Alcoa Power Generating Inc.
Yadkin Division

Yadkin Project Relicensing
(FERC No. 2197)

Fish Entrainment Assessment

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SUMMARY

This Draft Fish Entrainment Assessment Report presents the results of a study of the potential for impacts to fish due to entrainment at the Yadkin Project developments. The study was conducted by Normandeau Associates, Inc. (NAI) as part of the FERC relicensing process for the Yadkin Project. The study was conducted in accordance with the Final Study Plan that was developed by Yadkin in consultation with the Fish and Aquatics Issue Advisory Group (IAG). Specific objectives identified in the Final Study Plan included:

- Evaluate the potential for entrainment of resident fishes at the four Yadkin Project powerhouses.
- Evaluate the potential for entrainment of diadromous fish species, which are candidates for possible reintroduction to Yadkin Project waters.
- Evaluate fish survival rates at each development, taking into account site specific data such as turbine type, rotational speed (rpm), and size of entrained fish.

Entrainment is the passage of fish through water intakes (FERC 1995). In the case of hydropower developments, such as the Yadkin Project developments, fish entrained in the intakes are then passed through the penstock and turbine, and discharged to the downstream tailwater. Factors that determine the potential for entrainment at a hydropower project include the size and depth of the intakes, the velocity of water as it enters the intake, the location of the intake relative to fish habitat, and the characteristics (number, size, etc) of fish species present in the reservoir. Entrainment of fish at a hydropower project does not necessarily result in injury to the fish. Depending upon the characteristics of the individual units, survival rates through turbines by fish can be very high. Some of the factors that determine survival rates include the type of turbine, the number of blades, the blade spacing, the rotation speed of the turbine, and the water pressure created in the penstock, turbine or tailwater. Studies designed to measure the impact to fish passing through hydro turbines are called fish survival studies. Fish survival is the complement to fish mortality. In other words, a survival rate of 95% is equivalent to a 5% mortality rate. This study examines both entrainment potential and survival rates at each of the four Yadkin Project developments.

As outlined in the study plan, this fish entrainment evaluation was conducted as a “desk-top” evaluation utilizing existing literature and data on fish entrainment at other hydroelectric projects for relevant species at the Yadkin Project. The fish species considered in the evaluation were those identified by the Fish and Aquatics IAG as important management species and included both resident fish such as largemouth bass, black crappie, and stocked striped bass and diadromous fish such as American shad and American eel.

The study considered the potential for entrainment based on a number of physical characteristics of the Project reservoirs, dams and powerhouses. Some of the key characteristics considered included the location and depth of the powerhouse intakes, the potential abundance of fish in the literal zone, the propensity of fish to want to migrate, reservoir water levels, the approach velocities at the intakes and the hydraulic capacity and configuration of the turbines.

The study also considered the potential for fish survival in the event of entrainment into and through the Project turbines. The mortality/survival assessment was also based on an extensive review of literature and existing data and considered the important physical characteristics of the units, as well as the biological characteristics of the various fish species. Some of the important factors considered in this portion of the assessment included turbine type, turbine speed and intake and tunnel characteristics.

Overall, the results of the entrainment study indicate that the potential for impact to fishes due to entrainment and turbine passage at the four Yadkin Project developments (High Rock, Tuckertown, Narrows and Falls) is low. Although the entrainment potential for certain fish species was found to be high to moderate-high at all four developments, the mortality rates for fish entrained at the four developments was found to be low.

At High Rock, the study concludes that the overall impact to fishes due to entrainment and turbine passage is low. High Rock development does possess certain risk factors that suggest entrainment rates are likely to be high or moderate-high. In addition, High Rock is unique among the Yadkin developments because of the annual winter drawdown (12 ft average). The reduced reservoir volume in late fall and winter along with clupeid (primarily threadfin and gizzard shad) movements to lower reservoir areas, places these forage species and their predators at somewhat higher risk of entrainment than at the other reservoirs. However, because the High Rock turbines are large and rotate slowly, survival rates of the small fish that are most likely to be entrained are expected to be high. Thus, while entrainment rates at High Rock are likely to be high due to the prevalence of shad, the overall impact to fishes due to entrainment and turbine passage at High Rock development is expected to be low for all species considered due to the relatively benign turbine characteristics. The fact that High Rock supports a successful and popular sport fishery supports this conclusion.[1]

At Tuckertown, the study concludes that the overall potential impact to fishes due to entrainment and turbine passage is low. Like High Rock, the Tuckertown Development also has abundant clupeids (shad) and other risk factors that can cause high or moderate-high entrainment rates, except there is no winter drawdown. However, the Tuckertown Development houses large, slow Kaplan turbines, generally the most benign turbine type for the fishes of concern in this study. Thus, in spite of the high to moderate-high entrainment potential, expected high survival rates during turbine passage suggest that the overall potential impact due to entrainment at Tuckertown is low.

The entrainment and survival risk factors for fishes in Narrows Reservoir are similar to those for the Tuckertown Development, with a few exceptions. Penstock pressure at Narrows is slightly more than two atmospheres (approximately 70 psi) at the turbine entrance which could affect entrained fish depending upon the depth the fish was at as it entered the intake. The fish most likely to be entrained at Narrows would be pelagic clupeids that may experience brief disorientation but no additional mortality prior to reacclimation upon reaching the tailrace. In addition, the Narrows Development utilizes Francis turbines rather than Kaplans, but the Francis units at Narrows rotate at a slow speed which minimizes their potential impacts on fish. A final difference between Narrows and the other three developments is the design head of 175 ft compared to 52-55 ft of head at the other three sites. However, high head alone does not necessarily exacerbate turbine passage mortality. In summary, the potential entrainment of fishes at Narrows Development is probably high for clupeids (shad) and moderate-high for other fishes. However, given the specific turbine configurations, fish survival during turbine passage is at least moderate to high. Thus, given the overall abundance of Narrows Reservoir fishes and the overall health of the sport fisheries for striped bass, largemouth bass, and catfishes, any impact due to entrainment mortality is probably low.[1]

At the Falls Development, the study concludes that the overall impact to fishes due to entrainment and turbine passage is low. The potential for fish entrainment at the Falls Development was judged high

[1] An assessment of the overall condition of the High Rock and Narrows reservoir fisheries is the subject of a separate study report being prepared by Normandeau Associates as part of the Yadkin Project relicensing.

due to the abundance of clupeids (shad), and moderate-high for other types of abundant species, including yellow perch. In addition, the location of the Falls intakes is closer to reservoir shorelines (approximately 50 ft), than at the other Yadkin developments, a factor that could increase entrainment potential. However, due to the steep character of adjacent shorelines littoral zone habitat near the dam and powerhouse, that is likely to be inhabitated by fish, is limited. Moreover, the powerhouse contains one large, slow Francis unit, and two large, slow propeller runners with few blades that operate at low design head. These features enhance the likelihood of high fish survival during turbine passage. Thus, the overall potential for impacts to fishes due to turbine entrainment at Falls development is low.

1.0 INTRODUCTION AND BACKGROUND

The purpose of this report is to evaluate the potential for fish entrainment at the four developments comprising the Yadkin Hydroelectric Project. Alcoa Power Generating, Inc., Yadkin Division (Yadkin) is in the process of relicensing the Project using the Three-Stage Licensing Process in accordance with Federal Energy Regulatory Commission (FERC) relicensing regulations. The three-stage process develops information for the FERC to utilize when preparing its NEPA environmental analysis. Yadkin has incorporated enhanced communication opportunities into the required consultation process for stakeholder participants, including resource agencies, non-governmental organizations (NGOs) and other interested parties. An initial step was preparation of the Initial Consultation Document (ICD; Yadkin 2002) that summarized available environmental and resource information and issues. Based on comments received on the ICD, study plans were prepared and reviewed with the Fish and Aquatics Issue Advisory Group (IAG). The fish entrainment study plan specified evaluation of the potential for fish entrainment and survival relative to the physical features and fish communities of the developments in the Yadkin Project (Yadkin 2003).

As used throughout this report, entrainment is the passage of organisms (in this case, fish) through water intakes (FERC 1995). In the case of hydropower developments, such as the Yadkin Project developments, fish entrained in the intakes are then passed through the penstock and turbine, and discharged to the downstream tailwater. Fish drawn into hydro turbine intakes may be injured or killed. Studies designed to measure the impact to fish passing through hydro turbines are called fish survival studies. Fish survival is the complement to fish mortality. In other words, a survival rate of 95% is equivalent to a 5% mortality rate.

The overall approach to this assessment was to review existing fish entrainment and survival literature relative to the species of current management interest in the four Project reservoirs, and evaluate the potential for entrainment and survival of fishes relative to Project facilities, structures and operations that can influence entrainment. The North Carolina Wildlife Resources Commission (NCWRC) manages the reservoirs' warm water fisheries. In addition, several diadromous fishes not now present in the reservoirs but that are potential restoration targets in the Yadkin-PeeDee River system were included in the analysis as requested by NCWRC, the USFWS and the Fish and Aquatics IAG.

