CLIENT DRAFT

ANALYSIS OF ENTRAINMENT AND SURVIVAL OF TARGET FISH SPECIES AT THE SANTEE COOPER HYDROELECTRIC PROJECT, SOUTH CAROLINA

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EXECUTIVE SUMMARY

More than 40 entrainment studies conducted in the United States in recent years (FERC 1995), and numerous studies conducted to specifically estimate turbine passage survival (EPRI 1992, 1997) provided an extensive database that was used to estimate potential entrainment and survival. These estimates, along with a characterization of the Santee Cooper developments, were assessed to examine the potential impacts of entrainment at the Santee Cooper Hydroelectric Project (the Project) on the seven diadromous fish species that occur in the Project area.

The Project is operated as a semi-peaking hydroelectric generating facility based on an operating "rule curve." From Lake Marion, flow is passed through the single turbine unit of the Santee Hydroelectric Development to maintain a minimum flow of at least 500 cfs in the Santee River. Normal flow exceeding the minimum leaves Lake Marion and enters Lake Moultrie via a free flow diversion canal. Lake Moultrie has two possible outlets: flow is passed to the Cooper River through the turbines of Santee Cooper's Jefferies Hydroelectric Development or to the Santee River after passing through the U.S. Army Corps of Engineers (USACE) rediversion project that includes the St. Stephen Hydroelectric Development. The St. Stephen Development is not part of Santee Cooper's Federal Energy Regulatory Commission (FERC) licensed hydroelectric project. During high flow conditions, when inflow to the Project exceeds the generating capacity of all the hydroelectric developments, excess flow is passed through the Santee spillway.

At least seven diadromous fishes have been reported from the Santee and Cooper rivers, including: striped bass, American eel, Atlantic sturgeon, shortnose sturgeon, American shad, hickory shad and blueback herring. Upstream fish passage into Lake Moultrie occurs through the Santee Cooper Project Pinopolis lock at the Jefferies Development and a fish lift at the St. Stephen Development. Downstream passage is achieved through turbines at the Jefferies, Santee, and St. Stephen developments, through a downstream passage facility at the St. Stephen Development, and via the Santee Dam spill gates when flows exceed generation capacity. Emigration of the target species out of the Santee Cooper Project is the focus of this study.

A review of life history data relative to seasonal dispersal and movements was conducted for each species and physical attributes of the Santee and Jefferies Developments were characterized. An estimate of entrainment potential was developed based on rates observed at other sites where quantitative sampling of entrainment has been conducted. Acceptability criteria were developed to select the studies to be used in the analysis. Along with quantitative values, qualitative ratings of entrainment risk (high, moderate-high, moderate, moderate-low, or low) were assigned by examining where the average entrainment density for a given species fell within the range of densities observed for each size class. This provided a relative value of entrainment potential for each species.

An estimate of turbine passage survival was developed based on rates observed at other sites similar to the Santee Cooper Developments and on estimates derived from predictive models. A database of turbine passage survival studies was compiled and acceptability criteria were developed to screen for studies that were conducted at developments similar to the Santee

Cooper developments. In addition, mathematical models specific to each development were used to estimate survival. Both quantitative and qualitative survival estimates were generated, with qualitative probabilities described as follows: high (90 to 100%), moderate-high (85 to 89%), moderate (75 to 84%), moderate-low (70 to 74%), and low (less than 70%).

Finally, estimates of entrainment potential and survival probability were considered together for individual species and size groups. The ratings are somewhat subjective and conservative, with higher ratings given when estimates were questionable between two categories. The closing discussion reviews site characteristics and species specific life history traits in light of the overall impact.

This evaluation indicates that operation of the Santee Cooper Hydroelectric Project relative to entrainment is not likely to have a considerable impact on the target clupeid species (American shad, hickory shad and blueback herring) or possibly striped bass. American eel, Atlantic sturgeon and shortnose sturgeon are likely to be more impacted. Previous studies and model predictions suggest that the impact to adult American eel could be moderately-high; however, other life stages are not significantly impacted. Model predictions for Atlantic sturgeon and adult shortnose sturgeon, a federally endangered species, suggest that potential impact at the Santee Cooper Project is high. A moderate level of impact was predicted for juvenile shortnose sturgeon.

All of the target species are diadromous and are therefore expected to migrate downstream out of the Project area during some time in their life. The three species most impacted by the Project grow to considerable lengths, a life history trait that compromises their ability to pass through the Project unaffected.

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1.0 INTRODUCTION

South Carolina Public Service Authority, also known as Santee Cooper, is in the process of relicensing the Santee Cooper Hydroelectric Power Project (the Project) (FERC No. 199-SC). The Project is located in southeast South Carolina on the Santee and Cooper Rivers in Berkeley, Calhoun, Clarendon, Orangeburg, and Sumter Counties (Figures 1-1 and 1-2) and is operated in accordance with a Federal Energy Regulatory Commission (FERC) license that expires on March 31, 2006.

In the First Stage Consultation phase of the FERC relicensing process, Santee Cooper received study requests from the following state and federal agencies: South Carolina Department of Natural Resources (SCDNR), U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS) and the South Carolina Department of Health and Environmental Control (SCDHEC). Santee Cooper compiled the requests and combined similar study suggestions, resulting in a list of 16 study requests. This study addresses the objectives of phase 1 of study request 8: Entrainment and Mortality Studies.

The objective of this study was to characterize annual entrainment effects the Santee Cooper Hydroelectric Project may have on the seven diadromous target species of fish. This information will be used by Santee Cooper to consider enhancement measures at the Project, and by FERC in preparation of appurtenant NEPA documents. There are three aspects of interest in entrainment assessment for this project: (1) characterization of the Santee Cooper Project facilities relative to entrainment potential, (2) characterization of the size and time-frame target species may be entrained through the Project, and (3) survival of the entrained fish. This evaluation does not consider how fish move out of the project reservoirs (Study Request 4), but does consider the ultimate point of estimating survival of those that pass through the project facilities.

There are several potential downstream routes for emigrating diadromous fish, including the Santee Cooper Project turbines, Pinopolis Lock, and the Santee Dam spillway. In addition, downstream passage is available through the USACE St. Stephen Project downstream passage facility and the turbines.

Fish entrainment has been the subject of more than 40 studies nationwide over the past 10-15 years (FERC 1995, EPRI 1997), including several studies in South Carolina. Field studies typically sample fish from the flow of project turbines at regular intervals through the course of a year. These catch data are then extrapolated to un-sampled periods to estimate the number of fish that are entrained annually (EPRI 1997). Given the substantial variability associated with sampling and with periods of fish entrainment, estimates of the number of fish entrained have great variability and thus wide confidence limits. Much of the available empirical information, including the difficulties in conducting entrainment studies, was collected during relicensing activities associated with the ‘class of ‘93’ (a disproportionate number of FERC licensed project licenses expired in 1993).

Numerous studies have been conducted to estimate survival rates for fish of various species and sizes passing through hydroelectric turbines. The most reliable evaluations are conducted as controlled experiments using marked and recaptured fish (EPRI 1992, 1997). In controlled experiments, at least two groups of fish, control and treatment, are used. The purpose of the control group is to provide information on the effects induced by the experimental procedures or environmental factors not associated with the variable of interest (in this case turbine passage). Survival of the control group is used to adjust the survival of the treatment group for those biases associated with factors other than the treatment variable. The control group is exposed to all aspects of the experimental procedure except the treatment variable. High control group survival indicates that experimental procedures and environmental factors had little or no effect on the observed survival of the treatment group. Statistical models are used to adjust the observed treatment group survival for the effects observed in the control group. The result is an estimate of relative survival, or survival of treatment group fish relative to (i.e., adjusted for) the survival of the control group fish. Statistical treatments are used to estimate confidence limits around the estimates of survival. Mathur et al. (1996a) provide an example of recent passage survival statistical models.

The site characterization aspect of this analysis allows for the identification of temporal and spatial factors that may affect entrainment potential. The most common temporal factor is the amount of time a unit operates, those operating more often than others tend to entrain more fish. Spatial factors such as a units' proximity to the shoreline, may also influence differences in entrainment rates between units. Studies have shown that when one unit in a forebay is much closer to the shoreline than another, entrainment abundance is generally higher at the near-shore intake (FERC 1995), although this may not be the case for more pelagic groups such as clupeids.

2.0 PROJECT DESCRIPTION

2.1 Project History

As early as 1770, over 150 years before construction on the Santee Cooper Hydroelectric Project commenced, a plan to link the Santee and Cooper Rivers was proposed for the purpose of transporting goods from the interior of the state to the port of Charleston. The initial effort included a canal that was completed in 1800. Subsequently, railway transportation displaced commercial traffic in the canal.

Connecting the Santee and Cooper Rivers was considered again in 1913 when the Columbia Railway and Navigation Company (CRNC) proposed building a canal adjoining the rivers. The CRNC ran a steamship service from Columbia to Georgetown and was seeking a route bypassing the lower Santee River, a difficult area to navigate. Included in the proposal was the construction of a small hydroelectric generating station. In 1926, the Federal Power Commission (now the Federal Energy Regulatory Commission) granted the company a license to construct a canal, dam and power plant. However, because of the economic depression that began in 1929, it became apparent that government financing of the project would be required. To secure federal funding, establishment of a state agency for the project was necessary. In April, 1934 an act was passed by the General Assembly and a bill signed by the Governor of South Carolina to incorporate the South Carolina Public Service Authority (SCPSA), commonly know as Santee Cooper. The act empowered the SCPSA to build canals, dams and power plants, to divert the waters of the Santee River, to set rates for the electricity it produced, to borrow money and to issue bonds. But, under no circumstances was the state of South Carolina to be financially obligated by the authority. In May, a management board was formed, and the license and franchise of the CRNC was subsequently purchased. In the same year, a bill financing the Project was passed by the United States Congress.

Delayed by the filing and subsequent resolution of a lawsuit initiated by a group of private power companies, work did not begin on the Project until 1938, with land clearing for the dams and powerhouse initiated in 1939. Complete communities were relocated, including churches, schools, cemeteries, and more than 900 families to accommodate local residents. Over 12,000 men were employed. Malaria specialists were hired and succeeded in eliminating the deadly disease that had been a common threat to workers in the marshes of South Carolina. Sand and clay obtained on-site provided the principle construction material for over 40 miles of dams and dikes created for the Project.

In November, 1941 the last spillway gates were closed on the Santee Dam, filling Lakes Marion and Moultrie. An inland navigation route from Columbia to Charleston, encompassing a 122 mile, clearly defined, navigable stretch of waterway was established. By July, 1942 all five units of the Jefferies Hydroelectric Station were in service and in 1950, a minimum flow generating unit was installed at the Santee spillway.

Due to concerns about sediment deposition in Charleston Harbor, in the 1980's the USACE constructed the St. Stephen Project which rediverted a substantial portion of the Santee River flows back into the Santee River (more details below). The USACE project had a substantial impact on flow allocation resulting in operation of the Santee Cooper Jefferies Station based on an allocation of a weekly average of 4,500 cfs of water. Santee Cooper uses the water allocation based on electric power demands, but must conform with a maximum weekly average of 4,500 cfs. In addition to reducing sediment transport into Charleston Harbor, the amount allocated to Santee Cooper was in part based on the flow that would keep the salt wedge intrusion downstream of industrial water users on the mid- and lower Cooper River.

2.2 Project Location

The Project is located in southeast South Carolina on the Santee and Cooper Rivers in Berkeley, Calhoun, Clarendon, Orangeburg, and Sumter Counties, South Carolina. The Project is approximately 50 miles north of Charleston and 60 miles southeast of Columbia, South Carolina. The Project includes Lake Marion, impounded by the Santee Dam on the Santee River; Lake Moultrie, impounded by the Pinopolis Dam on the Cooper River; and a diversion canal connecting the two impoundments (Figure 1-2).

The drainage area for Lake Marion is approximately 14,700 square miles above the Santee Dam. The area is drained by three major rivers: Saluda, Broad and Catawba-Wateree. The Saluda and Broad Rivers join to form the Congaree River, which in turn joins the Wateree to form the Santee River. The drainage area for Lake Moultrie is only slightly larger than the impoundment area, as the impoundment covers most of the original headwaters of the Cooper River. The total drainage area for the Project is 15,000 square miles.

The Pinopolis Dam and the Jefferies Hydroelectric Station are located approximately 48 miles upstream from Charleston Harbor on the headwaters of the Cooper River. The Santee Dam on the Santee River is approximately 78 miles upstream from the Atlantic Ocean.

2.3 Description of Project Area and Characterization of Lakes Marion and Moultrie

The Santee River is fed from headwaters originating in the Blue Ridge Mountains and flows in a generally southeasterly direction, crossing the Piedmont Region and the Atlantic Coastal Plain before flowing into the Atlantic Ocean north of Charleston. The Cooper River was formerly a tidal estuary rising near Moncks Corner, South Carolina, and flowing in a southeasterly direction for about 50 miles before discharging into Charleston Harbor.

Lake Marion is 35 to 40 miles long with a normal pool elevation of 75.0 feet (ft) (all elevations are referenced to the National Geodetic Vertical Datum (NGVD)). According to FERC records, the surface area of Lake Marion is approximately 100,000 acres. Lake Moultrie is about 10 miles long with a normal pool elevation of approximately 75.0 ft. FERC records show a surface area of 60,000 acres for Lake Moultrie.

During construction in 1941, the threat of World War II created a need for electricity. In response, the National Defense Board declared the Santee Cooper Project necessary for the national defense. Land-clearing plans for Lake Marion were revised to speed the construction process, allowing selected areas to be flooded without clearing. As a result, Lake Marion has a wilder appearance, accented by occasional stands of trees and tree stumps. Lake Moultrie, having been cleared completely, has more of an open water appearance.

Lake Marion has a maximum depth of about 70 feet, and an average depth of about 12 feet. The shallow nature of upper areas of Lake Marion provides abundant littoral habitat. Lake Moultrie also has a maximum depth of about 70 feet, but has an average depth closer to 20 feet and more open water than Lake Marion. Both lakes have very shallow areas extending for considerable distances from their shorelines into their interiors. In the upper reaches of Lake Marion and smaller areas of both lakes, thousands of acres of flooded cypress forest provide a naturalistic setting. Much of the shoreline consists of flat or gradually sloping topography. The Project includes approximately 23,000 acres of shoreland surrounding the two impoundments, nearly 2,700 acres of islands, and over 400 miles of shoreline.

The Lakes support a wide variety of uses including navigation, power generation, recreation, fish and wildlife habitat, waste assimilation, and potable water supplies. Both lakes are considered eutrophic. Some of the branches of Lake Marion have impaired uses due to low dissolved oxygen concentrations and excessive vegetation. Both lakes have an abundance of nutrients available from agricultural non-point sources in the basin. Hydrilla has been the subject of an intensive management program on the Santee Cooper lakes. First found in the upper reaches of Lake Marion in 1982, by 1993 approximately 45,000 acres of the lake system had been infested. Control was eventually achieved by stocking sterile, triploid grass carp (*Ctenopharyngodon idella*), a species of fish that forages on hydrilla and other vegetation. Control efforts have been effective, leaving a small proportion (300 to 400 acres) of the lakes total area infested by 1998. The control program, including grass carp stocking, is a cooperative effort between Santee Cooper and the South Carolina Aquatic Plant Management Council.

Annual mean dissolved oxygen levels in the lakes, the diversion canal, and below the Santee and Pinopolis Dams were above 6.0 mg/L from 1994 through 1998, with lows occurring primarily between July and August. Water temperature in Lakes Marion and Moultrie exhibits seasonal cycles typical of a southern temperate climate. Maximum temperatures in the high 20s to 30^{o}C are reached in July and August followed by extreme lows of 5 to 7^{o}C in January or February. The greatest variation in temperature occurs during spring and fall. Although surface temperatures reached up to 30^{o}C during summer months, cooler temperatures were recorded in deep areas of the lakes.

Water temperature, pH, and dissolved oxygen levels were found to generally be within ranges suitable for survival and growth of the target species for which this information could be found (Table 2-1). No data were identified for hickory shad and only temperature information was available for sturgeon and American eel.

The diversity of habitat found in the Santee Cooper lakes provides for a variety of fish species. Deep water (>18 ft), deep littoral areas (6 to 18 ft), shallow littoral areas (0 to 6 ft), shoal areas, emergent wetlands, and diverse structure are found in the lakes. This varied habitat supports a diverse fish population and a valuable sport fishery. Of the over 50 fish species found within the Project area, 15 are considered game fish and at least 16 are resident forage fish. Seven species of diadromous fish use the Project waters during some part of their life cycle.

The first self-sustaining population of striped bass without access to the ocean was found in the Project lakes. Today the population is supplemented annually with hatchery reared fish to support the large recreational fishery on the Lakes. The recreational fishery includes a variety of native and non-native species such as largemouth bass (*Micropterus salmoides*), blue catfish (*Ictalurus furcatus*), channel catfish (*Ictalurus punctatus*), flathead catfish (*Pylodictis olivaris*) crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), and white perch (*Morone americana*). The current world record channel catfish, weighing 58 lbs., was caught in these lakes and state records are currently held for largemouth bass, black crappie, chain pickerel (*Esox niger*) and blue catfish caught in Santee Cooper waters.

2.4 Project Facilities and Operation

The Santee Cooper Hydroelectric Project comprises two major impoundments – Lake Marion on the Santee River and Lake Moultrie on the Cooper River. The two impoundments are connected by a 5-mile long canal that diverts water from Lake Marion to Lake Moultrie. Project structures include the Santee (formerly Wilson) Dam on the Santee River, the Pinopolis Dam on the Cooper River, the Diversion Canal, and the Santee and Jefferies Hydroelectric Developments.

In the early 1980s the USACE constructed a Re-diversion Canal that diverts water from Lake Moultrie to the Santee River via the St. Stephen Hydroelectric Development located near the town of St. Stephen. Although these structures are not part of the FERC-licensed Santee Cooper Project, they are integral to its operations through a contract with the Federal Government. Both St. Stephen and Jefferies are operated in accordance with the Cooper River Re-diversion Agreement dated December 27, 1976 (Contract No. DACW60-77-C-0005), and subsequent supplemental agreements executed by the USACE and Santee Cooper.

Locations of the Project structures described below are shown on the Project boundary map included as Figure 1-2. General design drawings of Project structures relevant to this analysis are included as Figures 2-1 to 2-6.

The Project is operated as a semi-peaking hydroelectric generating facility based on an operating "rule curve" (Figure 2-7). The rule curve indicates the most efficient operating levels of Lakes Marion and Moultrie for differing conditions at various times of the year. In general, the rule curve follows the annual hydrologic cycle typical to the area. Lake elevation is dropped by a few feet in the winter, brought back up in the spring where it is maintained through the summer, and then lowered in the fall.

The majority of inflows to the Project are from the Santee River entering Lake Marion. Lake Marion is impounded by the Santee Dam, which includes a minimum flow hydroelectric unit and gated spillway to pass flow. During normal flow conditions, flow exceeding the minimum flow passed at the Santee Dam leaves Lake Marion through the Diversion Canal and enters Lake Moultrie. There is no control structure associated with the Diversion Canal; therefore, the Lake Moultrie headwater level is approximately equal to the Lake Marion headwater level minus minimum head losses through the canal. Lake Moultrie is impounded by the Pinopolis Dam.

All normal flow exceeding the minimum flow passed at the Santee Dam is passed through either the Jefferies Hydroelectric Station or the USACE St. Stephen development. The St. Stephen development is not part of Santee Cooper's FERC-licensed hydroelectric project. During high flow conditions, when inflow to the Project exceeds the generating capacity of the development generating units, the excess flow is passed through the Santee Spillway.

2.4.1 Santee Dam

The Santee Dam impounds Lake Marion on the Santee River. The dam consists of the North and South Dam earthen embankments, the gated Santee Spillway section, and the Santee Hydroelectric Station. The average freeboard height for all embankments is 13 ft.

2.4.1.1 Santee North and South Dams

The North Dam is an earthen embankment approximately 4.4 miles long and rises to a maximum height of about 50 feet above the downstream toe. Crest elevation is 90 ft.

The South Dam is approximately 2.8 miles long with a maximum height of about 40 ft above the downstream toe. The crest is generally at elevation 88.0 ft.

2.4.1.2 Santee Hydroelectric Station

The Santee Hydroelectric Station is located near Pineville at the abutment of the Santee Spillway to the South Dam (Figures 2-1 and 2-2). The entrance to the intake is protected by trash racks with 7.6 in clear spacing that descend to within 2 ft of the bottom of the intake floor. An 8 x10 ft reverse tainter gate covers the entrance to the 160 ft long, 8 ft diameter steel pentstock. The intake opening runs from approximately 16 ft below normal pond elevation to near the bottom of the lake.

The station contains a single, vertical-shaft Francis turbine supplied by Leffel. The turbine has an installed generation capacity of 1.92 megawatt (MW) and can develop 2,700 horsepower at a rated net head of 46 ft while discharging approximately 500 cfs. The turbine has 16 runner buckets with a runner diameter of 4.3 ft at the inlet and 5.2 ft at the outlet, and operates at a speed of 180 rpm. Turbine specifications are summarized in Table 2-2. The FERC license required minimum flow is 500 cfs, however Santee Cooper operates at approximately 600 cfs to assure compliance with the license requirement over a range of headwater elevations. Required minimum flow is passed through either the turbine or the spill gates. Average flow through the turbine for the years 1985-1999 was 545 cfs, ranging from 0 to 660 cfs. Average flow through the spill gates for the same time period was 1,165 cfs, ranging from 0 to 86,200 cfs.

The plant is equipped with an electronic system that automatically lifts the gang gate on the spillway to compensate for a flow reduction in the plant if the intake becomes blocked or the unit trips off-line. Thus, at least minimum flow in the Santee River is assured.

2.4.1.3 Santee Spillway

The Santee Spillway is a reinforced-concrete buttressed weir 3,400 ft long with 62 steel tainter gates (Figure 2-3). Each gate is 14 ft high by 50 ft wide. Six of the gates near the center of the spillway (collectively called the gang gate) are operated simultaneously with an electrically-operated hoist. An auxiliary diesel-powered generator is maintained on site for operation of the gates in the event of a power outage. The remaining gates are lifted by chains using one of two traveling gantry cranes. Gate openings are maintained by manually inserting dogs that prevent the chains from slipping through the overhead support. The spillway is designed to pass 500,000 cfs at a headwater elevation of 75.0 ft (msl). Average flow passed for the years 1985-1999 was 1,227 cfs, with a range of 0 to 86,200 cfs. The estimated total discharge capacity of the spillway is 1,390,000 cfs under maximum flood conditions.

2.4.2 Diversion Canal

Most of the water from the Santee River impounded by the Santee Dam exits Lake Marion through the Diversion Canal to Lake Moultrie. The Diversion Canal is approximately 5 miles long, although only about 3 miles of the canal is bordered by land (Figure 1-2). The canal is 200 ft wide at the bottom (elevation 48.0 ft) and nearly 400 ft wide at the surface. A submerged riprap weir is located just downstream of the Route 45 bridge crossing and rises to within 18 ft of the water surface at normal levels. Santee Cooper maintains a stockpile of stone material at the banks of the canal near the weir to enable a full closure of the canal. This closure would stop the reversal of flows into Lake Marion should there be an uncontrolled release from the Santee Dam.

2.4.3 Pinopolis Dam

The Pinopolis Dam impounds Lake Moultrie and consists of the East and West Dams; an East Dam Extension; the East, West, and North Dikes; a Lock; and the Jefferies Hydroelectric Station. The average freeboard height for all embankments is 13 feet.

2.4.3.1 East Dam, East Dam Extension and West Dam

The East Dam extends from the Jefferies Hydroelectric Station for slightly more than 1 mile. The East Dam Extension is a continuation of the East Dam and is similar in construction. It is approximately 4.9 miles long and has a maximum height of 40 ft above the downstream toe.

The West Dam is approximately 6,600 ft long and rises to a maximum height of 75 ft above the downstream toe. An additional embankment section, which is a low freeboard dike, extends 1,250 ft west of the west end of the West Dam and is sometimes referred to as the West Dam Extension. Three bolster sections were constructed in the late 1980s against the downstream face of the existing dam as part of a seismic upgrade.

2.4.3.2 East, West, and North Dikes

The East Dike extends from the vicinity of Bonneau to the USACE Rediversion Canal. It is approximately 5.8 miles long, with an average height of 15 ft. The West Dike is approximately 9.6 miles long with an average height of 25 ft. The North Dike extends from the Rediversion Canal a distance of approximately 6.3 miles. The embankment has an average height of about 15 ft.

2.4.3.3 Pinopolis Lock

The Lock consists of two concrete gravity walls and a pre-stressed concrete floor. The lift is about 67.5 ft from the normal tailwater elevation of 7.5 ft to a normal headwater elevation of 75.0 ft in Lake Moultrie. The lock chamber is 60 ft wide and 180 ft long and was designed to pass vessels with up to a 12-ft draft between Lake Moultrie and the tailrace canal.
The original purpose of the Pinopolis Lock was to provide navigational access between the tailrace canal and Lake Moultrie which then provided a navigational route from Charleston to Columbia. Subsequently, the Lock has also been used as a fish passage facility for anadromous fish. The Lock is opened, as needed, to allow for the passage of boats between the two bodies of water. Operation for fish passage occurs approximately six times a day from 0700 hours to 1800 hours during the time when anadromous fish are migrating upriver, generally from February through April or May.

2.4.3.4 Jefferies Hydroelectric Station

The Jefferies Hydroelectric Station, located near the town of Pinopolis, is 380 ft long by 185 ft wide founded on limestone (Figures 2-4 to 2-6). The structure contains four 40,000 hp (Units 1 through 4) and one 13,300 hp (Unit 6) generating units with space for an additional 40,000 hp unit (Unit 5). Each of the turbine/generator blocks for Units 1 through 4 and Unit 6 has three openings equipped with gantry-operated gates, and emergency stoplog slots. The top of each intake opening is approximately 16 ft below normal headwater elevation and drops to the bottom of lake. Trash racks with 5.6 in clear spacing, fully cover the intake. The area reserved for a fifth large unit (Unit 5) is blocked so that no flow passes through.

Units 1 and 3 have fixed blade turbines supplied by Newport News Company and units 2, 4, and 6 have Kaplan adjustable blade turbines supplied by Allis Chalmers. Units 1 through 4 have an installed generation capacity of 27 MW each and can develop 40,000 hp under 70 ft of head while discharging approximately 5,500 cfs through units 1 and 3, and 4,500 cfs through units 2 and 4. Unit 6 has an installed generation capacity of 8 MW and can develop 13,300 hp under 70 ft of head while discharging 1,400 cfs. Units 1 and 3 have eight runner blades and units 2, 4, and 6 have six runner blades. The larger turbines (units 1 through 4) operate at a speed of 120 rpm, and the smaller turbine at 200 rpm. Additional specifications for each unit are provided in Table 2-2.

3.0 METHODS

The process followed for the assessment of entrainment and survival of target fish species at the Santee Cooper Project is shown in Figure 3-1. First, available life history information was gathered on the seven target species found within the Santee Cooper Project area and a characterization of the development sites relative to entrainment was prepared. An assessment of each species' potential for entrainment was developed by considering each species propensity to be entrained at other studied sites, life history factors, and Project site characteristics that could influence vulnerability to entrainment. A parallel effort was undertaken to develop an estimate of turbine passage survival for each species. This assessment included a review of the survival rates observed at other sites for the target species and for fish passed through similar turbines, and survival rates predicted by models. Observed entrainment and survival rates were summarized for the Santee and Jefferies Stations with consideration given to the unique life history aspects of each of the target species and the site characteristics of each Development.

3.1 Species of Consideration

3.1.1 Target Species

The primary species analyzed for this study were the seven diadromous fishes known to occur in or around the Project area. The seven target species are: Atlantic sturgeon, shortnose sturgeon, blueback herring, American shad, hickory shad, American eel, and striped bass. Life history information, particularly as it may relate to entrainment potential, was reviewed and summarized for each of these species.

3.1.2 Surrogate Species

Because the target species were not frequently studied at other hydro projects where empirical studies have been conducted, similar species were chosen as surrogates for some aspects of this analysis. Species chosen as surrogates were those with life histories similar to one or more of the target species and were represented in the entrainment and, or survival databases developed for this analysis. A brief life history description was compiled for these species.

3.1.3 Resident Species

To provide a basis of comparison for ranking entrainment potential of the target diadromous species, the entrainment potential for a number of resident species was also calculated. Species included in the analysis were those identified as both occurring in the Santee Cooper Project area (Mead & Hunt 2001; John Bulak, personal communication) and documented in the qualified entrainment source studies as described in Section 3.3.1 below. However, potential survival and overall potential impact were addressed only for the target species.

3.2 Site Characterization Relative to Entrainment

Reviews of entrainment and survival data (FERC 1995, EPRI 1997) suggest that temporal and spatial factors particular to a site may affect entrainment rates. For this assessment, potential entrainment factors relevant to the target species were considered as follows:

- Intake proximity to shoreline – Entrainment tends to be higher at near-shore intakes due to a tendency for fish to follow the shoreline of rivers.

- Intake located in littoral zone – The littoral zone is the most productive region of a reservoir and is inhabited by many of the target species during early life stages.

- Abundant clupeids – Entrainment rates tend to be highest at projects with clupeids such as gizzard shad and threadfin shad.

- Intake depth – Fish are usually more abundant in shallower portions of a lake throughout most of the year.

- Winter drawdown – Drawdown of a reservoir to provide storage of winter and spring runoff may place fish in closer proximity to water intakes.

- Hydraulic capacity – More water passed through intakes will entrain more fish for a given entrainment rate.

Intuitively, approach velocity at the intake would also appear to be a factor of entrainment; however, FERC (1995) was unable to find a significant trend between entrainment rate and intake velocity and concluded that other factors related to intake siting may be more important. Therefore, intake velocity was not considered as a factor of entrainment for this assessment.

The factors listed above were reviewed and summarized for both the Santee and Jefferies Developments. The results were considered in the final evaluation of entrainment effects.

3.3 Literature-Based Estimate of Entrainment Potential

For the development of a literature-based estimate of entrainment potential for the target species the following steps were taken: a screening process was developed to identify qualified source studies; average entrainment densities observed for each species were calculated; and overall entrainment potential for each species was determined.

3.3.1 Entrainment Studies Acceptability Criteria

Acceptability criteria were developed to select the studies to be used in the analysis. The criteria were used to evaluate the quality and reliability of data provided by each study, and whether a sufficient amount of information was available on entrainment rates observed for individual species and size classes of fish. The criteria for a study to be acceptable were as follows:

- A study must have utilized full-flow tailrace netting techniques (using nets that sample the entire flow volume exiting one or more turbines). Studies which used partial-flow sampling techniques were not included due to potential for contamination of samples from collection of fish resident in the tailrace and low collection efficiency of entrained fish.

- The study must have provided sufficient information on the species and size composition of the catch for each month sampled. This level of information was required in order to compile the data from all studies into a common format for analysis by size categories of fish.

- The results of net efficiency tests associated with each study must have been available for use in adjusting catch data. To adequately estimate entrainment, the nets should be "calibrated" to measure the efficiency of the net at collecting entrained fish. This is usually accomplished by introducing known numbers of fish of various sizes and species into the nets, and an estimate of collection efficiency can be developed based upon the proportion that are caught by the net. The actual count of entrained fish in the net is then adjusted by this efficiency estimate. Although no minimum acceptable collection efficiency was established, nearly all of the studies included in the analysis had collection efficiency rates exceeding 70% for fish larger than 3 or 4 in.

- Sufficient information must have been available to allow the total volume of water sampled during each month to be estimated. This information was necessary to convert the numbers of fish collected into entrainment densities for use as a common index (entrainment densities) to account for differences in sampling effort between different months and sites.

- The study must have had no major apparent flaws that affected the quality and reliability of the data. Commonly identified flaws include extensive intrusion of fish into the net from the tailrace, frequent and extensive net damage, low and variable collection efficiency and atypical operating conditions during sampling.

3.3.2 Entrainment Database Development

This task was facilitated by the completion of a database of entrainment studies by the Electric Power Research Institute (EPRI 1997). The EPRI database includes data from entrainment studies conducted at 43 sites. All of the studies examined in the review conducted by FERC (1995) were also reviewed and considered for inclusion. In addition, a phone survey of representatives from hydroelectric facilities in the southeast United States was conducted to determine whether applicable studies had been conducted in recent years. Individuals contacted were Christina Massey (South Carolina Electric and Gas Company), Duane Harrell (Duke Power) and Barry Lovett (Alabama Power). All candidate studies were reviewed to determine whether they met the defined acceptability criteria.

3.3.3 Calculation of Entrainment Densities

Entrainment data from qualified sites were compiled by species for three size classes of fish: <8 in, 8 to 15 in, and >15 in total length. These size classes were selected based on consideration of size-specific differences that may occur in the numbers of fish entrained and in the estimated survival rate associated with turbine passage. The <8 in class was selected to encompass the smaller sizes of fish that are frequently entrained in large numbers. The 8 to 15 and >15 in classes represent larger fish that are usually entrained in smaller numbers. Reported rates of survival for fish passing through large propeller turbines typically ranges between 90 and 98% for small fish but can be lower than 70% for larger-sized fish (See section 4.4).

Information extracted from qualified studies included the numbers of fish collected and sampling effort. The fish count data were adjusted for the collection efficiency of the sampling nets (this step was accomplished in the EPRI database). For example, if a net was found to be 75% efficient in collecting fish <8 in. in length, the raw count was divided by 0.75 to derive an adjusted estimate of entrainment for the sampled unit. The EPRI database also provided the collection efficiency rates that were used to make these adjustments for each study.

Sampling effort information was used to estimate the average entrainment density by species and size class. The EPRI database provides the number of hours that sampling was conducted in each month at each site. This information is provided in terms of unit hours (e.g., two units sampled for three hours would equal six unit hours of sampling). Although information on the hydraulic capacity of the sampled units is provided for all sites, direct estimates of the volume of water sampled were not available for all studies. In cases where this information was not available, the water volume sampled was estimated using the average hydraulic capacity of the sampled units and assuming an average unit factor of 78% (i.e., the unit is operated at 78% of maximum hydraulic capacity). This unit factor was derived by calculating the average percentage of maximum unit capacity utilized during sampling for 25 sites where both sample volume and hours of unit operation data were available.

For each species and size class, the average entrainment density was calculated based on the density values determined for all qualified sites where the species was collected in at least one month. Average annual entrainment densities for each species were then rated to examine the range of densities that were observed for each size class. Qualitative ratings of entrainment potential (low, moderate-low, moderate, moderate-high, or high) were assigned by examining where the average density for a given species fell within the range of densities observed for each size class. Bounds for each of the five ratings were set using break-points that separated the species in a size class into groups that showed relatively homogeneous average rates of entrainment. Since larger fish are generally less abundant and more highly valued than smaller fish, a lower set of bounds was chosen to define each of the five ratings of entrainment potential for medium and large fish than those that were selected for small fish (see Section 4.3.2).

3.4 Turbine Passage Survival Assessment

Numerous investigations of fish turbine passage survival have been conducted, particularly over the last 10 to 12 years, providing a considerable dataset from which a qualitative approach to assessing turbine passage survival at the Santee Cooper Project was developed.

Although turbine passage survival estimates may vary from site to site, some trends have been recognized. For example, the size of a fish relative to the water passage-way within a turbine can greatly affect survival rate (Heisey et al. 1996). In general, fish that are small relative to the water passage-way have high survival rates, while larger fish passing through the same system have lower survival rates. Similarity in survival rates across multiple species for a given size

group, particularly for small fish, suggests that "species" may not be an important variable with respect to the effects of turbine passage (Heisey et al. 1996).
Estimates of turbine passage survival for three size groups of fish and for each of the target or surrogate species were developed using a multiple step process. First, relevant information from turbine survival studies was collected from primary literature, reports, and literature reviews and put into a database. A set of criteria were developed to identify studies acceptable for inclusion in the assessment and were used to cull the database to obtain a subset of studies reasonably comparable to the Santee Cooper Project in terms of turbine characteristics and, or fish species tested. Some reasonable yet conservative flexibility based on professional judgment was built into the process so that an adequate number of studies remained in the database. The resulting database was then used to characterize the estimated rate of survival for target and surrogate fishes passing through the Santee Cooper Project turbines.

Finally, to supplement the database, mathematical models were used to estimate survival probabilities for fish of varying lengths passing through the various types of turbines at the Project. The models are described below.

3.4.1 Database Development and Acceptability Criteria

A number of resources was queried to identify the realm of studies conducted on fish survival through hydroelectric turbines, including: available literature (see citations in Tables 4-7 and 4-8), which included a review of tag-recapture methodologies and their application (Eicher Associates 1987; RMC and Kleinschmidt Associates 1995; EPRI 1992, 1997); FERC reports (specifically related to the class of 1993; e.g., FERC 1995); personal contacts; and discussion with project team members.

The studies identified were put into two databases, one for Kaplan or propeller turbines and another for Francis turbines. Criteria were developed to establish a baseline for comparability and acceptability relative to scientific merit. Acceptability criteria were as follows:

- Established mark-recapture technique. Acceptable experimental protocols include proper use of adequate control groups, reasonable recapture rates of experimental specimens, and where possible a testing of assumptions. Sufficient reliable survival estimates are now available for some species and size groups (e.g., juvenile clupeids) such that a reasonable range of survival probabilities can be used to determine if a particular study result is reasonably consistent with other studies.

- Completeness of reported data on the important turbine characteristics known to affect fish survival and information on the tested species (or family), fish size, and other relevant information such as station discharge or environmental conditions.

- Control group survival $\geq$50% and sample size >25. The use of a control group facilitates isolation of effects due to the experimental treatment variable from those of the experimental procedures (e.g., handling stress or scale loss injury due to netting). Low control group survival may mask treatment effects and indicates that the experimental design and/or implementation were flawed to an extent that the results may not be

reliable. Acceptable levels of control group survival can vary depending on the situation or species of concern. Ideally, control group survival would be greater than about 80-90%; however, in some studies that level of survival cannot be achieved.
Adequate sample size is important to achieve reasonable precision levels and to reduce the importance of each individual fish in a given test. For example, if 100 fish are used in a treatment group, each fish represents 1% of the sample. However, if 10 fish are used, each fish represents 10% of the sample. As control group survival decreases or the recapture rate of treatment and control fish decreases, the sample size must increase to achieve a particular level of precision.

