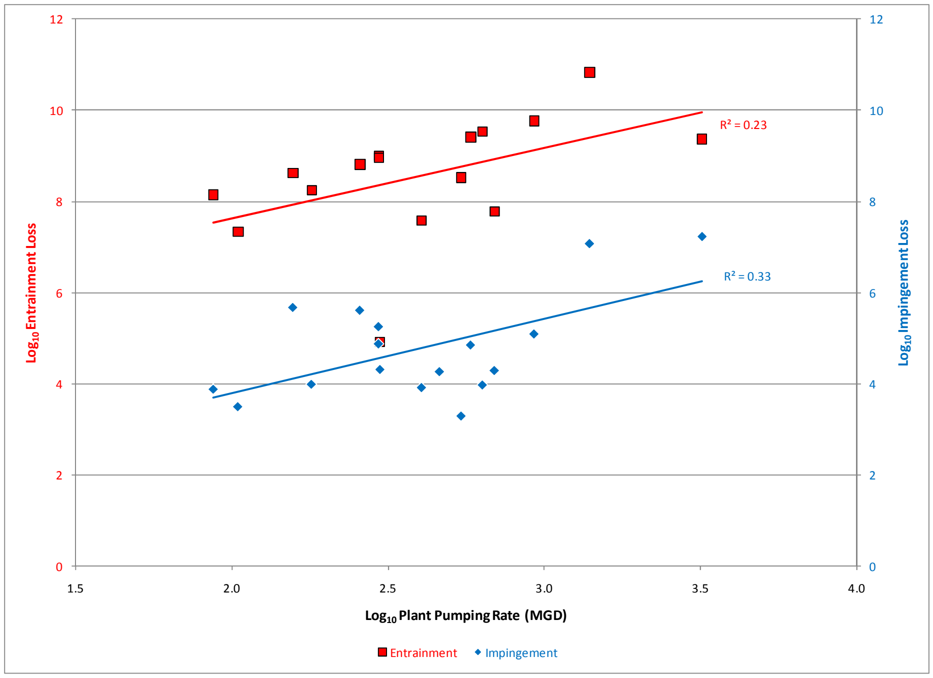

Figure 3-48
Regression of the Impingement Annual Estimates against Design Pumping Capacity for the Northeast Coastal Facilities (I=17, E=16) in the EPRI 316(b) Database

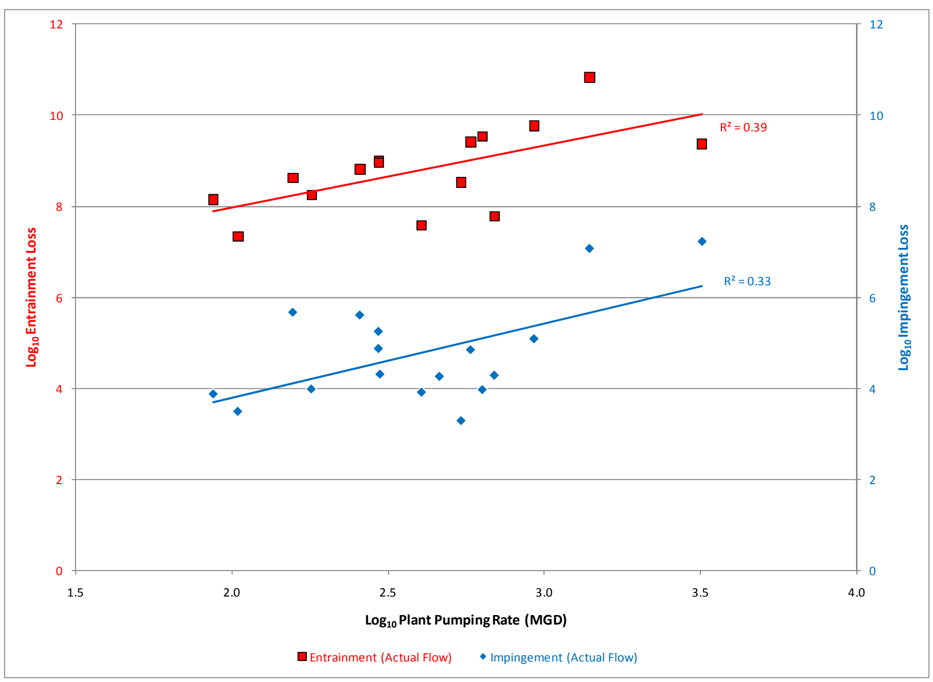

Figure 3-49
Regression of the Impingement Annual Estimates against Design Pumping Capacity at the Northeast Coastal Facilities (I=17, E=15) in the EPRI 316(b) Database excluding the Facility with the Lowest Entrainment Estimate

Great Lakes

In the Great Lakes region, the r-square for impingement was moderate (0.45) and the r-square for entrainment was low (0.14) (Figure 3-50). The low entrainment r-square value was the result of one plant at which the annual entrainment was estimated to be zero (Figure 3-50). If this point is removed, the r-square increases to 0.45 (Figure 3-51).

Southeastern Reservoirs

The impingement r-square value for this region was very low (<0.01) and, if anything, the relationship between pumping capacity and impingement was inverse (Figure 3-52).

Southwestern Cooling Lakes

As was the case in the southeast, the impingement r-square value in the Southwestern Cooling Lakes region was low (0.14, Figure 3-53). It appeared that this low r-square might be the result of low impingement at one plant (Figure 3-53), however, removal of that point increased the r-square only to 0.16 (Figure 3-54).

Large Rivers

The Large Rivers category was the largest data set (N=53); however, despite this robust data set, the r-square value for impingement was only moderate (0.35) indicating that pumping capacity explains only about a third of the variance at the 53 plants in this category (Figure 3-55).

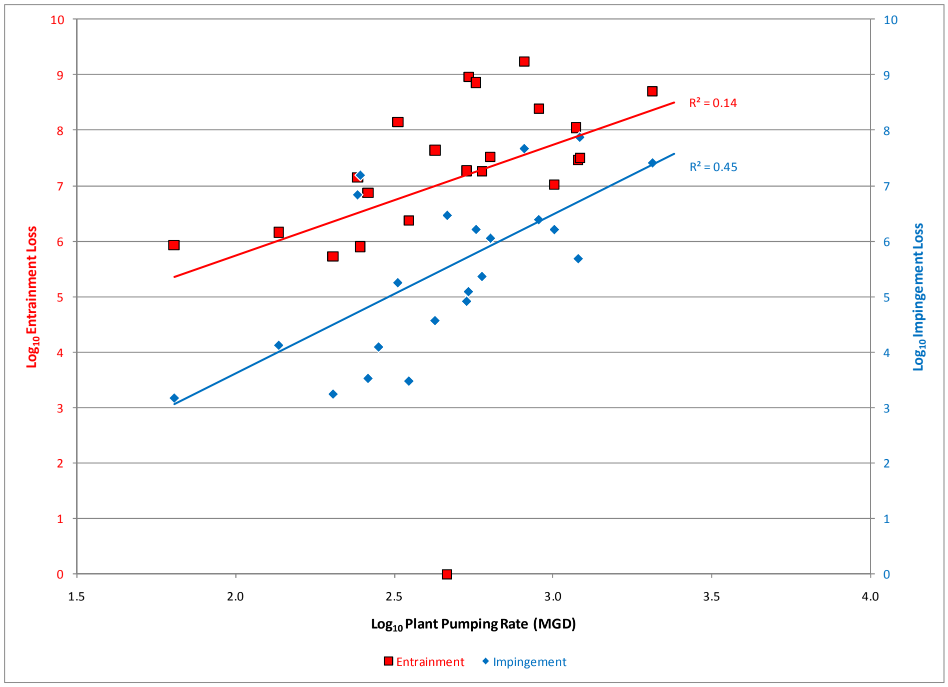

Figure 3-50
Regression of I&E Annual Estimates against Design Pumping Capacity for the Great Lakes Facilities (N=22) in the EPRI 316(b) Database