2.0 PROJECT DESCRIPTION AND GENERAL APPROACH

The Yadkin Project consists of four individual hydroelectric developments (High Rock, Tuckertown, Narrows and Falls) located in south-central North Carolina (Figure 2-1). The Narrows Reservoir is also known locally as Badin Lake. All of the developments are located in downstream succession on a 38-mile reach of the Yadkin River. The Yadkin Project is located upriver of two Progress Energy (formerly Carolina Power and Light Co.) hydro developments on the PeeDee River which begins at the confluence of the Yadkin and Uwharrie Rivers one mile below Falls Dam.

The three most upstream reservoirs within the Yadkin project are large (>2,560 acres) with abundant coves and flooded tributary mouths. High Rock and Narrows reservoirs are especially dendritic, each with four to six major flooded tributaries. Tuckertown Reservoir is somewhat more riverine. In contrast, Falls Reservoir is much smaller and largely constrained within the Yadkin River valley. More detailed, descriptive information for each development, including pertinent reservoir and generating facilities data, is provided below.

Brief summaries of each impoundment's fish populations are provided in addition to the respective physical characteristics. Each summary is related to a priority list of species that are either very abundant in the reservoir, or the focus of NCWRC management efforts. A river basin fisheries management plan is under development by NCWRC and may be completed during 2004. The most recent, comprehensive fish sampling in the Yadkin reservoirs was conducted on behalf of Yadkin by

Progress Energy biologists in 2000. (Project tailwaters were also electrofished in August 2003). The Progress Energy fisheries assessment utilized electrofishing and gill nets to determine relative abundance, among other objectives. The relative proportion of each species captured by each gear type was summed to determine the top seven species in each reservoir. These species were considered the most abundant fishes in each reservoir at present and of most interest to NCWRC from the standpoint of potential entrainment losses.

The Fish and Aquatics IAG also requested that Yadkin evaluate the potential effects of entrainment on four species of diadromous fish (alewife, blueback herring, American shad, American eel) that are potential future targets of a Yadkin-Pee Dee River Basin restoration plan. The restoration plan development is being guided by the U.S. Fish and Wildlife Service (FWS) in cooperation with NCWRC, NOAA Fisheries (formerly National Marine Fisheries Service, NMFS), and South Carolina Department of Natural Resources (SCDNR). The plan is expected to include proposed restoration activities at the two Progress Energy developments downriver as well as the four Yadkin developments. According to the USFWS (Ellis, personal communication), a draft of the plan will be available by mid 2004.

2.1 High Rock Development

2.1.1 Reservoir Description and Characteristics

High Rock Reservoir is the largest of the four project impoundments, and covers 15,180 acres with a maximum and mean depth of 62 ft and 17 ft, respectively (Table 2-1). High Rock features five major flooded tributary arms, several smaller ones, and a lengthy convoluted shoreline. Its large size enables High Rock Reservoir to serve as the main storage and water regulation reservoir for the Yadkin-Pee Dee system downstream. The High Rock Development is operated in a store-and-release mode. Normal daily fluctuation in water surface elevation due to operations is less than 1 ft, with a daily maximum of 2 to 4 ft (Yadkin 2002). Seasonal drawdowns have averaged 8 ft in spring, 5 ft in summer, 10 ft in fall, and 12 ft in winter. The maximum annual drawdown typically occurs in late winter.

The reservoir is eutrophic in character, with low water transparency and only occasional, weak thermal stratification. Dissolved oxygen (DO) can become depleted during May to October in waters below the relatively shallow photic zone, but the depletion seldom persists for more than two months. Occasional mixing of low DO bottom water with surface waters due to lack of stratification results in episodes of DO below state standards (5.0 mg/L) throughout the water column (Yadkin 2002).

2.1.2 Project Facilities

The High Rock powerhouse contains three similar vertical Francis runners with a licensed hydraulic capacity of 11,040 cfs. Normal hydraulic capacity at efficient gate is 7,800 cfs (Table 2-1). Design head is 52 ft (Table 2-2). The water intakes are located between a gated spillway and a non-overflow dam section approximately 180 ft from the left (descending) bank. The intakes are located 18 to 55 ft (centerline depth 36.5 ft) below normal full pond and are screened by bar racks with 4.125 in clear spacing (Table 2-1). The calculated approach velocity at the submerged intake with three unit operation at normal hydraulic capacity is 1.95 ft/s.[2]

2.1.3 Fish Populations and Management Species

High Rock Reservoir supports a diverse warmwater fish community comprised of at least 33 taxa based on various sampling events combined across several years (Table 2-3). The seven most abundant species documented during the 2000 field sampling conducted for Yadkin included threadfin

[2] Unit upgrades (new turbine runners) being considered for High Rock Units 1, 2, and 3 would not be expected to significantly change this approach velocity.

shad, gizzard shad, white perch, bluegill, black crappie, channel catfish, and largemouth bass (Table 2-4). Among these numerically dominant fishes, NCWRC management interest is focused on largemouth bass and black crappie (each with size and possession limits) due to their importance to recreational angling. Threadfin and gizzard shad are important forage species.

Striped bass are stocked annually by NCWRC to provide another target species for sport anglers and to take advantage of the abundant forage provided by shad. Striped bass stocking rates have remained relatively consistent for the last 15-20 years at about 5 fingerlings (1 to 2-inch size) per acre, totaling about 79,000 fish per year (L. Dorsey, NCWRC, personal communication). However, additional fingerlings were stocked in 2003 in High Rock Reservoir to provide a buffer against possible losses of fingerlings due to high predation levels in 2002 during extreme drought conditions that reduced reservoir volume (S. Van Horn, NCWRC, internet post).

The principal sport angling targets in High Rock Reservoir are largemouth bass, black crappie, striped bass, and catfishes (L. Dorsey, NCWRC, personal communication). However, fishing effort and harvest estimates are unavailable.

2.2 Tuckertown Development

2.2.1 Reservoir Description and Characteristics

Tuckertown Reservoir covers 2,560 acres at full pool with a maximum and mean depth of 55 ft and 16 ft, respectively (Table 2-1). The Tuckertown Reservoir is narrow relative to either adjacent High Rock or Narrows Reservoirs, and is mainly an enlargement of the old river channel with only a few small-to-moderately sized flooded tributary arms. The Tuckertown Development is operated as a run-of-river facility. Normal daily fluctuation in water surface elevation due to operations is less than 1 ft, with a daily maximum fluctuation of 1 to 3 ft (Yadkin 2002). Annual drawdown is limited to 3 ft by the Yadkin FERC license, and the annual drawdown has averaged 2 ft historically.

Water quality is generally considered fair, with water temperature and DO properties similar to High Rock Reservoir that provides most of the input (Yadkin 2002). Water transparency is low, and the reservoir exhibits only weak stratification near the dam. DO depletion occurs below the shallow photic zone, and episodes of low DO throughout the water column due to mixing of photic zone and deeper waters have been observed near the dam on occasion during the warmer months.

2.2.2 Project Facilities

The Tuckertown powerhouse contains three similar vertical Kaplan (adjustable propeller) runners with a licensed hydraulic capacity of 11,475 cfs (Yadkin 2002) and a normal hydraulic capacity at efficient operation of 8,025 cfs (Table 2-1). Design head is 55 ft (Table 2-2). The water intakes are located between a gated spillway and non-overflow and rock fill dam sections approximately 340 ft from the left (descending) bank. The intakes are located 32.5 to 59.5 ft (centerline depth 46.8 ft) below normal full pool and are screened by bar racks with 5.625 in clear spacing (Table 2-1). Calculated approach velocity at the water intake racks with three-unit operation is 2.33 ft/s.

2.2.3 Fish Populations and Management Species

A total of 38 taxa have been captured in Tuckertown Reservoir during various sampling events (Table 2-3). The most recent reservoir field sampling by electrofishing and gill nets in 2000 yielded 28 taxa, including hybrid striped bass x white bass (Table 2-5). The hybrid striped bass were not stocked in the lake but likely recruited from a tributary reservoir stocking (L. Dorsey, NCWRC, personal communication). The most abundant species in the warmwater fish community sampled in 2000 were threadfin shad, bluegill, white perch, gizzard shad, channel catfish, black crappie, and largemouth bass. Largemouth bass and black crappie are actively managed by NCWRC to support sport fishing.

Striped bass are stocked to enhance the sport fishery and as a management tool to consume shad. Approximately 13,000 striped bass fingerlings are stocked annually, a rate of about 5 fish per acre. Land-locked alewife, a restoration target species (anadromous form) within the river basin, have been collected historically but were likely the result of bait-bucket introduction.