- Statistically based studies that included tests of validity of assumptions were given greater weight for inclusion. This applied to some studies in the Pacific Northwest where even though recapture rates were low (<1%), sample sizes were adequate to obtain reasonable precision and therefore reliable estimates of survival.

- Estimates did not appear too extreme for species/size groups relative to estimates from similar sites for that species/size group(s). This entailed qualitative, professional judgment.

- Immediate (less than one hour) as opposed to extended (48 -120 hr) survival estimates were used in this analysis for the following reasons: (1) there was only a small (<3%) difference in survival rate between the two estimates; (2) in some cases the reported extended survival estimate exceeded the estimated 1 h survival estimate (this happens if control fish die at a greater rate than treatment fish over the extended holding period); and, (3) to maintain a relatively large database. Studies of salmonids involving coded wire/branding and PIT tag techniques were included because they used well documented statistical designs and assumptions tests; however they do not differentiate among 1 h and extended survival.

The databases were also culled to include only studies conducted at facilities similar to those at the Santee Cooper Project, and studies conducted with the target or surrogate species. Facility characteristics used to cull the databases were:

- Similarity of turbines and their characteristics with Santee Cooper Project turbines (Kaplan, propeller or bulb turbines for Jefferies and Francis turbines for Santee). For the Jefferies Development, the number of runner blades was not used as a criterion because the majority of sites reviewed had fewer blades than the Jefferies turbines, reducing the number of acceptable sites. Because survival generally decreases with an increasing number of blades, comparison with the predictive model will help to identify any variability.

- For the large Kaplan and propeller units at the Jefferies Development (units 1-4): turbines with a runner diameter between 100 and 300 in, discharge volume between 1,000 and 10,000 cfs, head <100 ft, and turbine speed between 75 and 175 rpm.

- For the small Kaplan unit at the Jefferies Development (unit 5): turbines with a runner diameter between 50 and 150 in, discharge volume between 500 and 2,600 cfs, head <100 ft, and turbine speed between 100 and 300 rpm.

- For the Santee Development: turbines with a runner diameter between 30 and 84 in, discharge volume <1,000 cfs, number of runner buckets between 14 and 18, head <100 ft, and a turbine speed of less than or equal to 300.

  Some exceptions were made if a particular study was relevant in some way to this evaluation (e.g., if a particular study reported turbine discharge <1,000 cfs but the species tested were important to this evaluation it could be included in the database).

Studies collected were scrutinized using the criteria above and the resulting data put into a spreadsheet database. Where multiple survival estimates for a particular species under similar conditions were provided for a particular turbine, the arithmetic average was calculated.

3.4.3 <u>Information Extracted from Acceptable Studies</u>

The following information was extracted from the acceptable studies and included in the databases. In some cases, particular information was not available or was not presented in a useable fashion.

- Station name, location and turbine type.

- Turbine characteristics (e.g., number of blades, rpm, discharge volume, runner diameter, head, etc.) and operational mode for testing.

- Direct effects *vs.* indirect effects. Direct effects of mortality are those that are attributable to turbine passage, such as mechanical injury from blade strike or impact, decompression trauma, or shear effects, and can only be determined with immediate recapture of test specimens after turbine passage. Indirect effects of mortality include secondary sources such as predation. Effects are classified as indirect when test specimens are not recaptured immediately after turbine passage (they are however, often recaptured at another dam downstream). Estimates from balloon tag and netting techniques provide a measure of direct effects of passage mortality while those derived from coded wire/branding and PIT tags offer a measure of both sources of mortality but direct and indirect effects cannot be separated.

- Tag-recapture methods used (e.g., full discharge netting, PIT tagging, coded wire tags, branding, balloon tag).

- Species and size of fish tested.

- Statement of assumptions and tests.

- Number of fish released (treatment and control).

- Number of tests conducted (a test is defined as a given set of operating conditions such as blade angles or turbine efficiency setting).

- Recapture rates (treatment and control).

- Control survival rate.

- Reliability of estimates (e.g., confidence intervals). The reliability or precision of a survival estimate improves as recapture rates of test specimens increases and as survival of control group fish increases (Mathur et al. 1994). High recapture rates reduce speculation as to the fate of test specimens; high control survival indicates little or no effect on test specimens due to experimental procedures.

- Species and size group specific survival estimates.

3.4.4 Survival Estimates Using Predictive Models

Several models have been developed to predict the survival rate of fish passing through hydroelectric turbines. The models allow for manipulation of fish size, turbine specifications, and station hydraulics, resulting in precise estimates of survival for particular configurations. Direct effects of turbine passage can be predicted as a probability event because the variables (such as turbine diameter, number of blades, etc.) and value ranges for those variables can be precisely defined. Cook et al. (1997) and Franke et al. (1997) provide detailed discussions of various predictive models.

To augment information derived from the pool of qualified empirical studies, turbine passage survival was estimated for six fish lengths ranging from 4 to 60 in, using predictive models developed by Franke et al. (1997). The Franke et al. (1997) models are based on one originally proposed by VonRaben (see Bell 1981). Franke et al. (1997) refined the VonRaben model to consider tangential projection of the fish length, and calculation of flow angles based on overall operating head and discharge parameters because most turbine passage mortality at low head dams (<100 ft) is likely caused by fish striking a turbine blade or other turbine structure.

For the Jefferies turbines (Kaplan and propeller), survival was calculated by:

$$P = \lambda\left[\frac{N * L}{D}\right]\left[\frac{\cos\alpha_a}{8Q_{\omega d}} + \frac{\sin\alpha_a}{\pi\frac{r}{R}}\right] \textit{ and}$$

S = 1 – P *where,*

P = probability of strike,
λ = strike mortality correlation factor,
N = number of turbine runner blades,

L = fish length,
D = maximum turbine runner diameter,
α_a = angle to axial of absolute flow upstream of turbine runner,
$Q_{\omega d}$ = discharge coefficient ($Q/\omega D^3$),
ω = rotational speed (rpm x $2\pi/60$),
R = turbine runner radius,
r = turbine runner radius at point fish enters turbine, and
S = survival probability.

For the Santee Development, containing a Francis turbine, survival was estimated by:

$$P = \lambda\left(\frac{N * L}{D}\right)\left[\frac{\sin\alpha_t\left(\frac{B}{D_1}\right)}{2Q_{\omega d}} + \frac{\cos\alpha_t}{\pi}\right]$$

S = 1 – P *where,*
α_t = Angle to tangential of absolute flow upstream of runner
B = Runner height at inlet
D_1 = Diameter of runner at inlet

In developing the formula, Franke et al. (1997) considered previous works that calculated turbine strike probability and new information developed by the authors. Existing empirical data were used to validate the model. A thorough discussion of the derivation and application of the formulas is provided in Franke et al. (1997).

3.4.5 Assignment of Survival Estimates to Species and Size Classes

Relevant data from studies that tested the Santee Cooper target/surrogate species and from stations with turbines similar to the Jefferies and Santee Developments were tabulated by species for the three size classes (<8 in, 8 to15 in, >15 in) used in the entrainment portion of this study. Quantitative and qualitative turbine passage survival estimates were assigned for each of the species and size classes. Survival estimates were defined as follows to produce qualitative classifications of survival probability: high (90 to 100%), moderate-high (85 to 89%), moderate (75 to 84%), low-moderate (70 to 74%), and low (less than 70%).

4.0 RESULTS

4.1 Species of Consideration
4.1.1 Target Species

In evaluating entrainment effects, the seven target species (hickory shad, American shad, blueback herring, Atlantic sturgeon, shortnose sturgeon, American eel, and striped bass) were considered separately. All of these species except American eel, and to some extent shortnose sturgeon and striped bass, are anadromous; they spend most of their lives in the sea and migrate to freshwater to spawn. The catadromous American eel migrates from freshwater to spawn in the Sargasso Sea. Shortnose sturgeon are estuarine anadromous in the southern part of their range, spawning in upper fresh water reaches of rivers and then returning to the lower esturarine area of the river. Striped bass in the southern region of their range (i.e., Florida, Georgia, and South Carolina) exhibit a semi-anadromous lifecycle (Raney and Wolcott 1955; Bulak et al. 1997; Secor et al. 2000) and often remain in rivers year-round (Scruggs 1957; Coutant 1985). Following are brief accounts for each of the seven target species considered in this study. A summary of the size of each species and time-frame they may occur in the Project area is included in Table 4-1.

Striped Bass

Striped bass is an important game species in South Carolina. Scruggs (1957) documented the first self-sustaining, freshwater population of striped bass in the Santee Cooper system, which subsequently supported a sport fishery of national significance (Stevens 1958). In the mid 1970s juvenile striped bass abundance in Santee Cooper and elsewhere along the Atlantic Coast, declined. A stocking program, initiated in 1984, now augments natural reproduction in Lakes Marion and Moultrie (Bulak et al. 1997).

Striped bass in the southeastern United States initiate spawning activity from early April to late May when water temperatures reach about 18^{o}C (Scruggs 1957; Dudley et al. 1977). Adults then migrate to summer habitats, which, for southeastern populations are generally freshwater rivers (Scruggs 1957). Semibuoyant eggs are transported via stream flow to nursery habitat. In the Santee Cooper system, most spawning occurs in the Congaree River with eggs transported to areas in and around the upper reaches of Lake Marion (Bulak et al. 1997). McIlvaine (1986) found significantly higher densities of zooplankton, the food of larval striped bass, in the headwaters of Lake Marion than in the Congaree, Wateree, or Santee rivers. In estuarine systems, juveniles generally remain in their natal estuary until about age-2 when the majority of females and some males migrate out to undertake seasonal coastal migrations.

In the Combahee River, South Carolina, during the spawning season, non-landlocked adult striped bass moved an average of 24 miles upstream in late April and May when water temperatures rose above 18.6^{o}C. Further upriver movement continued from late May through September as temperatures in the lower river and coastal waters rose above 20^{o}C. Downstream migration began in late September when water temperature dropped below 18^{o}C (Bjorgo et al. 2000). In both open and landlocked systems, striped bass actively seek the coolest water available when water temperatures become warmer than preferred (Cheek et al. 1985). Coutant (1985) defines suitable summer habitat for adult striped bass as having temperatures between about 18 and 25 ^{o}C and dissolved oxygen concentrations above about 2 to 3 mg/L.

American Eel

South Carolina supports a commercial and recreational American eel fishery. Population estimates for American eel are lacking; however, fishery-based regional analysis of eel densities suggest that the St. Lawrence estuary and the New Jersey-to-Virginia region support the highest population densities, whereas the Southeast Atlantic and Gulf of Mexico regions exhibit the lowest (Helfman et al. 1987).

American eel is a habitat generalist (Haro et al. 2000) occurring naturally in a broad diversity of habitats, including clear, small, unproductive headwater streams; large, turbid, productive rivers; blackwater swamps and rivers; clear, subterranean springs and caves; clear and turbid, deep and shallow, vegetated and barren lakes and ponds; and fresh, brackish, and saltwater marshes (Helfman et al. 1987).

The life history of American eel is complex and not fully documented. During spring, the entire population of sexually mature American eels migrates to the region known as the Sargasso Sea where they are believed to spawn. After hatching, developing larvae (leptocephali) drift at sea for up to a year or more before transforming into glass eels as they cross the edge of the Gulf Stream and approach the North American coast. Glass eels enter tidal marshes, bays, and coastal streams during winter and spring, a migration that occurs earlier in the southern portion of the range and later in the northern (Helfman et al. 1987; McCleave and Kleckner 1982). Before migrating upstream, glass eels spend some time in tidal marshes where they transform into the elver life stage and acquire a dark brownish-gray cutaneous pigmentation. In the Santee Cooper system, elvers may enter the lakes through the Pinopolis Lock and the St. Stephen fish lift. American eel juveniles are also very adept at scaling falls, dams, and other obstructions including nearly vertical concrete walls that are slightly wetted (Haro et al. 2000). It is highly likely that elvers scale the Santee Dam spillway where leakage occurs and perhaps other areas along the dams and dikes where a trickle of water enters the river.

After about two years elvers enter the yellow eel stage in which maturation occurs. Most of their life is spent in rivers, lakes, and estuaries where they remain until sexually mature. In the Cheaspeake Bay region maturation occurs in 8 to 24 years, but appears to occur earlier in more southern regions and later in northern regions (Helfman et al. 1987). When sexually mature, adults undergo a fall migration downstream en route to the Sargasso Sea. This migration is accompanied by a metamorphosis to the silver eel stage during which morphological and physiological changes take place.

An apparent decline in abundance of American eel in some river systems has occurred in recent years. Several factors may contribute to the decline, including over harvest (most life stages are fished and, because eels die after spawning, all eel fishing mortality is pre-spawning mortality), variable oceanic conditions, habitat degradation, structures impeding upstream and downstream passage, increased predation, and poor water quality (Castonguay et al. 1994; Haro et al. 2000).

Atlantic Sturgeon

Sturgeon once supported a valuable commercial fishery in the U.S. throughout its range, including South Carolina. In 1976, after a decline in the more northerly fishery, South Carolina produced about 55% of sturgeon landings along the U.S. Atlantic coast. The Atlantic sturgeon fishery is now closed and expected to remain so for about the next 20 years. (Collins and Smith 1997). Records dating from 1971 to 1995 document the presence of Atlantic sturgeon from the tidally influenced area of 11 rivers, three bays or sounds, and one reservoir in South Carolina. Available data are insufficient to determine the size or viability of populations found in South Carolina rivers (Collins and Smith 1997).

Atlantic sturgeon spawn in spring, migrating from the ocean to coastal estuaries and lower reaches of rivers. Individuals spawn once every two to six years. Typically, after spawning females leave the area within four to six weeks but males remain behind until fall. Most juveniles remain in their natal river or estuary from one to six years before migrating to the ocean in late fall and winter. Females become sexually mature between the ages of 7 and 30 and males between the ages of 5 and 24 with the age of sexual maturity decreasing with latitude. Mean fork length (FL) of age-1 Atlantic sturgeon in Winyah Bay, South Carolina was 17.3 in (Collins and Smith 1997). Sexually mature sturgeon collected in the Combahee and Edisto Rivers, South Carolina ranged in size from 51.6 to 92.1 in total length (TL) (Collins et al. 2000). Atlantic sturgeon may live to be 60 years old and grow to over 79 in long.

Based on tracking studies, Collins et al. (2000) reported that the migratory pattern of Atlantic sturgeon in two South Carolina rivers more closely resembled Gulf sturgeon than Atlantic sturgeon in the northern part of their range. The fish Collins et al. (2000) tagged overwintered in the ocean, migrated into the river in early spring, moved upriver to spawn, inhabited the river throughout the summer, and migrated out of the river in the fall. During their study, Collins et al. (2000) verified that spawning in the Ashepoo, Combahee, and Edisto rivers basin occurs in both spring and fall, but suggests that the participants represent two races of Atlantic sturgeon that may be distinguishable by size and spawning season. Occurrences of Atlantic sturgeon measuring 17.3 in long (age-1) and slightly longer, recorded from lower reaches of both the Cooper and Santee Rivers in recent years (1987 and 1995, respectively) suggests that spawning may occur in these systems (Collins and Smith 1997).

Shortnose Sturgeon

Prior to 1967 when shortnose sturgeon was listed as an endangered species, it was commonly taken in the commercially valuable Atlantic sturgeon fishery. Physical similarities between the two species at smaller sizes led to mis-identification and non-differentiation by fishermen and scientists preparing landing records and scientific reports. As a result, no reliable estimates of historical population sizes exist (NMFS 1998). Records dating from 1970 to 1995 document the presence of primarily adult shortnose sturgeon in 10 rivers (including the Santee and Cooper rivers), three bays, and two reservoirs (Lakes Marion and Moultrie) in South Carolina (Collins and Smith 1997).

Adult shortnose sturgeon in southern rivers are considered estuarine anadromous. They forage at the interface of fresh tidal water and saline estuaries and move upstream in rivers to spawn in late winter or early spring when water temperatures reach 8-9^{o}C. Males fertilize the female's eggs as the eggs are released close to the substrate. Spawning generally ends when water temperatures reach 12-15^{o}C. Larvae move downstream and juveniles are found at the saltwater and freshwater interface in most rivers (NMFS 1998). Juveniles grow fast, reaching up to 20 in after 2-4 years in the southern part of the range. Sexual maturity is reached at an earlier age in southern regions (2-5 years for males and around 6 years for females) compared to northern regions, but length at maturity (17-22 in) is similar throughout the range. Males appear to spawn more frequently than females; 2-year intervals for males compared to 3-5 year intervals for females (NMFS 1998).

Collins and Smith (1997) suggested a landlocked population of shortnose sturgeon resides in Lake Marion and migrates up the Congaree River during the spawning season. However, successful reproduction has not been verified for the population.

Management of shortnose sturgeon is guided by NMFS document "Final Recovery Plan for the Shortnose Sturgeon" (1998), a recovery plan initiated under the Endangered Species Act. The goal of the recovery plan is to de-list shortnose sturgeon populations throughout their range.

<u>Blueback Herring</u>

Blueback herring, a non-game species in South Carolina, supports, as forage, both commercial and sport fisheries in the state. The catch is most often used as bait for striped bass, crabs, and eels, or ground up for fish meal or pet food; however, a smaller percentage is consumed by humans. Blueback herring is an important prey species for estuarine and coastal predators, including striped bass. The recent depletion in river herring (blueback herring and alewife are similar species that are collectively referred to as river herring) has been attributed to overfishing, pollution, and loss of spawning habitat (including dams, road culverts, stream gauging stations and debris that inhibit or block access to spawning areas).

Blueback herring spend most of their adult life in salt water, inhabiting a narrow band of coastal waters from Nova Scotia to northern Florida. Adults make annual migrations to freshwater spawning areas in spring. Spawning generally occurs when water temperature reaches 14^{o}C (Loesch and Lund 1977) and ceases above 27^{o}C (Loesch 1969). Optimal spawning temperatures are reported to be between 21 and 25^{o}C (Klauda et al. 1991). In the Santee and Cooper rivers, spawning runs begin in late February and early March and continue through late April and early May (Cooke and Leach 2001). Although some straying occurs, blueback herring generally return to their natal rivers to spawn, migrating as far upstream as river mile 108.7 in the Altamaha River, Georgia (Adams and Street 1969) and river mile 84.5 in the Connecticut River, Massachusetts (Loesch and Lund 1977). Adults return to coastal waters after spawning. Eggs hatch in three to seven days depending on water temperature and juveniles generally remain in freshwater nursery areas through spring and summer. Cued by decreasing water temperature and increased flow, juveniles migrate to the sea in the fall over most of the species range and remain in coastal waters until reaching sexual maturity in three to six years. There is some evidence that juvenile clupeids move out of the Project lakes at other times of the year as well (D. Cooke personal communication).

American Shad

South Carolina supports a commercial and recreational fishery for American shad, a species that occurs along the Atlantic coast from southern Labrador to northern Florida, and was introduced to several drainages along the west coast of the U.S. Historically, it was a major fishery resource along the Atlantic seaboard. However, between 1897 and 1940, annual harvests declined from over 44 million to 11 million pounds (Klauda et al. 1991). Probable causes for the decline include pollution and siltation of spawning rivers, over harvesting, and impediments to reaching spawning grounds (Klauda et al. 1991).

American shad is the largest anadromous fish of the clupeid family, reaching maximum lengths of about 30 in. It is a highly migratory, schooling species that may migrate over 12,000 miles while at sea, over an average life span of four or six years, moving from summer feeding grounds in the Gulf of Maine to coastal over-wintering areas off the mid-Atlantic states (Scott and Crossman 1973).

When sexually mature (between age-3 and age-5) adults spawn in freshwater streams during spring. American shad generally home to natal streams to spawn, resulting in discrete spawning stocks occurring in each major shad producing river along the Atlantic seaboard. If possible, adults may migrate far upstream and typically spawn in freshwater areas dominated by extensive flats and over sandy or rocky shallows. Unlike alewife (*A. pseudoharengus*), American shad do not spawn in lakes (Scott and Crossman 1973). Water temperature is the primary factor triggering spawning, but photoperiod, current velocity, and turbidity also exert some influence. Adults enter coastal rivers when water temperatures are around 16-19^{o}C with spawning activity occurring in water temperatures between 12 and 21^{o}C. American shad are fractional spawners and typically a single female spawns with multiple males. Some evidence suggests a latitudinal gradient in frequency of repeat spawning, with southern stocks (Florida, Georgia, and South Carolina) dying after the first spawn and northern stocks returning for more than one spawn. However, anecdotal observations suggest there may be some repeat spawning in the South Carolina rivers (J. Isley, B. McCord, personal communication). Adults that survive the spawning process return to sea soon after spawning.

Eggs are slightly heavier than water, non-adhesive, and are carried along by the current. Survival and hatching success is maximized in water temperature ranging from 15.5 to 26.5^{o}C. Larvae are most abundant near the surface in fresh and brackish water. Transformation to the juvenile stage is completed in about 21-28 days when they reach 0.98-1.00 in TL. Juveniles congregate in schools when they reach 0.79-1.18 in TL and prefer deep pools away from shoreline in non-tidal areas. Like blueback herring, juvenile American shad undergo diel vertical migration in summer nursery areas, moving up to the surface at night and down to the bottom during the day. Over much of the range, downstream movement to the sea is triggered by a decrease in water temperature below 19 or 20^{o}C, increase in river flow, or a combination of both factors, and typically occurs in the fall. Peaks in seaward migrations of juveniles in the Chesapeake Bay region occur from late October to late November when water temperatures are below 15^{o}C. Unpublished data from South Carolina indicates that downstream migration may occur in winter months as well as at other times (D. Cooke, personal communication). Larger juveniles appear to move downstream earlier in the fall. Average length prior to the fall migration is about 3-5 in. Size at age is generally greater for females than males, and greater in northern stocks than southern stocks (Klauda et al. 1991).

Hickory Shad

Hickory shad is a medium-sized anadromous clupeid that is smaller than American shad but larger than blueback herring, growing to a maximum length of about 24 in. The species historically occurred from the Bay of Fundy, Canada to Florida. However, it now appears to be restricted to waters from New York southward and is viewed as a more southern species than American shad (Scott and Crossman 1973).

Although hickory shad have been little studied, some life history characteristics are understood. Hickory shad spawn in early spring, ascending freshwater streams when water temperatures reach 12-13^{o}C. Spawning occurs over a temperature range of 12-22^{o}C, peaking at 15-19^{o}C, often proceeding American shad runs. As with American shad, hickory shad peak spawning activity probably occurs between dusk and midnight. Gonadal maturation in females suggests that ripe eggs are released in small numbers over a prolonged period (fractional spawning) rather than during a single brief spawning event. Egg incubation time ranges from 48-72 hrs at temperatures between 21 and 18^{o}C. Larvae transform to juveniles at about 0.39-1.38 in in length. It is believed that most juvenile hickory shad leave their freshwater and brackish habitats in early summer and migrate to estuarine nursery areas at an earlier age than other anadromous alosids. This conclusion is based on evidence found on the fishes scales. The mark of the freshwater zone that forms on the scales of anadromous clupeids is difficult to see on scales from adult hickory shad (Klauda et al. 1991). Juvenile hickory shad tend to be larger than other alosid species, which may be due to the earlier spawning time and thus a longer growth period. Males and females mature by the time they reach approximately 11 and 12 in TL, respectively, which is around age-2 for males and age-3 for females.

Repeat spawning appears to be common but variable among river systems and can range from less than 10% to over 80%. Adults make about three to five spawning runs in a lifetime.

4.1.2 Surrogate Species

Existing information for all of the target species was not available. To make estimates of entrainment and survival probability, and subsequently potential impact, surrogate species were used in some cases. Atlantic and shortnose sturgeon were represented by the congener lake sturgeon (*Acipenser fulvescens*). Lake sturgeon inhabit large rivers and lakes of central North America and undergo a limited spring migration to spawn in flowing water when it reaches temperatures of about 12^{o}C. Adult lake sturgeon grow to about 4 to 5 ft (although individuals as large as 9 ft have been reported; Becker 1983), which is comparable to shortnose sturgeon (about 3.3 ft) but smaller than Atlantic sturgeon (greater than 13 ft).

American shad, blueback herring, and hickory shad are represented by alewife (*Alosa pseudoharengus*) and gizzard shad (*Dorosoma cepedianum*); all of these species are in the family Clupeidae. Alewife are very similar to blueback herring in both appearance and life history characteristics, with the exception that alewife easily acclimate to landlocked situations. Both species occur along the coastal mid-Atlantic; however, alewife range farther north and blueback herring farther south. Gizzard shad are not anadromous and are commonly found in deep, open water rivers, lakes and impoundments, as well as brackish water reaches of coastal streams. Gizzard shad seldom grow to lengths greater than 15 in. All of these species spawn in the spring, gather in schools and are important food items for larger piscivorous species. Juvenile gizzard shad are very similar in size to juvenile herring and shad.

Striped bass are represented by the congener white perch (*Morone americana*). White perch are endemic in marine, estuarine, and tidal fresh waters from Nova Scotia to South Carolina. It is an estuarine-anadromous species, moving from lower estuaries to fresh water to spawn when water temperatures reach 10 to 16^{o}C. Adults range in length from about 4 to 10 in. Juvenile (i.e., age-0+) white perch are similar in size and shape to striped bass.

4.1.3 Resident Species

Resident species included in the analysis of entrainment potential are listed in Table 4-2. These are species that occur in Lakes Marion and Moultrie and were represented in the entrainment studies examined for this analysis.

4.2 Site Characteristics

4.2.1 Santee Hydroelectric Development

There are a few factors that may affect the use of the Santee Powerhouse for downstream passage (Table 4-3). The primary factors are the abundance of clupeids found in Lake Marion, and the elevation of the intake structure. Clupeid species, including threadfin shad, gizzard shad, Atlantic menhaden, hickory shad, blueback herring, and American shad, dominate the piscine fauna in the lake system, with threadfin and gizzard shad being the most important (S. Lamprecht, SCDNR, personal communication). A deep intake structure may reduce the number of fish entrained; however, most of the Santee Cooper target species spend some or most of their time near the lake bottom (Table 4-1), possibly increasing their use of the Santee Powerhouse for downstream passage. Atlantic and shortnose sturgeon as well as adult American eel, are bottom feeders and dwellers. Juvenile American shad and blueback herring spend most daylight hours low in the water column and migrate to surface waters at night to feed.

Factors reducing entrainment potential include an intake structure away from the littoral zone and small hydraulic capacity. Winter draw-down of Lakes Marion and Moultrie is minimal (2-3 ft) and would not significantly alter entrainment characteristics at the site. Because of the minimum flow requirement for the Santee River, a continuous but relatively low flow passes through either the generating station or the spillway. The continuous flow may attract emigrating diadromous fish in the vicinity of the Santee Powerhouse intake, but it is believed that the flow 'net' of influence that would attract emigrating fish is small relative to that through the Diversion Canal, Jefferies Hydroelectric Station, and the USACE St. Stephen Project.

4.2.2 Jefferies Hydroelectric Development

The use of the Jefferies Hydroelectric Station may be influenced by a few factors (Table 4-3). Specifically, the hydraulic capacity of units 1 through 4 is high and, as stated above, clupeid species are abundant in the lake system. Although the hydraulic capacity of unit 6 is much smaller (i.e., lower likelihood of attraction due to flow) than the other four units, it is located in the littoral zone and is adjacent to the shoreline (i.e., may increase use of this unit for downstream passage).

The turbine intakes ceiling elevation at Jefferies is 16 ft below normal pool elevation, but this depth is likely near enough to the surface to attract surface dwelling species. The intakes structure appears to be as deep as the lake and, as discussed above for the Santee Development, may increase entrainment potential for many of the target species (see Table 4-1). Operation at the Jefferies station is semi-peaking, with most generation occurring during daylight hours through to about 2200 hrs. Since most of the Santee Cooper Project discharge passes through the Jefferies Hydroelectric Station, most entrainment is believed to occur at the Jefferies Station. In normal water years, a substantial amount of downstream passage likely occurs through the USACE St. Stephen Project, but during drought years, most fish will pass through the Jefferies Station turbines.

Winter drawdown of Lakes Marion and Moultrie in normal water years is minimal (2-3 ft), occurs over a period of months, and would not significantly alter entrainment characteristics at the site.

4.2.3 Effects of Project Operations

The typical operation of the Santee Cooper Project may influence entrainment of fishes through the various routes, including the USACE St. Stephen Project. During all inflow levels, the Jefferies Hydro Station discharges a weekly average of approximately 4,500 cfs. The range in discharge is 0 to approximately 27,000 cfs. How the Project operates is determined by the demand for electricity. Typically, electrical demand peaks in the morning, late afternoon, and early evening. Most natural clupeid downstream movement typically occurs in evening hours, however downstream movements have been observed to peak during mid-day based on hydro project operations (RMC and Harza, unpublished data). It is likely that most entrainment of target species occurs during the normal operations of the Jefferies hydro station, and, when river flows are high enough, the St. Stephen Project. Based on qualitative field observations, it is evident that some juvenile clupeids are entrained through the Santee Powerhouse, but it is believed that entrainment through that facility is low relative to the Jefferies development (and when operating, the St. Stephen development). In addition to the much lower hydraulic capacity of the Satnee Powerhouse, the proximity of the Diversion Canal in the southeast corner of Lake Marion (Figure 1-2), with its much greater hydraulic flow, likely attracts downstream moving fish to a greater degree than the Santee Powerhouse. Under flow conditions high enough to initiate spill through the Santee Dam spill gates, it is more likely that fish moving downstream in Lake Marion will pass downstream into the Santee River rather than into Lake Moultrie.

4.3 Literature-Based Estimation of Entrainment Potential

4.3.1 Study Screening

Entrainment studies reviewed were obtained from several sources. The EPRI database contained 43 studies and the 1995 FERC review provided 46 studies. Fourteen of the studies were included in both the FERC and EPRI databases. The phone survey of regional utility representatives garnered three additional studies for consideration.

Of the 78 sites considered, only the 43 studies in the EPRI database were found to meet the established acceptability criteria. The greater acceptance rate for studies from the EPRI database reflects both the use of similar acceptance criteria and the general trend towards the use of full-flow netting techniques and more comprehensive reporting of fish sizes by species and month in more recent studies. Twenty of the studies examined in FERC (1995) that were excluded from this analysis did not utilize full-flow tailrace netting techniques. Six of the studies in the EPRI database that met the acceptability criteria were conducted at hydroelectric projects in South Carolina and Georgia.

The hydraulic capacity of the 43 sites included in the EPRI database ranged from 404 to 60,000 cfs (Table 4-4). This compares to a hydraulic capacity of approximately 21,400 cfs for the five units at the Jefferies Development and 500-600 cfs for the minimum flow unit at the Santee Development. Trash rack spacing at 40 of the sites ranged from 1 to 10 inches, but could not be determined for three of the sites (Table 4-4). Trash rack clear spacing at the Jefferies and Santee Developments is 7.6 and 5.6 in, respectively.

Although several of the qualified source sites have a relatively wide trash rack spacing, others are as narrow as one to two inches, narrow enough to exclude some larger fish. However, in a review of the EPRI entrainment database, Winchell et al. (2000) found there to be little apparent difference in the size distribution of fish entrained at sites with very different measures of trash rack spacing (Table 4-5). The primary reason for this is that a very large majority of the entrained fish collected in empirical studies were smaller than approximately 4 in.

4.3.2 Entrainment Potential for Species in the Santee Cooper Project Area

Figures 4-2 through 4-5 show average annual entrainment densities calculated for the Santee Cooper target/surrogate and resident species based on data from the 43 qualified source sites. For fish in the small size category, alewife and gizzard shad (surrogates for American shad, hickory shad, and blueback herring) had the highest average entrainment densities of 34 and 16 fish per million cubic feet of water, respectively (see Appendix A for a detailed presentation of entrainment data by species). For extrapolation purposes, it is estimated, based on average flow data provided by Santee Cooper, that the Jefferies station passes approximately 140.16 billion cubic feet of water per year. Entrainment densities of medium and large fish were much lower than for small fish. In the medium size class, gizzard shad and alewife had the first and third highest entrainment densities of 0.219 and 0.078 fish per million cubic feet of water, respectively (Figure 4-4). American eel was the most frequently entrained large fish species, with an average entrainment density of 0.071 fish per million cubic feet of water (Figure 4-5).

The bounds of the five ratings of entrainment potential (high, moderate-high, moderate, moderate-low, and low) for each size class of fish were determined based on several considerations. For small fish, the bounds were defined by identifying break points where large differences in entrainment densities were observed (Figure 4-3). Fewer break points were noticeable for medium and large fish. The bounds for medium and large fish were set at levels 10 times more stringent than those used for small fish, providing a conservative estimate to reflect the generally higher value with regard to reproductive and sport fishery potential placed on larger fish (Figures 4-4 and 4-5).

Table 4-6 summarizes the entrainment potential ratings and numeric values for each target/surrogate species. Of the five target/surrogate species studied at the qualified source sites, small alewife and gizzard shad, medium gizzard shad and white perch, and large American eel had the highest entrainment potential (moderate-high or high). Small lake sturgeon and American eel and large lake sturgeon and white perch exhibited the lowest entrainment potential.

4.4 Empirical Estimates of Turbine Passage Survival

Survival estimation, presented quantitatively and qualitatively, is based on consideration of three sources: (1) empirical data from previous studies that sampled the Santee Cooper target or surrogate species; (2) empirical data from previous studies at projects with units similar to the Jefferies and Santee Developments; and (3) model calculations. Examination of survival estimates in the database indicates that turbine passage survival is generally high (>90%) for Kaplan and propeller turbines but lower for Francis turbines. Relative to turbine type, survival is consistent for a particular size class across a wide range of species and unit discharges. That is, survival potential appears to be influenced more by the size of an individual fish passing through a turbine than the species. Additionally, fish passage survival for a given fish size generally increases as turbine size increases because the water passage-way is greater, reducing the risk of mechanical injury due to striking some structure in the turbine. Therefore, survival of all fish sampled at units similar to the Jefferies and Santee Developments, as well as the target species, were considered.

The database of existing information on turbine passage survival for Kaplan, propeller and Francis turbines is extensive (Tables 4-7 and 4-8). However, the number of studies conducted at sites with similar turbine specifications and on the Santee Cooper target species are not as plentiful. Therefore, two assessments of survival were culled from the empirical data for each of the three turbine types (Francis at Santee, large Kaplan and propeller at Jefferies, and small Kaplan at Jefferies). One assessment included all studies conducted on target or surrogate species, regardless of turbine specifications, and the other addressed only sites with turbine specifications similar to the Developments.

Culling for the assessment of target species resulted in 14 studies at seven developments with Kaplan or propeller turbines, and seven studies at five developments with Francis turbines. When culled by turbine type, 32 studies conducted at eight developments represented the large Kaplan and propeller turbines at Jefferies; 25 studies from five developments represented the small Kaplan at Jefferies; and 48 studies at six sites represented the Francis turbine at the Santee Development.

4.4.2 Survival Estimates for Santee Cooper Target/Surrogate Species

Do to the limited number of survival studies that included the Santee Cooper target/surrogate species, sample sizes were small for the three fish sizes examined (Jefferies: $0 \leq N \leq 10$; Santee: $1 \leq N \leq 5$; Tables 4-11 and 4-12, respectively). American eel, alewife, American shad, and blueback herring were the only target or surrogate species studied at other sites; however, they were represented at sites with both Francis and Kaplan or propeller turbines.

4.4.2.1 Jefferies Development

Survival estimates for small target fish (<8 in) sampled at sites with Kaplan or propeller turbines were generally high, with average survival of all small fish greater than 95% (Table 4-11). Estimates from individual tests (N=10) ranged from 89 to 100%, resulting in an overall mean of 95.4% survival. No small American eels were sampled and American shad represented the species of interest most commonly sampled (N=7). One station (Crescent, NY) sampled blueback herring and two (Fourth Lakes, NS and Herrings, NY) sampled alewife. Both the lowest and highest survival estimates for this size group were reported for American shad.

No medium-sized target fish (8-15 in) were sampled at sites with Kaplan or propeller turbines.

Four survival estimates were available for large fish, three for American shad, ranging from 78.2 to 89.7%, and one for American eel, 73.5%. The overall survival estimate for large target species was 82.1%.

4.4.2.2 Santee Development

Alewife, American shad, and blueback herring represented the small-sized fish sampled at sites with Kaplan turbines (Table 4-12). Small fish were collected in five studies conducted at four sites (Holtwood, PA; Vernon, VT/NH; Columbia, SC; and Minetto, NY), with estimated survival ranging from 80.0 to 94.7%. Overall, average survival for small fish at these sites was 88.1%.

Blueback herring, studied at the Stevens Creek development in South Carolina, was the only sample representing medium sized fish. Estimated survival was 95.3%.

The large size group was represented by American eel studied at the Minetto development in NY. Estimated survival was 94.0%.

4.4.3 Survival Estimates Based on Fish Size

Based on the consistency of results from numerous studies, it has become apparent that fish size rather than species is the primary variable in determining the probability of survival through turbines (Cook et al. 1997; Franke et al. 1997). Therefore, the databases were culled to identify sites similar to the Santee and Jefferies developments relative to turbine design, and the survival estimates summarized based on fish size, regardless of species. This approach provided 48 studies from six developments similar to the Francis turbine at Santee; 25 studies at 5 developments similar to the small Kaplan turbine at Jefferies; and 32 studies conducted at eight developments similar to the large Kaplan and propeller turbines at Jefferies.

4.4.3.1 Jefferies Development – Small Kaplan (Unit 6)

Survival estimates for small (<8 in) fish sampled at sites with small Kaplan turbines similar to Jefferies Unit 6 were generally high, averaging over 95% (Table 4-13). Estimates from individual tests (N=16) ranged from 90.0% for salmonids at Herrings, NY to 100% for largemouth bass at Townsend Dam, PA. Two studies were conducted on clupeids (alewife and blueback herring) with survival percentages of 92.8 at Herrings, NY and 96.0 at Crescent, NY.

Nine studies included medium-sized fish; however, no target or surrogate species were included (Table 4-13). Average survival for this group was 92.0% and ranged from 85.1% for soft rayed fishes at Herrings, NY to 98.6% for salmonids at Herrings, NY.

No survival estimates were available for large fish passing through small Kaplan turbines similar to Unit 6 at the Jefferies development.