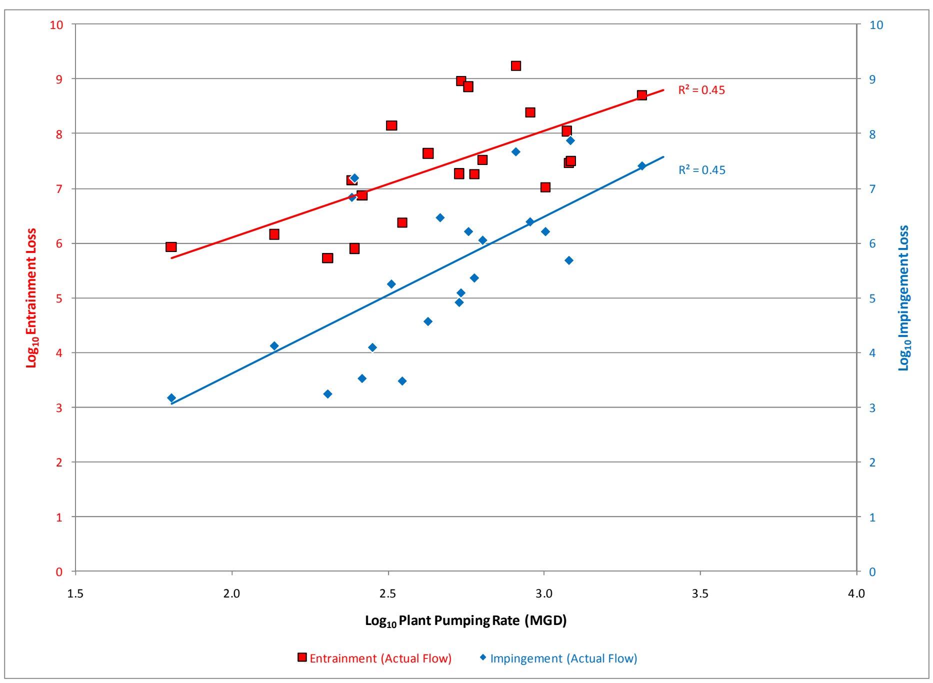

Figure 3-51
Regression of I&E Annual Estimates against Design Pumping Capacity for the Great Lakes Facilities (I=22, E=21) in the EPRI 316(b) Database excluding the Facility with the Lowest Entrainment Estimate

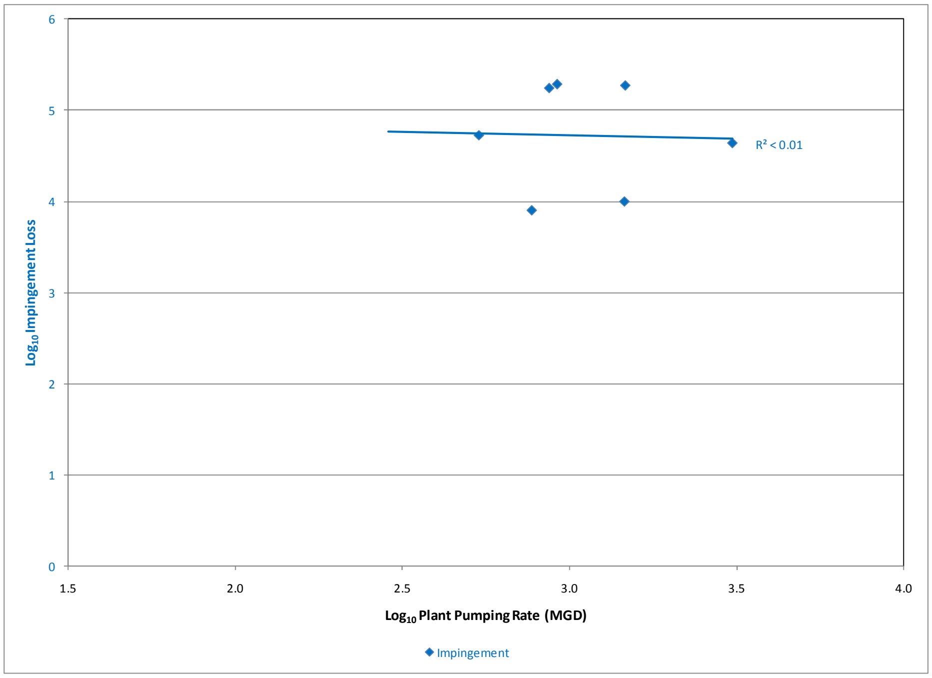

Figure 3-52
Regression of the Impingement Annual Estimates against Design Pumping Capacity for the Southeastern Reservoir Facilities (N=7) in the EPRI 316(b) Database

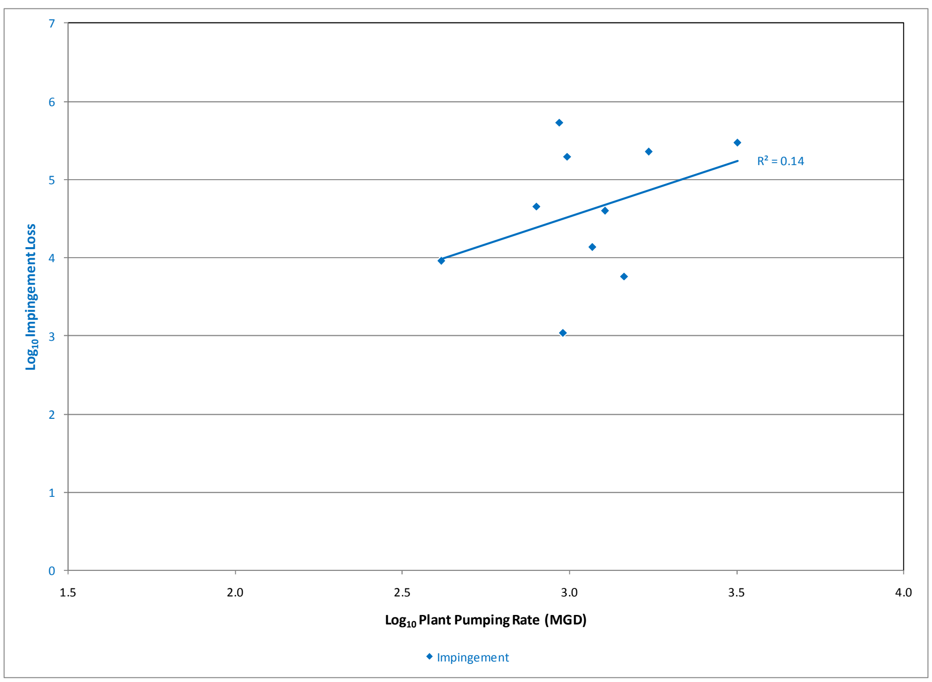

Figure 3-53
Regression of the Impingement Annual Estimates against Design Pumping Capacity for the Southwestern Cooling Lake Facilities (N=10) in the EPRI 316(b) Database