A three year creel survey of Tuckertown Reservoir estimated annual effort of 181,111 to 219,952 angler hours, directed primarily at crappie, largemouth bass, and catfishes. Crappie harvest ranged from 100,000 to 190,000 fish, about 82% of total numerical harvest. Largemouth bass harvest was low due to catch and release practices. Striped bass stocking in Tuckertown Reservoir did not result in establishment of a popular sport fishery as occurred in adjacent High Rock and Narrows Reservoirs. The reasons for the lack of striped bass fishery development are unclear (L. Dorsey, NCWRC, personal communication).

2.3 Narrows Development

2.3.1 Reservoir Description and Characteristics

Narrows Reservoir (Badin Lake) is the deepest of the four project impoundments and covers 5,355 acres at full pool (Table 2-1). The reservoir is broad with two main basins, each with numerous coves and flooded tributary mouths. Maximum depth is 175 ft and mean depth is 45 ft. The Narrows Development is usually operated as a run-of-river facility, but does have available storage to augment required minimum downstream releases in low flow periods. Normal daily fluctuation in water surface elevation due to operations is less than 1 ft with a daily maximum fluctuation of 1 to 2 ft (Yadkin 2002). The maximum average annual drawdown is approximately 3 ft.

Water quality is considered good, and, unlike the upstream reservoirs, Narrows Reservoir exhibits strong thermal stratification. A strong thermocline persists from spring through fall at depths between 12 to 20 m (39-66 ft). Anoxic conditions typically exist below the thermocline from June through December, whereas surface waters are always greater than 5.0 mg/L.

2.3.2 Project Facilities

The Narrows powerhouse contains four vertical Francis runners with a licensed hydraulic capacity of 10,000 cfs (Yadkin 2002). The normal hydraulic capacity of 8,200 cfs reflects the upgrade of Unit 4 completed in 2001 (Table 2-1). Design head is 175 ft (Table 2-2). There are slight differences in the number of buckets and runner speed among the four Francis runners. Intakes for the four units are located between the main gated spillway and a bypass spillway extending approximately 430 ft from the left (descending) bank. The intakes are submerged 31.1 to 66.1 ft (centerline depth 48.6 ft) below normal full pool and lead to 300 to 400 ft long steel penstocks that descend the dam face to the generators. Intakes are screened with bar racks with 4.375 in clear spacing (Table 2-1). The calculated approach velocity at the bar racks with one through four-unit operation is 2.93 ft/s.

2.3.3 Fish Populations and Management Species

Various sampling events in aggregate have yielded a warmwater fish community comprised of 39 taxa, including two hybrids (Table 2-3). Narrows Reservoir supports an abundant gamefish population. Sampling during the mid-1990s by NCWRC estimated that 44% of the captured fish biomass were gamefish species (Yadkin 2002). During the most recent field sampling in 2000 by Progress Energy, the most abundant species numerically were white perch, bluegill, gizzard shad, threadfin shad, yellow perch, largemouth bass, and black crappie (Table 2-6). Largemouth bass and black crappie are actively managed for sport fishing by size and possession limits, and were the targets of recent assessments by NCWRC (Yadkin 2002).

Striped bass are stocked in Narrows Reservoir at twice the densities of either High Rock or Tuckertown reservoirs. Approximately 62,000 striped bass fingerlings, or 11.6 fish per acre, are stocked annually to enhance sport fishing. Striped bass in Narrows Reservoir are currently the target of cooperative bioenergetics studies by NCWRC and North Carolina State University to evaluate striped bass growth in relation to available habitat, particularly the thermal environment.

Blueback herring, a river basin restoration target species (anadromous form), maintain a small, land-locked population in Narrows Reservoir as a result of NCWRC stocking during the 1970s.

A creel survey of Narrows Reservoir (Badin Lake) and Tuckertown tailrace in 1980-81 estimated nearly 220,000 angler hours of combined effort, 20% of which was estimated for the Tuckertown tailrace area (Chapman and Harris 1982). Although the total effort estimates were similar at Narrows and Tuckertown Reservoirs (Section 2.2.3), Narrows Reservoir is larger and fished less intensively. Effort in the reservoir for largemouth bass and striped bass combined was 52% of total lake effort; effort for striped bass in the Tuckertown tailrace was 31% of total tailrace effort. Total fish harvest was 45,553 kg. Striped bass formed 5.6% and 17.7% of the biomass harvested from the lake and tailrace, respectively. These data represent the most current available.

In addition to sustained interest in the striped bass fishery by recreational anglers and NCWRC, Narrows Reservoir (Badin Lake) is also becoming known for its fishery for large catfish, particularly blue catfish (L. Dorsey, NCWRC, personal communication). A state record 83 lb blue catfish was caught in Narrows Reservoir in May, 2003. Blue catfish are an introduced species that have been stocked by NCWRC for more than 30 years to take advantage of abundant forage. Similarly, flathead catfish are another non-native species stocked by NCWRC (Mickey and Simpson 1988) that have become established in project waters, including Narrows Reservoir. Neither catfish species at present receives game fish status by NCWRC, but regulation (size and/or creel limits) of the catfish fishery may be addressed in future management plan documents due to their increased popularity with sport anglers (L. Dorsey, NCWRC, personal communication).

2.4 Falls Development

2.4.1 Reservoir Description and Characteristics

Falls Reservoir is a small, narrow impoundment that covers 204 acres at full pool (Table 2-1). The reservoir is located on the Yadkin River approximately one mile above its confluence with the Uwharrie River, forming the Pee Dee River. Maximum depth is 52 ft and mean depth is 27 ft. Falls Reservoir has a comparatively straight, steep shoreline with only one moderately sized, flooded tributary arm. Daily water level fluctuations due to the run-of-river operation mode normally range 0-2 ft, with a maximum fluctuation up to 4 ft. No seasonal drawdowns occur due to limited storage capacity.

Water quality is characterized by the absence of stratification, and the clearest water of the project reservoirs. Anoxic conditions were absent during recent water quality investigations (Yadkin 2002), but occasional low water column DO may be the result of mixing of deep water with surface water, or low DO inputs from Narrows Reservoir. Recent and future turbine upgrades at Narrows Development immediately upstream include air injection capability designed to enhance DO in powerhouse discharges (Yadkin 2002).

2.4.2 Project Facilities

The Falls powerhouse contains one vertical Francis runner and two fixed propeller turbines with a licensed hydraulic capacity of 8,570 cfs (Yadkin 2002) and a normal hydraulic capacity of 7,500 cfs that reflects efficient operation (Table 2-1). Design head for all units is 54 ft. Water is delivered to the units through a shallow, submerged intake integral with the dam along the right (descending) bank. The intake is located 7 to 39 ft below normal full pool (centerline depth 23 ft). The intakes are screened by bar racks with 5.625-in clear spacing (Table 2-1). Calculated approach velocity at the intakes with two or three units in operation is 2.11 ft/s (Table 2-2).

2.4.3 Fish Populations and Management Species

The 28 taxa captured by various sampling efforts in Falls Reservoir are the fewest among the Yadkin Project developments (Table 2-3). The most recent sampling by Progress Energy in 2000 listed the numerically abundant fishes as: white perch, bluegill, gizzard shad, white catfish, largemouth bass, channel catfish, and blue catfish (Table 2-7). The proportions of catfishes represented among the most abundant species were higher than in the upstream reservoirs.

Striped bass are not stocked in Falls Reservoir (L. Dorsey, NCWRC, personal communication). However, their presence in the 2000 CP&L samples suggests successful recruitment from upstream reservoirs. Telemetered striped bass from the cooperative bioenergetics study in Narrows Reservoir have also been captured in Falls Reservoir, but it is unclear whether those fish recruited via the powerhouse or spillway. Blueback herring, a restoration target species, have been collected historically and were likely recruited from the land-locked population in Narrows Reservoir.

2.5 Diadromous Fishes and Species of Special Concern

The current status of diadromous fishes relative to the Yadkin Project was reviewed in Yadkin (2002). Briefly, two clupeid species potentially targeted for restoration in the river basin already exist as land-locked populations or have been collected in some of the Yadkin reservoirs. Blueback herring exist in project waters as the result of intentional stocking by NCWRC in Narrows Reservoir during the 1970s and subsequent recruitment from Narrows Reservoir into Falls Reservoir. Bait bucket introduction was likely the source of alewife in Tuckertown Reservoir, although none were collected during recent sampling in 2000 (Yadkin 2002). American shad currently exist only in the PeeDee River, downstream of the Yadkin and Progress Energy projects. Inconclusive historical records suggest that American eel may have existed in project waters, but eel are currently found only below project waters in the PeeDee River. Recent sampling by Progress Energy has collected American eel as far upriver as the base of Tillery Dam (J. Crutchfield, Progress Energy, personal communication). Each species listed above is targeted for river basin restoration within a restoration plan expected to be issued in late 2004 or 2005.