4.4.3.2 Jefferies Development – Large Kaplan and Propeller (Units 1-4)

Of the 32 studies conducted at sites similar to Jefferies units 1 through 4, 23 tested survival of small fishes, nine of which included clupeids (alewife, American shad, and blueback herring) (Table 4-14). Overall survival estimates for small fish ranged from 89.1 to 100%, and averaged 95.4%. American shad tested at Hadley Falls, MA had both the lowest and highest survival estimates. Average survival for clupeid species was 96.1%

No target or surrogate species were represented in the medium size class. Average survival of other fishes was 93.8%, ranging from 85.1% for soft rayed fishes at Herrings, NY to 98.6% for salmonids, also at Herrings, NY.

Four studies at three developments (Safe Harbor, PA; Hadley Falls, MA; and St. Lawrence-FDR, NY) included large fish, specifically American shad and American eel. Overall survival averaged 82.1%. Survival for large American shad, from three studies ranged from 78.2% at Hadley Falls, MA to 89.7% at Safe Harbor, PA; the average was 85.0%. American eel was studied at St. Lawrence-FDR, NY and had an estimated survival of 73.5%.

4.4.3.3 Santee Development

Overall, literature-based average survival for small fish passed through turbines representative of the Santee Development was 88.3% (Table 4-15). This represented 34 studies at eleven developments. Two of these developments, Minetto, NY and Columbia, SC sampled alewife and blueback herring, respectively. Alewife survival was 80% and blueback herring survival 92.7%. Other species represented in this category were centrarchids, fish with a fusiform shape, golden shiner, white sucker and channel catfish. The lowest survival (61.7%) was recorded for a fusiform fish at Potato Rapids, WI. Centrarchids from three developments and four studies had the highest survival of 100%.

Medium sized fish, represented by smallmouth bass and a group of fish categorized as fusiform, had an overall estimated survival of 67.8%. Of the 16 studies conducted, 12 estimated survival for fusiform fish. Within this group, survival ranged from 35.5 to 95.4%. No target or surrogate species were represented in the medium size class.

No large fish were studied at the selected sites with turbine characteristics similar to the Santee Development.

4.5 Model Predictions of Survival

Model iterations for six fish lengths over the range of 4 to 60 in, three *r* values (the point along the runner radius at which the fish enters the turbine – values used were 0.1, 0.5 and 0.9% of the runner radius for each turbine type), and two correlation factors, resulted in 36 survival estimates that likely bracket actual survival for each of the three turbine types at the Jefferies Development (Table 4-16). For the Francis turbine at the Santee Development, six fish lengths and three *r* values provided 18 survival estimates (Table 4-17). The range of parameters selected accounts for some of the variability expected to occur at any development.

The correlation factor (λ), used for the Kaplan and propeller turbines, was introduced originally by Von Raben (cited by Bell 1981) to adjust predicted turbine strike results to more closely match empirical results because contact of a fish with a turbine unit component does not always result in injury or mortality (Bell 1981; Cada 1990). More recently, Franke et al. (1997) recommended the value for the correlation factor, be 0.1 to 0.2 based on a substantial amount of empirical results with survival of salmonids. In this evaluation, correlation factors of 0.15 and 0.2 were used for all fish sizes.

Predicted survival values for the two large Kaplan units at the Jefferies Development ranged from 99.3% for a 4-in fish to 0% for a 60-in fish. The model predicted similar survival ranging from 98.3 to 0% for 4 in fish passing through the small Kaplan unit, and 97.2 to 0% through the propeller turbines. The flow line by which a fish enters a turbine can affect survival probabilities (Franke et al. 1997). It can be seen that with Kaplan and propeller turbines, the probability of survival decreases as the point of entry approaches the hub of the runner and as the size of the fish increases (Table 4-16).

For the Francis turbine at the Santee Development, survival predictions for a 4- and 60-in fish ranged from 94.2 to 0, respectively (Table 4-17). Here, too, survival decreases as fish length increases.

4.6 Comparison of Empirical and Modeled Survival Results

Survival estimates obtained from empirical data and the predictive models were compared for similarity. Results from the survival database developed for turbine type (which included all fish species) were compared to modeled survival results. Because the modeled results were considerably more detailed than the empirical results, averages were calculated for the modeled data. Average survival was calculated from predictive model iterations using the following parameters: 1) a correlation factor of 0.2; 2) all runner radius entry points; and, 3) a combination of size classes that relate to the three size classes in the empirical assessment as follows:

Previous Studies Assessment		Model Calculations
Small (<8 in)	=	4 and 8 in
Medium (8 to 15 in)	=	8, 12 and 15 in
Large (>8 in)	=	15, 36 and 60 in

In other words, the average survival of a small fish passing through a fixed propeller turbine at Jefferies was determined by averaging the six values for 4- and 8-in fish entering the turbine at all points and with a correlation factor of 0.2.

In general, the average model predictions of survival were less than summarized empirical data from other sites. For the Jefferies Development, overall survival from previous studies at sites similar to the small Kaplan turbine (Unit 6) was 95.1% for small fish and 92.0% for medium fish; no estimate for large fish was available. Comparably, average predicted survival for the small Kaplan turbine was 91.3%, 83.0% and 59.2% for small, medium and large fish, respectively. For the large turbines at Jefferies, empirical survival estimates were 95.4%, 93.8% and 82.1% for small, medium and large fish, respectively. This compares to averages of 90.7% and 94.9% for small fish in the propeller model and large Kaplan model, respectively, 81.8% and 89.8% for medium fish and 49.4% and 70.1% for large fish. The two metrics are most similar for the large Kaplan turbines. In all comparisons, empirical estimates of survival were higher than predicted estimates.

Average predicted estimates of survival for the Francis unit at Santee were derived by averaging the predictions obtained using a correlation factor of 0.2 and the size groups as described above for Jefferies. The results show very similar survival estimates between the two metrics. For the empirical data the estimates were 88.3% and 67.8% for small and medium fish; no estimate was available for large fish. Estimates for the predictive model were 88.4%, 77.3% and 33.6% for small, medium and large fish respectively.

4.7 Cumulative Survival Ratings for Santee Cooper Target/Surrogate Species

A review of survival estimates presented in Tables 4-11, 4-13, 4-14 and 4-16 for the Jefferies Development and Tables 4-12, 4-15 and 4-17 for the Santee Development provided sufficient information for assigning rated qualitative values of survival estimates to three of the target species (American eel, American shad, and blueback herring) and three size class of fish for each Development. Cumulative survival ratings for the three fish sizes and the three target species are summarized in Tables 4-18 and 4-19, respectively, for both the Jefferies and Santee Developments.

4.7.1 Survival as a Function of Size

Table 4-18 provides a summary of the quantitative ratings and corresponding qualitative ratings of survival for small, medium, and large fish studied at other sites similar to the Jefferies and

Santee Developments and estimated through predictive modeling. A cumulative, subjective rating that combines the two metrics has been designated for each category. The cumulative rating was developed for summary purposes only and does not necessarily directly reflect quantitative results.

4.7.1.1 Jefferies Development

For all turbines at the Jefferies Development, average survival of small fish, as estimated through previous studies, was High (90-100%). Corresponding estimates from predictive modeling ranged from High to Moderate (75-84%) for the large Kaplan and propeller turbines and High to Moderate-Low for the small Kaplan turbine. For 4-in fish, only one iteration of the model resulted in a predicted survival below 90%. At the small Kaplan a 4-in fish entering near the blade tip of the runner and with a correlation factor of 0.2 had a predicted survival of 86.9% (Moderate-High). All 8-in long fish entering all turbine types near the blade tip of the runner had predicted survival estimates below 90%; ranging from 73.3 to 88.2% (Moderate-Low to Moderate). Because average predicted survival for small fish was in the High range (see Section 4.6), and only a few iterations resulted in survival values below 90%, the cumulative rating assigned to all turbines at the Jefferies Development for small fish was High

A Moderate-High cumulative survival rating was designated for medium sized fish that might pass through any of the Jefferies turbines. Survival was high at other sites and model predictions ranged from High to Low (<70%), with averages of 89.9, 83.0, and 81.8% for the large Kaplan, small Kaplan and propeller turbines, respectively. Iterations of the predictive models for fish 8-, 12-, and 15-in long varied slightly for the different turbine types. Across the board, survival estimates were highest for the large Kaplan turbines (Units 2 and 4). Estimates were greater than 90% for medium sized fish approaching the runner of a large Kaplan turbine from either near the outer-end or the middle of the runner. Only when approaching the runner from near the blade tip did survival estimates fall to between 70.1 and 88.2% (Moderate-Low to Moderate). Similar results were obtained for the small Kaplan turbine in Unit 6, except that an iteration of the model for a 15-in fish approaching the middle of the runner had a survival estimate below 90% (ie. 89.9%). Survival estimates for fish entering near the blade tip ranged from 50.2 to 81.1% (Low to Moderate-Low). For the fixed propeller turbines (Units 1 and 3), survival estimates for fish approaching the runner from near the hub to the middle ranged from 85.1 to 94.1% (Moderate to High) and from 58.6 to 83.6% (Low to Moderate-Low) for fish entering near the blade tip.

For large fish, previous studies showed Moderate (75-84%) survival through large Kaplan and propeller turbines; no data were available for small Kaplan turbines. Predictive survival values ranged from High to Low, with the highest survival predicted for the large Kaplan turbine and lowest survival predicted for the propeller turbine. Predicted survival estimates ranged from 97.5% (High) to 0% (Low) for the large Kaplan units and 95.7% (High) to 0% (Low) for the small Kaplan units. Fish 60-in long entering the turbine near the blade tip showed the lowest survival for all turbine types. A cumulative rating of Moderate-Low was given to the large Kaplan turbines (Units 2 and 4), and a rating of Low given to the propeller (Units 1 and 3) and small Kaplan unit (Unit 6).

4.7.1.2 Santee Development

Survival estimates for the Santee, Francis turbine were lower than for the turbines at the Jefferies station. A cumulative rating of Moderate-High was given to small fish based on an average survival of 88.3% (Moderate-High) from other sites similar to the Santee Development, and predictive estimates of 94.2 to 84.6% (High to Moderate).

For medium sized fish, predicted estimates were higher than estimates from previous studies. A cumulative rating of Moderate-Low was given to this group based on low survival observed at other sites (67.8% average) and Moderate to Moderate-Low survival estimated from the model (82.5 – 70.8).

No sites with similar turbines sampled large fish; however, a rating of Low resulted from the predictive model. Therefore, a cumulative rating of Low was assigned to large fish passing through the Santee Development.

4.7.2 Survival by Species

4.7.2.1 American Shad and Blueback Herring

Blueback herring, American shad and alewife, a surrogate species for the group of clupeid target species, were sampled in survival studies at sites similar to the Jefferies Development (Tables 4-11, 4-13 and 4-14). All of theses species, when small, had high survival probabilities, with averages ranging from 94.4% at sites similar to Unit 6, to 96.1% at sites similar to Units 1 through 4. Given that the model also predicted high survival of small fish through the Jefferies turbines, a cumulative ranking of High was designated for this group (Table 4-19).

No medium sized shad or herring were sampled at other sites with Kaplan or propeller turbines.

Only American shad were represented in the large fish category (>15-in); they were sampled in three survival studies at sites similar to the large turbines and averaged 85.0% survival, a ranking of Moderate-High (85-89%). Considering the Moderate-Low cumulative rating for all large fish, discussed above, the cumulative rating designated for large clupeids was Moderate-Low.

At sites with Francis turbines, small American shad, blueback herring and alewife were all sampled, and averaged 88.1% survival. Coinciding with the Moderate-High cumulative rating given for small fish of all species sampled at sites similar to the Santee Development, a cumulative rating of Moderate-High was also given to the small clupeid fish for passage survival at the Santee Development

One study, at Stevens Creek, SC, sampled medium sized clupeids (blueback herring), obtaining a 95.3% survival. The cumulative rating given to medium sized clupeids was Moderate, considering the Moderate-Low cumulative rating given to medium sized fish passing through the Santee turbine.

No large clupeids were sampled at sites similar to the Santee Development.

4.7.2.2 American Eel

A cumulative ranking of Low was given to large American eel passing the Jefferies Development and Moderate for those at Santee. At the only site similar to Jefferies where American eel were studied, the St. Lawrence-FDR facility in New York, survival was estimated to be 73.5%. Similarly, a cumulative ranking of Moderate-Low to Low was given to large fish passing Jefferies (See Section 4.7.1.1); therefore a ranking of Low was deemed appropriate. For Santee the comparisons were not so clear. Large eel studied at Minetto, NY had a 94% survival estimate compared to a cumulative ranking of Low for large fish passing through Santee (see Section 4.7.1.2). Therefore, the subjective cumulative ranking assigned to American eel passing through Santee was Moderate. No small or medium sized eels were collected at other sites.

4.8 Assessment of the Potential Combined Impacts of Turbine Entrainment and Survival

Qualitative estimates of entrainment potential (Table 4-6) and turbine survival (Table 4-18 and 4-19) were used to assess the overall potential impact the Santee Cooper Project may have on the target species. The results are discussed below for each species and Development. Spatial and temporal characteristics of each Development (Table 4-3) and species life history traits were also considered.

Although the three turbine models at the Jefferies Development were evaluated individually for survival potential, the impact of the Development as a whole was considered in the analysis of the potential combined impact of entrainment and survival. It should be noted, however, that survival predictions differ slightly among the turbine types. The large Kaplan units (Units 2 and 4) generated the highest predictions of survival and the propeller units (Units 1 and 3) the lowest.

American Shad, Hickory Shad and Blueback Herring

The alosid target species are discussed together because they have similar life histories and were represented by the same surrogate species (alewife) in both the entrainment and survival analyses. These species are in the Santee Cooper system as adults from mid-winter to spring. Juveniles generally leave nursery areas in the fall in most systems. However, there is evidence that clupeid emigration occurs at other times of the year in the Santee Cooper lakes (D. Cooke, personal communication).

At the Jefferies Development, the proximity of Unit 6 (small Kaplan turbine) to the shoreline, the depth of the intake structures and the high hydraulic capacity, compared to the Santee Development, are all factors that may increase entrainment at that location. Because most of the water leaving the Santee Cooper Project flows through the Jefferies Development, it appears likely, in the absence of contradictory information, that entrainment will be higher here than at the Santee Development. Also, during daylight hours, when the Jefferies station is generally operating, juvenile American shad and blueback herring are expected to be near the lake bottom where the intake structures are located.

Alewife was the only clupeid target or surrogate species represented in the entrainment database. Entrainment potential was High for small fish and Moderate-High for medium sized fish.

Although no medium sized clupeids were entrained in the studies examined, it is expected that the adults of all three species (all of which may grow to 15 inches or larger) will attempt to migrate out of the spawning area and back to the sea. Many adult shad will perish due to natural causes after spawning, but a portion are likely to attempt the migration back to sea. Therefore, entrainment of medium and large size clupeids is likely. The probability of survival will vary with size. Cumulative ratings of survival were High and Moderate-Low for small and large clupeids, respectively, suggesting that survival of juvenile clupeids migrating to the sea for the first time will high. Survival of returning adults is likely to be lower.

It is anticipated that fewer fish will be entrained at the Santee Development due to less flow through the turbine. Although the Santee intake is not adjacent to the shoreline, it does extend to near the bottom of the lake, increasing the susceptibility of entrainment for juvenile American shad and blueback herring. Juveniles leaving the system via the Francis turbine at the Santee station have a slightly lower survival probability compared to those leaving via Jefferies. However, it appears that juvenile alosid's migrating through either outfall are minimally impacted. A higher overall impact is expected for the adults of the species.

American eel

Because American eels are catadromous, small eels are not expected to pass through the turbines in significant numbers. Adult or silver eels that fall into the medium and large size groups will pass through the turbines from about fall to winter on their way to spawning grounds in the Sargasso Sea. Overall impact on American eel at the two Santee Cooper Developments could be high.

For the Jefferies Development medium and large sized American eel had entrainment estimates of Moderate and Moderate-High respectively. Survival probabilities were Low at other sites where eels were tested and ranged from Moderate-High for medium sized generic fish to low for large sized generic fish.

Survival of American eel passing through the Francis turbine at the Minetto, NY Development was 94%, an unexpectedly high result considering the 47.4 to 0% survival predicted for large fish passing the Santee Development.

Atlantic and shortnose sturgeon

In the entrainment portion of this assessment, Atlantic and shortnose sturgeon were represented by lake sturgeon, a fish that typically grows larger than shortnose sturgeon but not as large as Atlantic sturgeon. However, migratory spawning behavior, a factor that will influence entrainment, differs between the three species to some degree. While lake sturgeon do migrate to spawning grounds within the lake or river system they inhabit, their movements are more limited than shortnose and Atlantic sturgeon. Atlantic sturgeon migrate from the ocean to estuarine and brackish water, while shortnose sturgeon move from estuaries to upper reaches of freshwater tributaries. Therefore, for the purpose of this exercise, it is assumed that all sturgeon that migrate above the Santee Cooper Project, along with juveniles spawned there, will attempt to migrate out of the Project area.

The entrainment potential for lake sturgeon from previous studies was Low for small and large fish, and Moderate-Low for medium fish. Since no sturgeon were sampled in the survival studies, ratings based on model predictions were used. Model predictions of survival at the Jefferies Development were High for small fish, Moderate to Moderate-High for medium sized fish and Low to Moderate-Low for large fish. Due to the large size and fast growth rate of Atlantic sturgeon, it is primarily fish within the large size category of this species that will be entrained (Table 4-1). Atlantic sturgeon migrating out of the system are likely to be entrained and have a Moderate-Low to Low probability of survival; therefore, the potential combined impact is expected to be high.

Juvenile and adult shortnose sturgeon fall into the medium and large size categories (Table 4-1). Given the predicted potential for survival of medium and large fish (Moderate-High to Low), it is likely that the overall impact at Jefferies will be modest for the smaller life stages and high for adults.

The overall impact at Santee is expected to be high for both sturgeon species. Medium and large sized fish have a Moderate-Low to Low cumulative survival rating.

Striped bass

Overall impact of the Jefferies station on striped bass is expected to be low for small fish and moderate for medium and large sized fish. The moderate impact assessed for large striped bass is based on a fairly low potential for entrainment. The surrogate species for striped bass in the entrainment portion of this assessment was white perch. Entrainment potential for small, medium and large white perch was Moderate-High, High and Low, respectively. Although striped bass, unlike white perch, undergo a spawning migration, they have also adapted to the landlocked situation of the Santee Cooper system. While a portion of the population may migrate back out to sea, some likely remain in the system. Therefore entrainment rates for white perch were considered applicable to striped bass. Cumulative survival ratings generated for small (High), medium (Moderate-High) and large fish (Moderate-Low to Low) were also appropriate.

Similar impacts are likely at the Santee Development, where cumulative survival ratings are Moderate-High, Moderate-Low and Low for small, medium and large fish.

5.0 DISCUSSION

Available information on entrainment and turbine passage survival from other hydroelectric projects was used to provide an assessment of the potential entrainment effects the Santee Cooper Project may have on the seven Santee Cooper target species. Improvements in, and standardization of, field methodologies in recent years have allowed for the compilation of useful and informative comparisons of existing data.

Because flow is believed to be one of the primary factors influencing the downstream movement of diadromous fishes (Coutant and Whitney 2000), site characteristics of the two Santee Cooper Developments suggest that entrainment of the target species will be higher at the Jefferies Development. This is based primarily on the substantially higher average annual flow passed through the Jefferies Development compared to the Santee Development (4,846 vs. 542 cfs, respectfully). Although flow patterns within the lakes are not well documented, it is reasonable to assume that an area of high flow in the system is more of an attractant to diadromous fish than areas of lower flow.

Survival predictions differ between the two sites, primarily because of the different types of turbines. At the Jefferies Development, average predicted survival for all fish sizes is highest through the large Kaplan turbines (Units 2 and 4) and lowest through the fixed propeller turbines (Units 1 and 3). As fish size increases relative to the passageway through a turbine runner, so too does the difference in average predicted survival, with as much as a 30% difference between Units 1 and 3, and 2 and 4 for a 36 inch fish (Table 4-16).

For this assessment, the most important life history characteristic of the target species is diadromy. The life histories of all of the target species include a period of migration downstream to the estuary or ocean. The degree to which each species adheres to this characteristic and the extent of the migration are factors influencing the potential for entrainment. Striped bass and Atlantic sturgeon in particular, may not be as vulnerable to entrainment as the other species. Striped bass in the southern part of its range generally forgo coastal migrations, remaining instead within natal rivers and landlocked lakes (Coutant 1985). Documentation of a successfully reproducing landlocked population of striped bass in the Santee Cooper system, from shortly after construction of the site to today, suggests that not all striped bass leave the system.

Atlantic sturgeon spawn in freshwater, but do not migrate as far upstream as shortnose sturgeon. After spawning, adults and juveniles may move between brackish and fresh water before adults and older juveniles migrate to the sea in the fall. Over-wintering juveniles are believed to congregate in lower estuarine areas (Collins et al. 1996). First year juveniles have been documented in the lower reaches of the Santee and Cooper rivers, but have not been collected above the Project. This suggests that a large segment of the Atlantic sturgeon populations in the Santee and Cooper Rivers are finding adequate spawning and nursery habitat below the dams where entrainment is not an issue.

Of the alosid species, which are somewhat impacted by the Project, American shad is the largest, growing to about 30 in. This factor would make it the most likely clupeid species to be affected by turbine passage, except that in waters south of North Carolina American shad are believed to be semelparous, or die after their first spawn (Klauda et al. 1991). There is anecdotal evidence, however, that as many as 50% of the population may return in subsequent years (J. Isley, B. McCord personal communication). Regardless, the survival rate of clupeids through the Jefferies and Santee Developments is expected to be relatively high based on observed and predicted results.

American eel and shortnose sturgeon are likely to be more impacted by the Project than the other species. American eel are large catadromous and semelparous fish. They move downstream to the ocean as adults and spawn only once before dying. Therefore, those that do not survive passage through the turbines will not spawn. American eel were sampled for survival studies at one site similar to the Jefferies Development and one site similar to the Santee Development. Observed survival was 73.5 and 94.0%, respectfully. Survival predictions based on model calculations of the size range of American eel expected to pass through the Jefferies Development averaged about 86% to 46% with a range of 98% to 0%.

Shortnose sturgeon, an endangered species, was not sampled at other sites. It is an estuarine-anadromous species that migrates from estuaries to the upper reaches of rivers to spawn. Juveniles leaving the Santee Cooper system may grow to almost 18 in (Table 4-1) and adults to about 50 in. Average predicted survival for fish 15, 36 and 60 inches passing through the Jefferies Development (averaging survival for all turbines at each radius and correlation factor of 0.20) is 83%, 60%, and 46%, respectively. At the two large Kaplan turbines (Units 2 and 4), for which survival predictions are highest, average predicted survival increases slightly to 87%, 69% and 54%, respectively.

This assessment of entrainment and survival focused on the likelihood of downstream migrating fish passing the Santee Cooper Project safely. Based on a substantial amount of existing data from other hydro projects and predictive model results, it is apparent that the very large majority of downstream migrating fish would pass the Santee Cooper Project safely in its current configuration. As stated above, the species with the largest risk of mortality would be adult American eel (even then, based on existing information, survival would be >73%) and adult sturgeon, if sturgeon is permitted to pass upstream from the lower river. Collins et al. (unpublished manuscript) have implied that it may not necessarily be a prudent management decision to pass adult shortnose sturgeon upstream due to the apparent functional separation of the Lake Marion and Cooper River populations; lack of quality habitat for sturgeon in the Santee Cooper lakes; and concerns about the Santee River population being genetically or functionally discreet from the Cooper River and Lake Marion populations and whether upstream passage into the lakes would cause genetic problems after the potentially discrete populations were permitted to mingle. Cooke et al. (2002) concur with the assessments in this report that downstream passage risk of mortality to juvenile sturgeon would be "relatively low," and that turbine passage survival of adults could be a problem. Ongoing Santee Cooper relicensing studies, being conducted by SCDNR and Clemson University, should help to determine whether upstream passage of shortnose sturgeon is warranted and whether it would be a wise fisheries management decision. If upstream passage of shortnose sturgeon is prescribed by National Marine Fisheries Service under section 18 of the Federal Power Act, and because shortnose sturgeon is a federally listed endangered species, risk and protection would be a serious consideration as there are currently no known downstream passage facilities that would assure protection of emigrating adult sturgeon.

One issue raised by regulators has been, "to determine when and where out-migrating fish are available for egress and the effectiveness of existing project facilities to afford safe passage under various flow scenarios" (Study Request 4, in 22 November 2002 document from SCDNR). Cooke and Leach (2001) conclude that American shad and blueback herring populations have been increasing over the past 10-15 years, even with an increase in a ratio of commercial exploitation to upstream passage numbers. This work indicates that entrainment and downstream passage survival are not limiting the population of these two species that the SCDNR considers to be important and to "support sizeable commercial fisheries on the Santee River" (Cooke and Leach 2001). Additionally, this assessment of downstream passage through the Santee Cooper Project facilities indicates that safe passage is not a significant issue. This conclusion on safe passage coupled with the SCDNR conclusion that American shad and blueback herring populations are increasing calls into question the need for an extensive and intensive multi-year study of the timing and location of downstream passage for the purposes of FERC relicensing.

As a closing statement, based on the premise that downstream migrating fish will follow the bulk of the flow, which for the Santee Cooper Project is through the Jefferies Hydroelectric Station, the fact that the Jefferies Hydro Station has large Kaplan and propeller turbines facilitates high survival for most fish that will pass through the station. With thriving recreational fisheries above and below the dams and with evidence that shad and herring populations are increasing, it is apparent that entrainment and passage survival should not be issues of significant concern based on the existing configuration and operations of the Project. If the FERC license includes a mandatory condition that shortnose sturgeon be provided with effective upstream passage, downstream passage survival of adult sturgeon would warrant significant additional evaluation.

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TABLES

Table 2-1. Suitable habitat requirements for different life stages of the target species at Santee Cooper.

Species and Life Stage	Temperature (°C)	pH	Dissolved oxygen (mgL^{-1})
Striped Bass			
Egg	12 - 23	7.0 - 9.5	>5.0
Larvae	12 - 23	7.0 - 8.5	>5.0
Juvenile	10 - 27	7.0 - 9.0	>5.0
American Shad			
Egg	13.0 - 26.0	>6.0	>5.0
Larvae	15.5 - 26.1	>6.7	>5.0
Juvenile	15.6 - 23.9	NIF	>5.0
Blueback herring			
Egg	14 - 26	5.7 - 8.5	NA
Larvae	14 - 26	6.2 - 8.5	>5.0
Juvenile	10 - 30	NIF	>4.0
Shortnose sturgeon			
Egg	9.0 - 18.0	NIF	NIF
Larvae	9.0 - 23.0	NIF	NIF
Juvenile	0.0 - 28.0	NIF	NIF
Atlantic sturgeon			
Egg	12.8 - 18.3	NIF	NIF
Larvae	12.8 - 21.1	NIF	NIF
Juvenile	10.0 - 26.7	NIF	NIF
American eel			
Adults	8 - 15	NIF	NIF
Hickory Shad	NIF	NIF	NIF

NIF = No information found

Table 2-2. Specifications for turbines installed at the Santee Cooper Hydroelectric Project.

	Jefferies Development					Santee Development
Unit Number	1	2	3	4	6	1
Manufacture	Newport News	Allis Chalmers	Newport News	Allis Chalmers	Allis Chalmers	Leffel
Type	Fixed Propeller	Kaplan	Fixed Propeller	Kaplan	Kaplan	Vertical Francis
No. Blades or Buckets	8	6	8	6	6	16
Runner Diameter (ft)	16	16.67	16	16.67	9.61	
Runner Diameter at Inlet (ft) *						8
Runner Diameter at Outlet (ft) *						17
Runner Height at Inlet (ft) *						
Speed (rpm)	120	120	120	120	200	180
Rating (hp)	40,000	40,000	40,000	40,000	13,300	
Rated Net Head (ft)	70	70	70	70	70	31-46
Best Operating Efficiency (%)	87-89	87-89	87-89	87-89	87-89	89.8 @ 43'
Discharge At Best Efficiency (cfs)	5,500	4,500	5,500	4,500	1,400	500 @ 43'

* Applicable to Francis unit only.

Table 4-1. Size range, activity pattern and time-frame target species are expected to be in the Santee Cooper lake system and, in parentheses, migrating downstream.

Species and Life Stage	Size range (in)	Time-Frames (downstream migration)	Activity Pattern
Striped bass		All Year	Diurnal; young found in littoral zone, juveniles and adults may use entire water column, but not frequently found at bottom depths
Juvenile		(Oct-Dec)	
Age-2	15.7 - 19.4		
Age-3	17.8 - 24.1		
Age-4	23.3 - 25.7		
Adult	19.7 - 29.6	(Oct-Dec)	
American eel		All Year	Nocturnal; usually found in deeper water but may make regular excursions to the surface
Silver (adult)	11.0 - 60.1	(Sept-Feb)	
Atlantic sturgeon		Feb-Jan	Diurnal; bottom dwellers
Juvenile	17.3 - 51.2	(Oct-Jan)	
Adult	51.2 - 94.6	(Feb-Oct)	
Shortnose sturgeon		Feb-Jan	Diurnal; bottom dwellers
Juvenile	5.5 - 17.7	(Sept-Jan)	
Adult	17.7 - 51.2	(Feb-May)	
American shad		Feb-Nov	Juveniles undergo diel vertical migrations, spending daylight hours near the bottom and evenings near the surface; pelagic zone
Juvenile	3.2 - 4.3	(Oct-Nov)	
Adult	15.0 - 29.9	(Feb-May)	
Hickory shad		Feb-Oct	Unknown
Juvenile	3.9 - 5.5	(July-Oct)	
Adult	11.2 - 23.6	(Feb-May)	
Blueback herring		Feb-Dec	Juveniles undergo diel vertical migrations, spending daylight hours near the bottom and evenings near the surface; littoral zone
Juvenile	3.0 - 4.1	(Oct-Dec)	
Adult	5.9 - 13.8	(Feb-May)	

Table 4-2. Fish speceis occuring in the Santee Cooper Project area (Mead & Hunt 2001; John Bulak, personal communication) and documented in the qualified entrainment source studies (EPRI 1997).

Common Name	Scientific Name
American eel	*Anguilla rostrata*
Black crappie	*Pomoxis nigromaculatus*
Bluegill	*Lepomis macrochirus*
Brook silverside	*Labidesthes sicculus*
Chain pickerel	*Esox niger*
Channel catfish	*Ictalurus punctatus*
Common carp	*Cyprinus carpio*
Gizzard shad	*Dorosoma cepedianum*
Golden shiner	*Notemigonus crysoleucas*
Johnny darter	*Etheostoma nigrum*
Largemouth bass	*Micropterus salmoides*
Longnose gar	*Lepisosteus osseus*
Pumpkinseed	*Lepomis gibbosus*
Shorthead redhorse	*Moxostoma macrolepidotum*
Silver redhorse	*Moxostoma anisurum*
Smallmouth bass	*Micropterus dolomieu*
Spottail shiner	*Notropis hudsonius*
Tessellated darter	*Etheostoma olmstedi*
White bass	*Morone chrysops*
White perch	*Marone americana*
White sucker	*Catostomus commersoni*
Yellow perch	*Perca flavescens*

Table 4-3. Evaluation of site characteristics that may influence entrainment rates at the Santee Cooper developments.

Influence Factors	Jefferies					Santee
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 6	
Intake adjacent to shoreline	No	No	No	No	Yes	No
Intake location in littoral zone	No	No	No	No	No	No
Abundant clupeids	Yes	Yes	Yes	Yes	Yes	Yes
Intake depth-ft (at top, full pond)	16	16	16	16	16	35
Winter drawdown	No	No	No	No	No	No
Hydraulic capacity (cfs)	5,500	4,500	5,500	4,500	1,400	500

Table 4-4. Location, hydraulic capacity and trash rack spacing of 43 sites included in the EPRI (1997) database.

Site Name	State	River	Total Plant Capacity (cfs)	Average Capacity of Sampled Units (cfs)	Clear Trash Rack Spacing (in)
Belding	MI	Flat	416	208	2
Bond Falls	MI	W.B. Ontonagon	900	450	3
Brule	WI	Brule	1,377	458	1.62
Buzzard's Roost	SC	Saluda	3,930	1,310	3.625
Caldron Falls	WI	Peshtigo	1,300	650	2
Centralia	WI	Wisconsin	3,640	550	3.5
Colton	NY	Raquette	1,503	450	2
Crowley	WI	N.F. Flambeau	2,400	1,200	2.375
E. J. West	NY	Sacandaga	5,400	2,450	4.5
Feeder Dam	NY	Hudson	5,000	1,000	2.75
Four Mile Dam	MI	Thunder Bay	1,500	500	2
Gaston Shoals	SC	Broad	2,211	837	1.5
Grand Rapids	MI/WI	Menominee	3,870	739	1.75
Herrings	NY	Black	3,610	1,203	4.125
High Falls	NY	Beaver	900	300	1.81
Higley	NY	Raquette	2,045	682	3.63
Hillman Dam	MI	Thunder Bay	270	270	3.25
Hollidays Bridge	SC	Saluda	4,396	370	unknown
Johnsonville	NY	Hoosic	1,288	644	2
Kleber	MI	Black	400	200	3
Lake Algonquin	NY	Sacandaga	750	750	1
Luray	VA	S.F. Shenandoah	1,477	369	2.75
Minetto	NY	Oswego	7,500	1,500	2.5
Moshier	NY	Beaver	660	330	1.5
Ninety-Nine Islands	SC	Broad	4,800	584	1.5
Ninth Street Dam	MI	Thunder Bay	1,650	550	1
Norway Point Dam	MI	Thunder Bay	1,775	575	1.69
Potato Rapids	WI	Peshtigo	1,380	500	1.75
Raymondville	NY	Raquette	1,640	1,640	2.25
Richard B. Russell	GA/SC	Savannah	60,000	7,200	8
Saluda	SC	Saluda	812	227	unknown
Sandstone Rapids	WI	Peshtigo	1,300	650	1.75
Schaghticoke	NY	Hoosic	1,640	410	2.125
Shawano	WI	Wolf	850	850	5
Sherman Island	NY	Hudson	6,600	1,650	3.125
Thornapple	WI	Flambeau	1,400	700	1.69

Table 4-4. Cont'd.

Site Name	State	River	Total Plant Capacity (cfs)	Average Capacity of Sampled Units (cfs)	Clear Trash Rack Spacing (in)
Tower	MI	Black	404	202	1
Townsend Dam	PA	Beaver	4,400	2,200	5.5
Twin Branch	IA	St. Joseph	3,200	600	3
Warrensburg	NY	Schroon	1,350	1,350	unknown
White Rapids	MI/WI	Menominee	3,994	1,225	2.5
Wisconsin River Division	WI	Wisconsin	5,150	431	2.19
Youghiogheny	PA	Youghiogheny	1,600	800	10

Table 4-5. Size composition of entrainment catch by bar rack spacing from 39 sites included in the EPRI (1997) database (after Winchell et al. 2000).

Clear Spacing (inches)	N	Average Composition (%) by Size Class (inches)					Representative Santee Cooper Development
		0 to 4	4 to 8	8 to 15	15 to 30	> 30	
1	3	61.5	32.2	5.5	0.9	0.0	
1.5-1.8	10	64.8	27.1	7.5	0.6	0.0	
2.0-2.75	12	68.9	25.3	5.1	0.7	0.0	
3.0-10.0	14	80.0	15.7	3.9	0.3	0.0	Jefferies & Santee
All	**39**	**71.3**	**22.9**	**5.3**	**0.5**	**0.0**	

Table 4-6. Average entrainment densities for Santee Cooper target and surrogate species from the EPRI (1997) database. Density shown as fish per million cubic feet of water.

	Small Fish (< 8 inches)			Medium Fish (8-15 inches)			Large Fish (>15 inches)		
Species	**No. Sites Present**	**Annual Density[1]**	**Entrainment Potential**	**No. Sites Present**	**Annual Density**	**Entrainment Potential**	**No. Sites Present**	**Annual Density**	**Entrainment Potential**
Alewife	3	34.05685	High	2	0.07845	Moderate-High	0	0.00000	None
White perch	4	0.22446	Moderate-High	4	0.18295	High	1	0.00003	Low
Lake sturgeon	2	0.00091	Low	2	0.00130	Moderate-Low	1	0.00005	Low
American eel	1	0.00001	Low	5	0.00535	Moderate	8	0.07084	Moderate-High

[1] Number of fish per million cubic feet of water

Assumptions (see text):

1) Alewife - surrogate for blueback herring, American shad and hickory shad

2) White perch - surrogate for striped bass

3) Lake sturgeon - surrogate for shortnose sturgeon and Atlantic sturgeon

Table 4-7. Physical and hydraulic characteristics of all hydroelectric dams equipped with Kaplan/propeller type turbines for which survival data are available.