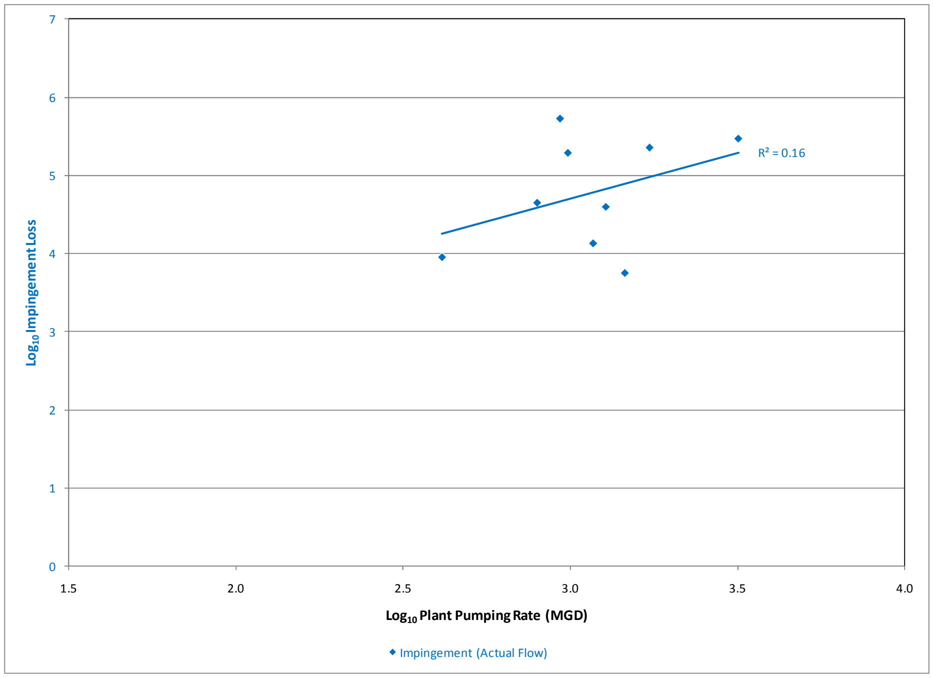

Figure 3-54
Regression of the Impingement Annual Estimates against Design Pumping Capacity for the Southwestern Cooling Lake Facilities (N=9) in the EPRI 316(b) Database excluding the Facility with the Lowest Estimate

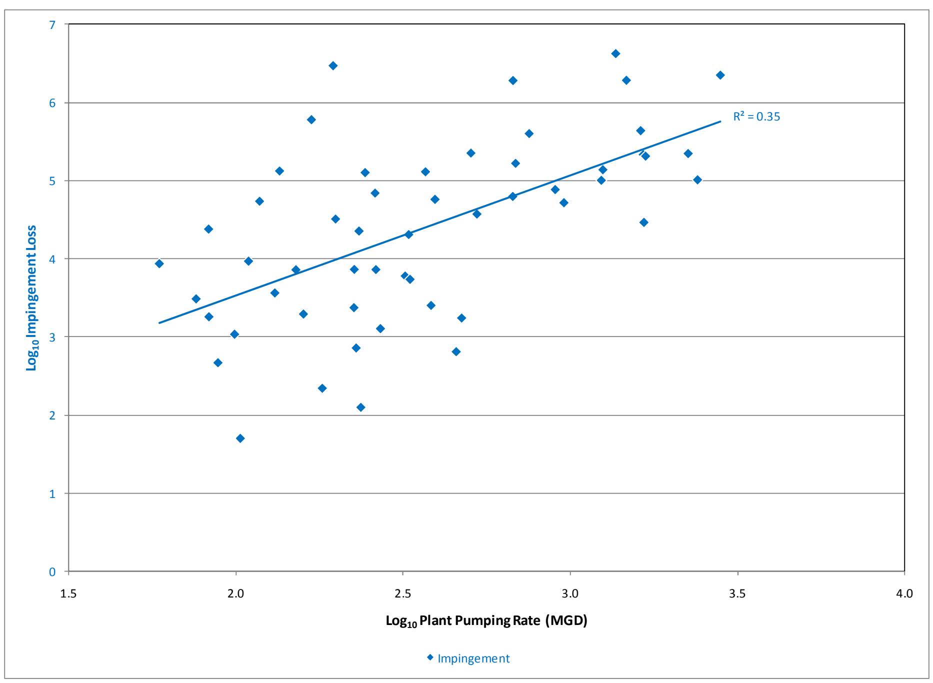

Figure 3-55
Regression of the Impingement Annual Estimates against Design Pumping Capacity for the Large River Facilities (N=53) in the EPRI 316(b) Database

Small Rivers

In the Small Rivers category, r-square values were lower than in the Large Rivers category. The Small Rivers r-square for impingement was 0.24 and the r-square for entrainment was 0.19 (Figure 3-56). Two of the entrainment data points appeared to be outliers; one value was higher than expected and the other lower than expected (Figure 3-56). Excluding these two data points increased the r-square from 0.19 (Figure 3-56) to 0.34 (Figure 3-57).

Hawaii

In Hawaii, the r-square for impingement was moderate (0.42) and the r-square for entrainment (0.93) was high (Figure 3-58).

Lakes and Reservoirs

Combining the various lake and reservoir regions into this category yielded low r-square values for both I&E, 0.08 and 0.14, respectively (Figure 3-59). Because the entrainment r-square value for this waterbody grouping was influenced by the zero estimate shown on Figure 3-59, the relationship was re-calculated excluding the data point increasing the r-square value from 0.14 to 0.46 (Figure 3-60).

Coastal

For all coastal plants combined, the r-square for impingement is low (0.29) and the r-square for entrainment was even lower (0.16) (Figure 3-61). Two entrainment data points are noticeably lower than the others on Figure 3-61. If these are removed, the entrainment r-square increases but is still low (0.28) (Figure 3-62).

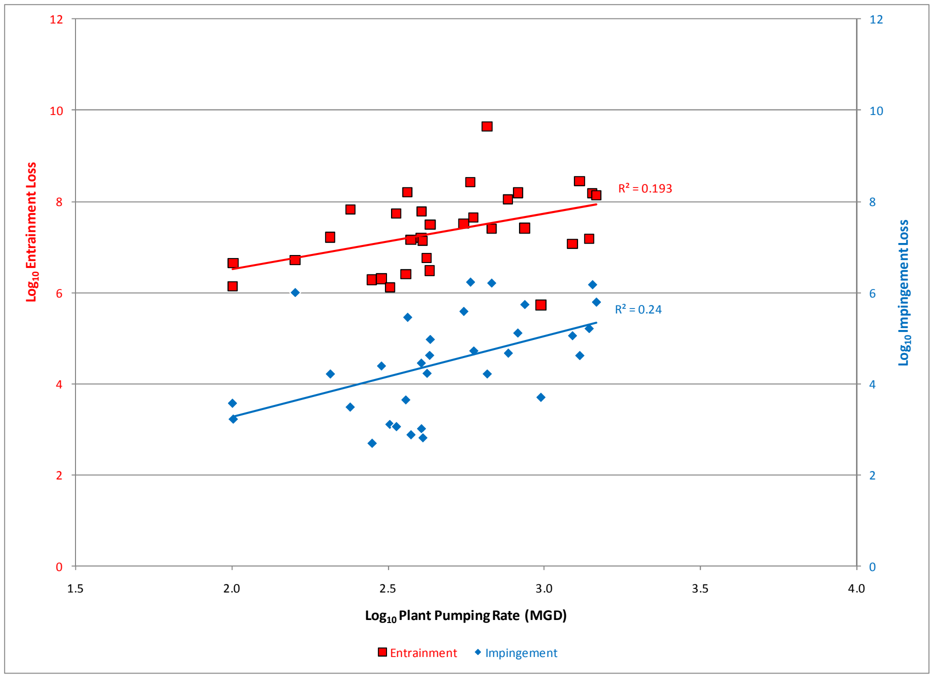

Figure 3-56
Regression of I&E Annual Estimates against Design Pumping Capacity for the Small River Facilities (N=32) in the EPRI 316(b) Database