One darter species and two redhorse species were identified as species of state and federal special concern during preparation of the ICD (Yadkin 2002). The Carolina darter (*Etheostoma collis*) in the Yadkin River basin was most recently collected within the Badin and Mt. Pleasant 7.5 minute USGS quad sheets (Yadkin 2002). The robust redhorse (*Moxostoma robustum*) and Carolina redhorse (*Moxostoma* sp.) both were collected recently by Progress Energy in PeeDee River shoal habitat located downstream from their two hydro developments.

3.0 OVERALL ENTRAINMENT ASSESSMENT

The entrainment assessment for the Yadkin Project focuses on those principal fish species either identified for active management (size and possession limits) by NCWRC, determined to be numerically abundant by recent field investigations, or a possible component of future river basin restoration plans. These species are summarized for each development in Table 3-1. For these species, a brief life history review is provided that focuses on those characteristics that affect susceptibility to entrainment. Following the selected life history information is a review of the Electric Power Research Institute (EPRI 1997) entrainment database summarized by Winchell *et al.* (2000) and other recent data (*e.g.*, FERC 1995) that synthesizes the susceptibility of the fishes of interest based on a review of entrainment at numerous hydro projects. The final section is an evaluation of the turbine types and other Yadkin Project facilities (*e.g.*, intake characteristics) that can affect fish entrainment and mortality.

The fish species of special concern to the resource agencies (see Section 2.5) are not specifically addressed herein because they are comparatively rare (*e.g.* robust and Carolina redhorse) and have not been documented in Yadkin Project waters, or alternatively, they exhibit life history characteristics that limit their potential to be impacted by entrainment. Among these latter species is the Carolina darter. The Carolina darter typically resides in the slower, sluggish portions of small Piedmont streams (Lee *et al*. 1980; Page 1983) and exhibits a patchy distribution throughout its central Piedmont range (Jenkins and Burkhead 1993). Such spatial isolation of less common or habitat-specific species limits downstream dispersal to relatively infrequent hydrological events such as high flow or flood events.

3.1 Characteristics of Management Species

The four Yadkin Project reservoirs generally share most of the fish species that exhibit high relative abundance or that are management targets by NCWRC (Table 3-1). Life history characteristics for family-level groupings of these species that generally share similar life histories are discussed below. Within each group, individual species traits or reservoir-specific characteristics of these species are addressed.

3.1.1 Clupeids (shad and river herring)

Gizzard shad and threadfin shad are highly prolific pelagic congeners that represent the primary components of a rich forage base within all the Yadkin impoundments. Each is a schooling species typically found in the upper 15 m of the water column. Gizzard shad and threadfin shad will typically spawn throughout spring and summer in inshore areas, tributary coves, and in open water. Significant mortality of threadfin shad occurs as waters cool below 7°C (45°F) (Jenkins and Burkhead 1993). Gizzard shad are more cold tolerant, but will succumb or become moribund at prolonged water temperatures below about 3°C (37°F). Young gizzard and threadfin shad typically pass out of reservoirs during fall and early winter. The tendency for both species to become moribund as their lower temperature threshold is approached furthers their susceptibility to entrainment. As a result, fall/winter shad entrainment peaks are typical in reservoirs where they are abundant (FERC 1995).

Land-locked alewife and blueback herring have been recorded in the Yadkin Project reservoirs. Landlocked populations of these species spawn in the reservoirs, headwaters, or tributaries. Pelagic schools of young or adults tend to seek warmer, deeper water in the lower reaches of the reservoirs as winter approaches. As a result of this behavior schools can become proximal to reservoir outlets or turbine intakes and suffer entrainment losses. Large predators may also pass out of reservoirs following the schools of prey (RMC 1992). At present, neither land-locked form is as abundant as threadfin or gizzard shad. Alewife and gizzard shad were the only clupeids represented among the source studies that comprised the EPRI (1997) database.

If included in future PeeDee River basin restoration plans, juvenile anadromous alewife, blueback herring, and American shad (all alosids) also represent potential pelagic forage species. Young of the year that might be spawned in the reservoirs (likely only alewife) or in individual tributaries, tailwaters, or other riverine areas would leave freshwater rearing sites each fall to migrate to marine environments for several years before returning to natal rivers as adults. Thus, young anadromous alosids, as obligatory seaward migrants, would be susceptible to entrainment at individual projects and cumulatively (depending on restoration progress). Adult river herring return to marine waters after spawning and a proportion may survive to spawn in subsequent years. Entrainment of spent adults through project facilities could occur. Adult American shad south of Cape Hatteras typically die after the first spawn (Jenkins and Burkhead 1993), thus entrainment of spent adult American shad would not be a concern in the Yadkin projects.

3.1.2 Centrarchids (black bass, crappie, and sunfishes)

Three species of centrarchids were typically found among the Yadkin Project species with the highest relative abundance. Bluegill generally represented the most abundant panfish sampled in 2000 in each reservoir. Largemouth bass and black crappie were also among the most abundant species throughout project waters, and are the principal species targeted by sport fisheries management regulations. Largemouth bass and black crappie harvests are each managed by NCWRC with size and creel limits. A creel survey of Tuckertown Reservoir identified crappie as the principal species harvested, followed by sunfish, including bluegill (Chapman and Van Horn 1992). Crappie harvest ranged from 56,000 to 75,000 fish over a three year period from 1988-1990. In comparison, harvest of sunfish was an order of magnitude less. Although highly sought by anglers, largemouth bass harvest was minimal as anglers preferred catch and release.

Bluegill, largemouth bass, and black crappie primarily inhabit littoral areas and orient to cover. Each is a highly fecund spring spawner that builds nests on the different substrates found in the littoral zone. Young largemouth bass school early while guarded by a parent, and then disperse throughout the littoral zone. After spawning, largemouth bass may move about within a variable-sized home range in summer. Where sunfish and crappie abundance in a reservoir is high, smaller individuals (young of year and juveniles) tend to form a large portion of the fishes entrained (FERC 1995). Bluegill, black crappie, and largemouth bass were each represented by at least 30 source studies in EPRI (1997).

3.1.3 Ictalurids (catfishes)

Channel catfish ranked among the most abundant species in three of four reservoirs during sampling in 2000 (Table 3-1). In Falls Reservoir, white catfish and blue catfish were also ranked among species with high relative abundance. Recreational anglers seek catfishes in all the Project reservoirs (L. Dorsey, NCWRC, personal communication), and their popularity is enhanced by the large size attained (Chapman and Van Horn 1992). For example, 4% of targeted effort in Tuckertown Reservoir was for flathead catfish that comprised 13% of the harvested biomass. Anglers also specifically target large blue catfish in Narrows Reservoir (see Section 2.3.3).

Channel catfish, white catfish, and blue catfish spawn after water temperatures attain 21°C in spring and build sheltered nests or nests associated with cover (Jenkins and Burkhead 1993; Smith 1985). Eggs and larvae are brooded by the male, and parental care is extended to young by white catfish (Smith 1985). Young disperse from schools to available habitats when about 25 mm (1 in) long (Becker 1983). FERC (1995) noted the tendency for channel catfish relative abundance in entrainment samples to generally exceed their relative abundance in impoundment populations. No comparable data were available for blue catfish or white catfish. Channel catfish and brown bullhead were the only catfish species represented in the source studies for the EPRI (1997) database.

3.1.4 Percichthyids (temperate basses)

White perch and striped bass represent this family in the Yadkin Project reservoirs. White perch were highly abundant in each reservoir during the 2000 sampling, and ranked first in relative abundance in Narrows and Falls Reservoirs (Table 3-1). White perch were represented by four entrainment studies among those included in the EPRI (1997) database, whereas striped bass were not represented in any of the 43 studies.

White perch and striped bass are pelagic piscivorous predators that typically forage in open water but may also be found in littoral areas. However, they are less cover-oriented than other littoral fishes such as centrarchids. Littoral areas may be occupied by white perch at night and during crepuscular periods, and more open waters during daytime. Their vertical distribution within a reservoir can be dependent on the depth of available prey. Further, white perch and striped bass could be susceptible to fall and winter entrainment due to pursuit of clupeid schools to deeper water, as has been noted for the congener white bass (Boaze 1972). The summer distribution of large striped bass in southern reservoirs may also depend on the availability of deep, cool water (<25°C) refugia in a reservoir (Coutant 1985).

Semi-anadromous white perch typically move upstream within estuaries to spawn in spring (Jenkins and Burkhead 1993). However, land-locked white perch spawning in Nebraska reservoirs concentrated in shallow shoreline areas around the entire reservoir perimeter (Zuerlein 1981). By summer, young of the year 40-50 mm long inhabited the same shallow littoral areas.