Station	Sampling Method	Species Tested	Treatment Sample Size	Control Sample Size	Avg. Fish Length (mm)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Control Survival (%)	Percent Recapture		Est. Percent Survival	Source****
												Treat.	Control		
Annapolis, NS	Radio telemetry	American shad	20	39	Adult	14,287	-	50	22	267	NA	NA	NA	53.7	Dadswell et al. (1986)
Big Cliff, OR (1964)	Full discharge netting	Chinook Salmon	3,500	3,500	100	1,854	6	163.6	91	148	NA	98.1	97.0	91.1	Oligher & Donaldson (1966)
Big Cliff, OR (1964)	Full discharge netting	Chinook Salmon	2,750	2,750	100	2,509	6	163.6	81	148	NA	98.1	97.0	94.5	Oligher & Donaldson (1966)
Big Cliff, OR (1964)	Full discharge netting	Chinook Salmon	3,500	3,500	100	2,510	6	163.6	71	148	NA	98.1	97.0	89.7	Oligher & Donaldson (1966)
Big Cliff, OR (1966)	Full discharge netting	Chinook Salmon	2,750	2,750	100	1,854	6	163.6	91	148	NA	93.2	98.9	92.2	Oligher & Donaldson (1966)
Big Cliff, OR (1966)	Full discharge netting	Chinook Salmon	3,750	3,750	100	2,509	6	163.6	81	148	NA	93.2	98.9	89.8	Oligher & Donaldson (1966)
Big Cliff, OR (1966)	Full discharge netting	Chinook Salmon	2,500	2,500	100	2,510	6	163.6	71	148	NA	93.2	98.9	90.6	Oligher & Donaldson (1966)
Big Cliff, OR (1967)	Full discharge netting	Steelhead	-	-	152	2,510	6	163.6	71	148	NA	-	-	90.4	Oligher & Donaldson (1966)
Bonneville, OR-WA	Brand, CWT/seine	Chinook Salmon	850,406	435,099	91	17,600	5	69.2	60	330	NA	<1.0	<1.0	97.5	Ledgerwood et al. (1990)
Chalk Hill, MI-WI	HI-Z Turb'N Tag	Bluegill	60	43	103	1,330	4	150	29	102	95.3	86.7	97.7	97.0	RMC (1993a)
Chalk Hill, MI-WI	HI-Z Turb'N Tag	Bluegill	50	67	153	1,330	4	150	29	102	95.5	94.0	97.0	98.0	RMC (1993a)
Chalk Hill, MI-WI	HI-Z Turb'N Tag	W. Sucker/R. Trout	77	70	119	1,330	4	150	29	102	94.3	80.5	94.3	91.0	RMC (1993a)
Chalk Hill, MI-WI	HI-Z Turb'N Tag	W. Sucker/R. Trout	38	45	261	1,330	4	150	29	102	100.0	97.4	100.0	97.0	RMC (1993a)
Conowingo, MD	HI-Z Turb'N Tag	American Shad	108	108	125	8,000	6	120	90	225	91.7	88.0	97.6	94.9	RMC (1994a)
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	43	28	180	600	4	229	21	69	100.0	93.0	100.0	93.0	Mathur et al. (1993)
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	63	28	180	200	4	229	-	69	100.0	90.0	100.0	90.0	Mathur et al. (1993)
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	39	22	277	200	4	229	-	69	100.0	90.0	100.0	81.0	Mathur et al. (1993)
Craggy Dam, NC	HI-Z Turb'N Tag	Bluegill	33	40	100	200	4	229	-	69	90.0	85.0	90.0	96.0	Mathur et al. (1993)
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	32	22	277	600	4	229	-	69	100.0	88.0	100.0	93.0	Mathur et al. (1993)
Craggy Dam, NC	HI-Z Turb'N Tag	Bluegill	72	54	155	200	4	229	-	69	96.0	90.0	96.0	86.0	Mathur et al. (1993)
Crescent, NY	HI-Z Turb'N Tag	Blueback Herring	125	125	91	1,520	5	144	27	108	90.0	84.0	86.0	96.0	Mathur et al. (1996a)
Essex, MA (bulb turbine)	Radio telemetry	Atlantic Salmon	50	0	-	4,400		128.6	29	144	NA	50.0	NA	98.0	Knight (1982)
Foster, OR	Fyke nets	Chinook Salmon	-	-	-	800	6	257	101	100	NA	-	-	93.9	Bell (1981)
Foster, OR (43 tests	Full discharge netting	Chinook Salmon	-	-	120	800	6	257	110	100	NA	-	-	88.8	Bell (1981)
Feeder Dam, NY*	Full discharge netting	Bluegill	-	-	91.6	1,040	6	120	15.5	115	100.0	-	-	97.3	Acres (1995)
Feeder Dam, NY*	Full discharge netting	Bluegill	-	-	128.6	1,040	6	120	17	115	97.7	-	-	92.3	Acres (1995)
Feeder Dam, NY*	Full discharge netting	Largemouth bass	-	-	87.7	1,040	6	120	18	115	90.1	-	-	98.0	Acres (1995)
Feeder Dam, NY*	Full discharge netting	Largemouth bass	-	-	190	1,040	6	120	19	115	96.3	-	-	90.0	Acres (1995)
Feeder Dam, NY*	Full discharge netting	Largemouth bass	-	-	292.1	1,040	6	120	20	115	99.2	-	-	86.8	Acres (1995)
Feeder Dam, NY*	Full discharge netting	Brown trout	-	-	205.5	1,040	6	120	21	115	93.1	80.5	93.1	86.4	Acres (1995)
Feeder Dam, NY*	Full discharge netting	Golden shiner	-	-	88	1,040	6	120	22	115	95.0	92.8	95.8	96.8	Acres (1995)
Fourth Lake, NS	Full dschrg/dye or brand	Atlantic Salmon	503	494	163	530	6	360	75	-	99.4	74.4	74.3	83.7	Ruggles et al. (1990)
Fourth Lake, NS	Full dschrg/dye or brand	Brook trout	1,908	NA	105.5	530	6	360	75	-	96.5	24.5	-	87.1	Ruggles et al. (1990)
Fourth Lake, NS	Full dschrg/dye or brand	Alewife	675	627	96	530	6	360	75	-	83.1	70.8	83.1	89.0	Ruggles et al. (1990)
Greenup Dam, OH	Radio telemetry	Sauger	48	NA	231	11,866	5	90	30	240	NA	85.4	NA	85.4	Olson et al. (1990)
Hadley Falls, MA	Radio telemetry	American Shad	36	69	560	4,200	5	128	52	170	98.6	-	-	78.2	Bell and Kynard (1985)
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	100	100	82	4,200	5	128	52	170	75.0	76.0	76.0	97.3	Mathur et al. (1994)
Hadley Falls, MA	Radio telemetry	Atlantic Salmon	108	89	285	4,200	5	128	52	170	92.5	100.0	100.0	93.7	Kynard et al. (1982)
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	100	100	82	1,550	5	128	-	170	77.0	81.0	78.0	100.0	Mathur et al. (1994)
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	120	120	82	4,200	5	150	-	170	83.3	74.2	83.3	89.1	RMC (1992a)
Herrings, NY	Full discharge netting	Centrarchid	74	65	<100	1,200	-	138	19	113	98.3	74.3	90.8	98.3	KA (1996a)
Herrings, NY	Full discharge netting	Centrarchid	77	63	175	1,200	-	138	19	113	100.0	96.0	100.0	97.3	KA (1996a)
Herrings, NY	Full discharge netting	Centrarchid	80	65	>250	1,200	-	138	19	113	100.0	91.3	70.8	93.2	KA (1996a)

Table 4-7. Continued.

Station	Sampling Method	Species Tested	Treatment Sample Size	Control Sample Size	Avg. Fish Length (mm)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Control Survival (%)	Percent Recapture Treat.	Percent Recapture Control	Est. Percent Survival	Source
Herrings, NY	Full discharge netting	Percid	46	51	<100	1,200	-	138	19	113	99.1	84.8	88.2	91.1	KA (1996a)
Herrings, NY	Full discharge netting	Salmonids	31	57	<100	1,200	-	138	19	113	100.0	32.3	22.8	90.0	KA (1996a)
Herrings, NY	Full discharge netting	Salmonids	74	63	100-250	1,200	-	138	19	113	100.0	32.4	1.6	87.5	KA (1996a)
Herrings, NY	Full discharge netting	Salmonids	82	72	>250	1,200	-	138	19	113	-	96.2	0.0	96.2	KA (1996a)
Herrings, NY	Full discharge netting	Centrarchid	90	65	<100	1,200	-	138	19	113	98.2	96.7	95.4	95.0	KA (1996a)
Herrings, NY	Full discharge netting	Centrarchid	90	69	100-250	1,200	-	138	19	113	100.0	92.2	97.1	96.4	KA (1996a)
Herrings, NY	Full discharge netting	Centrarchid	90	77	>250	1,200	-	138	19	113	100.0	88.9	97.4	92.5	KA (1996a)
Herrings, NY	Full discharge netting	Percid	185	78	<100	1,200	-	138	19	113	100.0	83.8	84.6	94.9	KA (1996a)
Herrings, NY	Full discharge netting	Percid	179	139	100-250	1,200	-	138	19	113	100.0	91.1	94.2	98.2	KA (1996a)
Herrings, NY	Full discharge netting	Percid	138	137	>250	1,200	-	138	19	113	100.0	84.8	94.2	96.2	KA (1996a)
Herrings, NY	Full discharge netting	Salmonids	91	74	<100	1,200	-	138	19	113	100.0	24.2	18.9	95.5	KA (1996a)
Herrings, NY	Full discharge netting	Salmonids	95	72	100-250	1,200	-	138	19	113	100.0	78.9	73.6	98.7	KA (1996a)
Herrings, NY	Full discharge netting	Salmonids	111	77	>250	1,200	-	138	19	113	100.0	64.0	72.7	98.6	KA (1996a)
Herrings, NY	Full discharge netting	Soft ray	188	144	<100	1,200	-	138	19	113	100.0	63.3	85.4	97.5	KA (1996a)
Herrings, NY	Full discharge netting	Soft ray	201	159	100-250	1,200	-	138	19	113	100.0	74.1	94.7	91.7	KA (1996a)
Herrings, NY	Full discharge netting	Soft ray	175	125	>250	1,200	-	138	19	113	100.0	95.4	99.2	85.1	KA (1996a)
Herrings, NY	Full discharge netting	Clupeids	196	166	<100	1,200	-	138	19	113	100.0	90.3	90.4	92.8	KA (1996a)
Kleber Dam, MI	Full discharge netting	Mixed resident fish	-	-	Adults	200	-	450	44	-	-	-	-	59.0	EPRI (1992)
la centrale de Beauharnois, Quebec, Canada	Float tag	American eel	122	-	881	9,275	6	94.7	79	249	NA	95.9	-	76.1	Desrochers (1995)
Lowell, MA	Radio telemetry	Atlantic Salmon	50	0	265	4,500	5	120	39	152	NA	100.0	NA	88.5	Nelson et al. (1992)
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	820	821	134	21,000	6	90	-	312	97.8	94.5	98.8	94.6	RMC et al. (1994)
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	320	320	151	18,000	6	90	-	312	98.4	96.8	98.7	94.9	Normandeau et al. (1995)
Lower Granite, WA	PIT tagging	Chinook Salmon	3,200	1,600	151	18,000	6	90	-	312	NA	-	-	92.7	Muir et al. (1995)
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	320	320	150	18,000	6	90	-	312	98.4	96.6	98.7	95.3	Normandeau et al. (1995)
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	250	250	148	13,500	6	90	-	312	98.4	96.4	99.6	97.2	Normandeau et al. (1995)
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	300	300	148	19,000	6	90	98	312	99.3	96.7	99.3	94.6	Normandeau et al. (1995)
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	250	250	151	18,000	6	90	-	312	99.6	98.1	98.1	97.5	Normandeau et al. (1995)
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	320	320	150	18,000	6	90	-	312	98.1	98.2	98.1	97.5	Normandeau et al. (1995)
McNary, WA	Brand and Partial netting	Chinook Salmon	120,000	120,000	52	12,300	6	87.5	80	280	NA	< 5.0	< 5.0	89.0	Schoeneman et al. (1961)
Marshall, NC	Partial netting	Resident	2,544	2,544	-	1,250	-	212	31.4	149.4	>80	-	39.0	92.3	EPRI (1992)
Morrow, MI (EPRI)	Full discharge netting	Resident	764	220	-	235	-	175	12	54	93.0	81.0	93.0	92.1	EPRI (1992)
Morrow, MI	Full discharge netting	Bluegill	218	59	Adult\YOY	235	-	175	12	54	76.0	190.0	55.0	70.0	EPRI (1992)
Morrow, MI	Full discharge netting	Brown Bullhead	117	39	Adult	235	-	175	12	54	100.0	75.2	84.6	97.0	EPRI (1992)
Morrow, MI	Full discharge netting	Pumpkinseed	88	22	Adult\YOY	235	-	175	12	54	100.0	86.4	100.0	90.0	EPRI (1992)
Morrow, MI	Full discharge netting	Black Crappie	90	33	Adult\YOY	235	-	175	12	54	93.0	67.8	90.9	74.0	EPRI (1992)
Morrow, MI	Full discharge netting	White Sucker	64	29	Adult\YOY	235	-	175	12	54	100.0	79.7	100.0	67.0	EPRI (1992)
Morrow, MI	Full discharge netting	Yellow Perch	39	5	Adult	235	-	175	12	54	100.0	82.1	100.0	78.0	EPRI (1992)
Morrow, MI	Full discharge netting	Redhorse	31	10	Adult	235	-	175	12	54	100.0	87.1	100.0	71.0	EPRI (1992)
Morrow, MI	Full discharge netting	Largemouth Bass	24	5	Adult	235	-	175	12	54	100.0	87.5	100.0	81.0	EPRI (1992)
Morrow, MI	Full discharge netting	Northern Pike	21	1	Adult	235	-	175	12	54	0.0	95.2	100.0	45.0	EPRI (1992)
Morrow, MI	Full discharge netting	Yellow Bullhead	39	5	Adult	235	-	175	12	54	100.0	82.1	100.0	92.0	EPRI (1992)

Table 4-7. Continued.

Station	Sampling Method	Species Tested	Treatment Sample Size	Control Sample Size	Avg. Fish Length (mm)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Control Survival (%)	Percent Recapture Treat.	Percent Recapture Control	Est. Percent Survival	Source
Racine, WI*	Partial netting	Gizzard shad	-	-	-	8,000	4	62.1	22	303.6	NA	-	-	93.5**	EPRI (1992)
Racine, WI*	Partial netting	Drum	-	-	-	8,000	4	62.1	22	303.6	NA	-	-	94.0*	EPRI (1992)
Racine, WI*	Partial netting	Game species	-	-	-	8,000	4	62.1	22	303.6	NA	-	-	94.0*	EPRI (1992)
Raymondville, NY	Full discharge netting	Eel	-	-	625	1,640	6	120	21	131	-	85.0	90.0	63.0	KA (1996b)
Rock Island, WA (bulb turb)	Brand and Partial netting	Coho Salmon	203,336	203,843	115	18,000	4	85.7	40	276	NA	18.4	19.5	93.0	Olson & Kaczynski (1980)
Rock Island, WA (bulb turb)	Brand and Partial netting	Steelhead	58,571	57,864	166	18,000	4	85.7	40	276	NA	17.9	18.5	96.9	Olson & Kaczynski (1980)
Rocky Reach, WA (30',U. 3)	HI-Z Turb'N Tag	Chinook Salmon	250	250	161	16,000	6	90	92	280	98.9	96.4	98.8	94.7	Mathur et al. (1996b)
Rocky Reach, WA (10',U. 3)	HI-Z Turb'N Tag	Chinook Salmon	350	350	161	16,000	6	90	92	280	98.9	95.0	96.0	93.9	Mathur et al. (1996b)
Rocky Reach, WA (10',U. 5)	HI-Z Turb'N Tag	Chinook Salmon	235	300	184	14,000	6	90	92	280	99.0	98.3	99.0	97.3	Normandeau & Skalski (1996)
Rocky Reach, WA (30',U. 5)	HI-Z Turb'N Tag	Chinook Salmon	241	220	184	14,000	6	90	92	280	97.3	96.3	97.7	94.4	Normandeau & Skalski (1996)
Rocky Reach, WA (10',U. 6)	HI-Z Turb'N Tag	Chinook Salmon	420	300	184	14,000	6	90	92	280	99.0	97.6	99.0	94.2	Normandeau & Skalski (1996)
Rocky Reach, WA (30',U. 6)	HI-Z Turb'N Tag	Chinook Salmon	235	220	184	14,000	6	90	92	280	97.3	97.1	97.7	95.8	Normandeau & Skalski (1996)
Rocky Reach, WA (10',U. 8)	HI-Z Turb'N Tag	Chinook Salmon	265	265	114	20,000	5	85.7	86.5	311	88.7	85.7	88.7	96.9	RMC & Skalski (1994)
Safe Harbor, PA (Unit 7)	HI-Z Turb'N Tag	American Shad	98	100	424	8,300	5	109	55	220		97.0	100.0	89.7	Normandeau Assoc. (In prep)
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	100	100	424	9,200	7	76.6	55	240		100.0	100.0	87.0	Normandeau Assoc. (In prep)
Safe Harbor, PA (7&8 poole	HI-Z Turb'N Tag	American Shad	-	-	-	-	-	-	-	-	-	-	-	88.3	Normandeau Assoc. (In prep)
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	100	100	118	9,200	7	75	55	242	92.0	92.0	92.0	97.8	Heisey et al. (1992)
Safe Harbor, PA (Unit 7)	HI-Z Turb'N Tag	American Shad	100	100	118	8,300	5	109	55	222	99.0	99.0	99.0	98.0	Heisey et al. (1992)
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	100	100	118	9,200	7	75	55	242	98.0	96.0	98.0	98.9	Heisey et al. (1992)
St. Lawrence-FDR (Unit 28)	HI-Z Turb'N Tag	American eel	240	134	1020	9,700	6	94.7	81	240	93.3	86.3	94.8	73.5	Normandeau Assoc. (1997)
Thornapple, WI	Full discharge netting	Indigenous sp	3,378	-	-	700	6	120	15	110	NA	-	-	95.3	EPRI (1992)
Thornapple, WI	Full discharge netting	Bullheads & Catfish	-	-	-	-	6	120	-	110	NA	-	-	91.9	EPRI (1992)
Thornapple, WI	Full discharge netting	Suckers & Redhorse	-	-	-	-	6	120	-	110	NA	-	-	93.4	EPRI (1992)
Thornapple, WI	Full discharge netting	Panfish & Y. Perch	-	-	-	-	6	120	-	110	NA	-	-	93.5	EPRI (1992)
Thornapple, WI	Full discharge netting	N. Pike & Muskllng	-	-	-	-	6	120	-	110	NA	-	-	94.1	EPRI (1992)
Thornapple, WI	Full discharge netting	Burbot	-	-	-	-	6	120	-	110	NA	-	-	96.9	EPRI (1992)
Thornapple, WI	Full discharge netting	Minnow/Dace/Darte	-	-	-	-	6	120	-	110	NA	-	-	97.1	EPRI (1992)
Thornapple, WI	Full discharge netting	Small/Largemth Bas	-	-	-	-	6	120	-	110	NA	-	-	97.4	EPRI (1992)
Thornapple, WI	Full discharge netting	Walleye	-	-	-	-	6	120	-	110	NA	-	-	97.6	EPRI (1992)
Townsend Dam, PA	HI-Z Turb'N Tag	Largemouth Bass	31	NA	217	1,500	3	152	16	113	NA	96.8	NA	96.8	RMC (1994b)
Townsend Dam, PA	HI-Z Turb'N Tag	Rainbow Trout	54	52	139	800	3	152	16	113	100.0	96.3	100.0	94.4	RMC (1994b)
Townsend Dam, PA	HI-Z Turb'N Tag	Rainbow Trout	52	51	344	800	3	152	16	113	100.0	92.3	94.1	86.5	RMC (1994b)
Townsend Dam, PA	HI-Z Turb'N Tag	Largemouth Bass	51	50	102	800	3	152	16	113	98.0	98.0	98.0	100.0	RMC (1994b)
Townsend Dam, PA	HI-Z Turb'N Tag	Largemouth Bass	50	50	217	800	3	152	16	113	100.0	100.0	100.0	86.0	RMC (1994b)
Townsend Dam, PA	HI-Z Turb'N Tag	Rainbow Trout	21	NA	139	1,500	3	152	16	113	NA	100.0	NA	100.0	RMC (1994b)
Tusket, NS (Unit 1,2,3)	Draft tube net	Atlantic Salmon	-	-	-	-	-	225	27	-	-	-	-	84.5	Ruggles et al. (1990)
Twin Branch, IN	Full discharge netting	Steelhead Trout	300	300	186	411	4	241	21.4	NA	-	65.0	79.7	93.2	RMC (1994c)
Twin Branch, IN	Full discharge netting	Chinook Salmon	600	450	121	411	4	241	21.4	NA	-	97.5	99.3	99.3	RMC (1994c)
Twin Branch, IN	Full discharge netting	Bluegill	300	300	126	411	4	241	21.4	NA	-	73.0	57.7	94.7	RMC (1994c)
T. W. Sullivan, OR (Unit 7)	Full discharge netting	Steelhead	-	-	-	390	6	240	42	192	-	-	-	92.3	Bell (1981)
T. W. Sullivan, OR (Unit 7)	Full discharge netting	Chinook Salmon	-	-	-	390	6	240	42	192	-	-	-	88.2	Bell (1981)
T. W. Sullivan, OR (Unit 8)	Full discharge netting	Steelhead	-	-	-	260	-	240	42	192	-	-	-	90.1	Bell (1981)
T. W. Sullivan, OR (Unit 8)	Full discharge netting	Chinook Salmon	-	-	-	260	-	240	42	192	-	-	-	89.5	Bell (1981)

Table 4-7. Continued.

Station	Sampling Method	Species Tested	Treatment Sample Size	Control Sample Size	Avg. Fish Length (mm)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Control Survival (%)	Percent Recapture Treat.	Percent Recapture Control	Est. Percent Survival	Source
Walterville, OR(61% wckt)	Brand, full dschrg netting	Rainbow Trout	991	631	fingerling	2,010	-	-	55	120	-	63.0	94.9	97.5	Eicher Associates (1987)
Walterville, OR(77% wckt)	Brand, full dschrg netting	Rainbow Trout	991	631	fingerling	2,010	-	-	55	120	-	36.4	68.3	92.5	Eicher Associates (1987)
Walterville, OR	Brand,dwnstrm bypass	Chinook Salmon	30,000	30,000	135	2,000	-	-	55	120	-	-	-	87.0	Eicher Associates (1987)
Wanapum, WA (10ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	638	640	154	13,000***	6	85.7	75	285	98.1	91.8	98.1	91.6***	Normandeau et al. (1996)
Wanapum, WA (10ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	640	640	154	13,000***	6	85.7	75	285	98.1	96.3	98.1	97.1***	Normandeau et al. (1996)
Wells, WA(Unit 1)	Brand, Partial netting	Steelhead	-	-	smolts	20,000	6	85.7	65	292.5	NA	-	-	84.0	Parametrix (1986)
West Enfield, ME	Radio telemetry	Atlantic Salmon	148	NA	212	5,300	3	89	21	192	NA	100.0	NA	96.0	Shepard (1993)
Wilder, VT-NH	HI-Z Turb'N Tag	Atlantic Salmon	125	125	191	4,500	5	112.5	51	180	100.0	99.2	100.0	96.0	RMC (1994d)

NA = Not Available, Not Applicable
NE = Not Entrained
*   Agency agreed upon estimates
**   Release numbers unavailable at present but the study appears valid and meets the screening criteria.
*** Averaged over 4 test conditions
****Complete references are included in Literature Cited.
[1]Survival estimate includes indirect effects (88 h post test). Immediate survival was 84.0%.

Table 4-8. Physical and hydraulic characteristics of all hydroelectric dams equipped with Francis type turbines for which survival data are available.

Station	Sampling Method	Species Tested	Test sample size	Control sample size	Avg. Fish Length (mm)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Percent Recap. Test	Percent Recap. Control	Est. Percent Survival (1 hr)	Source
Alcona, MI	Full dschrg netting	Bluegill	97	-	118	1660	16	90	43	8.33	97	-	90.2	LMS (1991)
Alcona, MI	Full dschrg netting	Bluegill	102	-	170	1661	16	90	43	8.33	86	-	84.1	LMS (1991)
Alcona, MI	Full dschrg netting	Gold./Common Shiner	51	-	114	1662	16	90	43	8.33	96	-	80.9	LMS (1991)
Alcona, MI	Full dschrg netting	Gold./Common Shiner	58	-	154	1663	16	90	43	8.33	90	-	84.7	LMS (1991)
Alcona, MI	Full dschrg netting	Grass Pickerel	30	-	235	1664	16	90	43	8.33	100	-	86.7	LMS (1991)
Alcona, MI	Full dschrg netting	Northern Pike	44	-	352	1665	16	90	43	8.33	98	-	51.2	LMS (1991)
Alcona, MI	Full dschrg netting	Rainbow Trout	40	-	108	1666	16	90	43	8.33	70	-	100	LMS (1991)
Alcona, MI	Full dschrg netting	Rainbow Trout	40	-	317	1667	16	90	43	8.33	70	-	89.4	LMS (1991)
Alcona, MI	Full dschrg netting	Spottail Shiner	40	-	116	1668	16	90	43	8.33	88	-	59.5	LMS (1991)
Alcona, MI	Full dschrg netting	Walleye	47	-	162	1669	16	90	43	8.33	100	-	16.4	LMS (1991)
Alcona, MI	Full dschrg netting	Walleye	45	-	385	1670	16	90	43	8.33	100	-	38.7	LMS (1991)
Alcona, MI	Full dschrg netting	White Sucker	60	-	180	1671	16	90	43	8.33	100	-	94.4	LMS (1991)
Alcona, MI	Full dschrg netting	White Sucker	54	-	290	1672	16	90	43	8.33	100	-	90.4	LMS (1991)
Alcona, MI	Full dschrg netting	Yellow Perch	55	-	107	1673	16	90	43	8.33	100	-	65.1	LMS (1991)
Alcona, MI	Full dschrg netting	Yellow Perch	45	-	186	1674	16	90	43	8.33	89	-	55.1	LMS (1991)
Baker, WA	Fyke net	Sockeye salmon	-	-	-	550	19	300	250	5.00	-	-	64	Eicher Associates (1987)
Baker, WA	Fyke net	Coho salmon	-	-	-	550	19	300	250	5.00	-	-	72	Eicher Associates (1987)
Buchanan, MI	Full dschrg netting	Chinook salmon	600	400	420	100	-	-	-	-	79.7	98.3	79.6	RMC (1992b)
Buchanan, MI	Full dschrg netting	Steelhead trout	600	400	420	220	-	-	-	-	75.3	87.8	79.4	RMC (1992b)
Bond Falls, MI	Full dschrg netting	Rainbow Trout	350	225	210	450	-	300	210	-	82	97.8	83.8	RMC (1996)
Bond Falls, MI	Full dschrg netting	Yellow Perch	360	225	102	450	-	300	210	-	82.5	98.7	79.5	RMC (1996)
Bond Falls, MI	Full dschrg netting	Golden Shiner	405	225	70	450	-	300	210	-	70.4	93.3	77.9	RMC (1996)
Bond Falls, MI	Full dschrg netting	Bluegill	660	450	115	450	-	300	210	-	82.1	97.3	81.7	RMC (1996)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Centrarchiforms	144	94	76	650	15	226	80	6.00	99.3	87.2	100	Harza (1995)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Centrarchiforms	141	90	127	650	15	226	80	6.00	87.2	92.2	98.2	Harza (1995)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Centrarchiforms	76	35	178	650	15	226	80	6.00	100	100	86.8	Harza (1995)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	145	86	76	650	15	226	80	6.00	86.9	95.3	80.3	Harza (1995)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	139	92	127	650	15	226	80	6.00	95.7	91.3	84.8	Harza (1995)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	125	58	178	650	15	226	80	6.00	95.2	100	70.3	Harza (1995)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	136	63	229	650	15	226	80	6.00	100	98.4	64.3	Harza (1995)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	146	94	292	650	15	226	80	6.00	97.9	85	59.5	Harza (1995)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	153	76	>292	650	15	226	80	6.00	95.4	81.6	35.5	Harza (1995)
Centralia, WI (Unit 2)	Full dschrg netting	White Sucker	-	-	125	510	15	90	20	2.33	-	-	97.9	Harza (1995)
Centralia, WI (Unit 1)	Full dschrg netting	Bluegill	-	-	125	510	15	90	20	2.33	-	-	98.2	Harza (1995)
Centralia, WI (Unit 1)	Full dschrg netting	Bluegill	-	-	175	510	15	90	20	2.33	-	-	86.8	Harza (1995)
Centralia, WI	Full dschrg netting	resident	-	-	< 100	variable	15	90	15.5	2.33	-	-	64	Harza (1992)
Colton, NY	Full dschrg netting	Centrarchid	-	-	< 100	497	19	360	265	4.92	-	-	3	KA (1995a)
Colton, NY	Full dschrg netting	Centrarchid	-	-	175	497	19	360	265	4.92	-	-	1	KA (1995a)
Colton, NY	Full dschrg netting	Centrarchid	-	-	> 250	497	19	360	265	4.92	-	-	0	KA (1995a)
Colton, NY	Full dschrg netting	Percid	-	-	< 100	497	19	360	265	4.92	-	-	65	KA (1995a)
Colton, NY	Full dschrg netting	Percid	-	-	175	497	19	360	265	4.92	-	-	14	KA (1995a)
Colton, NY	Full dschrg netting	Percid	-	-	> 250	497	19	360	265	4.92	-	-	17	KA (1995a)
Colton, NY	Full dschrg netting	Salmonid	-	-	< 100	497	19	360	265	4.92	-	-	68	KA (1995a)
Colton, NY	Full dschrg netting	Salmonid	-	-	175	497	19	360	265	4.92	-	-	31	KA (1995a)
Colton, NY	Full dschrg netting	Salmonid	-	-	> 250	497	19	360	265	4.92	-	-	7	KA (1995a)

Table 4-8. Continued.

Station	Sampling Method	Species Tested	Test sample size	Control sample size	Avg. Fish Length (mm)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Percent Recap. Test	Percent Recap. Control	Est. Percent Survival (1 hr)	Source
Colton, NY	Full dschrg netting	Soft Ray	-	-	100	497	19	360	265	4.92	-	-	75	KA (1995a)
Colton, NY	Full dschrg netting	Soft Ray	-	-	175	497	19	360	265	4.92	-	-	47	KA (1995a)
Colton, NY	Full dschrg netting	Soft Ray	-	-	> 250	497	19	360	265	4.92	-	-	17	KA (1995a)
Columbia, SC	Balloon tag	Channel catfish	95	65	143	833	14	164	28	5.33	92.7	100	93.6	NAI (1999)
Columbia, SC	Balloon tag	Sunfishes	100	100	106	833	14	164	28	5.33	96	98	95.9	NAI (1999)
Columbia, SC	Balloon tag	Blueback herring	100	100	140	833	14	164	28	5.33	90	97	92.7	NAI (1999)
Crown Zellerbach, OR (Unit 20)*	Full dschrg netting	Steelhead trout	1,777	500	-	411	-	277	39	-	52.1	96	69.4	Massey (1967)
Crown Zellerbach, OR (Unit 20)*	Full dschrg netting	Chinook salmon	1,800	500	-	411	-	277	39	-	52.2	98.6	71.6	Massey (1967)
Crown Zellerbach, OR (Unit 21)*	Full dschrg netting	Steelhead trout	17,999	500	-	521	-	255	42.8	-	51	70.8	80	Massey (1967)
Crown Zellerbach, OR (Unit 21)*	Full dschrg netting	Chinook salmon	1,798	500	-	521	-	255	42.8	-	74.3	91.8	81.2	Massey (1967)
Cushman Plant 2 (1960)	Full dschrg netting	Salmonids	25,108	-	58	800	17	300	450	6.92	85.8-99.7	70.4-90.9	44.6-77.3	Cramer/Oligher (1964)
Cushman Plant 2 (1961)	Full dschrg netting	Silver Salmon	7,923	4,000	89	800	17	300	450	6.92	94	82	34.5 - 72	Cramer/Oligher (1964)
Cushman Plant 2 (1961)	Full dschrg netting	Steelhead	1,590	800	127	800	17	300	450	6.92	77	46	33.8 - 51.9	Cramer/Oligher (1964)
E. J. West, NY	Full dschrg netting	Centrarchid	320	320	< 100	2,700	15	113	63	10.92	62.5	79.1	71.7	KA (1995b)
E. J. West, NY	Full dschrg netting	Centrarchid	159	160	175	2,700	15	113	63	10.92	73	62.8	85.5	KA (1995b)
E. J. West, NY	Full dschrg netting	Centrarchid	128	128	> 250	2,700	15	113	63	10.92	86.7	94.9	59.8	KA (1995b)
E. J. West, NY	Full dschrg netting	Percid	240	240	< 100	2,700	15	113	63	10.92	69.6	62	56.1	KA (1995b)
E. J. West, NY	Full dschrg netting	Soft Ray	157	159	< 100	2,700	15	113	63	10.92	54.8	49.7	32.3	KA (1995b)
E. J. West, NY	Full dschrg netting	Soft Ray	160	159	175	2,700	15	113	63	10.92	67.5	79..9	71.3	KA (1995b)
E. J. West, NY	Full dschrg netting	Soft Ray	160	160	> 250	2,700	15	113	63	10.92	71.3	58.1	67.5	KA (1995b)
E. J. West, NY	Full dschrg netting	Salmonid	280	280	< 100	2,700	15	113	63	10.92	41.1	31.8	65.2	KA (1995b)
E. J. West, NY	Full dschrg netting	Salmonid	160	160	175	2,700	15	113	63	10.92	72.5	53.8	90.6	KA (1995b)
E. J. West, NY	Full dschrg netting	Salmonid	160	160	> 250	2,700	15	113	63	10.92	99.4	49.4	95.6	KA (1995b)
Elwha, WA	Partial netting	Chinook salmon	42,168	20,030	-	500	-	300	104	4.90	13.1	9.9	100	Eicher Associates (1987)
Faraday, OR	Partial netting	Chinook salmon	1,700	0	-	500	-	360	120	3.30	-	-	50	Eicher Associates (1987)
Finch Pruyn, NY (Unit 4)	Balloon tag	Smallmouth Bass	61	44	191	708	15	225	46	3.00	96.7	97.8	95	RMC (1990)
Finch Pruyn, NY (Unit 4)	Balloon tag	Smallmouth Bass	49	37	210	708	15	225	46	3.00	89.8	97.4	91	RMC (1990)
Finch Pruyn, NY (Unit 4)	Balloon tag	Smallmouth Bass	28	44	271	708	15	225	46	3.00	96.4	93.6	93	RMC (1990)
Finch Pruyn, NY (Unit 5)	Balloon tag	Smallmouth Bass	25	44	191	836	15	225	46	3.00	68	97.8	94	RMC (1990)
Finch Pruyn, NY (Unit 5)	Balloon tag	Smallmouth Bass	32	37	210	836	15	225	46	3.00	84.4	97.5	91	RMC (1990)
Finch Pruyn, NY (Unit 5)	Balloon tag	Smallmouth Bass	43	44	271	836	15	225	46	3.00	95.3	93.6	71	RMC (1990)
Five Channels, MI	Full dschrg netting	Bluegill	95	-	118	1,167	16	150	36	4.58	99	-	93.6	LMS (1991)
Five Channels, MI	Full dschrg netting	Bluegill	91	-	170	1,167	16	150	36	4.58	86	-	89.2	LMS (1991)
Five Channels, MI	Full dschrg netting	Gold./Common Shiner	59	-	114	1,167	16	150	36	4.58	86	-	81.8	LMS (1991)
Five Channels, MI	Full dschrg netting	Gold./Common Shiner	60	-	154	1,167	16	150	36	4.58	87	-	85.5	LMS (1991)
Five Channels, MI	Full dschrg netting	Northern Pike	31	-	352	1,167	16	150	36	4.58	97	-	91.3	LMS (1991)
Five Channels, MI	Full dschrg netting	Rainbow Trout	40	-	108	1,167	16	150	36	4.58	60	-	95.8	LMS (1991)
Five Channels, MI	Full dschrg netting	Rainbow Trout	46	-	317	1,167	16	150	36	4.58	20	-	70	LMS (1991)
Five Channels, MI	Full dschrg netting	Spottail Shiner	30	-	116	1,167	16	150	36	4.58	37	-	36.4	LMS (1991)
Five Channels, MI	Full dschrg netting	Walleye	55	-	162	1,167	16	150	36	4.58	100	-	71.2	LMS (1991)
Five Channels, MI	Full dschrg netting	Walleye	60	-	385	1,167	16	150	36	4.58	100	-	76.7	LMS (1991)
Five Channels, MI	Full dschrg netting	White Sucker	56	-	180	1,167	16	150	36	4.58	86	-	88.6	LMS (1991)
Five Channels, MI	Full dschrg netting	White Sucker	60	-	290	1,167	16	150	36	4.58	82	-	71.4	LMS (1991)
Five Channels, MI	Full dschrg netting	Yellow Perch	25	-	107	1,167	16	150	36	4.58	88	-	72.7	LMS (1991)

Table 4-8. Continued.