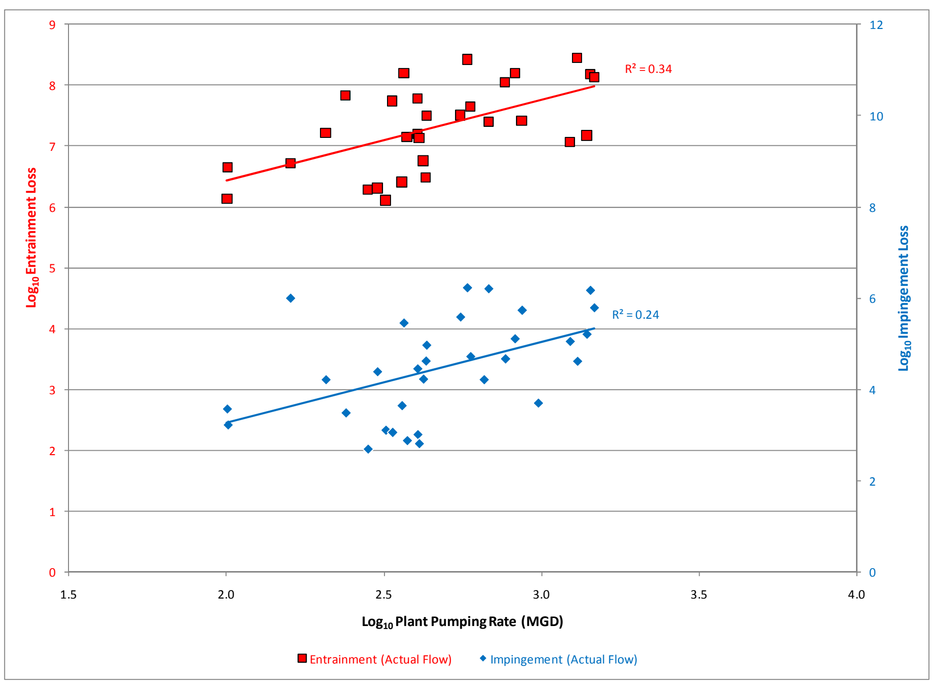

Figure 3-57
Regression of I&E Annual Estimates against Design Pumping Capacity for the Small River Facilities (I=32, E=30) in the EPRI 316(b) Database excluding Facilities with the Highest and Lowest Entrainment Estimates

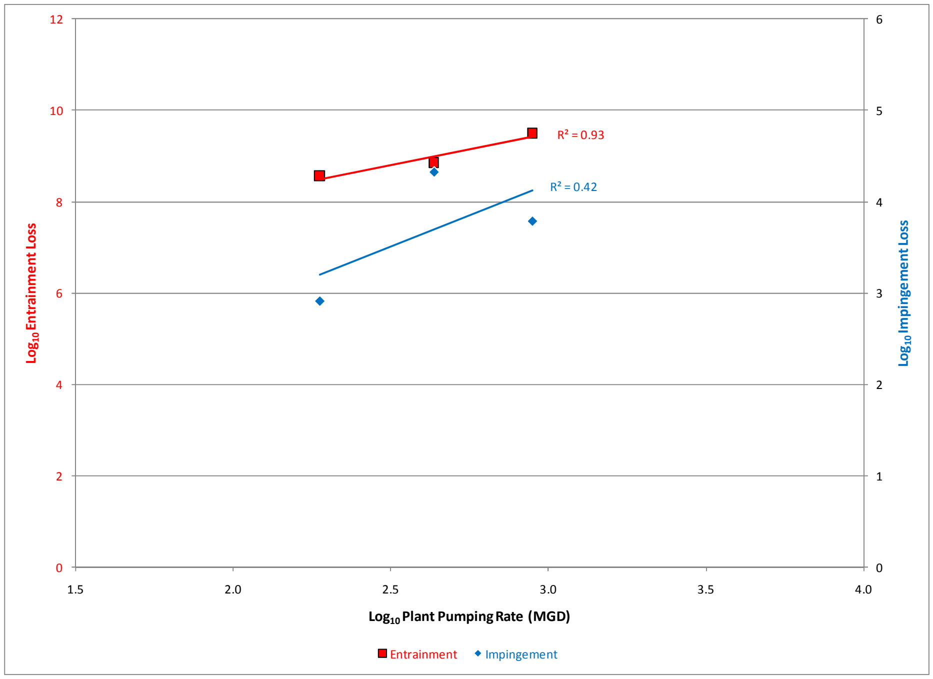

Figure 3-58
Regression of I&E Annual Estimates against Design Pumping Capacity for the Hawaiian Facilities (N=3) in the EPRI 316(b) Database

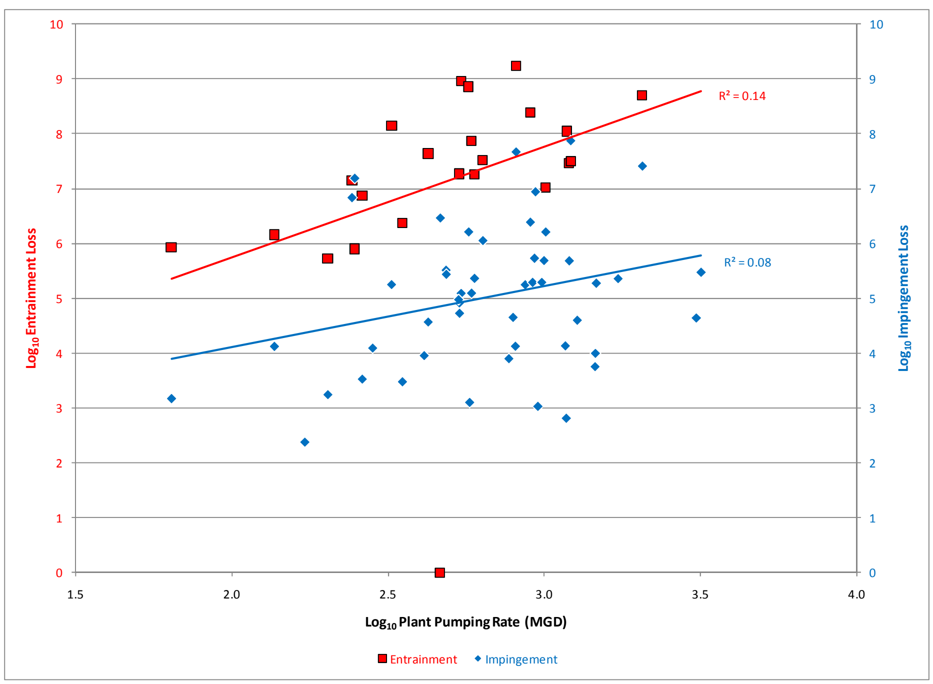

Figure 3-59
Regression of I&E Annual Estimates against Design Pumping Capacity for Facilities in the combined Lakes and Reservoir Group (I=49, E=23) in the EPRI 316(b) Database