Striped bass are maintained in Yadkin impoundments by NCWRC stocking of 25-50 mm (1-2 in) fingerlings annually except in Falls Reservoir. Fingerlings are produced from anadromous Roanoke River stock or land-locked Dan River (John H. Kerr Reservoir, VA/NC) stock from Milton, NC. The sport fisheries for striped bass in High Rock and, especially, Narrows Reservoir are popular and highly developed (L. Dorsey, NCWRC, personal communication). However, the sport fishery has failed to develop to such an extent in Tuckertown Reservoir, based on findings of the 1988-1990 creel survey. Striped bass effort and harvest was negligible during the three years surveyed (Chapman and Van Horn 1992). One reason suggested for the lack of striped bass fishery development may be the more riverine nature of Tuckertown Reservoir relative to the larger, more dendritic nature of High Rock and Narrows Reservoirs (L. Dorsey, NCWRC, personal communication).

3.1.5 American eel

The American eel is currently absent from Project waters, but may be included in future planning documents for river basin restoration of diadromous fish. Atlantic Coast eel populations, including those in the PeeDee river drainage, are currently managed by an Interstate Fisheries Management Plan for American eel (ASMFC 2000). At present, American eel are known to attain the base of Tillery Dam, the second upstream dam owned by Progress Energy in the PeeDee River (Yadkin 2002). It is likely that American eel historically attained Yadkin River basin locations now within the Yadkin Project although historical distribution data are inconclusive.

The American eel is catadromous, spawning in the Atlantic Ocean and rearing and maturing in estuaries and a variety of freshwater riverine and lacustrine habitats. Some juvenile eels move beyond estuaries upriver into rearing habitats as elvers (< 6 in long) or larger yellow eels. Individuals may remain in distant upriver rearing habitats for a lengthy period (10-15 years or more) and attain large size, exceeding 1 m or more in length. Large individuals that attain the furthest upriver habitats are invariably females. A restoration scenario that provides passage or transport of young eels past Yadkin Project dams would ultimately put large female eels approaching maturation at risk of injury or mortality due to turbine entrainment as obligatory downstream migrants.

3.1.6 Species of Special Concern

The Carolina darter may exist in tributaries to Yadkin Project reservoirs. Their preferred habitat is slow portions of small Piedmont streams. Most Carolina darters likely occur in scattered, limited tributary stream habitats upstream of reservoir influence and, under normal stream conditions, are not likely candidates for entrainment due to low abundance and spatial isolation in the tributary.

3.2 EPRI (1997) Review of Entrainment Rates

EPRI (1997) recently compiled entrainment data from 43 selected sites. The compilation filtered site entrainment data through acceptability criteria such as:

- Requirement for utilization of full-flow netting
- Sufficient data for seasonal analyses
- Performance of net efficiency tests
- Sufficient operational data to calculate entrainment densities
- Lack of major study flaws such as net intrusion, extensive net damage, etc.

The thorough data screening enabled calculation of reliable seasonal and annual estimated entrainment rates for fishes of three size groups. The annual estimated entrainment rates for small, medium, and large fish for most of the species considered for this assessment are summarized in Table 3-2. The range of densities among included sites for a species were used by EPRI (1997) to develop a 5-step qualitative scale of entrainment potential from Low to Moderate to High. The qualitative rating was determined within the distribution of entrainment densities by identifying "break points". A different set of "break-points" from among higher density values were used to describe entrainment potential for small fish compared to medium and large fish since small fish are more abundant in a reservoir than either medium or large fish.

The entrainment densities and associated entrainment potential shown in Table 3-2 represent up to 41 sites per species without regard to variations in local conditions (*e.g.*, intake configuration, reservoir size, etc.) that may influence entrainment. Further, not all species of management interest within the Yadkin Project were represented in the EPRI (1997) database. As a result, we assumed that information deemed relevant for several species or species groups considered herein were represented by surrogate species included in the EPRI (1997) review. The surrogate species and the Yadkin Project species they represent are listed as footnotes to Table 3-2.

As would be expected, small fish densities were substantially higher than for medium and large fish (Table 3-2). In fact, most studies have shown that entrainment is highest for fish less than 4 in (FERC 1995; Winchell *et al.* 2000). Alewife and gizzard shad (and by surrogate blueback herring, American shad, and threadfin shad) generally have the highest potential for entrainment in reservoirs where they are abundant. The entrainment potential for small yellow perch was also rated "High" based on the results from 41 sites. The potential for entrainment of small bluegill and other sunfish, black crappie, white perch, channel catfish, blue and white catfish (as suggested by surrogates), and largemouth bass was Moderate-High. The young of these species, particularly the centrarchids, are considered primarily littoral zone inhabitants.

The entrainment potential of small striped bass (based on the surrogate white bass) and juvenile American eel was judged Low. Despite the Low entrainment potential rating, stocked striped bass are known to readily escape inland reservoirs and establish fisheries in downstream reaches. Striped bass stocked in High Rock Reservoir migrated downstream to Narrows (Badin) Reservoir prior to the initial Narrows reservoir stocking (Chapman and Harris 1982). Similarly, striped bass occur in Falls Reservoir as a result of upriver stocking.

Substantial numbers of juvenile American eels ≤ 8 in are unlikely in project waters given the inland distance from estuarine waters. Were upstream passage eventually provided at the Yadkin-PeeDee River dams, most eels likely to inhabit Yadkin Project waters would be yellow-phase eels > 8 in. As an example, yellow eels utilizing recently-installed (2003) passage facilities at Millville Dam on the Shenandoah River in West Virginia, approximately 200 river miles from Chesapeake Bay, ranged 8 to 20 in long. Most were 11 to 13 in. Eels were measured during restoration program studies underway in the Potomac River basin (L. Earnest, Allegheny Energy Supply, personal communication).

Although annual entrainment densities were substantially lower for all fish ≥ 8-15 in except white bass (surrogate for striped bass) and American eel, several species retained a qualitative potential rating of High or Moderate-High. These include gizzard shad, white perch, alewife, and black crappie, plus channel catfish and brown bullhead (surrogates for blue and white catfish, respectively), and white bass. However, though the qualitative potential for entrainment of medium or large fish relative to small fish may be comparable for some species, the numbers of many fishes > 8 in that are available for entrainment, including sunfishes, catfishes, black crappie, and particularly alewife and gizzard shad, are relatively low.

The entrainment potential among all large-sized fishes considered was no more than moderate except for American eels >15 in. Once established in inland freshwater rearing habitat, yellow-phase American eels reside and grow for periods as long as 15-20 years. Large ($\geq$2.5-3 ft or longer), maturing American eels leave fresh water habitat and migrate downstream each fall toward oceanic spawning grounds, and are thus obligatory migrants out of reservoirs and reservoir tributaries where reared. Entrainment potential at present is nil, but ultimately will depend on eel population densities that may be achieved during restoration.

Water intakes at each of the four developments in the Yadkin Project all utilize relatively wide bar rack spacing (Table 2-1). However, among studies reviewed in Winchell *et al.* (2000) little difference in fish size distributions existed for the wide range of bar rack clear spacing represented in the reviewed studies. Across all rack spacings, 94% of the fish entrained were < 8 in (Table 3-3). Since most entrained fishes are small, the relatively wide bar rack spacing at individual Yadkin developments would not likely affect the potential entrainment rates. In other words, fish size distribution or entrainment potential would not be altered if narrower bar racks were used (except possibly for adult American eel).

3.3 Turbine Passage Survival Assessment

3.3.1 General Survival Data

Winchell *et al.* (2000) summarized turbine passage survival data reported in the EPRI (1997) database by turbine type and characteristics and fish size. The survival rates reported represented field tests at up to 19 turbines per size class of test fish that met specific acceptability criteria for control fish mortality (could not exceed 10%). These data are reproduced herein for the two general turbine types represented among the four developments in the Yadkin Project (Table 3-4). High Rock, Narrows, and Unit 1 at Falls development contain low-speed Francis (radial-flow) turbines. All three Francis turbines at High Rock and Unit 1 at Falls rotate at 90 rpm, compared to the four turbines at Narrows that rotate somewhat faster (Table 2-2). However, Winchell *et al.* (2000) treated all Francis units that rotate slower than 250 rpm as a single group or turbine class. All turbines at Tuckertown are Kaplan units (axial flow, adjustable propeller type) that rotate at 138.5 rpm. The runners at Falls Units 2 and 3 are also axial flow, but fixed propeller types that rotate at 126.8 rpm.