Station	Sampling Method	Species Tested	Test sample size	Control sample size	Avg. Fish Length (mm)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Percent Recap. Test	Percent Recap. Control	Est. Percent Survival (1 hr)	Source
Five Channels, MI	Full dschrg netting	Yellow Perch	30	-	186	1,167	16	150	36	4.58	93	-	77.1	LMS (1991)
Glines, WA	Partial netting	Silver salmon	31,256	23,442	-	1500	-	225	194	7.70	5	49.3	69.6	Eicher Associates (1987)
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	Bluegill	-	-	76	645	15	90	28	4.83	-	-	96.7	NAI (1994)
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	Bluegill	-	-	127	645	15	90	28	4.83	-	-	100	NAI (1994)
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	Bluegill	-	-	178	645	15	90	28	4.83	-	-	94.9	NAI (1994)
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	-	-	76	645	15	90	28	4.83	-	-	100	NAI (1994)
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	-	-	127	645	15	90	28	4.83	-	-	100	NAI (1994)
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	-	-	178	645	15	90	28	4.83	-	-	94.9	NAI (1994)
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	-	-	229	645	15	90	28	4.83	-	-	93.7	NAI (1994)
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	-	-	292	645	15	90	28	4.83	-	-	90.4	NAI (1994)
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	-	-	>292	645	15	90	28	4.83	-	-	80.5	NAI (1994)
Hardy, MI (Unit 2)	Full dschrg netting	Bluegill	63	-	118	510	16	163.6	100	6.98	56	-	89.5	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	Bluegill	30	-	170	510	16	163.6	100	6.98	80	-	91.5	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	Gold./Common Shiner	30	-	114	510	16	163.6	100	6.98	82	-	85.5	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	Gold./Common Shiner	59	-	154	510	16	163.6	100	6.98	81	-	88.7	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	Largemouth Bass	60	-	118	510	16	163.6	100	6.98	65	-	76.2	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	Northern Pike	58	-	352	510	16	163.6	100	6.98	86	-	76	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	Rainbow Trout	59	-	108	510	16	163.6	100	6.98	44	-	71.4	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	Rainbow Trout	60	-	317	510	16	163.6	100	6.98	60	-	68.6	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	Walleye	60	-	385	510	16	163.6	100	6.98	95	-	77.3	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	White Sucker	59	-	180	510	16	163.6	100	6.98	65	-	76.9	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	White Sucker	60	-	290	510	16	163.6	100	6.98	76	-	64.5	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	Yellow Perch	60	-	107	510	16	163.6	100	6.98	63	-	83.1	LMS (1991)
Hardy, MI (Unit 2)	Full dschrg netting	Yellow Perch	-	-	186	510	16	163.6	100	6.98	82	-	95.5	LMS (1991)
High Falls (Unit 5)	Full dschrg netting	Centrarchiforms	154	88	76	275	12	358	83	3.25	90.9	84.1	85.5	Harza (1995)
High Falls (Unit 5)	Full dschrg netting	Centrarchiforms	90	48	127	275	12	358	83	3.25	90	81.3	78.1	Harza (1995)
High Falls (Unit 5)	Full dschrg netting	Centrarchiforms	111	70	178	275	12	358	83	3.25	90.9	84	58.9	Harza (1995)
High Falls (Unit 5)	Full dschrg netting	Fusiforms	146	95	76	275	12	358	83	3.25	80.1	82.1	87.8	Harza (1995)
High Falls (Unit 5)	Full dschrg netting	Fusiforms	81	49	127	275	12	358	83	3.25	-	-	67.9	Harza (1995)
High Falls (Unit 5)	Full dschrg netting	Fusiforms	184	79	178	275	12	358	83	3.25	-	-	48.4	Harza (1995)
High Falls (Unit 5)	Full dschrg netting	Fusiforms	96	66	229	275	12	358	83	3.25	-	-	46.2	Harza (1995)
High Falls (Unit 5)	Full dschrg netting	Fusiforms	160	58	292	275	12	358	83	3.25	-	-	20.1	Harza (1995)
High Falls (Unit 5)	Full dschrg netting	Fusiforms	71	41	>292	275	12	358	83	3.25	-	-	2.7	Harza (1995)
Higley, NY	Full dschrg netting	Centrarchid	-	-	< 100	675	13	257	46	4.00	-	-	81	KA (1995a)
Higley, NY	Full dschrg netting	Centrarchid	-	-	175	675	13	257	46	4.00	-	-	14	KA (1995a)
Higley, NY	Full dschrg netting	Centrarchid	-	-	> 250	675	13	257	46	4.00	-	-	17	KA (1995a)
Higley, NY	Full dschrg netting	Percid	-	-	< 100	675	13	257	46	4.00	-	-	59	KA (1995a)
Higley, NY	Full dschrg netting	Percid	-	-	> 250	675	13	257	46	4.00	-	-	40	KA (1995a)
Higley, NY	Full dschrg netting	Salmonid	-	-	< 100	675	13	257	46	4.00	-	-	70	KA (1995a)
Higley, NY	Full dschrg netting	Salmonid	-	-	175	675	13	257	46	4.00	-	-	44	KA (1995a)
Higley, NY	Full dschrg netting	Salmonid	-	-	> 250	675	13	257	46	4.00	-	-	61	KA (1995a)
Higley, NY	Full dschrg netting	Soft Ray	-	-	< 100	675	13	257	46	4.00	-	-	60	KA (1995a)
Higley, NY	Full dschrg netting	Soft Ray	-	-	175	675	13	257	46	4.00	-	-	72	KA (1995a)
Higley, NY	Full dschrg netting	Soft Ray	-	-	> 250	675	13	257	46	4.00	-	-	40	KA (1995a)

Table 4-8. Continued.

Station	Sampling Method	Species Tested	Test sample size	Control sample size	Avg. Fish Length (mm)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Percent Recap. Test	Percent Recap. Control	Est. Percent Survival (1 hr)	Source
Hoist, MI	Full dschrg netting	Brown Trout	150	150	85	300	-	360	142	-	56	99.3	45.1	RMC (1993b)
Hoist, MI	Full dschrg netting	Brook Trout	150	150	135	300	-	360	142	-	73.3	1	43	RMC (1993b)
Hoist, MI	Full dschrg netting	Brown Trout	150	150	220	300	-	360	142	-	90.7	1	22.8	RMC (1993b)
Hoist, MI	Full dschrg netting	Bluegill	150	150	65	300	-	360	142	-	44	98.7	19.7	RMC (1993b)
Hoist, MI	Full dschrg netting	Bluegill	150	150	115	300	-	360	142	-	65.3	1	75	RMC (1993b)
Holtwood, PA(U10/single runner)	Balloon tag	American Shad	100	100	125	3,500	16	94.7	62	12.46	81	90	89.4	RMC (1992c)
Holtwood, PA (U3/double runner)	Balloon tag	American Shad	100	80	125	3,500	17	102.8	62	9.33	78	93.8	83.5	RMC (1992c)
la centrale Beaurharnois, QE	Float tag	American eel	100	-	888	7,000	13	75	79	17.67	97.1	-	84.2	Desrochers (1995)
Leaburg, OR	Full dschrg netting	Rainbow trout	1,249	624	-	1100	-	225	89	7.50	67	96.2	95.2	Eicher Associates (1987)
Lequille, NS	Full dschrg netting	Atlantic salmon	-	-	-	350	13	519	387	4.50	-	-	52	Eicher Associates (1987)
Luray, VA	Full dschrg netting	American Eel	393	-	853	369	12	164	16	5.17	-	-	99	RMC (1995)
McClure, MI	Full dschrg netting	Resident spp.	NA	NA	-	155	-	600	424	-	-	NA	-	RMC (1993c)
Minetto, NY	Full dschrg netting	Centrarchid	164	104	< 100	1,500	16	72	17	11.58	64	86.5	62	KA (1995c)
Minetto, NY	Full dschrg netting	Centrarchid	236	110	175	1,500	16	72	17	11.58	90.7	91.3	83	KA (1995c)
Minetto, NY	Full dschrg netting	Centrarchid	165	120	> 250	1,500	16	72	17	11.58	85.5	91.7	84	KA (1995c)
Minetto, NY	Full dschrg netting	Percid	133	117	< 100	1,500	16	72	17	11.58	44.4	47	80	KA (1995c)
Minetto, NY	Full dschrg netting	Percid	243	142	175	1,500	16	72	17	11.58	68.7	85.2	86	KA (1995c)
Minetto, NY	Full dschrg netting	Soft Ray	348	220	< 100	1,500	16	72	17	11.58	49.7	42.3	82	KA (1995c)
Minetto, NY	Full dschrg netting	Soft Ray	214	133	175	1,500	16	72	17	11.58	72.9	98.5	94	KA (1995c)
Minetto, NY	Full dschrg netting	Soft Ray	177	160	> 250	1,500	16	72	17	11.58	94.4	90	84	KA (1995c)
Minetto, NY	Full dschrg netting	Salmonids	237	160	< 100	1,500	16	72	17	11.58	62.5	83.3	92	KA (1995c)
Minetto, NY	Full dschrg netting	Salmonids	184	107	175	1,500	16	72	17	11.58	81.5	84.1	91	KA (1995c)
Minetto, NY	Full dschrg netting	Salmonids	178	159	> 250	1,500	16	72	17	11.58	78.1	67.9	92	KA (1995c)
Minetto, NY	Full dschrg netting	American Eel	107	92	625	1,500	16	72	17	11.58	43.9	66.3	94	KA (1995c)
Minetto, NY	Full dschrg netting	Alewife	189	140	<100	-	-	-	-	-	74.1	90	80	KA (1995c)
North Fork, OR	Partial netting	Coho salmon	4,076	5,158	-	2500	-	139	136	9.67	18.2	23.1	74	Eicher Associates (1987)
Peshtigo, WI (Unit 4)	Full dschrg netting	Centrarchiforms	146	84	76	460	15	100	13	6.67	88.4	91.7	100	Harza (1995)
Peshtigo, WI (Unit 4)	Full dschrg netting	Centrarchiforms	140	77	127	460	15	100	13	6.67	79.3	79.2	98.9	Harza (1995)
Peshtigo, WI (Unit 4)	Full dschrg netting	Centrarchiforms	121	75	178	460	15	100	13	6.67	71.9	69.3	100	Harza (1995)
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	158	103	76	460	15	100	13	6.67	85.4	97.1	94	Harza (1995)
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	141	90	127	460	15	100	13	6.67	86.5	95.6	93.7	Harza (1995)
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	166	109	178	460	15	100	13	6.67	92.2	93.6	96.6	Harza (1995)
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	158	93	229	460	15	100	13	6.67	94.9	91.4	95.4	Harza (1995)
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	166	105	292	460	15	100	13	6.67	85.5	84.8	85.5	Harza (1995)
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	128	79	>292	460	15	100	13	6.67	83.6	79.7	82.8	Harza (1995)
Potato Rapids, WI (Unit 1)	Full dschrg netting	Centrarchiforms	134	94	76	500	15	123	17	7.00	94	93.6	100	Harza (1995)
Potato Rapids, WI (Unit 1)	Full dschrg netting	Centrarchiforms	154	93	127	500	15	123	17	7.00	75.3	96.8	84.7	Harza (1995)
Potato Rapids, WI (Unit 1)	Full dschrg netting	Centrarchiforms	111	70	178	500	15	123	17	7.00	49.5	98.6	83	Harza (1995)
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	168	104	76	500	15	123	17	7.00	87.5	92.3	89.2	Harza (1995)
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	104	69	127	500	15	123	17	7.00	93.3	98.6	76.5	Harza (1995)
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	150	91	178	500	15	123	17	7.00	98	93.4	68.4	Harza (1995)
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	160	96	229	500	15	123	17	7.00	75.6	96.9	61.1	Harza (1995)
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	136	83	292	500	15	123	17	7.00	89	100	53.3	Harza (1995)
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	145	112	>292	500	15	123	17	7.00	89.7	94.6	34.5	Harza (1995)

Table 4-8. Continued.

Station	Sampling Method	Species Tested	Test sample size	Control sample size	Avg. Fish Length (mm)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Percent Recap. Test	Percent Recap. Control	Est. Percent Survival (1 hr)	Source
Potato Rapids, WI (Unit 2)	Full dschrg netting	Centrarchiforms	166	105	76	500	15	123	17	7.00	89.2	97.1	93.4	Harza (1995)
Potato Rapids, WI (Unit 2)	Full dschrg netting	Centrarchiforms	58	28	178	440	15	135	17	6.67	100	96.4	91.4	Harza (1995)
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	179	123	76	440	15	135	17	6.67	74.3	67.5	84.5	Harza (1995)
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	134	93	127	440	15	135	17	6.67	90.3	100	61.7	Harza (1995)
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	138	92	178	440	15	135	17	6.67	97.8	98.9	75.1	Harza (1995)
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	158	98	229	440	15	135	17	6.67	91.8	99	61	Harza (1995)
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	156	91	292	440	15	135	17	6.67	89.7	97.8	57.8	Harza (1995)
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	149	85	>292	440	15	135	17	6.67	92.3	94.1	48.2	Harza (1995)
Pricket, MI	Full dschrg netting	Bluegill	256	150	52	326	15	257	54	4.46	57	62.7	97.7	RMC (1991)
Pricket, MI	Full dschrg netting	Golden Shiner	182	120	< 100	326	15	257	54	4.46	93.3	70	93.9	RMC (1991)
Pricket, MI	Full dschrg netting	Bluegill	131	90	102	326	15	257	54	4.46	80.9	80	92.5	RMC (1991)
Pricket, MI	Full dschrg netting	Bluegill	21	21	> 127	326	15	257	54	4.46	100	90.5	85.7	RMC (1991)
Pricket, MI	Full dschrg netting	Mixed resident	-	-	-	326	15	257	54	4.46			97.8	RMC (1991)
Pricket, MI	Full dschrg netting	White Sucker	201	119	165	326	15	257	54	4.46	81.6	80.7	70.8	RMC (1991)
Pricket, MI	Full dschrg netting	White Sucker	15	10	> 254	326	15	257	54	4.46	93.3	70	35.7	RMC (1991)
Publishers, OR (1960)**	Full dschrg netting	Steelhead trout	1,768	500	-	275	-	255	40	-	36.2	58	87.9	Massey (1967)
Publishers, OR (1960)**	Full dschrg netting	Chinook salmon	1,798	503	-	275	-	255	40	-	51.2	100	87.4	Massey (1967)
Publishers, OR (1961)**	Full dschrg netting	Steelhead trout	1,800	500	-	275	-	255	40	-	24.9	36	84.5	Massey (1967)
Publishers, OR (1961)**	Full dschrg netting	Chinook salmon	1,800	500	-	275	-	255	40	-	43.5	69.6	87.1	Massey (1967)
Puntledge, BC	Floating net	Steelhead trout	1,500	-	124	-	-	277	340	7.10	3.5	-	58.1	Eicher Associates (1987)
Puntledge, BC	Floating net	Kamploops	1,500	-	69	-	-	277	340	7.10	3.4	-	72.5	Eicher Associates (1987)
Puntledge, BC	Floating net	Kamploops	1,500	-	46	-	-	277	340	7.10	4.9	-	71.2	Eicher Associates (1987)
Puntledge, BC	Floating net	Salmon	1,500	-	36	-	-	277	340	7.10	2.5	-	67.4	Eicher Associates (1987)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Bluegill	90	-	118	383	15	150	39	5.00	96	-	96	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Bluegill	92	-	170	383	15	150	39	5.00	96	-	85.2	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Gold./Common Shiner	60	-	114	383	15	150	39	5.00	98	-		LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Gold./Common Shiner	34	-	154	383	15	150	39	5.00	53	-	92.5	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Largemouth Bass	60	-	118	383	15	150	39	5.00	92	-	77.4	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Northern Pike	47	-	352	383	15	150	39	5.00	89	-	83.4	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Rainbow Trout	30	-	108	383	15	150	39	5.00	100	-	89.9	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Rainbow Trout	30	-	317	383	15	150	39	5.00	83	-	61.2	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Spottail Shiner	31	-	116	383	15	150	39	5.00	100	-	73.5	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Walleye	40	-	385	383	15	150	39	5.00	95	-	86.2	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	White Sucker	55	-	180	383	15	150	39	5.00	73	-	91.2	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	White Sucker	57	-	290	383	15	150	39	5.00	88	-	88.1	LMS (1991)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Yellow Perch	78	-	107	383	15	150	39	5.00	96	-	91.8	LMS (1991)
Ruskin, BC	Fyke netting dwnstrm	Sockeye Salmon	12,125	12,159	86	4,000	-	120	130	12.42	-	-	89.5	Eicher Associates (1987)
Sandstone Rapids,WI	Full dschrg netting	Centrarchiforms	165	99	76	650	15	150	42	7.25	89.1	94.9	97	Harza (1995)
Sandstone Rapids,WI	Full dschrg netting	Centrarchiforms	141	90	127	650	15	150	42	7.25	97.8	100	80.7	Harza (1995)
Sandstone Rapids,WI	Full dschrg netting	Centrarchiforms	61	53	178	650	15	150	42	7.25	100	98.1	79.9	Harza (1995)
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	169	100	76	650	15	150	42	7.25	62.1	94	64.9	Harza (1995)
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	132	96	127	650	15	150	42	7.25	86.4	99	75	Harza (1995)
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	145	97	178	650	15	150	42	7.25	97.2	100	76	Harza (1995)
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	127	78	229	650	15	150	42	7.25	91.3	91	69.8	Harza (1995)

Table 4-8. Continued.

Station	Sampling Method	Species Tested	Test sample size	Control sample size	Avg. Fish Length (mm)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Percent Recap. Test	Percent Recap. Control	Est. Percent Survival (1 hr)	Source
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	119	71	292	650	15	150	42	7.25	87.3	98.6	58.4	Harza (1995)
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	144	92	>292	650	15	150	42	7.25	93.1	89.1	47.1	Harza (1995)
Schaghiticoke, NY	Full dschrg netting	Centrarchid	149	144	<100	410	17	300	143	6.67	84.3	95.1	27	KA (1996b)
Schaghiticoke, NY	Full dschrg netting	Centrarchid	160	160	175	410	17	300	143	6.67	92.8	84.4	59	KA (1996b)
Schaghiticoke, NY	Full dschrg netting	Centrarchid	200	200	>250	410	17	300	143	6.67	80.5	89	7	KA (1996b)
Schaghiticoke, NY	Full dschrg netting	Percid	239	237	<100	410	17	300	143	6.67	74.4	79.7	68	KA (1996b)
Schaghiticoke, NY	Full dschrg netting	Percid	80	80	175	410	17	300	143	6.67	100	87.5	39	KA (1996b)
Schaghiticoke, NY	Full dschrg netting	Soft ray	160	160	<100	410	17	300	143	6.67	67.5	85.6	60	KA (1996b)
Schaghiticoke, NY	Full dschrg netting	Soft ray	241	240	175	410	17	300	143	6.67	92.9	92.5	17	KA (1996b)
Schaghiticoke, NY	Full dschrg netting	Soft ray	149	150	>250	410	17	300	143	6.67	66.4	74	22	KA (1996b)
Schaghiticoke, NY	Full dschrg netting	Salmonid	159	160	<100	410	17	300	143	6.67	86.2	76.3	56	KA (1996b)
Schaghiticoke, NY	Full dschrg netting	Salmonid	240	240	175	410	17	300	143	6.67	92.5	89.2	27	KA (1996b)
Schaghiticoke, NY	Full dschrg netting	Salmonid	162	160	>250	410	17	300	143	6.67	80.2	60.6	11	KA (1996b)
Seton Creek, BC	Fyke net in tailrace	Sockeye Salmon	-	-	86	4,500	-	120	142	12.00	-	-	90.8	Andrew & Geen (1958)
Shasta, CA (January)	Full dschrg netting	Chinook Salmon	4,800	***	102	3,200	15	138.5	380	15.33	72.0*	66.0*	54.8 - 72.1	Cramer/Oligher (1964)
Shasta, CA (January)	Full dschrg netting	Rainbow Trout	1,000	***	254	3,200	15	138.5	380	15.33	*	*	53.1 - 71.2	Cramer/Oligher (1964)
Shasta, CA (January)	Full dschrg netting	Steelhead	3,200	***	152	3,200	15	138.5	380	15.33	*	*	75.4 - 89.3	Cramer/Oligher (1964)
Shasta, CA (November)	Full dschrg netting	Chinook Salmon	11,500	***	102	3,200	15	138.5	380	15.33	93.0*	73.8*	61.7 - 84.5	Cramer/Oligher (1964)
Shasta, CA (November)	Full dschrg netting	Steelhead	4,400	***	152	3,200	15	138.5	380	15.33	*	*	50.5 - 69.2	Cramer/Oligher (1964)
Shasta, CA (November)	Full dschrg netting	Rainbow Trout	1,025	***	254	3,200	15	138.5	380	15.33	*	*	39.6 - 90.5	Cramer/Oligher (1964)
Stevens Creek, SC	Balloon tag	Bluegill	110	110	122	1,000	14	75	28	11.25	95.5	99.1	95.4	RMC (1994d)
Stevens Creek, SC	Balloon tag	Blueback Herring	131	120	203	1,000	14	75	28	11.25	90.8	89.2	95.3	RMC (1994d)
Stevens Creek, SC	Balloon tag	Spotted Sucker/Y. Perch	120	120	165	1,000	14	75	28	11.25	96.7	98.3	98.3	RMC (1994d)
T. W. Sullivan, OR	Discharge netting	Steelhead trout	-	-	-	-	-	242	41	-	-	-	74.1	Massey (1967)
T. W. Sullivan, OR	Discharge netting	Chinook salmon	-	-	-	260	-	242	41	-	-	-	85.7	Massey (1967)
Vernon, VT/NH	Balloon tag	American Shad	153	150	95	1,834	15	74	34	13.00	93.5	98.7	94.7	NAI (1996a)
Vernon, VT/NH	Balloon tag	Atlantic salmon	105	80	154	1,834	15	74	34	13.00	96.2	98.8	97.4	NAI (1996b)
Vernon, VT/NH	Balloon tag	Atlantic salmon	25	80	143	1,280	14	133	34	5.20	100	98.8	85.1	NAI (1996b)
White Rapids, WI	Balloon tag	White Sucker	42	36	204	900	14	100	29	11.17	90.5	91.7	93	RMC (1992d)
White Rapids, WI	Balloon tag	White Sucker	58	64	112	900	14	100	29	11.17	96.6	98.4	100	RMC (1992d)
White Rapids, WI	Balloon tag	Bluegill	56	62	90	900	14	100	29	11.17	92.9	98.4	95	RMC (1992d)
White Rapids, WI	Balloon tag	Bluegill	44	38	155	900	14	100	29	11.17	93.2	97.4	100	RMC (1992d)
Youghiogheny, PA	Full dschrg netting	Alewife	Naturally entrained		51	750	-	-	120	-	-	-	0.1	RMC (1992e)
Youghiogheny, PA	Full dschrg netting	Walleye	Naturally entrained		376	750	-	-	120	-	-	-	39.5	RMC (1992e)
Youghiogheny, PA	Full dschrg netting	Rock bass	Naturally entrained		-	750	-	-	120	-	-	-	4	RMC (1992e)
Youghiogheny, PA	Full dschrg netting	Yellow perch	Naturally entrained		-	750	-	-	120	-	-	-	7	RMC (1992e)
Youghiogheny, PA	Full dschrg netting	Crappies	Naturally entrained		-	750	-	-	120	-	-	-	0.2	RMC (1992e)
Youghiogheny, PA	Full dschrg netting	White sucker	Naturally entrained		-	750	-	-	120	-	-	-	9.5	RMC (1992e)

* Decommissioned.

** Presently Blue Heron Development.

*** Composite number of fish introduced and their recapture rates; November tests - test=91.0% and control=73.8%, January tests - test=72% and control=66%.

Table 4-9. Physical and hydraulic characteristics of low head (≤100 ft) hydroelectric dams equipped with Kaplan/propeller type turbines deemed similar to Unit 6 (small Kaplan) (=SK) and Units 1-4 (large Kaplan and propeller) (=LKP) at the Jefferies Development, or where Santee Cooper target/surrogate species were tested (=T/S).

Station	SK	LKP	T/S	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)
Chalk Hill, MI-WI	x	x		1,330	4	150	29	102
Conowingo, MD		x	x	8,000	6	120	90	225
Craggy Dam, NC	x			600	4	229	21	69
Crescent, NY	x	x	x	1,520	5	144	27	108
Fourth Lake, NS			x	530	6	360	75	-
Hadley Falls, MA			x	1,550	5	128	-	170
Hadley Falls, MA		x	x	4,200	5	128	52	170
Hadley Falls, MA		x	x	4,200	5	150	-	170
Herrings, NY	x	x	x	1,200	-	138	19	113
Safe Harbor, PA (Unit 7)		x	x	8,300	5	109	55	220
Safe Harbor, PA (Unit 8)		x	x	9,200	7	76.6	55	240
Safe Harbor, PA (Unit 8)		x	x	9,200	7	75	55	242
St. Lawrence-FDR (Unit 28)			x	9,700	6	94.7	81	240
Townsend Dam, PA	x			800	3	152	16	113
Wilder, VT-NH		x		4,500	5	112.5	51	180

Table 4-10. Physical and hydraulic characteristics of hydroelectric dams equipped with Francis type turbines similar to the Santee Development (=F), or where Santee Cooper target/surrogate species were tested (=T/S).

Station	F	T/S	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)
Caldron Falls, WI (Unit 1)	x		650	15	226	80	6.00
Columbia, SC	x	x	833	14	164	28	5.33
Cushman, WA (Plant 2)	x		800	17	300	450	6.92
Finch Pruyn, NY (Unit 4)	x		708	15	225	46	3.00
Finch Pruyn, NY (Unit 5)	x		836	15	225	46	3.00
Holtwood, PA (Unit 3)		x	3,500	17	102.8	62	9.33
Holtwood, PA (Unit 10)		x	3,500	16	94.7	62	12.46
Minetto, NY	x	x	1,500	16	72	17	11.58
Peshtigo, WI (Unit 4)	x		460	15	100	13	6.67
Potato Rapids, WI (Unit 1)	x		500	15	123	17	7.00
Potato Rapids, WI (Unit 2)	x		440	15	135	17	6.67
Pricket, MI	x		326	15	257	54	4.46
Stevens Creek, SC		x	1,000	14	75	28	11.25
Vernon, VT/NH		x	1,834	15	74	34	13.00

Table 4-11. Empirical turbine passage survival rates observed at sites with Kaplan/propeller turbines (Jefferies development) where the Santee Cooper target/surrogate species were tested.

Species	Small (<8 in)	Medium (8-15 in)	Large (>15 in)	Station	Notes
American eel			73.5	St. Lawrence, NY	Used indirect effects results (i.e., survival at 88 h post test)
Average survival			***73.5***		
Alewife	89.0			Fourth Lake, NS	
	92.8			Herrings, NY	Reported as "clupeids", known to be alewife
Average survival	***90.9***				
American shad			78.2	Hadley Falls, MA	
			87.0	Safe Harbor, PA	Unit 8, Mixed Flow Turbine
			89.7	Safe Harbor, PA	Unit 7, Kaplan Turbine
	89.1			Hadley Falls, MA	
	94.9			Conowingo, MD	
	97.3			Hadley Falls, MA	
	97.8			Safe Harbor, PA	Unit 8, Mixed Flow Turbine
	98.0			Safe Harbor, PA	Unit 7, Kaplan Turbine
	98.9			Safe Harbor, PA	Unit 8, Mixed Flow Turbine
	100.0			Hadley Falls, MA	
Average survival	***96.6***		***85.0***		
Blueback Herring	96.0			Crescent, NY	
Average survival	***96.0***				
Overall Average survival by size	***95.4***		***82.1***		

Table 4-12. Empirical turbine passage survival rates observed at sites with Francis turbines (Santee development) where the Santee Cooper target/surrogate species were tested.

Species	Small (<8 in)	Medium (8-15 in)	Large (>15 in)	Station	Notes
American eel			94.0	Minetto, NY	
Average survival			***94.0***		
Alewife	80.0			Minetto, NY	
Average survival	***80.0***				
American shad	83.5			Holtwood, PA	Unit 3, double runner
	89.4			Holtwood, PA	Unit 10, single runner
	94.7			Vernon, VT/NH	
Average survival	***89.2***				
Blueback Herring	92.7			Columbia, SC	
		95.3		Stevens Creek, SC	
Average survival	***92.7***	***95.3***			
Overall Average survival by size	***88.1***	***95.3***	***94.0***		

Table 4-13. Percent of fish surviving turbine passage at stations deemed similar to Unit 6 (small Kaplan turbine) at the Jefferies Development.

Species or Group	Small (<8 in)	Medium (8-15 in)	Large (>15 in)	Station	Notes
Clupeids					
Alewife	92.8			Herrings, NY	Reported as Clupeid, know to be alewife
Blueback Herring	96.0			Crescent, NY	
Average survival	***94.4***				
Salmonids					
Salmonids	90.0			Herrings, NY	
	95.5			Herrings, NY	
		98.6		Herrings, NY	
Rainbow Trout	94.4			Townsend Dam, PA	
		86.5		Townsend Dam, PA	
W. Sucker/R. Trout	91.0			Chalk Hill, MI-WI	
		97.0		Chalk Hill, MI-WI	
Average survival	***92.7***	***94.0***			
Centrarchids					
Bluegill	97.0			Chalk Hill, MI-WI	
	98.0			Chalk Hill, MI-WI	
Centrarchid	97.3			Herrings, NY	
	95.0			Herrings, NY	
	98.3			Herrings, NY	
		92.5		Herrings, NY	
		93.2		Herrings, NY	
Largemouth Bass	100.0			Townsend Dam, PA	
		86.0		Townsend Dam, PA	
Average survival	***97.6***	***92.9***			
Channel Catfish	93.0			Craggy Dam, NC	
		93.0		Craggy Dam, NC	
Average survival	***93.0***	***93.0***			
Percid	91.1			Herrings, NY	
	94.9			Herrings, NY	
		96.2		Herrings, NY	
Average survival	***93.0***	***96.2***			
Soft ray	97.5			Herrings, NY	
		85.1		Herrings, NY	
Average survival	***97.5***	***85.1***			
Average survival by size	***95.1***	***92.0***			

Table 4-14. Percent of fish surviving turbine passage at stations deemed similar to units 1 through 4 (large Kaplan and propeller turbines) at the Jefferies Development.

Species or Group	Small (<8 in)	Medium (8-15 in)	Large (>15 in)	Station	Notes
Clupeids					
Alewife	92.8			Herrings, NY	Reported as Clupeid, know to be alewife
American Shad	89.1			Hadley Falls, MA	
	97.3			Hadley Falls, MA	
	100.0			Hadley Falls, MA	
	97.8			Safe Harbor, PA	Unit 8, Mixed flow turbine
	98.0			Safe Harbor, PA	Unit 7, Kaplan turbine
	98.9			Safe Harbor, PA	Unit 8, Mixed flow turbine
	94.9			Conowingo, MD	
			87.0	Safe Harbor, PA	Unit 8, Mixed flow turbine
			89.7	Safe Harbor, PA	Unit 7, Kaplan turbine
			78.2	Hadley Falls, MA	
Blueback Herring	96.0			Crescent, NY	
Average survival	***96.1***		***85.0***		
American Eel			73.5	St. Lawrence-FDR	Used indirect effects results
Average survival			***73.5***		
Salmonids					
Atlantic Salmon	96.0			Wilder, VT-NH	
		93.7		Hadley Falls, MA	
Salmonids	90.0			Herrings, NY	
	95.5			Herrings, NY	
		98.6		Herrings, NY	
W. Sucker/R. Trout	91.0			Chalk Hill, MI-WI	
		97.0		Chalk Hill, MI-WI	
Coho Salmon	91.6			Wanapum, WA	Averaged over 4 test conditions
	97.1			Wanapum, WA	
Average survival	***93.5***	***96.4***			
Centrarchids					
Bluegill	97.0			Chalk Hill, MI-WI	
	98.0			Chalk Hill, MI-WI	
Centrarchid	97.3			Herrings, NY	
	95.0			Herrings, NY	
	98.3			Herrings, NY	
		92.5		Herrings, NY	
		93.2		Herrings, NY	
Average survival	***97.1***	***92.9***			

Table 4-14. Continued

Species or Group	Small (<8 in)	Medium (8-15 in)	Large (>15 in)	Station	Notes
Percid	91.1			Herrings, NY	
	94.9			Herrings, NY	
		96.2		Herrings, NY	
Average survival	***93.0***	***96.2***			
Soft ray	97.5			Herrings, NY	
		85.1		Herrings, NY	
Average survival	***97.5***	***85.1***			
verage survival by size	***95.4***	***93.8***	***82.1***		

Table 4-15. Percent of fish surviving turbine passage through Francis turbines at stations deemed similar to the Santee Development.

Species or Group	Small (<8 in)	Medium (8-15 in)	Large (>15 in)	Station	Notes
Blueback herring	92.7			Columbia, SC	
Average survival	***92.7***				
Alewife	80.0			Minetto, NY	
Average survival	***80.0***				
Golden Shiner	93.9			Pricket, MI	
Average survival	**93.9**				
White Sucker	70.8			Pricket, MI	
Average survival	**70.8**				
Centrarchids					
Smallmouth Bass	95.0			Finch Pruyn, NY (Unit 4)	
	94.0			Finch Pruyn, NY (Unit 5)	
		91.0		Finch Pruyn, NY (Unit 4)	
		93.0		Finch Pruyn, NY (Unit 4)	
		91.0		Finch Pruyn, NY (Unit 5)	
		71.0		Finch Pruyn, NY (Unit 5)	
Bluegill	97.7			Pricket, MI	
	92.5			Pricket, MI	
Centrarchiforms	83.0			Potato Rapids, WI (Unit 1)	
	84.7			Potato Rapids, WI (Unit 1)	
	100.0			Potato Rapids, WI (Unit 1)	
	83.7			Potato Rapids, WI (Unit 2)	
	93.4			Potato Rapids, WI (Unit 2)	
	91.4			Potato Rapids, WI (Unit 2)	
	86.8			Caldron Falls, WI (Unit 1)	
	98.2			Caldron Falls, WI (Unit 1)	
	100.0			Caldron Falls, WI (Unit 1)	
	98.9			Peshtigo, WI (Unit 4)	
	100.0			Peshtigo, WI (Unit 4)	
	100.0			Peshtigo, WI (Unit 4)	
Sunfishes	95.9			Columbia, SC	
Average survival	***93.8***	***86.5***			
Channel catfish	93.6			Columbia, SC	
Average survival	***93.6***				
Fusiforms	61.7			Potato Rapids, WI (Unit 2)	
	70.3			Caldron Falls, WI (Unit 1)	
	80.3			Caldron Falls, WI (Unit 1)	
	84.8			Caldron Falls, WI (Unit 1)	
	93.7			Peshtigo, WI (Unit 4)	
	94.0			Peshtigo, WI (Unit 4)	

Table 4-15. Continued

Species or Group	Small (<8 in)	Medium (8-15 in)	Large (>15 in)	Station	Notes
Fusiforms - continued	96.6			Peshtigo, WI (Unit 4)	
	68.4			Potato Rapids, WI (Unit 1)	
	76.5			Potato Rapids, WI (Unit 1)	
	89.2			Potato Rapids, WI (Unit 1)	
	75.1			Potato Rapids, WI (Unit 2)	
	84.5			Potato Rapids, WI (Unit 2)	
		35.5		Caldron Falls, WI (Unit 1)	
		59.5		Caldron Falls, WI (Unit 1)	
		64.3		Caldron Falls, WI (Unit 1)	
		82.8		Peshtigo, WI (Unit 4)	
		85.5		Peshtigo, WI (Unit 4)	
		95.4		Peshtigo, WI (Unit 4)	
		34.5		Potato Rapids, WI (Unit 1)	
		53.3		Potato Rapids, WI (Unit 1)	
		61.1		Potato Rapids, WI (Unit 1)	
		48.2		Potato Rapids, WI (Unit 2)	
		57.8		Potato Rapids, WI (Unit 2)	
		61.0		Potato Rapids, WI (Unit 2)	
Average survival	***81.3***	***61.6***			
Average survival by size	***88.3***	***67.8***			

Table 4-16. Predicted survival values derived from the Franke et al. (1997) model for fish of various lengths (4 - 60 in) passing through the Jefferies Development. Predictive model formulas are presented in Section 3.4.4.

Units 1 and 3 - Fixed Propeller

Runner Radius at Point Fish Enters (ft)	Correlation Factor	Predicted Survival (%) by Fish Length (in)					
		4	8	12	15	36	60
0.8	0.15	91.8	83.6	75.1	68.9	25.4	0.0
(1% of radius)	0.20	89.1	78.1	66.9	58.6	0.6	0.0
4.0	0.15	97.1	94.1	91.1	88.8	73.2	55.4
(50% of radius)	0.20	96.1	92.1	88.1	85.1	64.3	40.5
7.2	0.15	97.2	94.4	91.5	89.4	74.5	57.5
(90% of radius)	0.20	96.3	92.5	88.7	85.8	66.0	43.3

Units 2 and 4 - Large Kaplan

Runner Radius at Point Fish Enters (ft)	Correlation Factor	Predicted Survival (%) by Fish Length (in)					
		4	8	12	15	36	60
0.8	0.15	94.1	88.2	82.1	77.6	46.3	10.4
(1% of radius)	0.20	92.1	84.2	76.1	70.1	28.3	0.0
4.2	0.15	98.9	97.7	96.5	95.7	89.6	82.7
(50% of radius)	0.20	98.5	97.0	95.4	94.2	86.2	76.9
7.5	0.15	99.3	98.7	98.0	97.5	94.0	90.0
(90% of radius)	0.20	99.1	98.2	97.3	96.7	92.0	86.7

Unit 6 - Small Kaplan

Runner Radius at Point Fish Enters (ft)	Correlation Factor	Predicted Survival (%) by Fish Length (in)					
		4	8	12	15	36	60
0.5	0.15	90.5	81.1	71.3	64.2	14.0	0.0
(1% of radius)	0.20	86.9	73.7	60.2	50.2	0.0	0.0
2.4	0.15	98.0	96.0	94.0	92.4	81.9	69.8
(50% of radius)	0.20	97.3	94.7	91.9	89.9	75.8	59.7
4.3	0.15	98.9	97.7	96.5	95.7	89.6	82.7
(90% of radius)	0.20	98.5	96.9	95.4	94.2	86.1	76.9

Table 4-17. Predicted survival values derived from the Franke et al. (1997) model for fish of various lengths (4 - 60 in) passing through the Santee Developments single Francis turbine. Predicitive model formulas are presented in Section 3.4.4.

Correlation Factor	Predicted Survival (%) by Fish Length (in)					
	4	8	12	15	36	60
0.15	94.21	88.43	82.47	78.08	47.40	12.34
0.20	92.29	84.57	76.62	70.78	29.87	0.00

Table 4-18. Qualitative and quantitative survival ratings for fish of various sizes as observed at other sites similar to the Santee Cooper developments and as predicted through modeling. Cumulative rating is subjective qualitative rating.

Size Class and Metric	Santee Development Francis Turbine Unit 1		Jefferies Development Large Kaplan Turbine Units 2 and 4		Jefferies Development Propeller Turbine Units 1 and 3		Jefferies Development Small Kaplan Turbine Unit 6	
Small Fish								
Other sites (<8 in)	88.5	MH	95.4	H	95.4	H	95.1	H
Model (4 and 8 in)	94.2-84.6	H-M	99.3-84.2	H-M	97.2-83.6	H-M	98.9-73.7	H-ML
Cumulative Rating	Moderate-High		High		High		High	
Medium Fish								
Other sites (<8 in)	67.8	L	93.8	H	93.8	H	92	H
Model (8, 12 and 15 in)	82.5-70.8	M-ML	98.0-70.1	H-ML	91.5-58.6	H-L	96.5-50.2	H-L
Cumulative Rating	Moderate-Low		Moderate-High		Moderate-High		Moderate-High	
Large Fish								
Other sites (<8 in)	----*	----	82.1	M	82.1	M	----	----
Model (15, 36 and 60 in)	47.4-0	L	94.0-0	H-L	74.5-0	ML-L	89.6-0	MH-L
Cumulative Rating	Low		Moderate-Low		Low		Low	

** ---- = no data available*

Rating System	
High (H)	100 - 90%
Moderate-High (MH)	89 - 85%
Moderate (M)	84 - 75%
Moderate-Low (ML)	74 - 70%
Low (L)	< 70%

Table 4-19. Qualitative and quantitative survival ratings for Santee Cooper target species based on results from previous survival studies at other sites. Cumulative rating is a subjective qualitative rating.