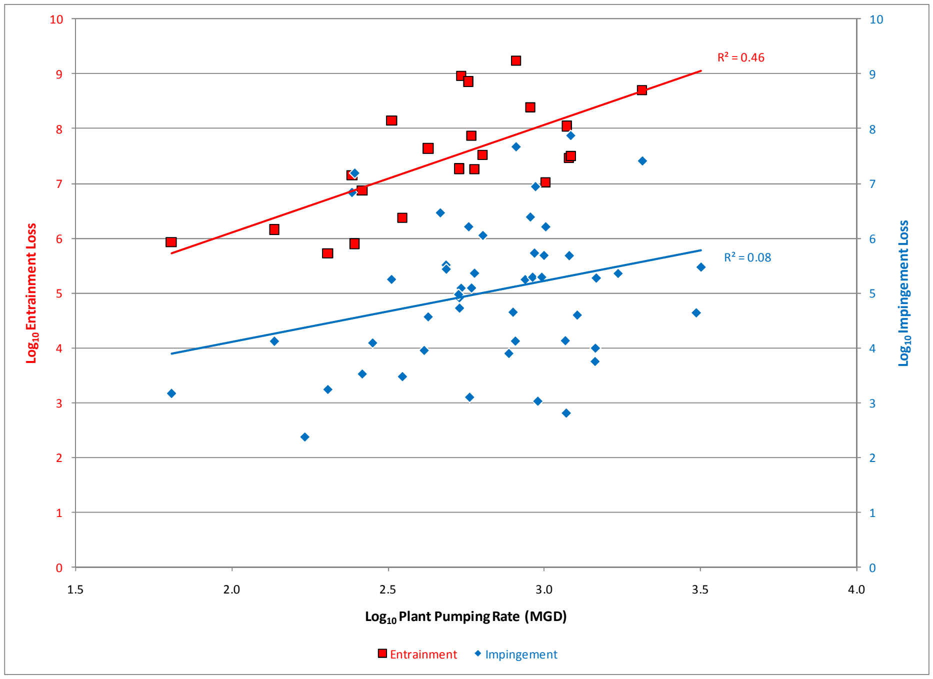

Figure 3-60
Regression of I&E Annual Estimates against Design Pumping Capacity for Facilities in the combined Lakes and Reservoir Group (I=49, E=22) in the EPRI 316(b) Database excluding the Facility with the Lowest Annual Entrainment Estimate

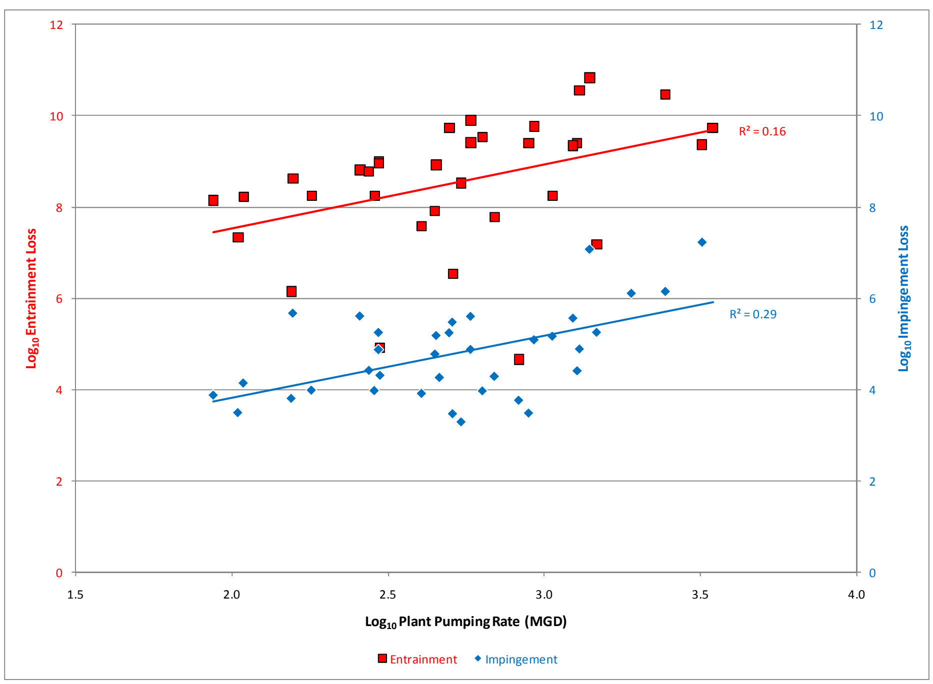

Figure 3-61
Regression of I&E Annual Estimates against Design Pumping Capacity for Facilities in the combined Coastal Group (I=38, E=34) in the EPRI 316(b) Database

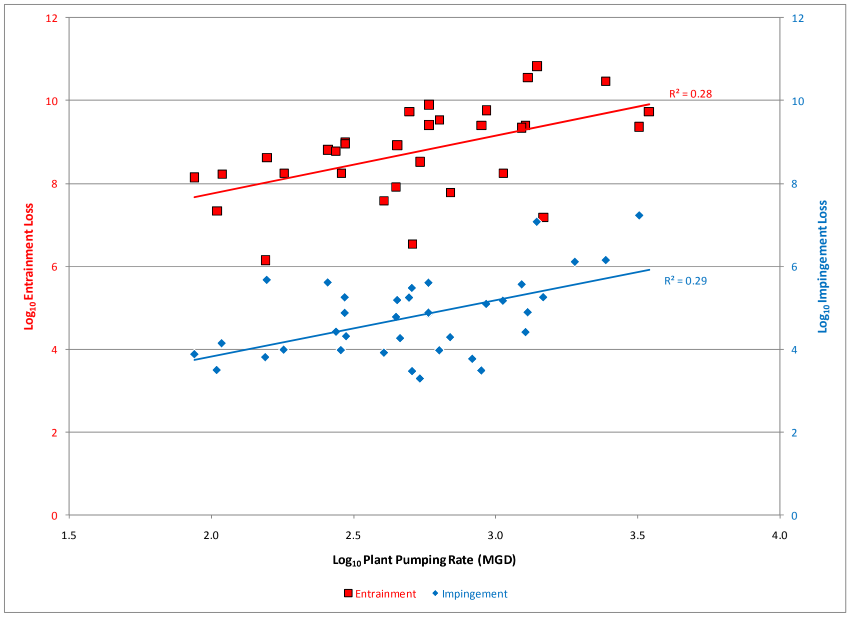

Figure 3-62
Regression of I&E Annual Estimates against Design Pumping Capacity for Facilities in the combined Coastal Group (I=38, E=32) in the EPRI 316(b) Database excluding Facilities with the Lowest Annual Entrainment Estimates

Rivers

This combination of small and large rivers results in the largest impingement data set (N=85). Despite this large data set, the impingement r-square value is low (0.31) (Figure 3-63). The entrainment r-square value is even lower (0.19).

All Plants

Although this grouping includes a wide variety of plant sizes and waterbody types, one might expect a size relationship to be discernable given the robustness of the data set; however, the r-square for entrainment is low (0.14) and the r-square for impingement (0.25) is only slightly higher (Figure 3-64). If the zero entrainment estimate is removed, the r-square for entrainment increases only slightly (0.19) (Figure 3-65).

It is important to note that a rigorous analysis of the relationship between flow and impingement and entrainment would require a comparison of densities with the actual flow at the time of the event. Such an analysis is beyond the scope of the current database and this analysis. In general, the regression analyses show that as the design capacity flow rate increases, I&E increases; however, the correlations are weak good. This is likely due to site specific factors not addressed in this analysis. Therefore, while this analysis did not find a strong correlation between flow and impingement or entrainment for the national or regional/waterbody types with the data that are available, the underlying relationship remains unclear.