Immediate survival rates were used for this assessment since they enabled use of a larger sample size (N). The mean rates are reported irrespective of local site conditions such as shallow or deep intakes or tailrace configuration that could affect ultimate fish survival after turbine passage. Additionally, the survival rates are reported for all species combined. More importantly, recent evidence suggests that fish size is more important than species *per se* when assessing fish survival potential (Franke *et al.* 1997; Winchell *et al.* 2000).

The principal survival trend among the reviewed studies summarized in Table 3-4 was a higher survival rate for small fish (generally those less than 200 mm or 7.9 in). The largest number of studies reviewed occurred at low speed (< 250 rpm) Francis installations (Table 3-4). Mean survival of the two size groups of fish <200 mm (7.9 in) was 93.9% and 91.6%. Survival declined for both larger size groups tested. The highest mean survival rates reported were from Kaplan/propeller sites with runner speeds < 300 rpm. The mean survival rate of both size groups of fishes <200 mm (7.9 in) was 95.4% and 94.8% for the 13 studies reviewed. Thus, for the mostly small fish entrained through a site with Kaplan runners approximately 5% or fewer fish would be killed immediately. Survival at Kaplan/propeller sites for larger fish tested was moderate or high.

3.3.2 Site Specific Survival Data for Restoration Species

The survival data summarized by Winchell *et al.* (2000) and reported in Table 3-4 and Section 3.3.1 represent most of the Yadkin reservoirs' resident fish species of concern, including landlocked forms of anadromous species (*e.g.*, alewife). However, the results of some additional survival studies not included in the EPRI (1997) source data were reviewed for the diadromous species targeted for Yadkin-PeeDee River basin restoration. This section summarizes new empirical survival data for American shad, blueback herring, and American eel, plus additional empirical survival data for alewife.

Survival through Francis turbines for small (juveniles <8 in long, the principal life stage affected) anadromous alosids targeted for restoration averaged 88.1% overall (Table 3-5). The range of survival estimates was 80.0% for alewife tested by net recovery to 94.7% for American shad tested using the balloon tag technique. Survival of medium-sized blueback herring at Stevens Creek development, drawn from a land-locked stock, was 95.3%. The results of medium sized blueback herring survival tests may also be representative of similar length post-spawned adult anadromous herring returning to the ocean.

More test results were available for juvenile alosids at Kaplan/propeller installations (Table 3-6). Average juvenile survival for the three alosid species was 95.4%, ranging among individual estimates and species from 89.0% to 100.0%.

Three adult American eel survival estimates each were available for Francis and Kaplan/propeller turbines. Average survival through Francis units was 84.1% compared to 70.9% through Kaplan/propeller runners (Tables 3-5 and 3-6). A pattern of higher eel survival estimates and fewer injuries through Francis turbines than Kaplan/propeller units has been noted previously (EPRI 2001).

4.0 INDIVIDUAL DEVELOPMENT ENTRAINMENT IMPACT ASSESSMENT

Each of the four developments in the Yadkin Project was assessed with respect both entrainment and turbine passage mortality. The assessment examined individual characteristics among dam, intake, and hydroplant structural elements, reservoir characteristics, and fish populations that can affect entrainment and mortality. Various comprehensive reviews of entrainment and mortality data (FERC 1995: EPRI 1997) as well as fish behavior relative to turbine passage (Coutant and Whitney 2000) suggest that one or more of the factors listed in Table 4-1 may influence the risk of turbine passage entrainment or mortality. Among factors that can influence entrainment rates, this assessment examined the following:

- Intake adjacent to shoreline--Nearshore intakes typically entrain fishes at higher rates than offshore intakes, as fish tend to follow shorelines or orient to physical structure associated with shorelines.
- Intake location in littoral zone--The littoral zone is the most productive region of a reservoir and most fish rear in the shallower littoral areas.
- Abundant littoral zone species--Fishes such as centrarchids that spawn, rear, and spend most of their lives in shallow nearshore waters tend to be among the most abundant species in a fish assemblage.
- Abundant clupeids--Entrainment rates trend highest at projects with clupeids such as gizzard shad and threadfin shad.
- Intake depth--Fish are usually more abundant in shallower portions of a reservoir throughout most of the year.
- Winter drawdown--Drawdown of a reservoir to provide storage of winter and spring runoff reduces reservoir volume and may place fishes in closer proximity to water intakes.
- Hydraulic capacity--More water passed through intakes will entrain more fish for a given entrainment rate.

- Water quality factor--poor water quality (*e.g.* low dissolved oxygen in the hypolimnion) in a reservoir may form a barrier and reduce fish susceptibility to entrainment.
- Approach velocity--approach velocities may positively correlate with entrainment rates, although FERC (1995) was unable to find a significant trend between entrainment rate and intake velocity. Other factors related to intake siting may be more important.
- Presence of obligatory migrants. “Resident” fishes are usually entrained inadvertently but relative to their use of near-intake habitats. Migrants out of freshwater systems must locate an exit route and turbine intakes provide the bulk flow cues used to guide outmigration.

Factors examined that can influence fish survival/mortality during turbine passage included:

- Turbine type--Among factors related to passage survival, the size of water passage spaces available relative to fish size influences susceptibility to contact with structural elements. Francis runners have more closely spaced buckets/blades than Kaplan/propeller runners and thus spaces available for passage are smaller, particularly for larger-sized fish in Francis turbines.
- High turbine speed--Higher rpm's increase the likelihood of contact with structural elements.
- Survival rate of small fish (<8 in)--More than 90% of fishes entrained at hydro projects are small (EPRI 1997). High survival of small fish reduces the overall impact of entrainment to fish populations.
- Pressurized intake tunnel--High hydrostatic pressure in penstocks at high head sites may be suddenly released as fish acclimated to higher pressure pass from pressurized areas or deep water to tailwaters at normal hydrostatic pressure. The sudden relief from high pressure increases the risk to fish of decompression trauma.

Each reservoir is examined individually below with respect to those unique features listed above that may affect entrainment or mortality. However, the Yadkin Project developments also share multiple design and biological characteristics, including a similar fish fauna (Tables 2-4 to 2-7), intake siting away from littoral areas, relatively shallow intake ceilings, similar normal hydraulic capacities and intake velocities, and slow turbine speed (rpm) (Tables 2-2 and 4-1). Additionally, three of the four developments have unpressurized intakes without penstocks. Each of these factors is treated for the project developments as a group prior to the individual analyses.

Additionally, long range plans for the Yadkin-PeeDee River basin may foresee possible restoration of anadromous alosids and American eel to project waters. Juvenile anadromous alewife, blueback herring, and American shad, and adult catadromous American eel represent obligatory migrants from freshwater systems to the ocean. Whereas non-migratory fish entrainment may be viewed as accidental (Coutant and Whitney 2000) obligate migrants must pass out of freshwater to complete their life cycle. All such migrants are subject to entrainment through turbines unless alternate exit routes are provided. In addition, obligate migrants are subject to the effects of cumulative mortality when passing out of rivers with multiple hydro projects. Entrainment of obligate migrants, including a cumulative assessment, is treated separately below (Section 4.5).

The entrainment potential at all Yadkin developments is rated “high” to “moderate high” principally due to abundant clupeids throughout the system, as well as numerous and abundant centrarchid species (Table 4-1). Young gizzard and threadfin shad, as well as young bluegill, other sunfishes, and crappie, typically form the bulk of entrainment catches where they are abundant in hydropower reservoirs (FERC 1995). Young shad form large, open-water schools and both shad species tend to be susceptible to torpor by cold water temperatures. As a result entrainment of shad tends to be episodic due to the clumped reservoir distribution (schooling behavior), and more prevalent during fall and winter. Natural movements of shad may also increase the risk of entrainment to those predatory species utilizing shad as prey. Young shad in fall and winter, including those stressed by cold water, may move to deeper waters of Yadkin reservoirs seeking warmer water. Movements to the lower portions of the reservoirs increases exposure of shad and the predatory fishes that follow schools of these forage species to water proximal to the intakes, thus increasing the risk of entrainment. Winter losses may be exacerbated by reduced reservoir volume during drawdown.

Young centrarchids tend to be very abundant in shoreline areas and in shallow water, and are usually major contributors to entrainment. However, the mean entrainment densities of small centrarchids in Table 3-2 are nowhere near the densities typical for clupeids, thus the rating “Moderate-High”. Although centrarchid entrainment can be substantial, the Yadkin reservoirs are mostly eutrophic, very productive systems that sustain large, diverse fish populations. Despite the “Moderate High” fish entrainment potential, the reservoirs support good recreational fishing for a variety of species. The reservoirs are acknowledged as “forage-rich” environments (due to clupeids as well as young of non-game species) which support numerous popular sport fisheries for striped bass, largemouth bass, black crappie and other panfish, and catfishes.