Species	Santee Development Francis Turbine		Jefferies Development Kaplan and Propeller	
American Eel				
Large (>15 in)	94	H	73.5	ML
Large fish cumulative rating*	Low		Moderate-Low to Low	
Cumulative Rating	Moderate		Low	
Am. Shad and Herring				
Small (< 8 in)	88.1	MH	95.4	H
Small fish cumulative rating	Moderate-High		High	
Cumulative Rating	Moderate-High		High	
Medium (8-15 in)	95.3	H	----**	----
Medium fish cumulative rating	Moderate-Low		Moderate-High	
Cumulative Rating	Moderate		----	
Large (>15 in)	----	----	85	MH
Large fish cumulative rating	Low		Moderate-Low to Low	
Cumulative Rating	----		Moderate-Low	

** Cumulative ratings from Table 4-18*

*** ---- = no data available*

Rating System	
High (H)	100 - 90%
Moderate-High (MH)	89 - 85%
Moderate (M)	84 - 75%
Moderate-Low (ML)	74 - 70%
Low (L)	< 70%

FIGURES

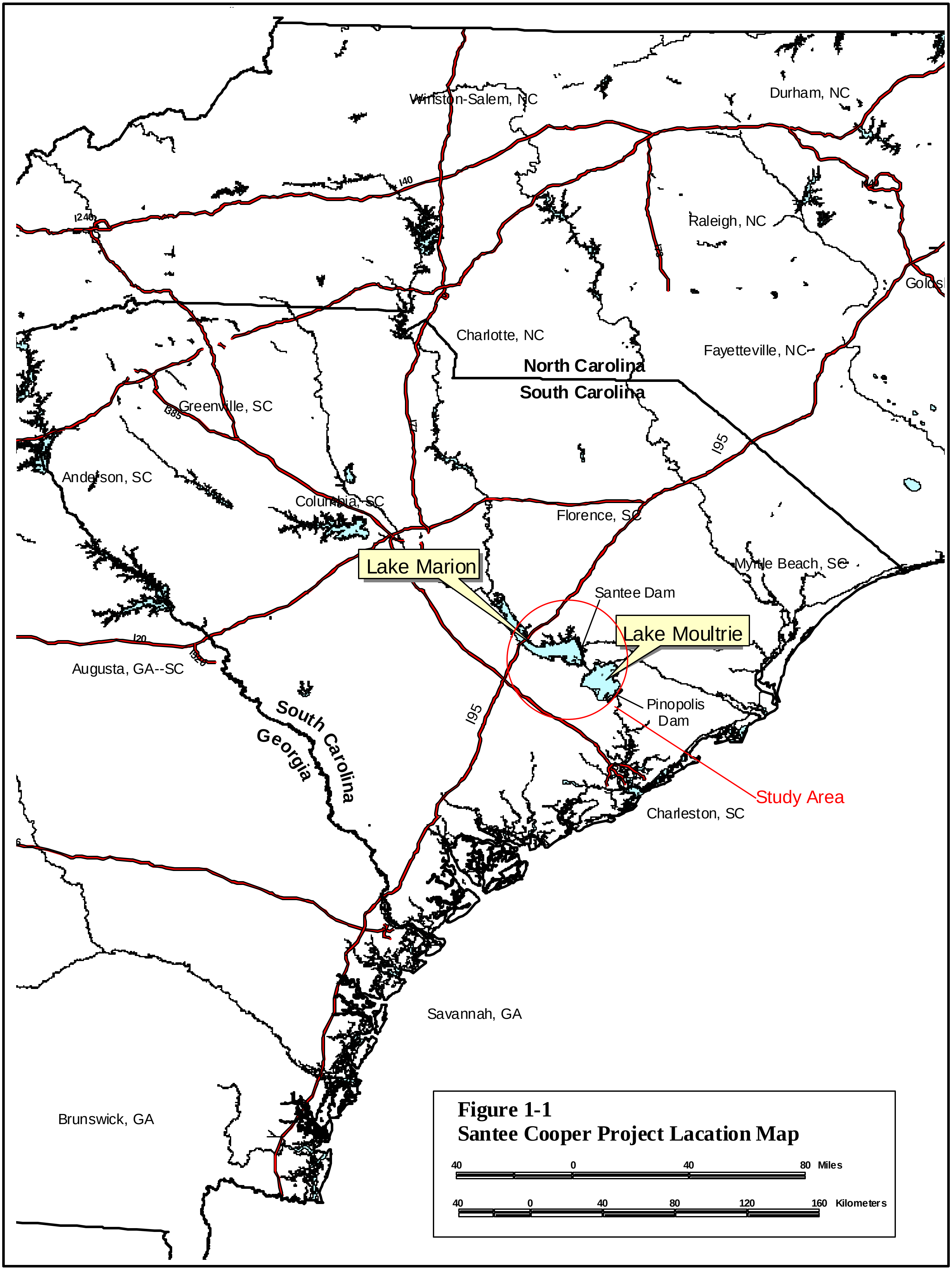


Figure 1-1
Santee Cooper Project Lacation Map

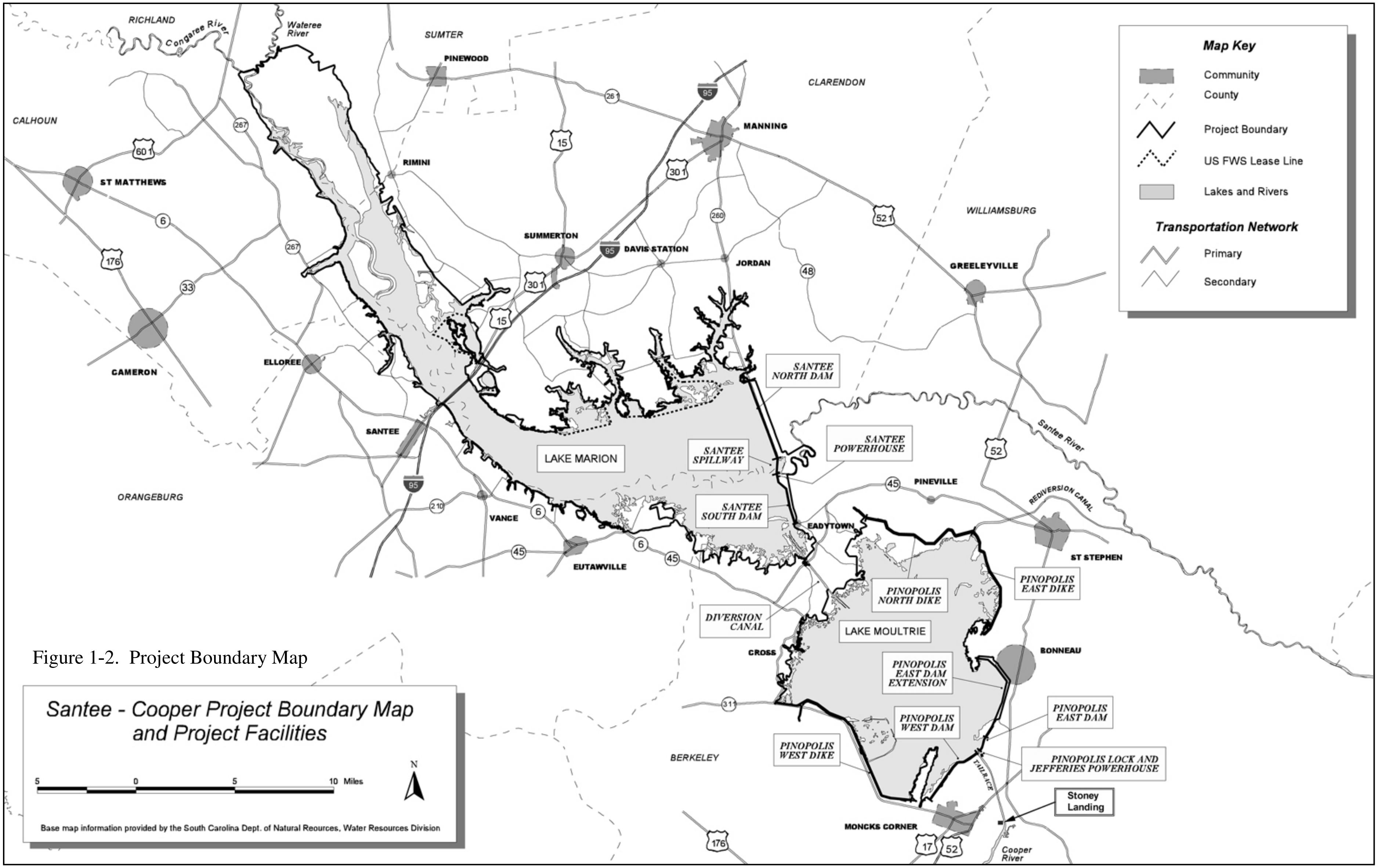


Figure 1-2. Project Boundary Map

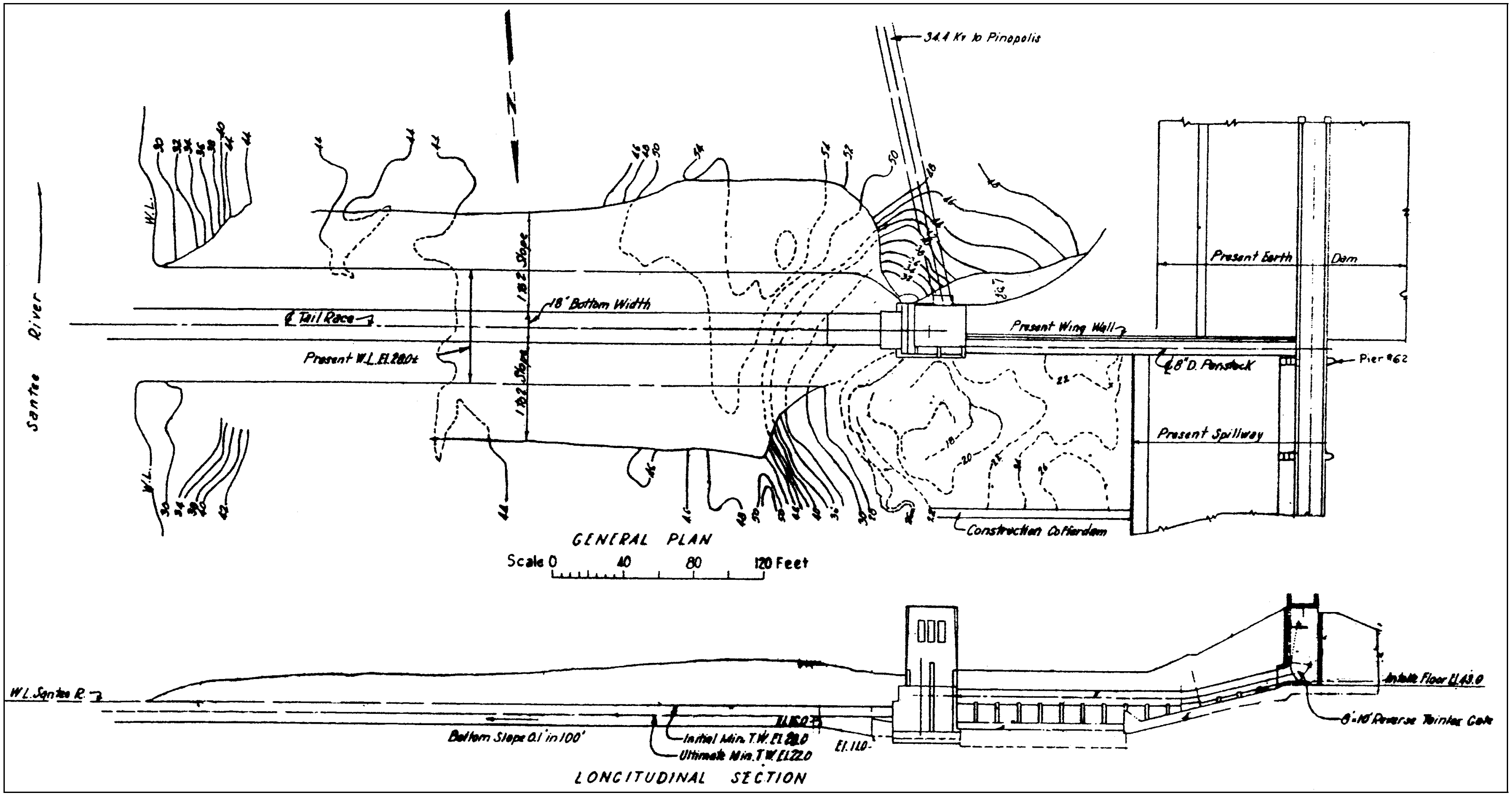


Figure 2-1. Plan and section view of the Santee Powerhouse and Spillway. Drawing provided by Santee Cooper.

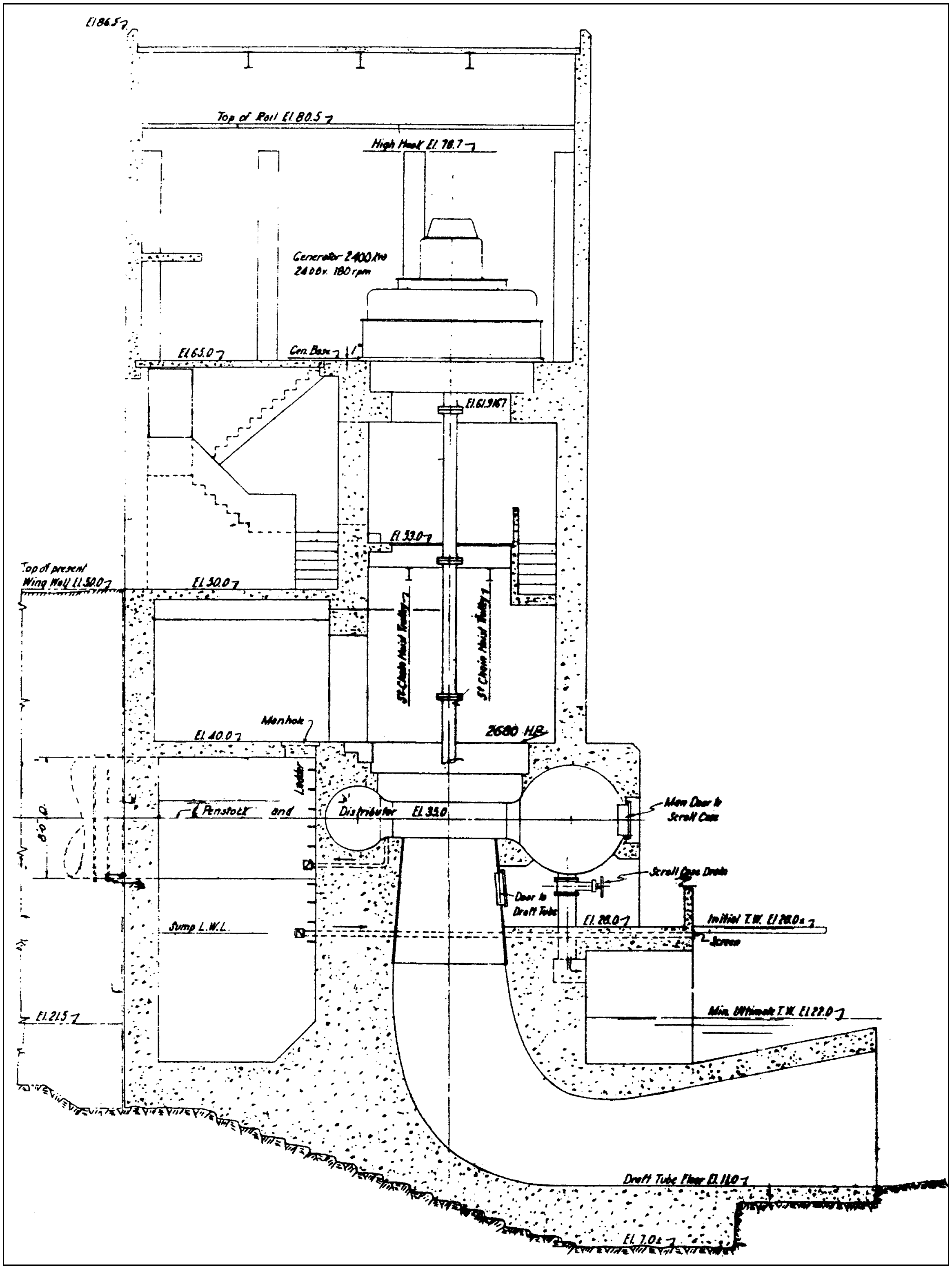


Figure 2-2. Section view of the Santee Powerhouse showing the 2,700 hp Francis turbine. Drawing provided by Santee Cooper.

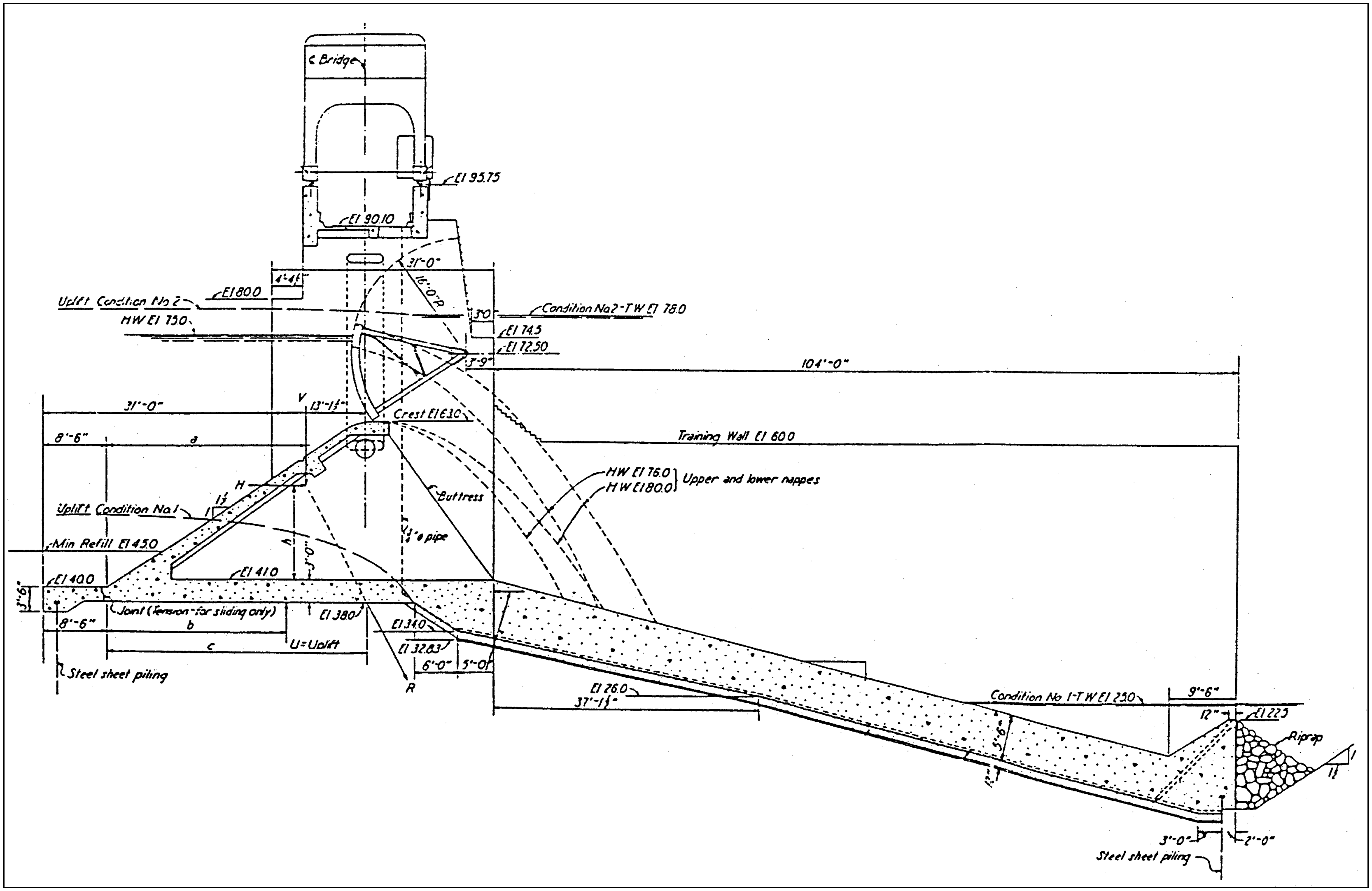


Figure 2-3. Section view of the Santee spillway. Drawing provided by Santee Cooper.

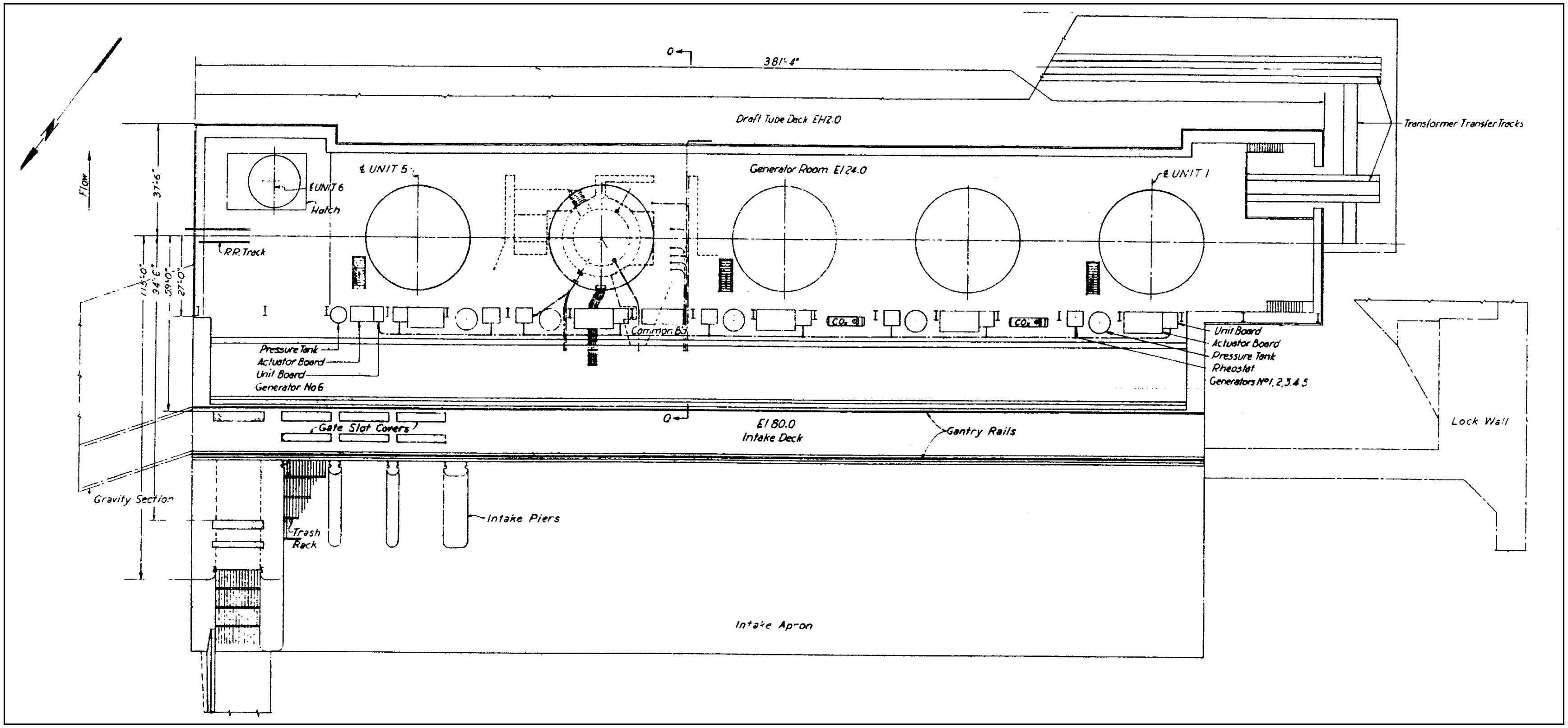


Figure 2-4. Plan view of the Jefferies Powerhouse. Drawing provided by Santee Cooper.

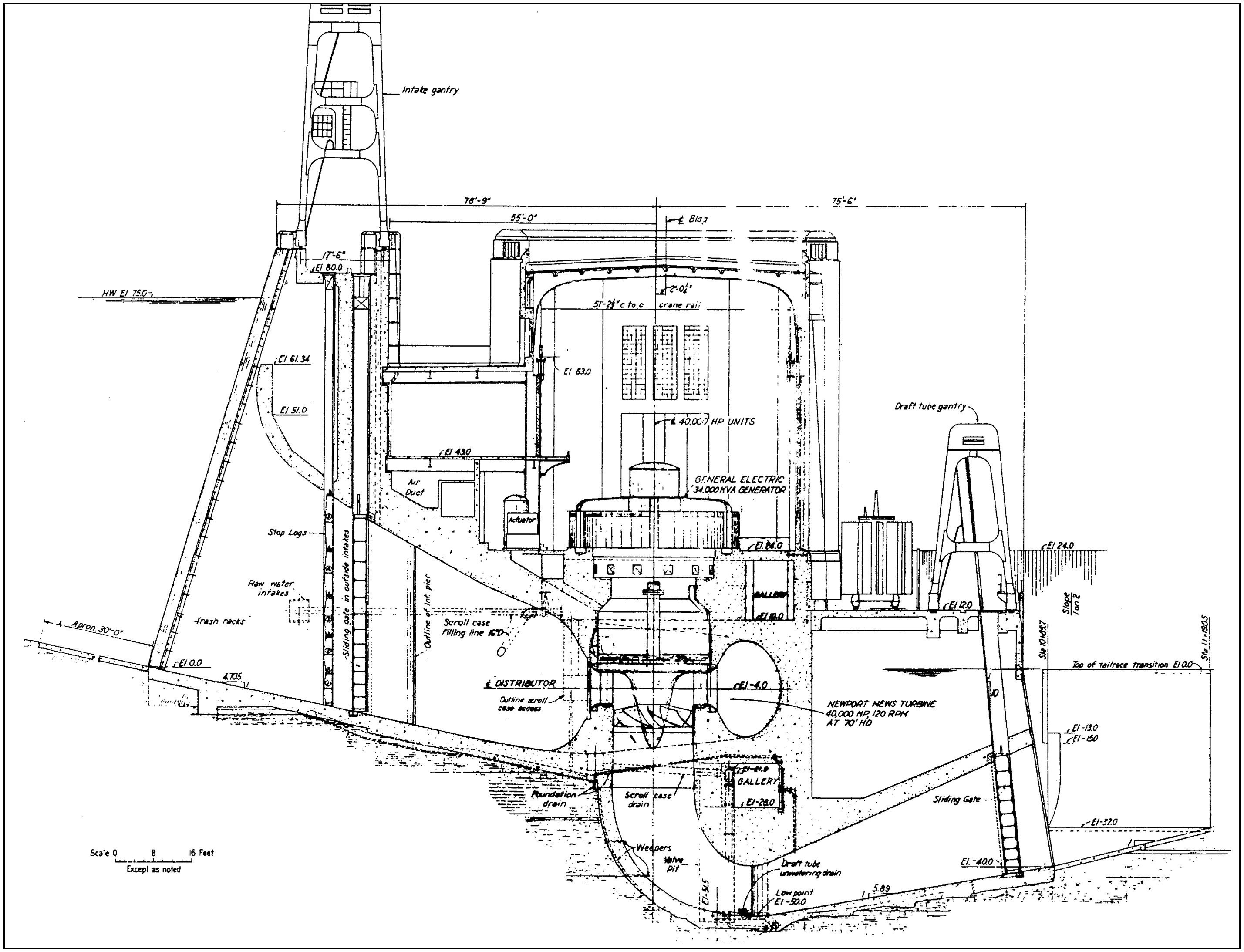


Figure 2-5. Section view of the Jefferies Powerhouse showing the 40,000 hp turbine unit. Units 2, 4, and 6 are Kaplan models and Units 1 and 3 are fixed propeller models. Drawing provided by Santee Cooper.

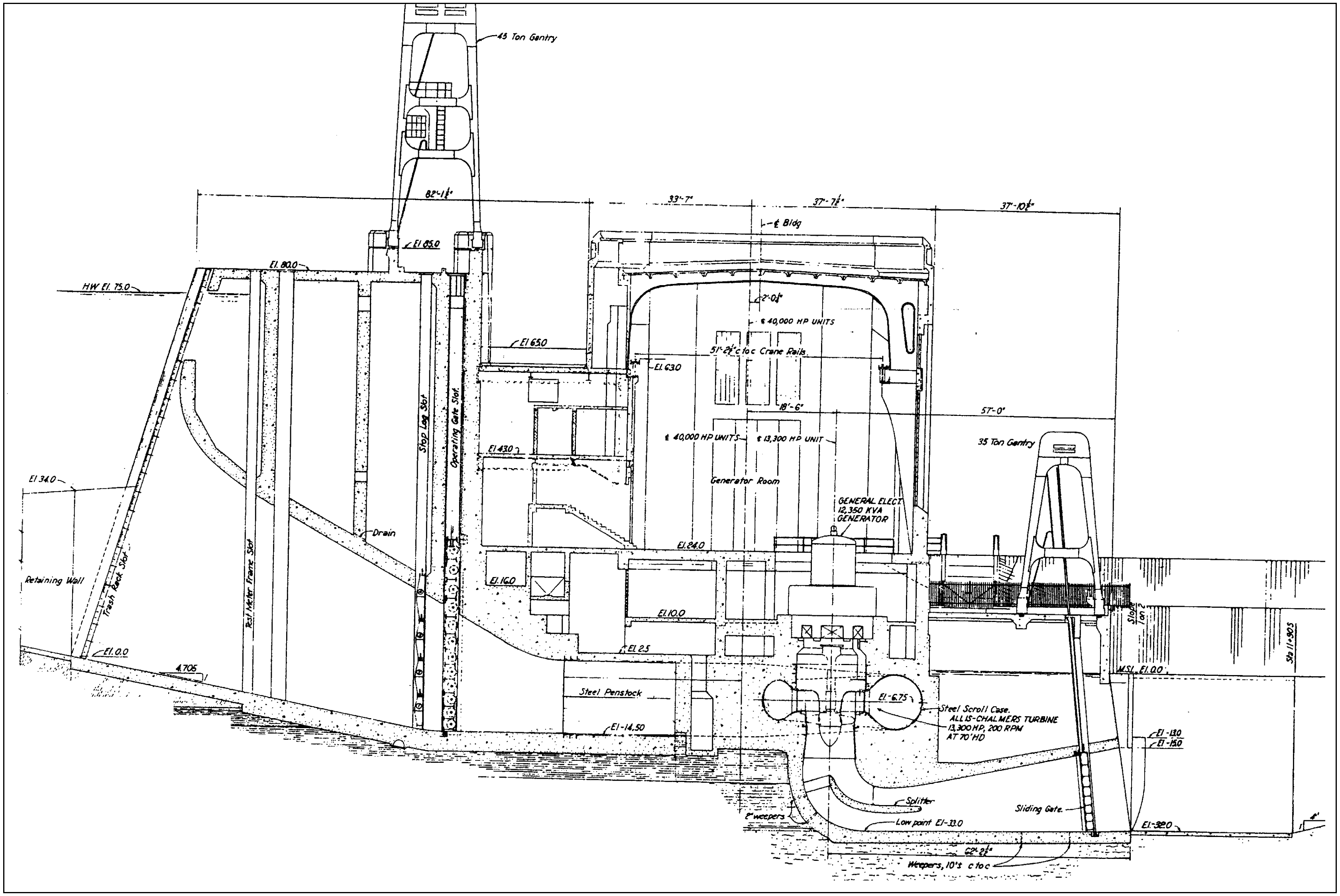
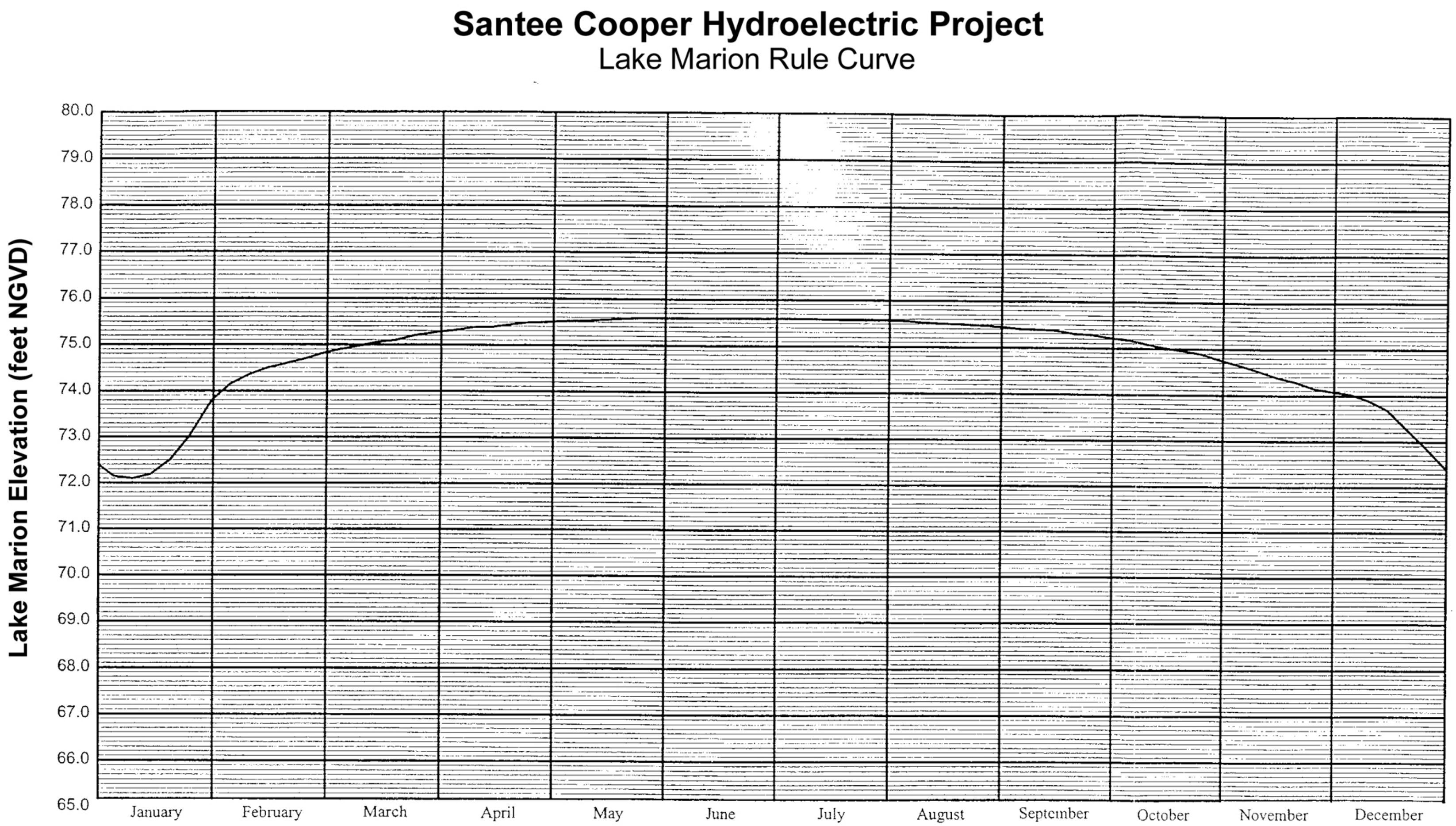


Figure 2-6. Section view of the Jefferies Powerhouse showing the 13,300 hp Kaplan turbine unit.



Rule curve taken from Santee Cooper Project
Operations and Maintenance Document, March 1997.

Figure 2-7. Lake Marion rule curve for the Santee Cooper Hydroelectric Project.

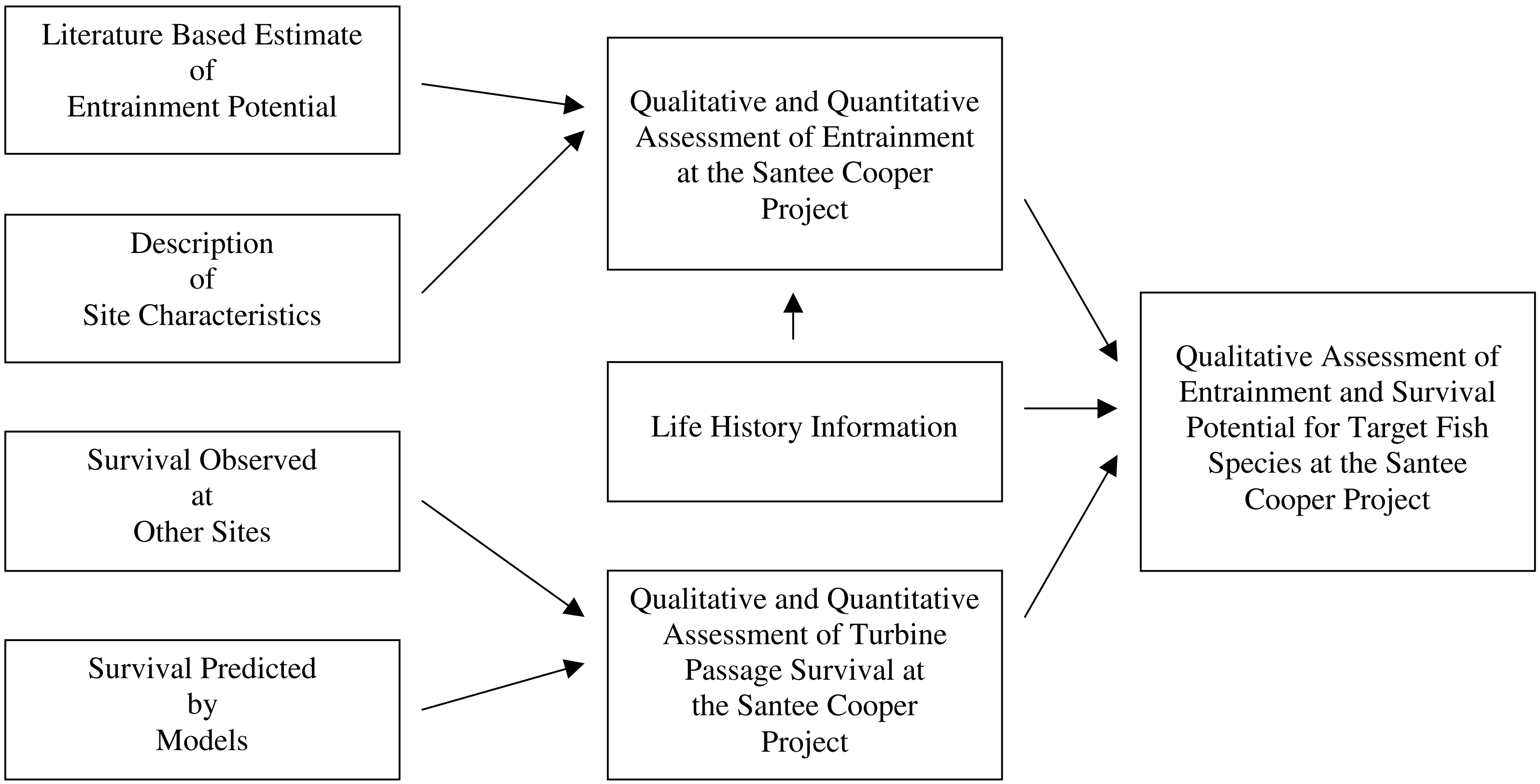


Figure 3-1. Schematic overview of the approach used to develop an assessment of entrainment and survival potential for target fish species at the Santee Cooper Project.