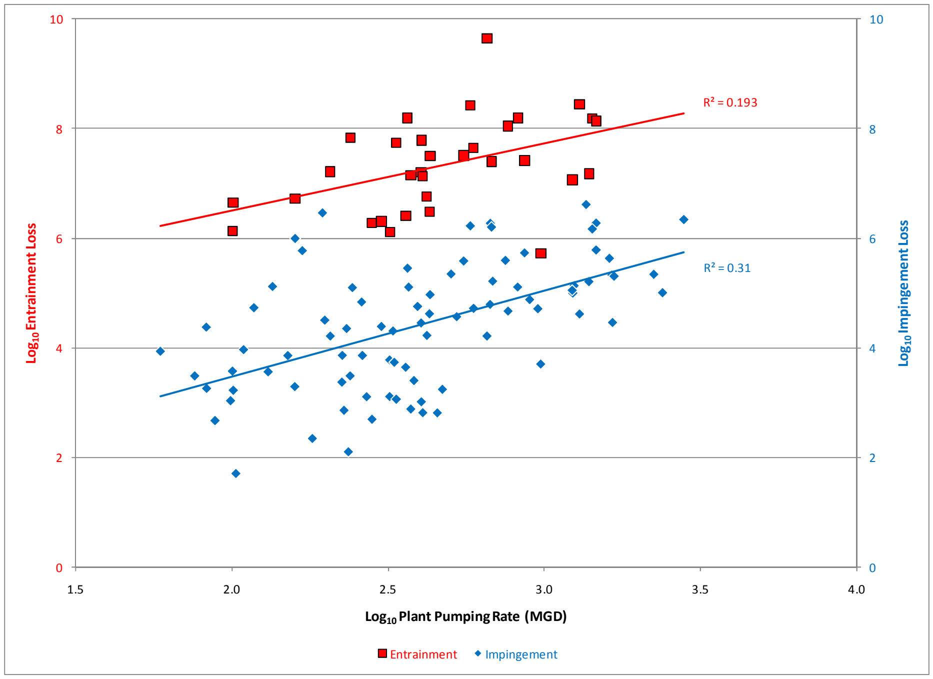

Figure 3-63
Regression of I&E Annual Estimates against Design Pumping Capacity for Facilities in the combined Rivers Group (I=85, E=32) in the EPRI 316(b) Database

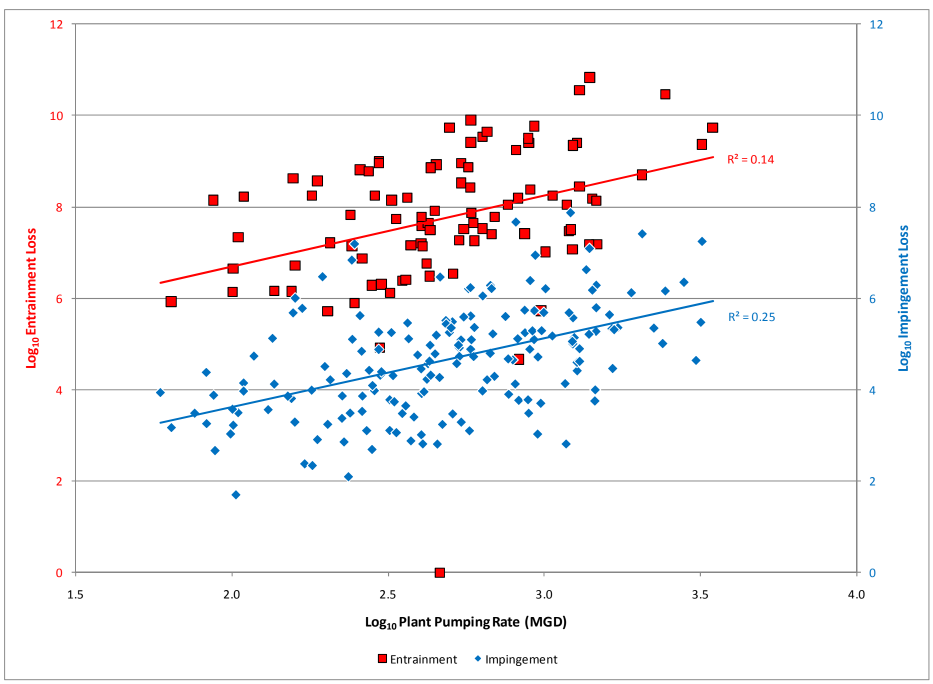

Figure 3-64
Regression of I&E Annual Estimates against Design Pumping Capacity for all Facilities (I=175, E=92) in the EPRI 316(b) Database

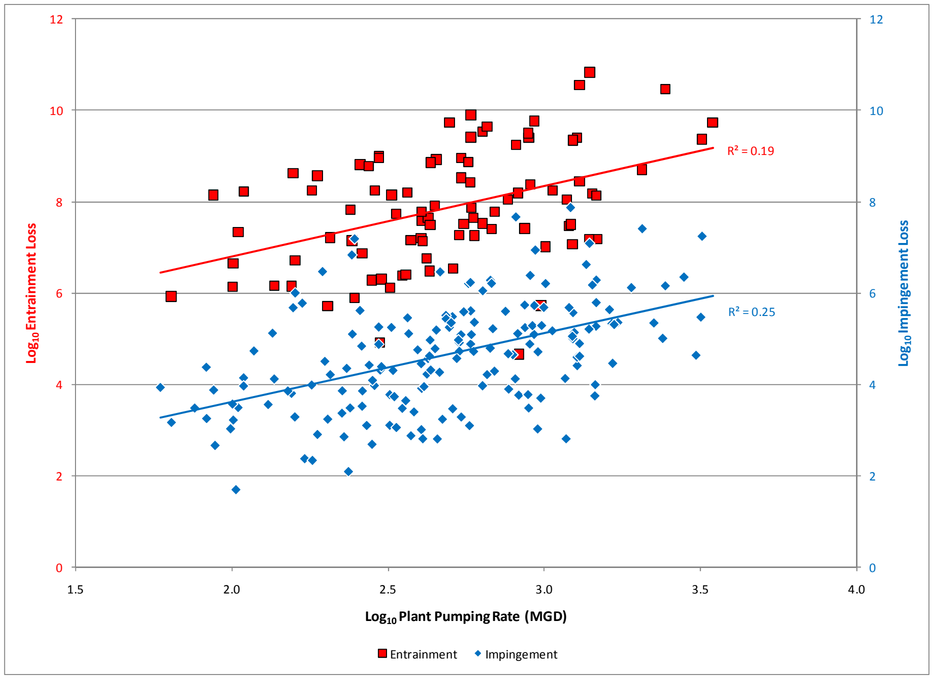

Figure 3-65
Regression of I&E Annual Estimates against Design Pumping Capacity for all Facilities (I=175, E=91) in the EPRI 316(b) Database excluding the Facility with the Lowest Annual Entrainment Estimate

3.3.4 Comparisons of I&E Data Collected during Two Different Sampling Years

Forty-two facilities collected impingement data during two different years and 13 facilities collected entrainment data during two years (Table 3-8). Examination of these data indicates considerable differences between sampling years. Over half the impingement values differed by an order of magnitude between the two years and at seven facilities the difference between the two years was at least 30-fold (Table 3-8). If the two years are treated as replicates, the coefficient of variation for the impingement data was 353 percent meaning that, on average, impingement rates change by 3.5-fold from one year to the next. A study of impingement at 13 power plants on the Ohio River found similar results, with an average change between years of 80 percent and a change of 95-98 percent at 7 of the 13 plants (King et al. 2010).

Entrainment data also varied considerably between years but not to the extent exhibited by the impingement data. Nine of the 13 facilities showed less than a 2-fold difference between years, with the remaining four plants showing differences of 2.4 to 4.7 fold (Table 3-8). The entrainment data had a between-year coefficient of variation of 71 percent meaning that, on average, the difference between years was 1.7-fold.