All Yadkin Project intakes withdraw from shallow to moderately deep water. Intake ceilings range from 7 to 32 ft below normal pool level. Whereas deep (*e.g.*, >60 ft) intakes may be isolated from areas of fish abundance, shallower intakes are in closer proximity to the reservoir areas where fish are most abundant. However, none of the Yadkin intakes are considered proximal to the littoral zone. Intakes at High Rock and Tuckertown Reservoirs are sited at least 180 ft offshore, and, at Narrows Reservoir, separated from the shoreline by a 500-ft wide bypass spillway. At Falls Reservoir, the intakes are much closer to shore but the adjacent shoreline is steep with little or no littoral zone. Thus, relatively shallow water withdrawals may be mediated by the distance from or lack (at Falls Reservoir) of littoral areas.

Each development intake also shares similar, moderate water velocities at the intake racks (1.93 to 2.93 ft/s) and large withdrawal volume (normally 7,500 to 8,200 cfs). The larger volumes would entrain more fish for a given entrainment rate.

Although three different turbine types characterize the four developments, all units rotate slowly (90-163.6 rpm). Fish survival is higher at hydro projects with low speed turbines (EPRI 1997; Winchell at al. 2000). The summaries of turbine survival data from Winchell *et al.* (2000) in Table 3-4, as well as the additional empirical survival results in Tables 3-5 and 3-6, clearly identify high (>91%) survival of the mostly small fish that pass through project turbines, regardless of turbine type. Further, entrained fish at three of four developments are not subject to pressurized intakes, surge tanks, or penstocks. However, Narrows (see Section 4.3) has penstocks with pressure at the bottom end near the turbine in the range of 70 psi, or slightly more than two atmospheres (Shiers, personal communication, 2004). Shallow water intakes and passage at or near normal atmospheric pressure enhances survival since entrained fish are not acclimated to deep water or high hydrostatic pressure and, thus, are not forced to equilibrate to rapid reductions to normal pressure when passed into a hydro station tailrace.

4.1 High Rock Development

The High Rock Development possesses many of the risk factors that suggest entrainment rates are likely to be high or moderate-high. In addition, High Rock is unique among Yadkin developments because of the annual winter drawdown (12 ft average). The reduced reservoir volume in late fall and winter along with clupeid movements to lower reservoir areas places these forage species (and potentially the predators that follow the forage schools) at somewhat higher risk of entrainment than at other reservoirs. The risk posed by natural movements of young clupeids out of reservoirs can be exacerbated by the susceptibility of threadfin shad to cold stress in some winters. This is less of a concern at local latitudes for gizzard shad. However, because the High Rock turbines are large and rotate slowly (90 rpm) survival rates of the mostly small fish entrained are likely high (Winchell et al. 2000; Table 4-1).

In summary, although the entrainment rates at High Rock are likely to be high due to shad, the overall impact to fishes due to entrainment and turbine passage at High Rock development is expected to be low for all species considered due to the relatively benign turbine characteristics. The viability of popular sport fisheries at High Rock supports this conclusion.[3]

4.2 Tuckertown Development

The Tuckertown Development exhibits most risk factors that can cause high (abundant clupeids) or moderate-high entrainment rates, except there is no winter drawdown. However, Tuckertown houses large, slow Kaplan turbines, generally the most benign for the fishes considered herein. In spite of the potential for high or moderate-high entrainment, expected high survival rates during turbine passage suggest that the overall potential impact due to entrainment at Tuckertown is low.

4.3 Narrows Development

The entrainment and survival risk profiles of fishes in Narrows Reservoir are nearly identical to that for the Tuckertown Development, except for turbine type and penstock pressure (Table 4-1). Penstock pressure at Narrows is slightly more than two atmospheres (approximately 70 psi) at the turbine entrance. Any effects on fish passing via the turbine would depend upon the original acclimation depth. Fish originating from shallow or surface waters would experience a doubling of pressure at the bottom of the penstock before passing the turbine into the tailrace, where ambient atmospheric pressure is normal (one atmosphere). Fish originating at depths equivalent to the intake ceiling or deeper would be acclimated to approximately two atmospheres and be less affected. Most fish passing through the turbines are likely to be pelagic clupeids that may experience brief disorientation but no additional mortality prior to reacclimation upon reaching the tailrace.

Although Narrows Reservoir is the only Yadkin impoundment that routinely stratifies in summer (Yadkin 2002), the thermocline is typically deeper than the turbine intake ceiling (submerged 31.1 ft) and thus poor water quality (low dissolved oxygen) below the thermocline would not represent a barrier to fish entrainment.

Narrows Development utilizes Francis units with a range of design flows and bucket configurations, and slight differences in rotation speed (156.5 and 163.6 rpm). However, either rotation speed is considered slow (Winchell *et al.* 2000). Another difference at Narrows relative to other Yadkin developments is design head of 175 ft compared to 52-55 ft of head at the other three sites. However, high head alone does not necessarily exacerbate turbine passage mortality. Recent field studies performed with two salmonid species at Mayfield Dam, Cowlitz River, Washington with 181 ft of head demonstrated survival rates at each of two Francis units of 82.6% to 84.7% and 97.1% to 97.2% (Normandeau and Skalski 2003). Such rates are deemed moderate and high, respectively, for the present analysis. The survival differences between units tested were attributed to turbine design characteristics. The unit with more buckets, more wicket gates, and narrower wicket gate spacing exhibited lower survival rates. As expected, however, the survival differences between units were greater than the differences between tested species.

As a result, based on the Mayfield test results, some slight differences in survival are possible between specific units at Narrows Dam. Survival may be higher at Unit 4 with 13 buckets than at Unit 3 with 21 buckets. However, such differences may be more likely among the relatively few larger-sized fishes entrained.

[3] An assessment of the overall condition of High Rock reservoir fisheries is the subject of a separate study report being prepared by Normandeau Associates as part of the Yadkin Project relicensing.

In summary, the potential entrainment of fishes at Narrows Development is probably high for clupeids and moderate-high for other fishes. Given the specific turbine configurations, fish survival during turbine passage is at least moderate to high. However, given the overall abundance of Narrows Reservoir fishes and the overall health of the sport fisheries for striped bass, largemouth bass, and catfishes, any impact due to entrainment mortality is probably low. [4]

4.4 Falls Development

The overall potential for fish entrainment at the Falls Development was judged high due to clupeids, and moderate-high for centrarchids, yellow perch, and other abundant species. Although the location of the intakes is approximately 50 ft from reservoir shorelines, more proximal than other Yadkin developments, due to the steep character of adjacent shorelines the littoral zones near the dam are limited. Lack of nearby littoral zones may moderate entrainment of centrarchids.

Although there is moderate-high to high potential for entrainment at Falls Development, the likelihood for survival of turbine passed fishes is also high (Table 4-1). The powerhouse contains one large, slow Francis unit, and two large, slow propeller runners with few blades that operate at low design head (54 ft). These features enhance the likelihood of high fish survival during turbine passage. Both types of units exhibited survival rates >91% for small entrained fishes in the summary analyses described in Winchell *et al.* (2000). The overall potential for impacts to fishes due to turbine entrainment at Falls development is low.

4.5 Restoration Species and Cumulative Effects

The species represented by the individual assessments in Sections 4.1 to 4.4 represent resident or riverine species that need not migrate to complete their life cycle. In contrast, diadromous species that may be targeted for restoration are all obligate migrants at a specific life stage and, as such, are all subject to turbine entrainment (absent an alternative passage route such as a spillway or bypass). Further, each restoration species could be impacted by turbine passage (alosids as juveniles and adult American eel) past one up to possibly four individual Yadkin developments and two Progress Energy developments. The number of developments passed during outmigration is dependent upon the provision of upstream passage during implementation of any future restoration plan that is adopted.

Table 4-2 was developed to illustrate the potential range of turbine passage cumulative effects on the restoration species for downstream turbine passage past one (Falls) to four (High Rock) developments. The first column in Table 4-2 lists survival rates for either alosids (treated as a single group) or American eel as shown in Tables 3-5 or 3-6 as appropriate for the turbine type (see Section 3.3.2 for discussion of individual species' survival rates from the empirical source studies). Thus, the development rate represents passage survival for that species or group past only that development. The individual survival rates shown for High Rock, Tuckertown, and Narrows developments represent those for the respective single turbine type (*e.g.*, Francis or Kaplan/propeller) housed at each site (see Table 2-2). At Falls Development, the single development rate shown reflects flow-proportional passage through one Francis and two fixed propeller units. There was no attempt made to estimate passage at Falls Development if selective use of turbines occurs.