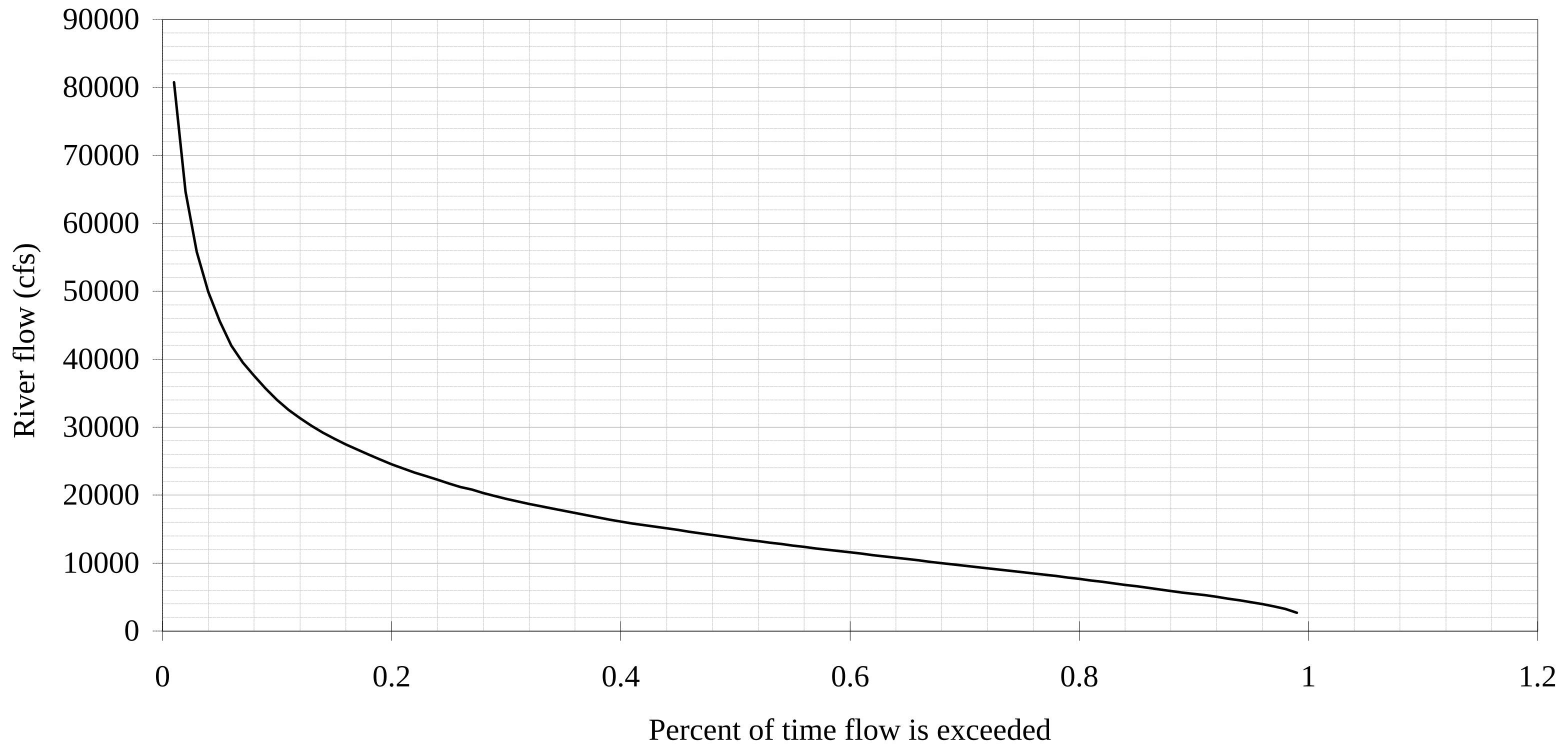


Figure 4-1. Annual flow duration curve for the Santee Cooper Hydroelectric Project.

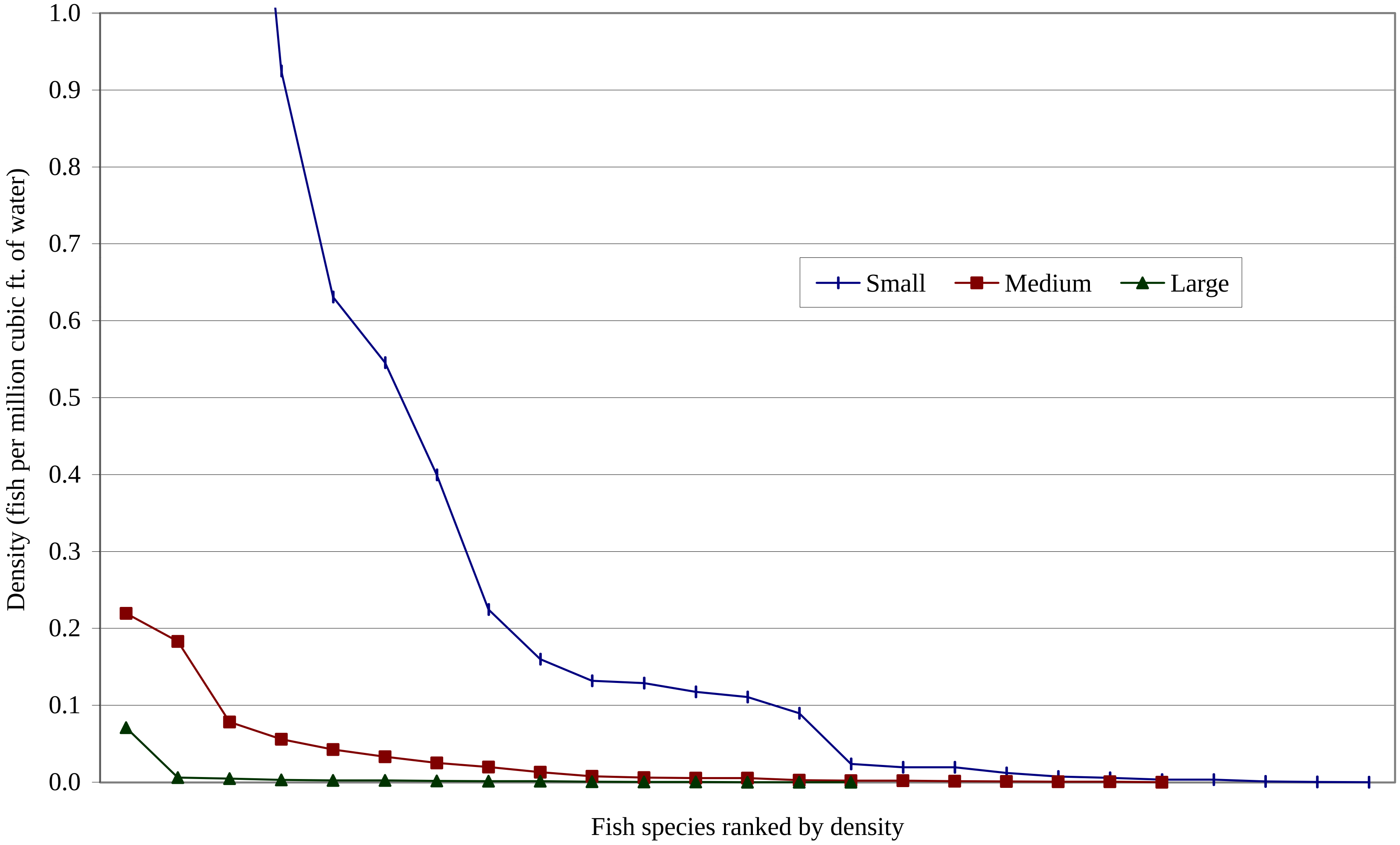


Figure 4-2. Fish entrainment densities for three size classes of species identified in both the Santee Cooper Project area and the EPRI database. Data obtained from EPRI (1997).

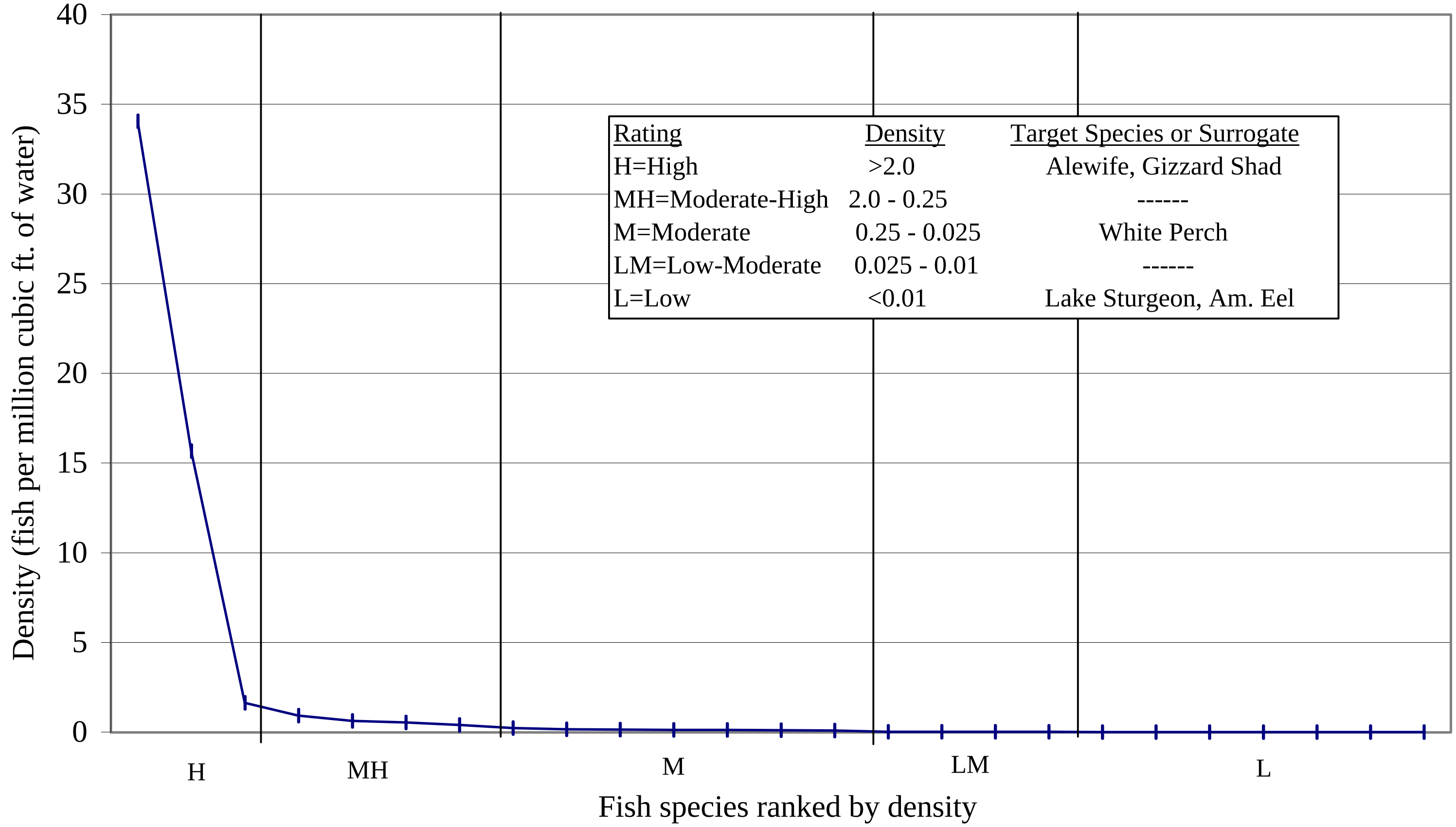


Figure 4-3. Entrainment densities for small (<8 in) sized fish species identified in both the Santee Cooper Project area and the EPRI (1997) database.

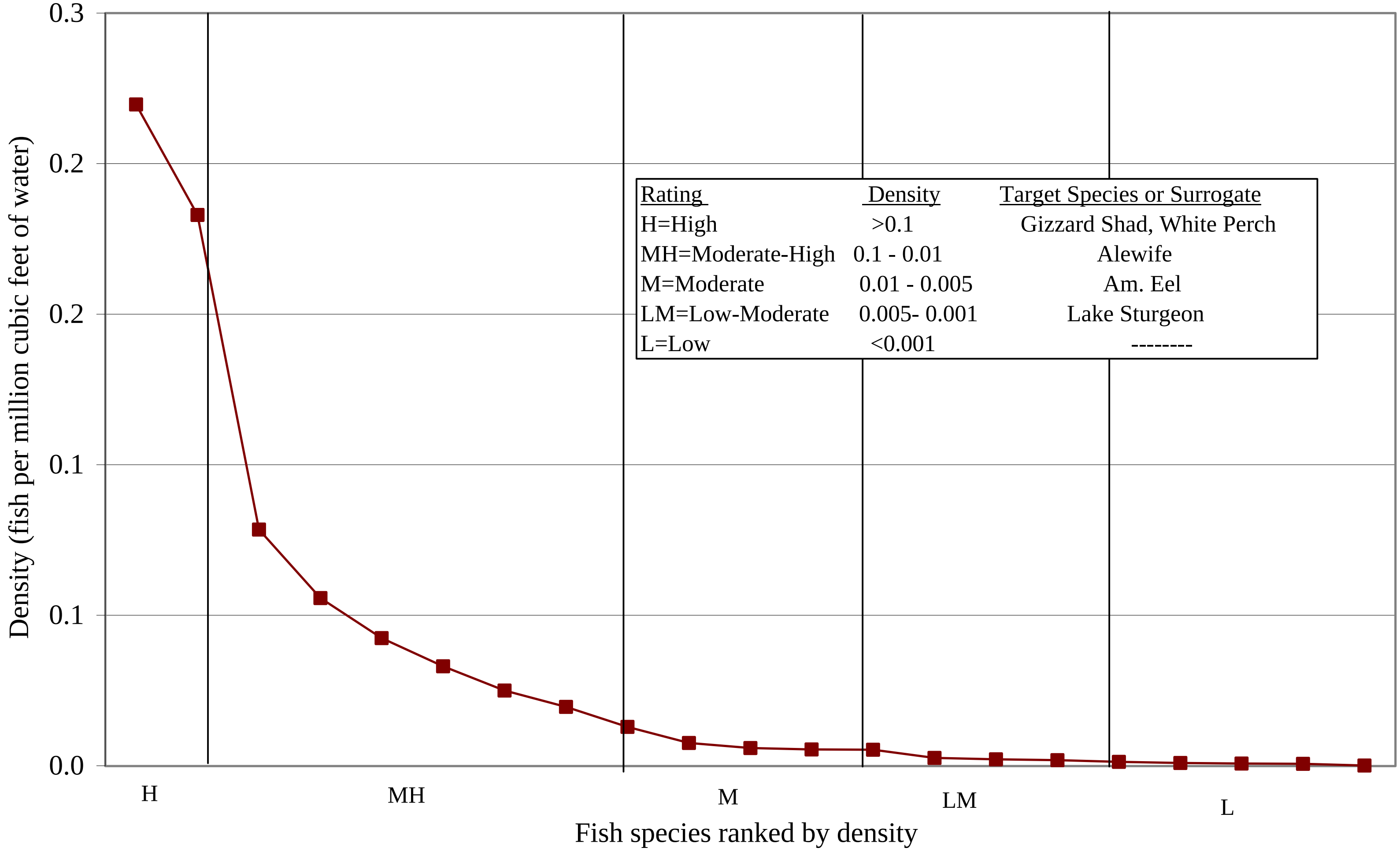


Figure 4-4. Entrianment densities for medium (8-15 in) sized fish species identified in both the Santee Cooper Project area and the EPRI (1997) database.

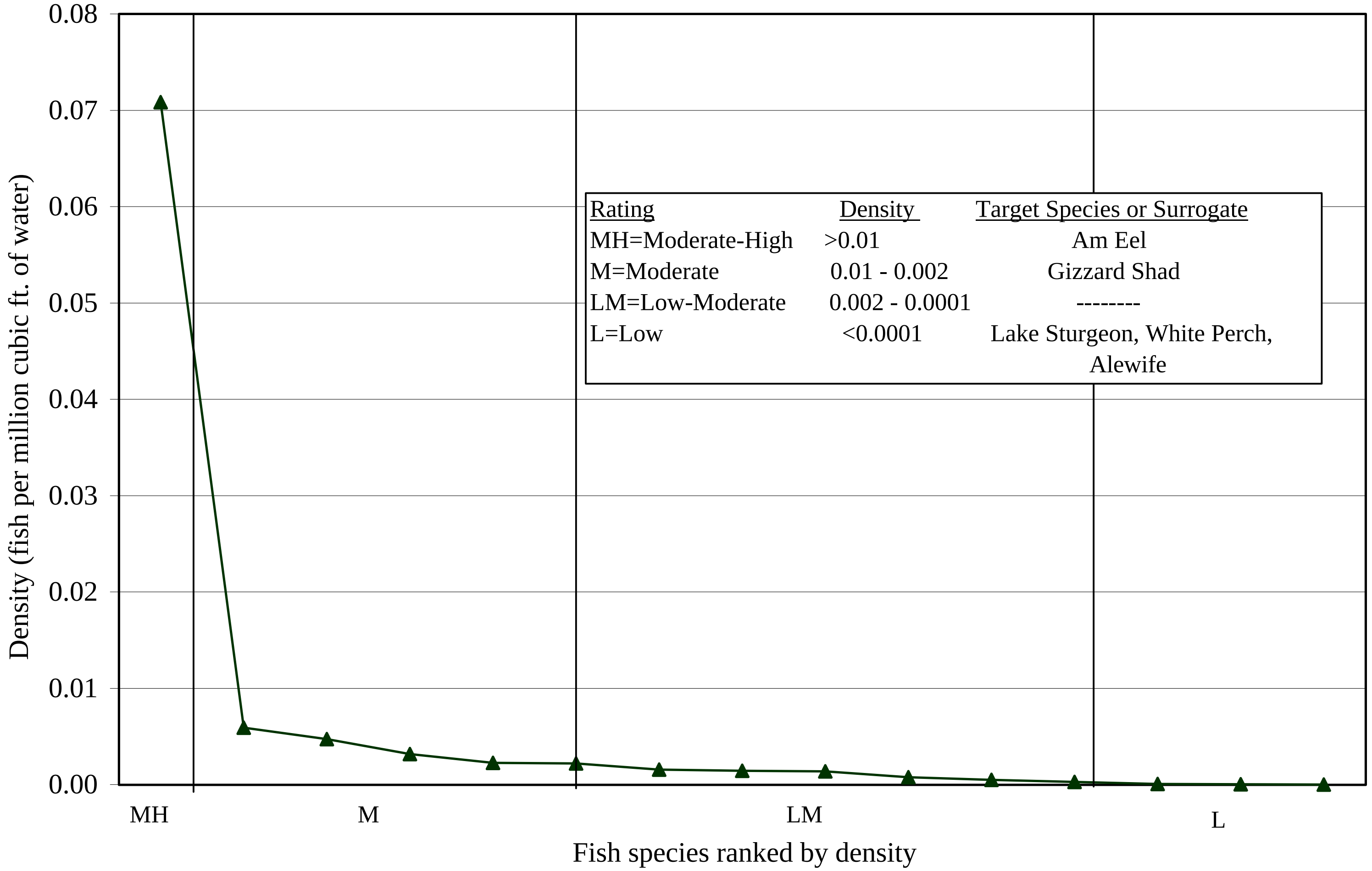


Figure 4-5. Entrainment densities for large (>15 in) sized fish species identified in both the Santee Cooper Project area and the EPRI (1997) database.

APPENDIX A

Entrainment Data From Other Sites For Species Occurring Within The Santee Cooper Project Area

Appendix A

Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Minetto	2.5	1	105	3	Sea lamprey	0	0	3
Raymondville	2.25	1	105	3	Sea lamprey	4	8	7
Crowley	2.375	2	201	1	Lake sturgeon	5	2	0
Grand Rapids	1.75	2	201	1	Lake sturgeon	1	20	1
Belding	2	3	301	2	Longnose gar	1	12	0
Buzzards Roost		3	301	2	Longnose gar	0	1	3
Minetto	2.5	3	301	2	Longnose gar	0	7	6
Potato Rapids	1.75	3	301	2	Longnose gar	0	1	0
Twin Branch	3	3	301	2	Longnose gar	2	0	1
Buzzards Roost		6	601	1	American eel	0	4	4
Colton	2	6	601	1	American eel	0	0	1
Feeder Dam	2.75	6	601	1	American eel	0	0	3
Herrings	4.125	6	601	1	American eel	0	0	1
Luray	2.75	6	601	1	American eel	0	0	279
Minetto	2.5	6	601	1	American eel	1	10	22
Ninth Street Dam	1	6	601	1	American eel	0	1	0
Raymondville	2.25	6	601	1	American eel	0	160	401
Schaghticoke	2.125	6	601	1	American eel	0	4	20
Minetto	2.5	7	701	4	Alewife	24285	197	0
Ninth Street Dam	1	7	701	4	Alewife	7	0	0
Youghiogheny	10	7	701	4	Alewife	1574965	3448	0
Buzzards Roost		7	703	4	Gizzard shad	345	68	0
Gaston Shoals		7	703	4	Gizzard shad	5	1	2
Hollidays Bridge		7	703	4	Gizzard shad	30	3	0
Minetto	2.5	7	703	4	Gizzard shad	128283	738	0
Ninety-Nine Islands		7	703	4	Gizzard shad	15	30	4
Ninth Street Dam	1	7	703	4	Gizzard shad	1	0	0
Richard B. Russell	8	7	703	4	Gizzard shad	3	36	0
Saluda		7	703	4	Gizzard shad	42	0	0
Schaghticoke	2.125	7	703	4	Gizzard shad	0	1	0
Townsend Dam	5.5	7	703	4	Gizzard shad	403054	4653	1
Belding	2	8	805	2	Bluntnose minnow	42	0	0
Bond Falls	3	8	805	2	Bluntnose minnow	18	0	0
Brule	1.62	8	805	2	Bluntnose minnow	22	0	0
Caldron Falls	2	8	805	2	Bluntnose minnow	5	0	0
Feeder Dam	2.75	8	805	2	Bluntnose minnow	3	0	0
Grand Rapids	1.75	8	805	2	Bluntnose minnow	38	0	0
Herrings	4.125	8	805	2	Bluntnose minnow	3	0	0
Potato Rapids	1.75	8	805	2	Bluntnose minnow	4	0	0
Raymondville	2.25	8	805	2	Bluntnose minnow	9	0	0
Sandstone Rapids	1.75	8	805	2	Bluntnose minnow	14	0	0
Shawano	5	8	805	2	Bluntnose minnow	9	0	0
Sherman Island	3.125	8	805	2	Bluntnose minnow	5	0	0
Thornapple	1.69	8	805	2	Bluntnose minnow	1	0	0

Appendix A

Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Tower	1	8	805	2	Bluntnose minnow	5	0	0
Townsend Dam	5.5	8	805	2	Bluntnose minnow	6	0	0
White Rapids	2.5	8	805	2	Bluntnose minnow	7	0	0
Belding	2	8	809	3	Common carp	13	0	0
Centralia	3.5	8	809	3	Common carp	4	0	4
E.J. West	4.5	8	809	3	Common carp	0	0	4
Feeder Dam	2.75	8	809	3	Common carp	3	0	0
Four Mile Dam	2	8	809	3	Common carp	0	2	0
Gaston Shoals		8	809	3	Common carp	3	1	1
Grand Rapids	1.75	8	809	3	Common carp	3	0	0
Herrings	4.125	8	809	3	Common carp	17	0	0
Johnsonville	2	8	809	3	Common carp	9	1	1
Minetto	2.5	8	809	3	Common carp	3	0	2
Ninety-Nine Islands		8	809	3	Common carp	0	0	2
Ninth Street Dam	1	8	809	3	Common carp	3	0	0
Potato Rapids	1.75	8	809	3	Common carp	0	2	0
Sandstone Rapids	1.75	8	809	3	Common carp	2	0	0
Townsend Dam	5.5	8	809	3	Common carp	21	8	25
Twin Branch	3	8	809	3	Common carp	6	0	0
White Rapids	2.5	8	809	3	Common carp	7	2	0
Wisc. Riv. Division	2.19	8	809	3	Common carp	2	0	0
Belding	2	8	811	2	Creek chub	27	1	0
Bond Falls	3	8	811	2	Creek chub	11	0	0
Caldron Falls	2	8	811	2	Creek chub	2	0	0
Colton	2	8	811	2	Creek chub	1	0	0
Gaston Shoals		8	811	2	Creek chub	1	0	0
Grand Rapids	1.75	8	811	2	Creek chub	10	0	0
Herrings	4.125	8	811	2	Creek chub	2	0	0
High Falls	1.81	8	811	2	Creek chub	6	0	0
Johnsonville	2	8	811	2	Creek chub	6	1	0
Kleber	3	8	811	2	Creek chub	29	4	0
Lake Algonquin	1	8	811	2	Creek chub	3	0	0
Moshier	1.5	8	811	2	Creek chub	2	0	0
Potato Rapids	1.75	8	811	2	Creek chub	3	0	0
Sandstone Rapids	1.75	8	811	2	Creek chub	1	0	0
Schaghticoke	2.125	8	811	2	Creek chub	2	0	0
Shawano	5	8	811	2	Creek chub	2	0	0
Thornapple	1.69	8	811	2	Creek chub	1	0	0
Tower	1	8	811	2	Creek chub	5	0	0
Townsend Dam	5.5	8	811	2	Creek chub	1	0	0
Twin Branch	3	8	811	2	Creek chub	11	0	0
Warrensburg	?	8	811	2	Creek chub	9	0	0
Lake Algonquin	1	8	812	2	Cutlips minnow	2	0	0
Warrensburg	?	8	812	2	Cutlips minnow	3	0	0

Appendix A

Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Colton	2	8	815	2	Fallfish	7	0	0
Feeder Dam	2.75	8	815	2	Fallfish	21	0	0
Higley	3.63	8	815	2	Fallfish	5	0	0
Lake Algonquin	1	8	815	2	Fallfish	4	0	0
Raymondville	2.25	8	815	2	Fallfish	10	1	0
Townsend Dam	5.5	8	815	2	Fallfish	3	1	0
Warrensburg	?	8	815	2	Fallfish	6	1	0
Belding	2	8	816	2	Fathead minnow	199	0	0
Bond Falls	3	8	816	2	Fathead minnow	1	0	0
Brule	1.62	8	816	2	Fathead minnow	34	0	0
Caldron Falls	2	8	816	2	Fathead minnow	32	0	0
Centralia	3.5	8	816	2	Fathead minnow	18	0	0
Crowley	2.375	8	816	2	Fathead minnow	39	0	0
E.J. West	4.5	8	816	2	Fathead minnow	1	0	0
Gaston Shoals		8	816	2	Fathead minnow	1	0	0
Grand Rapids	1.75	8	816	2	Fathead minnow	185	0	0
Higley	3.63	8	816	2	Fathead minnow	1	0	0
Johnsonville	2	8	816	2	Fathead minnow	143	0	0
Kleber	3	8	816	2	Fathead minnow	91	0	0
Minetto	2.5	8	816	2	Fathead minnow	3	0	0
Potato Rapids	1.75	8	816	2	Fathead minnow	111	0	0
Raymondville	2.25	8	816	2	Fathead minnow	6	0	0
Sandstone Rapids	1.75	8	816	2	Fathead minnow	31	0	0
Schaghticoke	2.125	8	816	2	Fathead minnow	11	0	0
Shawano	5	8	816	2	Fathead minnow	101	0	0
Sherman Island	3.125	8	816	2	Fathead minnow	12	0	0
Thornapple	1.69	8	816	2	Fathead minnow	1	0	0
Tower	1	8	816	2	Fathead minnow	37	0	0
Twin Branch	3	8	816	2	Fathead minnow	5	0	0
White Rapids	2.5	8	816	2	Fathead minnow	10	0	0
Wisc. Riv. Division	2.19	8	816	2	Fathead minnow	24	0	0
Belding	2	8	819	2	Golden shiner	54	0	0
Bond Falls	3	8	819	2	Golden shiner	5533	0	0
Brule	1.62	8	819	2	Golden shiner	118	0	0
Caldron Falls	2	8	819	2	Golden shiner	459	0	0
Centralia	3.5	8	819	2	Golden shiner	3	0	0
Colton	2	8	819	2	Golden shiner	34	0	0
Crowley	2.375	8	819	2	Golden shiner	46	0	0
E.J. West	4.5	8	819	2	Golden shiner	7	0	0
Feeder Dam	2.75	8	819	2	Golden shiner	162	4	0
Gaston Shoals		8	819	2	Golden shiner	6	0	0
Grand Rapids	1.75	8	819	2	Golden shiner	34	0	0
Herrings	4.125	8	819	2	Golden shiner	26	0	0
High Falls	1.81	8	819	2	Golden shiner	254	0	0

Appendix A

Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Higley	3.63	8	819	2	Golden shiner	44	0	0
Hollidays Bridge		8	819	2	Golden shiner	5	0	0
Johnsonville	2	8	819	2	Golden shiner	136	2	0
Kleber	3	8	819	2	Golden shiner	2	0	0
Lake Algonquin	1	8	819	2	Golden shiner	25	0	0
Minetto	2.5	8	819	2	Golden shiner	19	2	0
Moshier	1.5	8	819	2	Golden shiner	1	0	0
Ninety-Nine Islands		8	819	2	Golden shiner	2	0	0
Potato Rapids	1.75	8	819	2	Golden shiner	133	0	0
Raymondville	2.25	8	819	2	Golden shiner	101	0	0
Sandstone Rapids	1.75	8	819	2	Golden shiner	150	0	0
Schaghticoke	2.125	8	819	2	Golden shiner	15	1	0
Shawano	5	8	819	2	Golden shiner	53	0	0
Sherman Island	3.125	8	819	2	Golden shiner	16	0	0
Thornapple	1.69	8	819	2	Golden shiner	19	0	0
Tower	1	8	819	2	Golden shiner	8	0	0
Townsend Dam	5.5	8	819	2	Golden shiner	24	0	0
Twin Branch	3	8	819	2	Golden shiner	12	0	0
Warrensburg	?	8	819	2	Golden shiner	10	0	0
White Rapids	2.5	8	819	2	Golden shiner	65	0	0
Wisc. Riv. Division	2.19	8	819	2	Golden shiner	4	0	0
Belding	2	8	836	2	Spottail shiner	3	0	0
Bond Falls	3	8	836	2	Spottail shiner	578	0	0
Buzzards Roost		8	836	2	Spottail shiner	4	0	0
Caldron Falls	2	8	836	2	Spottail shiner	5	0	0
Centralia	3.5	8	836	2	Spottail shiner	12	0	0
E.J. West	4.5	8	836	2	Spottail shiner	5	0	0
Feeder Dam	2.75	8	836	2	Spottail shiner	5	0	0
Gaston Shoals		8	836	2	Spottail shiner	2	0	0
Grand Rapids	1.75	8	836	2	Spottail shiner	171	0	0
Herrings	4.125	8	836	2	Spottail shiner	8	0	0
High Falls	1.81	8	836	2	Spottail shiner	4	0	0
Johnsonville	2	8	836	2	Spottail shiner	3221	0	0
Lake Algonquin	1	8	836	2	Spottail shiner	1	0	0
Minetto	2.5	8	836	2	Spottail shiner	5	0	0
Ninety-Nine Islands		8	836	2	Spottail shiner	7	0	0
Potato Rapids	1.75	8	836	2	Spottail shiner	401	0	0
Raymondville	2.25	8	836	2	Spottail shiner	1	0	0
Richard B. Russell	8	8	836	2	Spottail shiner	24	0	0
Saluda		8	836	2	Spottail shiner	14	0	0
Sandstone Rapids	1.75	8	836	2	Spottail shiner	14	0	0
Schaghticoke	2.125	8	836	2	Spottail shiner	194	0	0
Shawano	5	8	836	2	Spottail shiner	48	0	0
Sherman Island	3.125	8	836	2	Spottail shiner	45	0	0

Appendix A

Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Townsend Dam	5.5	8	836	2	Spottail shiner	4	0	0
Twin Branch	3	8	836	2	Spottail shiner	413	0	0
Warrensburg	?	8	836	2	Spottail shiner	19	0	0
Grand Rapids	1.75	9	909	3	Shorthead redhorse	3	70	39
Ninety-Nine Islands		9	909	3	Shorthead redhorse	0	4	0
Potato Rapids	1.75	9	909	3	Shorthead redhorse	28	139	6
Raymondville	2.25	9	909	3	Shorthead redhorse	0	1	0
Sandstone Rapids	1.75	9	909	3	Shorthead redhorse	536	9	0
Shawano	5	9	909	3	Shorthead redhorse	6	108	5
Thornapple	1.69	9	909	3	Shorthead redhorse	7	85	7
Townsend Dam	5.5	9	909	3	Shorthead redhorse	0	2	0
Twin Branch	3	9	909	3	Shorthead redhorse	18	54	9
White Rapids	2.5	9	909	3	Shorthead redhorse	117	23	0
Centralia	3.5	9	910	3	Silver redhorse	0	0	1
Gaston Shoals		9	910	3	Silver redhorse	2	2	0
Grand Rapids	1.75	9	910	3	Silver redhorse	100	14	26
Ninety-Nine Islands		9	910	3	Silver redhorse	0	1	1
Potato Rapids	1.75	9	910	3	Silver redhorse	1	0	1
Raymondville	2.25	9	910	3	Silver redhorse	83	4	0
Sandstone Rapids	1.75	9	910	3	Silver redhorse	4	0	0
Shawano	5	9	910	3	Silver redhorse	1	1	0
Twin Branch	3	9	910	3	Silver redhorse	10	0	0
White Rapids	2.5	9	910	3	Silver redhorse	77	9	16
Belding	2	9	917	3	White sucker	2298	73	22
Bond Falls	3	9	917	3	White sucker	617	5	1
Brule	1.62	9	917	3	White sucker	108	11	0
Caldron Falls	2	9	917	3	White sucker	387	0	1
Centralia	3.5	9	917	3	White sucker	10	1	0
Colton	2	9	917	3	White sucker	4	0	0
Crowley	2.375	9	917	3	White sucker	130	12	0
E.J. West	4.5	9	917	3	White sucker	0	1	1
Feeder Dam	2.75	9	917	3	White sucker	0	1	0
Four Mile Dam	2	9	917	3	White sucker	17	30	0
Gaston Shoals		9	917	3	White sucker	0	1	0
Grand Rapids	1.75	9	917	3	White sucker	358	12	0
Herrings	4.125	9	917	3	White sucker	12	2	0
High Falls	1.81	9	917	3	White sucker	2	0	0
Higley	3.63	9	917	3	White sucker	2	0	0
Hillman Dam	3.25	9	917	3	White sucker	505	220	0
Johnsonville	2	9	917	3	White sucker	279	42	2
Kleber	3	9	917	3	White sucker	344	236	16
Lake Algonquin	1	9	917	3	White sucker	7	2	1
Minetto	2.5	9	917	3	White sucker	3	1	2
Moshier	1.5	9	917	3	White sucker	1	0	0

Appendix A

Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Ninety-Nine Islands		9	917	3	White sucker	0	1	0
Ninth Street Dam	1	9	917	3	White sucker	24806	35	0
Norway Point Dam	1.69	9	917	3	White sucker	94	85	0
Potato Rapids	1.75	9	917	3	White sucker	7615	23	31
Raymondville	2.25	9	917	3	White sucker	38	35	2
Saluda		9	917	3	White sucker	0	1	0
Sandstone Rapids	1.75	9	917	3	White sucker	5401	6	0
Schaghticoke	2.125	9	917	3	White sucker	29	1	1
Shawano	5	9	917	3	White sucker	184	71	0
Sherman Island	3.125	9	917	3	White sucker	3	0	0
Thornapple	1.69	9	917	3	White sucker	78	85	21
Tower	1	9	917	3	White sucker	48	38	14
Townsend Dam	5.5	9	917	3	White sucker	6	7	1
Twin Branch	3	9	917	3	White sucker	278	7	3
Warrensburg	?	9	917	3	White sucker	24	4	12
White Rapids	2.5	9	917	3	White sucker	36	0	0
Wisc. Riv. Division	2.19	9	917	3	White sucker	35	0	2
Youghiogheny	10	9	917	3	White sucker	0	2	84
Belding	2	10	1002	3	Brown bullhead	3	1	0
Buzzards Roost		10	1002	3	Brown bullhead	0	3	0
Colton	2	10	1002	3	Brown bullhead	23	1	0
Crowley	2.375	10	1002	3	Brown bullhead	4	0	0
E.J. West	4.5	10	1002	3	Brown bullhead	5	0	0
Feeder Dam	2.75	10	1002	3	Brown bullhead	60	23	40
Gaston Shoals		10	1002	3	Brown bullhead	11	3	0
Grand Rapids	1.75	10	1002	3	Brown bullhead	59	12	1
Herrings	4.125	10	1002	3	Brown bullhead	8	1	0
High Falls	1.81	10	1002	3	Brown bullhead	258	9	0
Higley	3.63	10	1002	3	Brown bullhead	24	0	0
Johnsonville	2	10	1002	3	Brown bullhead	1020	108	0
Kleber	3	10	1002	3	Brown bullhead	171	24	0
Lake Algonquin	1	10	1002	3	Brown bullhead	40	0	0
Minetto	2.5	10	1002	3	Brown bullhead	7	3	0
Moshier	1.5	10	1002	3	Brown bullhead	181	7	0
Ninety-Nine Islands		10	1002	3	Brown bullhead	0	1	0
Potato Rapids	1.75	10	1002	3	Brown bullhead	3	1	0
Raymondville	2.25	10	1002	3	Brown bullhead	46	6	0
Richard B. Russell	8	10	1002	3	Brown bullhead	204	31	1
Sandstone Rapids	1.75	10	1002	3	Brown bullhead	0	1	0
Schaghticoke	2.125	10	1002	3	Brown bullhead	3	1	0
Shawano	5	10	1002	3	Brown bullhead	1	1	0
Sherman Island	3.125	10	1002	3	Brown bullhead	65	4	0
Tower	1	10	1002	3	Brown bullhead	166	72	0
Townsend Dam	5.5	10	1002	3	Brown bullhead	0	1	0