Table 3-8
Comparisons of I & E Annual Estimates Collected during Two Different Years

	Impingement			Entrainment		
Facility	**Year 1**	**Year 2**	**Percent Change**	**Year 1**	**Year 2**	**Percent Change**
1	3,155	3,018	-4%	2,549,376,893	–	–
2	130,803	119,799	-8%	8,447,807,489	3,189,196,597	-62%
3	13,706,709	10,626,765	-22%	51,816,524,580	84,261,011,375	63%
4	85,342	36,555	-57%	101,228,558	60,352,918	-40%
5	–	–	0%	6,318,044,396	4,329,475,902	-31%
6	171,031	140,458	-18%	841,279,999	–	–
7	39,685	34,441	-13%	51,263,117	36,346,837	-29%
8	129,451	35,611	-72%	7,092,010	30,107,502	325%
9	–	–	0%	184,473,045	39,180,483	-79%
10	4,279,644	580,982	-86%	280,357,595	204,452,005	-27%
11	120,848	268,625	122%	–	–	–
12	2,677	1,082	-60%	–	–	–
13	359,142	91,412	-75%	–	–	–
14	32,096	42,769	33%	–	–	–
15	54,271	151,032	178%	–	–	–
16	18,212	13,666	-25%	–	–	–
17	1,471,127	25,225	-98%	–	–	–
18	1,839,727	271,561	-85%	–	–	–
19	41,756	234,441	461%	–	–	–
20	581	875	51%	–	–	–
21	4,230,782	233,122	-94%	–	–	–
22	943,182	54,476	-94%	–	–	–

Table 3-8 (continued)
Comparisons of I & E Annual Estimates Collected during Two Different Years

	Impingement			Entrainment		
Facility	**Year 1**	**Year 2**	**Percent Change**	**Year 1**	**Year 2**	**Percent Change**
23	44,849	94,043	110%	–	–	–
24	75,119	796,106	960%	–	–	–
25	136,685	3,125	-98%	–	–	–
26	647,592	150,746	-77%	–	–	–
27	186,856	224,584	20%	–	–	–
28	1,988,682	66,278	-97%	–	–	–
29	178,037	9,116	-95%	–	–	–
30	60,114	1,345	-98%	–	–	–
31	19,587	38,952	99%	–	–	–
32	24,964,466	8,503,561	-66%	–	–	–
33	342,607	35,999	-89%	–	–	–
34	361,826	27,673	-92%	–	–	–
35	5,689,074	205,990	-96%	–	–	–
36	105,634	324,877	208%	–	–	–
37	322,018	7,571	-98%	–	–	–
38	1,033,701	207,488	-80%	111,898,211	161,827,024	45%
39	19,527	13,658	-30%	4,770,000,000	4,000,000,000	-16%
40	355,844	2,641,186	642%	122,123,878	183,196,758	50%
41	19,104	83,861	339%	45,180,468	60,902,572	35%
42	88,856	138,762	56%	6,731,000	16,431,000	144%
43	3,206,267	39,215	-99%	21,400,986	–	–
44	754,511	25,164	-97%	29,373,350	–	–

3.3.5 Threatened and Endangered Species

Threatened and endangered (T&E) organisms were impinged at 8 percent of the responding plants and entrained at 3 percent of the plants, typically in relatively low numbers. No federally listed T&E fish species were impinged in any of the studies. Species identified by states as threatened, endangered, or otherwise of concern were reported as part of impingement at plants in only four of the 12 regions; Great Lakes, Large Rivers, Midwestern Reservoirs, and Small Rivers. During impingement sampling, T&E species were collected at 19 of the 240 responding plants. At plants in the Small Rivers category, lake sturgeon was the most commonly reported listed species with a total of 52 individuals impinged. At plants in the Large Rivers category, river darter (321 individuals) was the most abundant listed species impinged. At plants on the Great Lakes, longnose sucker was the most commonly listed species impinged (N= 7). The only regions where T&E organisms were entrained were Great lakes and the Mid-Atlantic Coastal, representing three plants (out of 112 plants nationwide reporting entrainment data). The number of entrained T&E organisms was low at two of the three plants but much higher (12,750 shortnose sturgeon larvae) at the third plant. This number, although higher than any others provided for this study, represents fewer larvae than are produced by one fish, as female shortnose sturgeon produce 48,000-99,000 eggs (Dodswell 1976). Shortnose sturgeon is federally listed, the only such species reported by any of the 112 respondents with entrainment data.

Section 4: Discussion

4.1 Intake Characteristics

Based on information provided by respondents to survey questions on cooling water intake structure characteristics, the assumptions EPA made regarding the intake configuration of a "typical" once-through power plant appear reasonable, although there were a number of exceptions. EPA had assumed that most intakes were located along shorelines and according to the survey, 52 percent of the plants do indeed have shoreline intakes. EPA also assumed that the typical intake was at the surface and this was also found to be the case as 54 percent of the plants responding had surface intakes. Thus, for both of these measures, slightly more than half the plants were "typical". According to the survey, 35 percent of the plants had canals or forebays and 9 percent had offshore intakes. In terms of the depth from which water was withdrawn, 30 percent of the plants had submerged CWIS and 17 percent had CWIS that had a combination of surface and submerged intakes.

4.2 Study Design

The suspended 2004 EPA 316(b) Phase II Rule provided generic guidance for I&E studies. For example, it required that applicants provide, *"sufficient data to characterize annual, seasonal, and diel variations in impingement mortality and entrainment,"* that those data *"be collected during periods of representative operational flows for the cooling water intake structure and the flows associated with the samples must be documented,"* and *"the sampling and data analysis methods you propose must be appropriate for a quantitative survey and include consideration of the methods used in other studies performed in the source waterbody."* The Rule, however, did not provide detailed guidance on study methodology (e.g., how many samples to collect or how to collect those samples), so each company developed a design and submitted it to their permit authority for review. Given this wide latitude, it was not surprising that study design varied considerably. Most impingement studies were conducted for one year, thus allowing seasonal patterns to be considered. Similarly, most entrainment studies comprised a full larval season so that changes in larval abundance for each species or taxa could be detected. It should also be noted that as part of the Rule, facilities were required to prepare PICs (Proposal for Information Collection) that described certain data they had, data they proposed to collect, and how they proposed to collect it. These PICs were submitted to the appropriate regulatory agency for review. Thus, the studies summarized in this report were all based on sampling designs that were sent to the appropriate agency for review prior to implementation.

4.3 Biological Results

4.3.1 Impingement Composition

At estuarine and marine plants, each geographic region had a different composition regarding the species and taxa impinged. Even along the East and Gulf coasts, there was relatively little overlap among dominant organisms. The only exception was blue crab which ranked in the top five in all three non-western coastal regions. Composition was more consistent in freshwater where, based on rankings, clupeids, either gizzard shad or threadfin shad were the dominant group in all six of the freshwater regions (Table 3-3). Based on relative abundance, these two clupeids were also numerically dominant in all freshwater regions (Figures 3-7 through 3-12). Alewife, another clupeid, contributed appreciably to impingement in the Great Lakes and Southeastern Reservoirs. Based on relative abundance the contribution of clupeids in the six freshwater regions was:

Table 4-1
Contribution of Clupeids in the Six Freshwater Regions

Region	% Clupeids
Great Lakes	71.3
Southeastern Reservoirs	66.5
Midwestern Reservoirs	97.4
Southwestern Cooling Lakes	73.3
Small Rivers	90.7
Large Rivers	90.3
Average	81.6

Clearly, in freshwater, impingement is primarily a clupeid-dominated phenomenon. Although not numerically dominant, bluegill was a key component of impingement in several freshwater regions, with impingement of freshwater drum, channel catfish, and emerald shiner being appreciable in some regions or waterbody types.

4.3.2 Entrainment Composition

As was the case for impingement, the composition of entrainment in estuarine and marine areas differed considerably among regions except for bay anchovy. Bay anchovy eggs and/or larvae ranked in the top five at all three non-western coastal plants (Table 3-4). Although bay anchovy ranked high at many plants, it was numerically dominant only in the Mid-Atlantic Coastal region where its eggs and larvae accounted for 46 percent of the ichthyoplankton entrained (Figure 3-27). In the two freshwater regions where multiple entrainment studies were conducted, clupeids were important (28 to 33 percent) (Figures 3-31 and 3-32), but did not overwhelmingly dominate entrainment estimates as they did the impingement estimates. Other important contributors to entrainment in freshwater systems were freshwater drum, centrarchids, and various minnows (Figures 3-31 and 3-32).

4.3.3 I&E Abundance

Annual impingement or entrainment values for the various species are not an indication of adverse impact to those species. Adverse environmental impact associated with impingement and entrainment would depend on numerous site-specific factors such as:

- Magnitude of those losses;
- Size (age) of the individuals lost (note - impinged fish for most species tend to be juveniles rather than adult fish; this is especially true for fish that reach larger sizes at maturity);
- Life history of the species involved, especially their fecundity;
- Size of the at risk populations;
- Availability of recruitment from other sources (most important for species with "open" populations that are wide-ranging, such as many marine species);
- Biological compensation;
- Losses from other sources such as recreational or commercial fishing; and
- Presence of other stressors such as disease and pollution.

Except for the first bullet, these factors are outside the scope of this project and the current database base does not contain the information necessary to address them. Equivalent adult or production foregone analyses and other information are necessary to put these losses into perspective (EPRI 2004b, 2005b, 2011b). Information on the relationship between water withdrawal and environmental impacts is reviewed in EPRI (2003) and a more recent review on the scientific evidence for adverse environmental impact from I&E is reviewed in EPRI (2011a). Information on the economic value of I&E can be found in EPRI (2011b)

4.3.4 Relationship between Design Pumping Capacity and I&E

The EPA's 2011 proposed Existing Facility Rule as well as the suspended 2004 EPA Phase II Rule assume there is a direct and positive relationship between the volume of water pumped and I&E. To examine the reasonableness of this assumption, log-transformed I&E annual estimates were regressed against the design pumping capacity (also log-transformed) of each plant, by region (Section 3.3.3). It was evident that in many cases, there was not a strong relationship between I&E and pumping rates. It was also shown that occasionally a single point greatly affected the r-square values and slope of the regression lines. This is not meant to suggest that these high or low values are erroneous but only to demonstrate that because of how regressions are calculated, a single point can greatly influence the r-square value and the perceived relationship between the two variables being compared, particularly if the sample size is small (e.g., see Figures 3-44 and 3-45). The data and regression calculations also demonstrate the need to assess I&E on a site-by-site basis. Table 4-2 summarizes the r-square values for all the regions. It shows that at the freshwater plants, r-square values for impingement range from very low (<0.01) to moderate (0.45) and that entrainment r-square values were low (<0.20) for both freshwater regions (Small Rivers and Great Lakes). This indicates that at freshwater plants, pumping capacity is not an accurate predictor of I&E. Estuarine and marine sites generally had higher r-squared values than the freshwater sites. Impingement r-square values ranged from 0.15 to 0.49 (Table 4-2). Entrainment r-square values at estuarine and marine sites ranged from <0.01 to 0.93, and, before any adjustments, were high at one of the four coastal regions and in Hawaii. After adjustment, r-square values increased in the Northeastern Coastal region and especially in the Southeastern Coastal region. All three of the three combined groups (i.e., lakes/reservoirs, rivers, and coastal) had low r-square values for impingement. Interestingly, when the four coastal regions were combined, the resulting r-square (0.29) was lower than the r-square for three of the four regions making up this group. When all the data are combined (i.e., all plants), the r-square values for I&E are 0.25 and 0.14, respectively, suggesting only a weak relationship with pumping capacity. As indicated earlier, a rigorous analysis of the relationship between flow and impingement and/or entrainment would require correlating sampling events with actual flow at the time of the event which was beyond the scope of the study. Others have reported a similar lack of a strong relationship between the volume pumped and the number of organisms entrained. For example, EPRI (2003) concluded that "except for some specific regions—power plants on the Great Lakes and Northeast—no relationship between the numbers of organisms entrained and the volume of water withdrawn was found in the United States. High variability was common in all analyses performed."

Recent studies have shown other factors are important in terms of influencing impingement. King et al. (2010) found that impingement at 15 Ohio River power plants did not vary based on plant size. Instead they found that impingement varies seasonally in response to YOY production and as a result of episodic events. Other reports indicate that impingement increased when river flows and debris loads were high (EPRI 2006 and 2007). Studies at Plant Barry in Alabama found that a disproportionate number of impinged fish were emaciated or diseased (EPRI 2010), indicating that most healthy fish can avoid impingement. Lastly, large numbers of fish, especially clupeids, are often impinged during cold water periods suggesting that during this period many fish impinged may be moribund (EPRI 2011c and 2008; King et al. 2010). It remains unclear to what extent the volume of water pumped is a good predictor of impingement. At estuarine and marine plants, there does appear to be some relationship between entrainment and pumping rates but any such relationship for the freshwater plants was weak at best (r-square=0.14 to 0.19 without any adjustments) (Table 4-2).

An examination of data from facilities that conducted sampling during two different years showed significant between-year variation in I&E. This information suggests that I&E at a facility is highly variable, episodic in nature, and may not correlate to plant flow.

Table 4-2
Summary of R-square Values for Regressions between Plant Pumping Capacity and Estimated Annual I&E for Facilities in the EPRI 316(b) Database

Region	R-square	
	Impingement	Entrainment
Freshwater		
Large Rivers (N=53)	0.35	-
Small Rivers (N=32)	0.24	0.19 (0.34)[b]
Rivers (N=85)	0.31	-
Southeastern Reservoirs (N=7)	<0.01	-
Southwestern Cooling Lakes (N=10)	0.14 (0.16)[a]	-
Great Lakes (N=22)	0.45	0.14 (0.45)[a]
Midwestern Reservoirs (N=10)	0.14 (0.47)[a]	-
Lakes and Reservoirs (N=49)	0.08	-
Marine/Estuarine		
West Coast (N=6 for IM, 5 for E)	0.15	0.80
Northeastern Coastal (N=17 for IM, 16 for E)	0.33	0.23 (0.39)[a]
Southern Coastal and Gulf (N=8 for IM, 5 for E)	0.35	<0.01 (0.91)[a]
Mid-Atlantic Coastal (N=7 for IM, 8 for E)	0.49	0.46
Coastal (N=38 for IM, 34 for E)	0.29	0.16 (0.28)[b]
Hawaii (N=3 for both IM & E)	0.42	0.93
All Plants (N=175 for I, 92 for E)	0.25	0.14 (0.19)[a]

[a] R-square after a single point was removed from the dataset.

[b] R-square after two points were removed from the dataset.

4.3.5 Threatened and Endangered Species

Only eight percent of the plants reported listed species during impingement and only three percent reported any entrained. In most of the cases where T&E species were reported, the numbers were for a few (<50) individuals. The only exceptions were river darter in the Large Rivers category and shortnose sturgeon at one plant. However, it is important to note that by definition protected species in most cases and especially for federally listed threatened and endangered species are expected to be found in relatively low abundance. Therefore, they may not be collected at some facilities, especially those which sampled on a less frequent basis (e.g., monthly entrainment sampling). Also, especially in freshwater, taxonomic resolution is fairly low, so some T&E fishes may have been overlooked.

Section 5: References

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