Appendix A

Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Twin Branch	3	10	1002	3	Brown bullhead	26	17	0
Warrensburg	?	10	1002	3	Brown bullhead	7	4	0
White Rapids	2.5	10	1002	3	Brown bullhead	5	8	0
Youghiogheny	10	10	1002	3	Brown bullhead	0	5	0
Belding	2	10	1003	3	Channel catfish	1	0	1
Centralia	3.5	10	1003	3	Channel catfish	5747	1	0
Feeder Dam	2.75	10	1003	3	Channel catfish	8	0	0
Gaston Shoals		10	1003	3	Channel catfish	30	19	0
Grand Rapids	1.75	10	1003	3	Channel catfish	1	2	1
Hollidays Bridge		10	1003	3	Channel catfish	12	1	0
Minetto	2.5	10	1003	3	Channel catfish	20	63	3
Ninety-Nine Islands		10	1003	3	Channel catfish	40	34	0
Ninth Street Dam	1	10	1003	3	Channel catfish	1	0	0
Raymondville	2.25	10	1003	3	Channel catfish	7	0	0
Richard B. Russell	8	10	1003	3	Channel catfish	78	7	1
Saluda		10	1003	3	Channel catfish	1	1	1
Schaghticoke	2.125	10	1003	3	Channel catfish	3	0	0
Sherman Island	3.125	10	1003	3	Channel catfish	6	0	0
Thornapple	1.69	10	1003	3	Channel catfish	15	1	6
Townsend Dam	5.5	10	1003	3	Channel catfish	143	42	9
Twin Branch	3	10	1003	3	Channel catfish	2900	546	3
Wisc. Riv. Division	2.19	10	1003	3	Channel catfish	1135	0	0
Feeder Dam	2.75	11	1101	2	Chain pickerel	7	3	4
Herrings	4.125	11	1101	2	Chain pickerel	98	8	5
Lake Algonquin	1	11	1101	2	Chain pickerel	1	1	1
Sherman Island	3.125	11	1101	2	Chain pickerel	1	1	1
Warrensburg	?	11	1101	2	Chain pickerel	0	1	1
Bond Falls	3	11	1102	1	Muskellunge	1	0	2
Brule	1.62	11	1102	1	Muskellunge	0	0	3
Crowley	2.375	11	1102	1	Muskellunge	0	0	1
Potato Rapids	1.75	11	1102	1	Muskellunge	5	0	0
Sandstone Rapids	1.75	11	1102	1	Muskellunge	1	0	0
Shawano	5	11	1102	1	Muskellunge	1	0	0
Thornapple	1.69	11	1102	1	Muskellunge	4	4	0
Townsend Dam	5.5	11	1102	1	Muskellunge	0	0	1
Twin Branch	3	11	1102	1	Muskellunge	2	0	0
Belding	2	11	1103	1	Northern pike	25	36	2
Bond Falls	3	11	1103	1	Northern pike	14	16	7
Colton	2	11	1103	1	Northern pike	18	0	0
Feeder Dam	2.75	11	1103	1	Northern pike	1	0	0
Four Mile Dam	2	11	1103	1	Northern pike	3	30	0
Grand Rapids	1.75	11	1103	1	Northern pike	976	17	1
Higley	3.63	11	1103	1	Northern pike	0	0	1
Hillman Dam	3.25	11	1103	1	Northern pike	49	30	0

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Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Kleber	3	11	1103	1	Northern pike	0	0	4
Ninth Street Dam	1	11	1103	1	Northern pike	1	3	0
Norway Point Dam	1.69	11	1103	1	Northern pike	13	117	0
Potato Rapids	1.75	11	1103	1	Northern pike	335	18	15
Raymondville	2.25	11	1103	1	Northern pike	0	3	5
Sandstone Rapids	1.75	11	1103	1	Northern pike	183	5	2
Shawano	5	11	1103	1	Northern pike	0	8	14
Sherman Island	3.125	11	1103	1	Northern pike	0	1	2
Thornapple	1.69	11	1103	1	Northern pike	4	12	13
Tower	1	11	1103	1	Northern pike	0	5	18
Twin Branch	3	11	1103	1	Northern pike	31	0	0
Warrensburg	?	11	1103	1	Northern pike	22	6	0
White Rapids	2.5	11	1103	1	Northern pike	0	2	3
Wisc. Riv. Division	2.19	11	1103	1	Northern pike	35	0	0
Belding	2	12	1201	2	Central mudminnow	326	0	0
Bond Falls	3	12	1201	2	Central mudminnow	139	0	0
Brule	1.62	12	1201	2	Central mudminnow	7	0	0
Caldron Falls	2	12	1201	2	Central mudminnow	4	0	0
Colton	2	12	1201	2	Central mudminnow	29	0	0
Crowley	2.375	12	1201	2	Central mudminnow	4	0	0
Four Mile Dam	2	12	1201	2	Central mudminnow	2	0	0
Grand Rapids	1.75	12	1201	2	Central mudminnow	135	0	0
Higley	3.63	12	1201	2	Central mudminnow	5	0	0
Hillman Dam	3.25	12	1201	2	Central mudminnow	16	0	0
Kleber	3	12	1201	2	Central mudminnow	9	0	0
Ninth Street Dam	1	12	1201	2	Central mudminnow	6	0	0
Norway Point Dam	1.69	12	1201	2	Central mudminnow	26	0	0
Potato Rapids	1.75	12	1201	2	Central mudminnow	24	0	0
Raymondville	2.25	12	1201	2	Central mudminnow	1430	0	0
Sandstone Rapids	1.75	12	1201	2	Central mudminnow	1	0	0
Shawano	5	12	1201	2	Central mudminnow	5	0	0
Sherman Island	3.125	12	1201	2	Central mudminnow	5	0	0
Thornapple	1.69	12	1201	2	Central mudminnow	1	0	0
Tower	1	12	1201	2	Central mudminnow	22	0	0
Twin Branch	3	12	1201	2	Central mudminnow	4	0	0
Warrensburg	?	12	1201	2	Central mudminnow	9	0	0
White Rapids	2.5	12	1201	2	Central mudminnow	8	0	0
Wisc. Riv. Division	2.19	12	1201	2	Central mudminnow	4	0	0
Colton	2	13	1301	4	Rainbow smelt	5	0	0
E.J. West	4.5	13	1301	4	Rainbow smelt	13	0	0
Feeder Dam	2.75	13	1301	4	Rainbow smelt	48	0	0
Herrings	4.125	13	1301	4	Rainbow smelt	6	0	0
High Falls	1.81	13	1301	4	Rainbow smelt	7	0	0
Higley	3.63	13	1301	4	Rainbow smelt	8	0	0

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Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Minetto	2.5	13	1301	4	Rainbow smelt	485	0	0
Moshier	1.5	13	1301	4	Rainbow smelt	24888	0	0
Sherman Island	3.125	13	1301	4	Rainbow smelt	156	0	0
Warrensburg	?	13	1301	4	Rainbow smelt	24	0	0
Bond Falls	3	14	1403	5	Brown trout	25	1	0
Brule	1.62	14	1403	5	Brown trout	5	0	3
Caldron Falls	2	14	1403	5	Brown trout	31	12	0
Crowley	2.375	14	1403	5	Brown trout	0	1	0
E.J. West	4.5	14	1403	5	Brown trout	0	0	2
Feeder Dam	2.75	14	1403	5	Brown trout	11	5	0
Grand Rapids	1.75	14	1403	5	Brown trout	10	6	0
Johnsonville	2	14	1403	5	Brown trout	20	35	0
Lake Algonquin	1	14	1403	5	Brown trout	5	8	0
Potato Rapids	1.75	14	1403	5	Brown trout	7	9	0
Sandstone Rapids	1.75	14	1403	5	Brown trout	11	5	2
Shawano	5	14	1403	5	Brown trout	21	19	1
Sherman Island	3.125	14	1403	5	Brown trout	2	0	1
Tower	1	14	1403	5	Brown trout	2	0	0
Twin Branch	3	14	1403	5	Brown trout	1	0	0
White Rapids	2.5	14	1403	5	Brown trout	1	2	0
Youghiogheny	10	14	1403	5	Brown trout	0	1	0
Bond Falls	3	15	1501	2	Trout-perch	1351	0	0
Centralia	3.5	15	1501	2	Trout-perch	16	0	0
Crowley	2.375	15	1501	2	Trout-perch	1	0	0
Johnsonville	2	15	1501	2	Trout-perch	3	0	0
Kleber	3	15	1501	2	Trout-perch	2	0	0
Schaghticoke	2.125	15	1501	2	Trout-perch	3	0	0
Thornapple	1.69	15	1501	2	Trout-perch	249	0	0
Wisc. Riv. Division	2.19	15	1501	2	Trout-perch	34	0	0
Belding	2	16	1601	3	Burbot	12	12	0
Brule	1.62	16	1601	3	Burbot	26	16	0
Centralia	3.5	16	1601	3	Burbot	4	0	0
Crowley	2.375	16	1601	3	Burbot	4	8	0
Four Mile Dam	2	16	1601	3	Burbot	0	10	0
Grand Rapids	1.75	16	1601	3	Burbot	261	10	0
Hillman Dam	3.25	16	1601	3	Burbot	84	76	0
Kleber	3	16	1601	3	Burbot	42	0	0
Ninth Street Dam	1	16	1601	3	Burbot	3	0	0
Norway Point Dam	1.69	16	1601	3	Burbot	3	12	0
Potato Rapids	1.75	16	1601	3	Burbot	48	5	0
Raymondville	2.25	16	1601	3	Burbot	1	2	1
Sandstone Rapids	1.75	16	1601	3	Burbot	39	8	0
Thornapple	1.69	16	1601	3	Burbot	91	21	0
Tower	1	16	1601	3	Burbot	2	2	2

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Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
White Rapids	2.5	16	1601	3	Burbot	0	2	6
Belding	2	17	1701	2	Banded killifish	1	0	0
Colton	2	17	1701	2	Banded killifish	6	0	0
Herrings	4.125	17	1701	2	Banded killifish	141	0	0
High Falls	1.81	17	1701	2	Banded killifish	2	0	0
Higley	3.63	17	1701	2	Banded killifish	28	0	0
Hillman Dam	3.25	17	1701	2	Banded killifish	3	0	0
Minetto	2.5	17	1701	2	Banded killifish	16	0	0
Ninth Street Dam	1	17	1701	2	Banded killifish	39	0	0
Potato Rapids	1.75	17	1701	2	Banded killifish	5	0	0
Raymondville	2.25	17	1701	2	Banded killifish	305	0	0
Sandstone Rapids	1.75	17	1701	2	Banded killifish	1	0	0
Sherman Island	3.125	17	1701	2	Banded killifish	11	0	0
Belding	2	18	1801	2	Brook silverside	51	0	0
Shawano	5	18	1801	2	Brook silverside	57	0	0
Twin Branch	3	18	1801	2	Brook silverside	2	0	0
Belding	2	19	1901	2	Brook stickleback	157	0	0
Bond Falls	3	19	1901	2	Brook stickleback	55	0	0
Brule	1.62	19	1901	2	Brook stickleback	19	0	0
Caldron Falls	2	19	1901	2	Brook stickleback	61	0	0
Centralia	3.5	19	1901	2	Brook stickleback	3	0	0
Crowley	2.375	19	1901	2	Brook stickleback	83	0	0
Grand Rapids	1.75	19	1901	2	Brook stickleback	868	0	0
Herrings	4.125	19	1901	2	Brook stickleback	10	0	0
Minetto	2.5	19	1901	2	Brook stickleback	53	0	0
Potato Rapids	1.75	19	1901	2	Brook stickleback	7	0	0
Raymondville	2.25	19	1901	2	Brook stickleback	3078	0	0
Sandstone Rapids	1.75	19	1901	2	Brook stickleback	32	0	0
Shawano	5	19	1901	2	Brook stickleback	5	0	0
Tower	1	19	1901	2	Brook stickleback	6	0	0
Wisc. Riv. Division	2.19	19	1901	2	Brook stickleback	67	0	0
Bond Falls	3	20	2001	3	Mottled sculpin	15	0	0
Brule	1.62	20	2001	3	Mottled sculpin	39	0	0
Caldron Falls	2	20	2001	3	Mottled sculpin	94	0	0
Grand Rapids	1.75	20	2001	3	Mottled sculpin	2	0	0
Herrings	4.125	20	2001	3	Mottled sculpin	1	0	0
High Falls	1.81	20	2001	3	Mottled sculpin	4	0	0
Kleber	3	20	2001	3	Mottled sculpin	2	0	0
Sandstone Rapids	1.75	20	2001	3	Mottled sculpin	4	0	0
White Rapids	2.5	20	2001	3	Mottled sculpin	3	0	0
Youghiogheny	10	20	2001	3	Mottled sculpin	15	0	0
Buzzards Roost		21	2104	5	White bass	0	2	0
Minetto	2.5	21	2104	5	White bass	23	1	0
Saluda		21	2104	5	White bass	0	4	0

Appendix A

Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Townsend Dam	5.5	21	2104	5	White bass	31	99	0
Buzzards Roost		21	2105	5	White perch	308	293	0
Minetto	2.5	21	2105	5	White perch	1826	180	1
Richard B. Russell	8	21	2105	5	White perch	194	6	0
Saluda		21	2105	5	White perch	2	3	0
Belding	2	22	2201	2	Black crappie	58	0	0
Bond Falls	3	22	2201	2	Black crappie	2667	1	0
Brule	1.62	22	2201	2	Black crappie	39	5	0
Buzzards Roost		22	2201	2	Black crappie	21	4	0
Caldron Falls	2	22	2201	2	Black crappie	3385	23	0
Centralia	3.5	22	2201	2	Black crappie	124	10	0
Colton	2	22	2201	2	Black crappie	3	0	0
Crowley	2.375	22	2201	2	Black crappie	445	19	0
E.J. West	4.5	22	2201	2	Black crappie	1	0	0
Feeder Dam	2.75	22	2201	2	Black crappie	13	1	0
Grand Rapids	1.75	22	2201	2	Black crappie	612	0	0
Herrings	4.125	22	2201	2	Black crappie	1	1	0
High Falls	1.81	22	2201	2	Black crappie	2	0	0
Higley	3.63	22	2201	2	Black crappie	30	0	0
Hollidays Bridge		22	2201	2	Black crappie	4	1	0
Johnsonville	2	22	2201	2	Black crappie	7973	47	0
Kleber	3	22	2201	2	Black crappie	18	4	0
Minetto	2.5	22	2201	2	Black crappie	55	4	0
Ninety-Nine Islands		22	2201	2	Black crappie	2	5	0
Potato Rapids	1.75	22	2201	2	Black crappie	2972	2	0
Richard B. Russell	8	22	2201	2	Black crappie	452	3	0
Saluda		22	2201	2	Black crappie	1	4	0
Sandstone Rapids	1.75	22	2201	2	Black crappie	3692	10	0
Schaghticoke	2.125	22	2201	2	Black crappie	157	24	0
Shawano	5	22	2201	2	Black crappie	323	67	0
Thornapple	1.69	22	2201	2	Black crappie	916	16	0
Townsend Dam	5.5	22	2201	2	Black crappie	45	1	0
Twin Branch	3	22	2201	2	Black crappie	10	3	0
White Rapids	2.5	22	2201	2	Black crappie	2205	33	0
Wisc. Riv. Division	2.19	22	2201	2	Black crappie	45	2	0
Belding	2	22	2202	2	Bluegill	833	0	0
Bond Falls	3	22	2202	2	Bluegill	557	0	0
Brule	1.62	22	2202	2	Bluegill	77	0	0
Buzzards Roost		22	2202	2	Bluegill	1131	13	0
Caldron Falls	2	22	2202	2	Bluegill	667	2	0
Centralia	3.5	22	2202	2	Bluegill	302	0	0
Colton	2	22	2202	2	Bluegill	20	0	0
Crowley	2.375	22	2202	2	Bluegill	19	0	0
E.J. West	4.5	22	2202	2	Bluegill	1	0	0

Appendix A

Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Feeder Dam	2.75	22	2202	2	Bluegill	28	0	0
Gaston Shoals		22	2202	2	Bluegill	58	0	0
Grand Rapids	1.75	22	2202	2	Bluegill	151	0	0
Herrings	4.125	22	2202	2	Bluegill	20	0	0
High Falls	1.81	22	2202	2	Bluegill	53	0	0
Higley	3.63	22	2202	2	Bluegill	5	0	0
Hollidays Bridge		22	2202	2	Bluegill	27	0	0
Johnsonville	2	22	2202	2	Bluegill	615	4	0
Kleber	3	22	2202	2	Bluegill	3271	0	0
Minetto	2.5	22	2202	2	Bluegill	3191	1	0
Moshier	1.5	22	2202	2	Bluegill	5	0	0
Ninety-Nine Islands		22	2202	2	Bluegill	93	0	0
Potato Rapids	1.75	22	2202	2	Bluegill	157	6	0
Raymondville	2.25	22	2202	2	Bluegill	2	0	0
Richard B. Russell	8	22	2202	2	Bluegill	612	1	0
Saluda		22	2202	2	Bluegill	109	5	0
Sandstone Rapids	1.75	22	2202	2	Bluegill	187	0	0
Schaghticoke	2.125	22	2202	2	Bluegill	263	0	0
Shawano	5	22	2202	2	Bluegill	801	1	0
Sherman Island	3.125	22	2202	2	Bluegill	29	0	0
Thornapple	1.69	22	2202	2	Bluegill	119	0	0
Tower	1	22	2202	2	Bluegill	102	0	0
Townsend Dam	5.5	22	2202	2	Bluegill	178	1	0
Twin Branch	3	22	2202	2	Bluegill	663	0	0
White Rapids	2.5	22	2202	2	Bluegill	1497	3	0
Wisc. Riv. Division	2.19	22	2202	2	Bluegill	839	0	0
Youghiogheny	10	22	2202	2	Bluegill	30	3	0
Belding	2	22	2205	2	Largemouth bass	2170	5	0
Bond Falls	3	22	2205	2	Largemouth bass	4	0	0
Brule	1.62	22	2205	2	Largemouth bass	2	0	0
Buzzards Roost		22	2205	2	Largemouth bass	6	0	0
Caldron Falls	2	22	2205	2	Largemouth bass	307	3	0
Centralia	3.5	22	2205	2	Largemouth bass	4	3	0
Colton	2	22	2205	2	Largemouth bass	63	1	0
Crowley	2.375	22	2205	2	Largemouth bass	169	0	0
E.J. West	4.5	22	2205	2	Largemouth bass	0	2	0
Feeder Dam	2.75	22	2205	2	Largemouth bass	69	4	0
Gaston Shoals		22	2205	2	Largemouth bass	2	0	0
Grand Rapids	1.75	22	2205	2	Largemouth bass	132	0	0
Herrings	4.125	22	2205	2	Largemouth bass	1	0	0
Higley	3.63	22	2205	2	Largemouth bass	39	0	0
Johnsonville	2	22	2205	2	Largemouth bass	684	11	0
Kleber	3	22	2205	2	Largemouth bass	16	2	0
Lake Algonquin	1	22	2205	2	Largemouth bass	7	0	0

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Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Minetto	2.5	22	2205	2	Largemouth bass	199	2	0
Ninety-Nine Islands		22	2205	2	Largemouth bass	0	0	1
Potato Rapids	1.75	22	2205	2	Largemouth bass	4230	0	0
Raymondville	2.25	22	2205	2	Largemouth bass	2	1	0
Richard B. Russell	8	22	2205	2	Largemouth bass	0	0	2
Saluda		22	2205	2	Largemouth bass	1	0	3
Sandstone Rapids	1.75	22	2205	2	Largemouth bass	2523	0	0
Schaghticoke	2.125	22	2205	2	Largemouth bass	61	5	0
Shawano	5	22	2205	2	Largemouth bass	431	16	1
Sherman Island	3.125	22	2205	2	Largemouth bass	10	0	0
Thornapple	1.69	22	2205	2	Largemouth bass	43	1	0
Tower	1	22	2205	2	Largemouth bass	5	3	0
Townsend Dam	5.5	22	2205	2	Largemouth bass	20	12	0
Twin Branch	3	22	2205	2	Largemouth bass	13	0	1
Warrensburg	?	22	2205	2	Largemouth bass	0	6	1
White Rapids	2.5	22	2205	2	Largemouth bass	108	3	0
Wisc. Riv. Division	2.19	22	2205	2	Largemouth bass	5	0	0
Belding	2	22	2207	2	Pumpkinseed	55	0	0
Bond Falls	3	22	2207	2	Pumpkinseed	34	0	0
Brule	1.62	22	2207	2	Pumpkinseed	63	0	0
Buzzards Roost		22	2207	2	Pumpkinseed	6	0	0
Caldron Falls	2	22	2207	2	Pumpkinseed	17	0	0
Colton	2	22	2207	2	Pumpkinseed	63	0	0
Crowley	2.375	22	2207	2	Pumpkinseed	37	0	0
E.J. West	4.5	22	2207	2	Pumpkinseed	2	0	0
Feeder Dam	2.75	22	2207	2	Pumpkinseed	246	35	0
Grand Rapids	1.75	22	2207	2	Pumpkinseed	58	0	0
Herrings	4.125	22	2207	2	Pumpkinseed	5	0	0
High Falls	1.81	22	2207	2	Pumpkinseed	30	0	0
Higley	3.63	22	2207	2	Pumpkinseed	212	3	0
Johnsonville	2	22	2207	2	Pumpkinseed	888	0	0
Kleber	3	22	2207	2	Pumpkinseed	380	2	0
Lake Algonquin	1	22	2207	2	Pumpkinseed	135	0	0
Minetto	2.5	22	2207	2	Pumpkinseed	230	0	0
Moshier	1.5	22	2207	2	Pumpkinseed	16	0	0
Potato Rapids	1.75	22	2207	2	Pumpkinseed	101	0	0
Raymondville	2.25	22	2207	2	Pumpkinseed	358	0	0
Sandstone Rapids	1.75	22	2207	2	Pumpkinseed	13	0	0
Schaghticoke	2.125	22	2207	2	Pumpkinseed	22	0	0
Shawano	5	22	2207	2	Pumpkinseed	302	0	0
Sherman Island	3.125	22	2207	2	Pumpkinseed	141	19	0
Thornapple	1.69	22	2207	2	Pumpkinseed	154	0	0
Tower	1	22	2207	2	Pumpkinseed	54	0	0
Townsend Dam	5.5	22	2207	2	Pumpkinseed	30	0	0

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Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Twin Branch	3	22	2207	2	Pumpkinseed	127	0	0
Warrensburg	?	22	2207	2	Pumpkinseed	43	0	0
White Rapids	2.5	22	2207	2	Pumpkinseed	59	2	0
Youghiogheny	10	22	2207	2	Pumpkinseed	17	0	0
Belding	2	22	2211	2	Rock bass	1055	8	1
Bond Falls	3	22	2211	2	Rock bass	217	14	0
Brule	1.62	22	2211	2	Rock bass	103	0	0
Caldron Falls	2	22	2211	2	Rock bass	181	22	0
Centralia	3.5	22	2211	2	Rock bass	13	1	0
Colton	2	22	2211	2	Rock bass	101	1	0
Crowley	2.375	22	2211	2	Rock bass	50	0	0
E.J. West	4.5	22	2211	2	Rock bass	109	3	0
Feeder Dam	2.75	22	2211	2	Rock bass	431	91	0
Four Mile Dam	2	22	2211	2	Rock bass	512	13	0
Grand Rapids	1.75	22	2211	2	Rock bass	474	0	0
Herrings	4.125	22	2211	2	Rock bass	67	35	0
High Falls	1.81	22	2211	2	Rock bass	16	0	0
Higley	3.63	22	2211	2	Rock bass	117	2	0
Hillman Dam	3.25	22	2211	2	Rock bass	837	4	0
Johnsonville	2	22	2211	2	Rock bass	93	9	0
Kleber	3	22	2211	2	Rock bass	2853	11	0
Lake Algonquin	1	22	2211	2	Rock bass	28	3	0
Minetto	2.5	22	2211	2	Rock bass	87	2	0
Moshier	1.5	22	2211	2	Rock bass	50	5	0
Ninth Street Dam	1	22	2211	2	Rock bass	425	7	0
Norway Point Dam	1.69	22	2211	2	Rock bass	129	1	0
Potato Rapids	1.75	22	2211	2	Rock bass	731	60	0
Raymondville	2.25	22	2211	2	Rock bass	535	2	0
Sandstone Rapids	1.75	22	2211	2	Rock bass	172	5	0
Schaghticoke	2.125	22	2211	2	Rock bass	27	8	0
Shawano	5	22	2211	2	Rock bass	548	0	0
Sherman Island	3.125	22	2211	2	Rock bass	544	14	0
Thornapple	1.69	22	2211	2	Rock bass	23	0	0
Tower	1	22	2211	2	Rock bass	268	0	0
Townsend Dam	5.5	22	2211	2	Rock bass	16	1	0
Twin Branch	3	22	2211	2	Rock bass	28	1	0
Warrensburg	?	22	2211	2	Rock bass	273	7	0
White Rapids	2.5	22	2211	2	Rock bass	147	3	0
Wisc. Riv. Division	2.19	22	2211	2	Rock bass	1	0	0
Youghiogheny	10	22	2211	2	Rock bass	383	15	2
Belding	2	22	2212	1	Smallmouth bass	192	10	4
Bond Falls	3	22	2212	1	Smallmouth bass	75	31	0
Brule	1.62	22	2212	1	Smallmouth bass	307	11	0
Caldron Falls	2	22	2212	1	Smallmouth bass	19	13	1

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Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Centralia	3.5	22	2212	1	Smallmouth bass	18	1	0
Colton	2	22	2212	1	Smallmouth bass	17	0	0
Crowley	2.375	22	2212	1	Smallmouth bass	97	2	0
E.J. West	4.5	22	2212	1	Smallmouth bass	584	43	2
Feeder Dam	2.75	22	2212	1	Smallmouth bass	33	37	1
Gaston Shoals		22	2212	1	Smallmouth bass	0	2	0
Grand Rapids	1.75	22	2212	1	Smallmouth bass	120	0	0
Herrings	4.125	22	2212	1	Smallmouth bass	78	12	0
High Falls	1.81	22	2212	1	Smallmouth bass	6	0	0
Higley	3.63	22	2212	1	Smallmouth bass	341	15	0
Johnsonville	2	22	2212	1	Smallmouth bass	765	14	0
Kleber	3	22	2212	1	Smallmouth bass	2	2	0
Lake Algonquin	1	22	2212	1	Smallmouth bass	76	2	0
Minetto	2.5	22	2212	1	Smallmouth bass	183	158	0
Moshier	1.5	22	2212	1	Smallmouth bass	49	0	0
Ninety-Nine Islands		22	2212	1	Smallmouth bass	0	0	1
Potato Rapids	1.75	22	2212	1	Smallmouth bass	2033	84	4
Raymondville	2.25	22	2212	1	Smallmouth bass	359	73	15
Sandstone Rapids	1.75	22	2212	1	Smallmouth bass	1178	5	0
Schaghticoke	2.125	22	2212	1	Smallmouth bass	67	7	0
Shawano	5	22	2212	1	Smallmouth bass	36	51	1
Sherman Island	3.125	22	2212	1	Smallmouth bass	48	49	0
Thornapple	1.69	22	2212	1	Smallmouth bass	507	66	0
Tower	1	22	2212	1	Smallmouth bass	5	0	0
Townsend Dam	5.5	22	2212	1	Smallmouth bass	20	8	0
Twin Branch	3	22	2212	1	Smallmouth bass	19	21	1
Warrensburg	?	22	2212	1	Smallmouth bass	10	1	0
White Rapids	2.5	22	2212	1	Smallmouth bass	196	20	0
Wisc. Riv. Division	2.19	22	2212	1	Smallmouth bass	161	3	0
Youghiogheny	10	22	2212	1	Smallmouth bass	2	1	0
Caldron Falls	2	23	2306	3	Iowa darter	39	0	0
Crowley	2.375	23	2306	3	Iowa darter	14	0	0
Grand Rapids	1.75	23	2306	3	Iowa darter	6	0	0
Potato Rapids	1.75	23	2306	3	Iowa darter	12	0	0
Sandstone Rapids	1.75	23	2306	3	Iowa darter	13	0	0
Shawano	5	23	2306	3	Iowa darter	13	0	0
Thornapple	1.69	23	2306	3	Iowa darter	12	0	0
Belding	2	23	2307	3	Johnny darter	12	0	0
Bond Falls	3	23	2307	3	Johnny darter	9	0	0
Brule	1.62	23	2307	3	Johnny darter	1	0	0
Caldron Falls	2	23	2307	3	Johnny darter	268	0	0
Crowley	2.375	23	2307	3	Johnny darter	125	0	0
Grand Rapids	1.75	23	2307	3	Johnny darter	271	0	0
Kleber	3	23	2307	3	Johnny darter	2	0	0

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Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Potato Rapids	1.75	23	2307	3	Johnny darter	174	0	0
Raymondville	2.25	23	2307	3	Johnny darter	175	0	0
Sandstone Rapids	1.75	23	2307	3	Johnny darter	112	0	0
Shawano	5	23	2307	3	Johnny darter	13	0	0
Thornapple	1.69	23	2307	3	Johnny darter	6	0	0
Twin Branch	3	23	2307	3	Johnny darter	8	0	0
Belding	2	23	2309	3	Logperch	1	0	0
Bond Falls	3	23	2309	3	Logperch	3	0	0
Brule	1.62	23	2309	3	Logperch	276	0	0
Caldron Falls	2	23	2309	3	Logperch	6	0	0
Centralia	3.5	23	2309	3	Logperch	10	0	0
Colton	2	23	2309	3	Logperch	65	0	0
Crowley	2.375	23	2309	3	Logperch	782	0	0
E.J. West	4.5	23	2309	3	Logperch	11	0	0
Feeder Dam	2.75	23	2309	3	Logperch	19	0	0
Grand Rapids	1.75	23	2309	3	Logperch	1543	0	0
Herrings	4.125	23	2309	3	Logperch	13	0	0
Johnsonville	2	23	2309	3	Logperch	2	0	0
Kleber	3	23	2309	3	Logperch	2	0	0
Minetto	2.5	23	2309	3	Logperch	17	0	0
Potato Rapids	1.75	23	2309	3	Logperch	9	0	0
Raymondville	2.25	23	2309	3	Logperch	114	0	0
Sandstone Rapids	1.75	23	2309	3	Logperch	1	0	0
Schaghticoke	2.125	23	2309	3	Logperch	9	0	0
Shawano	5	23	2309	3	Logperch	76	0	0
Sherman Island	3.125	23	2309	3	Logperch	25	0	0
Thornapple	1.69	23	2309	3	Logperch	277	0	0
Tower	1	23	2309	3	Logperch	31	0	0
Townsend Dam	5.5	23	2309	3	Logperch	19	0	0
Twin Branch	3	23	2309	3	Logperch	134	0	0
White Rapids	2.5	23	2309	3	Logperch	369	0	0
Wisc. Riv. Division	2.19	23	2309	3	Logperch	35	0	0
Feeder Dam	2.75	23	2314	3	Tessellated darter	45	0	0
Gaston Shoals		23	2314	3	Tessellated darter	1	0	0
Herrings	4.125	23	2314	3	Tessellated darter	21	0	0
Johnsonville	2	23	2314	3	Tessellated darter	36	0	0
Lake Algonquin	1	23	2314	3	Tessellated darter	23	0	0
Moshier	1.5	23	2314	3	Tessellated darter	1	0	0
Raymondville	2.25	23	2314	3	Tessellated darter	105	0	0
Schaghticoke	2.125	23	2314	3	Tessellated darter	13	0	0
Sherman Island	3.125	23	2314	3	Tessellated darter	64	0	0
Warrensburg	?	23	2314	3	Tessellated darter	49	0	0
Belding	2	23	2317	1	Walleye	13	9	1
Bond Falls	3	23	2317	1	Walleye	1335	46	5

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Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Brule	1.62	23	2317	1	Walleye	554	46	8
Caldron Falls	2	23	2317	1	Walleye	779	31	4
Centralia	3.5	23	2317	1	Walleye	27	5	0
Colton	2	23	2317	1	Walleye	1	0	0
Crowley	2.375	23	2317	1	Walleye	2283	31	3
E.J. West	4.5	23	2317	1	Walleye	3	140	29
Feeder Dam	2.75	23	2317	1	Walleye	5	3	0
Four Mile Dam	2	23	2317	1	Walleye	132	301	0
Grand Rapids	1.75	23	2317	1	Walleye	1466	112	6
Herrings	4.125	23	2317	1	Walleye	35	16	5
Higley	3.63	23	2317	1	Walleye	26	0	2
Hillman Dam	3.25	23	2317	1	Walleye	10	37	0
Kleber	3	23	2317	1	Walleye	0	0	2
Minetto	2.5	23	2317	1	Walleye	0	136	17
Ninth Street Dam	1	23	2317	1	Walleye	194	31	0
Norway Point Dam	1.69	23	2317	1	Walleye	125	78	0
Potato Rapids	1.75	23	2317	1	Walleye	726	128	6
Raymondville	2.25	23	2317	1	Walleye	1	14	3
Sandstone Rapids	1.75	23	2317	1	Walleye	202	29	0
Shawano	5	23	2317	1	Walleye	0	0	3
Sherman Island	3.125	23	2317	1	Walleye	2	5	2
Thornapple	1.69	23	2317	1	Walleye	72	372	4
Townsend Dam	5.5	23	2317	1	Walleye	20	30	2
Twin Branch	3	23	2317	1	Walleye	43	53	22
White Rapids	2.5	23	2317	1	Walleye	908	54	6
Wisc. Riv. Division	2.19	23	2317	1	Walleye	24	8	2
Youghiogheny	10	23	2317	1	Walleye	0	219	71
Belding	2	23	2319	1	Yellow perch	710	0	0
Bond Falls	3	23	2319	1	Yellow perch	11694	21	0
Brule	1.62	23	2319	1	Yellow perch	1839	5	0
Buzzards Roost		23	2319	1	Yellow perch	2333	7	0
Caldron Falls	2	23	2319	1	Yellow perch	5103	4	0
Centralia	3.5	23	2319	1	Yellow perch	3	0	0
Colton	2	23	2319	1	Yellow perch	41	0	0
Crowley	2.375	23	2319	1	Yellow perch	786	42	0
E.J. West	4.5	23	2319	1	Yellow perch	3380	0	0
Feeder Dam	2.75	23	2319	1	Yellow perch	165	69	0
Four Mile Dam	2	23	2319	1	Yellow perch	108	15	0
Grand Rapids	1.75	23	2319	1	Yellow perch	42	2	0
Herrings	4.125	23	2319	1	Yellow perch	3	7	0
High Falls	1.81	23	2319	1	Yellow perch	394	34	0
Higley	3.63	23	2319	1	Yellow perch	12787	19	0
Hillman Dam	3.25	23	2319	1	Yellow perch	75	9	0
Hollidays Bridge		23	2319	1	Yellow perch	1	1	0

Appendix A

Observed entrainment rates for species occurring at the Santee Cooper Project and represented in the EPRI (1997) database (numbers shown represent the total collected after adjustment for net collection efficiency).

Site Name	TR spacing (no entry if excluded for other reason)	Fam. Code	Tax. Code	Guild Code	Species/Group	<8"	8-15"	>15"
Johnsonville	2	23	2319	1	Yellow perch	472	42	0
Kleber	3	23	2319	1	Yellow perch	3744	0	0
Lake Algonquin	1	23	2319	1	Yellow perch	141	0	0
Minetto	2.5	23	2319	1	Yellow perch	50	19	0
Moshier	1.5	23	2319	1	Yellow perch	2569	18	0
Ninety-Nine Islands		23	2319	1	Yellow perch	1	0	0
Ninth Street Dam	1	23	2319	1	Yellow perch	33277	0	0
Norway Point Dam	1.69	23	2319	1	Yellow perch	97	25	0
Potato Rapids	1.75	23	2319	1	Yellow perch	1031	27	0
Raymondville	2.25	23	2319	1	Yellow perch	16	3	0
Richard B. Russell	8	23	2319	1	Yellow perch	1971	3	0
Saluda		23	2319	1	Yellow perch	5	0	0
Sandstone Rapids	1.75	23	2319	1	Yellow perch	545	8	0
Schaghticoke	2.125	23	2319	1	Yellow perch	110	4	0
Shawano	5	23	2319	1	Yellow perch	35	0	0
Sherman Island	3.125	23	2319	1	Yellow perch	81	23	0
Thornapple	1.69	23	2319	1	Yellow perch	301	0	0
Tower	1	23	2319	1	Yellow perch	2	2	0
Townsend Dam	5.5	23	2319	1	Yellow perch	8	0	0
Twin Branch	3	23	2319	1	Yellow perch	4	0	0
Warrensburg	?	23	2319	1	Yellow perch	73	43	0
White Rapids	2.5	23	2319	1	Yellow perch	1031	5	0
Wisc. Riv. Division	2.19	23	2319	1	Yellow perch	7	0	0
Youghiogheny	10	23	2319	1	Yellow perch	1223	58	2
Minetto	2.5	24	2401	3	Freshwater drum	46	24	4
Townsend Dam	5.5	24	2401	3	Freshwater drum	547	74	5

[a] MCF = million cubic feet of water sampled