The turbine passage survival percentage for alosids past a single development ranged from 88.1% to 95.4%, and for American eels ranged from 70.9% to 84.1%. Cumulative survival estimates were based on an assumed cohort size of 1,000 animals emigrating from any given starting point. The individual development survival rate is shown for alosids and American eel (as shown in Tables 3-5 and 3-6), as well as the cumulative survival rate and total loss of individuals past the developments individually or in aggregate. The cumulative survival rate for juvenile alosids and adult silver American

[4] An assessment of the overall condition of Narrows reservoir fisheries is the subject of a separate study report being prepared by Normandeau Associates as part of the Yadkin Project relicensing.

eels will decrease as the emigration starting point within the Yadkin Project progresses upstream (Table 4-2). The estimated loss of juvenile alosids passing only Falls Development is 68, compared to 310 animals if initial turbine passage is out of High Rock Reservoir. The estimated loss of adult American eels is 251 if passing only the Falls Development, compared to 624 eels lost during passage past all the Yadkin developments. In addition to the loss of more individuals than for alosids, adult American eels killed represent mature or maturing adult females, a more significant impact to the overall population. American eels are a panmictic species with a single breeding population (ASMFC 2000).

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6.0 TABLES AND FIGURES

Table 2-1

Reservoir and intake characteristics of developments in the Yadkin Hydroelectric Project.

Project	Surface Area at full pond (acres)	Maximum Reservoir and (Mean) depth-ft	Normal Full Pond Elevation (ft)	Intake Elevation			Intake Width[3] (ft)	Gross Area[3] (sq ft)	Trash Rack Bars		Number of Units Operating	Normal Hydraulic Capacity (cfs)	Approach Velocity (ft/s)
				Top (ft)	CL (ft)	Bottom (ft)			Width (in)	Clear Spacing (in)			
High Rock	15,180	62 (17)	623.9	605.9	587.4	568.9	36	1,332.0	0.375	4.125			
											1	2,600	1.95
											2	5,200	1.95
											3	7,800	1.95
Tuckertown	2,560	55 (16)	564.7	532.2	518.7	505.2	42.5	1,147.5	0.375	5.625			
											1	2,675	2.33
											2	5,350	2.33
											3	8,025	2.33
Narrows	5,355	175 (45)	509.8	478.7	461.2	443.7	20	700.0	0.375	4.375			
											1	2,050	2.93
											2	4,100	2.93
											3	6,150	2.93
											4	8,200	2.93
Falls	204	52 (27)	332.8	325.8	309.8	293.8	37	1,184.0	0.375	5.625			
											1	2,500	2.11
											2	5,000	2.11
											3	7,500	2.11

Notes:

1. All elevations are USGS datum. To convert to local datum add 31.1' to High Rock elevations, 31.3' to Tuckertown and Narrows elevations, and 31.2' to Falls elevations.
2. Ref. Dwgs: High Rock: A-5657-YH, A-5663-YH, and A-9169-YH.
   Tuckertown: A-322.2-YK-17, A-322.2-YK-27, and A-322.2-YK-28.
   Narrows: A-3050-YB, A-3054-YB, and A-9064-YB.
   Falls: A-3244-YY, A-3243-YY, and A-9119-YB.
3. Values are per unit.
4. Flows are based on the 20% of operating time of the hourly flow duration analysis of the turbine flow.

Table 2-2

Physical and hydraulic characteristics of turbines at developments in the Yadkin Project.

Development	Turbine Type	Design Head (ft)	Individual Unit Design Flow (cfs)	No. of Blades/Buckets	Runner Discharge Diameter (in)	Runner Speed (rpm)
High Rock						
Units 1, 2, 3	Vertical Francis	52	2,597	15	158	90
Tuckertown						
Units 1, 2, 3	Kaplan (adjustable propeller)	55	2,673	6	146	138.5
Narrows						
Units 1, 2	Vertical Francis	175	1,947	17	115	163.6
Unit 3	Vertical Francis	175	2,345	21	115	156.5
Unit 4	Vertical Francis	175	1,947	13	115	156.5
Falls						
Unit 1	Vertical Francis	54	2,240	13	150	90
Units 2, 3	Fixed propeller	54	2,608	8	134.4	128.6

Table 2-3
Fish composition of Yadkin Project Reservoirs.

		Yadkin Project Reservoir			
Common Name	**Scientific Name**	**High Rock**	**Tuckertown**	**Narrows**	**Falls**
Longnose gar	*Lepisosteus osseus*	X	X	X	
Bowfin	*Amia calva*	X			
Blueback herring	*Alosa aestivalis*			X	X
Alewife	*Alosa pseudoharengus*		X		
Gizzard shad	*Dorosoma cepedianum*	X	X	X	X
Threadfin shad	*Dorosoma petenense*	X	X	X	X
Shiner	*Notropis spp.*	X	X	X	X
Satinfin shiner	*Cyprinella analostana*		X		X*
Goldfish	*Carassius auratus*	X		X	
Bluehead chub	*Nocomis leptocephalus*			X	
Carp	*Cyprinus carpio*	X	X	X	X
Golden shiner	*Notemigonus crysoleucas*	X	X	X	X
River carpsucker	*Carpiodes carpio*	X	X	X	
Quillback	*Carpiodes cyprinus*	X	X	X*	
Creek chubsucker	*Erimyzon oblongus*	X	X	X	
Redhorse	*Moxostoma spp.*	X	X	X	
Shorthead redhorse	*Moxostoma macrolepidotum*	X	X	X	X
Silver redhorse	*Moxostoma anisurum*		X	X*	
Spotted sucker	*Minytrema melanops*	X			
Smallmouth buffalo	*Ictiobus bubalus*		X*		X
Snail bullhead	*Ameiurus brunneus*			X	
White catfish	*Ameiurus catus*	X	X	X	X
Black bullhead	*Ameiurus melas*		X		
Yellow bullhead	*Ameiurus natalis*			X	
Brown bullhead	*Ameiurus nebulosa*	X	X	X	
Flat bullhead	*Ameiurus platycephalus*		X	X	X*
Channel catfish	*Ictalurus punctatus*	X	X	X	X
Blue catfish	*Ictalurus furcatus*		X	X	X
Flathead catfish	*Pylodictis olivaris*	X	X	X	X
Eastern mosquitofish	*Gambusia holbrooki*		X	X	X
White perch	*Morone americana*	X	X	X	X
White bass	*Morone chrysops*	X	X	X	
Striped bass	*Morone saxatilis*	X	X	X	X
Redbreast sunfish	*Lepomis auritus*	X	X	X	X

Green sunfish	*Lepomis cyanellus*	X	X	X	X
Pumpkinseed	*Lepomis gibbosus*	X	X	X	X
Warmouth	*Lepomis gulosus*	X	X	X	X
Bluegill	*Lepomis macrochirus*	X	X	X	X
Redear sunfish	*Lepomis microlophus*	X	X	X	X
Largemouth bass	*Micropterus salmoides*	X	X	X	X
White crappie	*Pomoxis annularis*	X	X	X	X
Black crappie	*Pomoxis nigromaculatus*	X	X	X	X
Johnny darter	*Etheostoma nigrum*		X		
Yellow perch	*Perca flavescens*	X	X	X	X
Striped bass x white bass		X	X	X	
Carp x goldfish		X			
Sunfish hybrid				X	X
Total taxa		**33**	**38**	**39**	**28**

* Additions to reservoir fauna list in ICD resulting from 2003 tailwater sampling by Normandeau.

Table 2-4

Percent composition and CPUE of fishes collected by electrofishing (fish/h) and gillnets (fish/24-h set) in High Rock Reservoir.

	Electrofishing		Gillnets	
Species	**%Comp**	**CPUE**	**%Comp**	**CPUE**
Black crappie	7.53%	15.17	10.77%	10.94
Bluegill	21.92%	44.17	0.86%	0.87
Bowfin	0.00%	0	0.02%	0.02
Brown bullhead	0.00%	0	0.09%	0.09
Channel catfish	0.91%	1.83	11.29%	11.46
Common carp	3.80%	7.67	1.33%	1.35
Common carp x goldfish hybrid	0.00%	0	0.38%	0.39
Creek chubsucker	0.00%	0	0.02%	0.02
Flathead catfish	0.50%	1.0	0.65%	0.66
Gizzard shad	28.04%	56.5	5.61%	5.7
Golden shiner	0.74%	1.5	0.23%	0.23
Goldfish	0.74%	1.5	0.29%	0.3
Green sunfish	0.50%	1.0	0.00%	0
Largemouth bass	7.69%	15.5	0.54%	0.55
Longnose gar	0.00%	0	0.27%	0.27
Pumpkinseed	0.66%	1.33	0.05%	0.05
Quillback	0.33%	0.67	1.10%	1.12
Redbreast sunfish	0.17%	0.33	0.00%	0
Redear sunfish	0.17%	0.33	0.05%	0.05
Shiner unid.(notropis)	0.00%	0	0.02%	0.02
Shorthead redhorse	0.91%	1.83	1.13%	1.14
Spotted sucker	0.17%	0.33	0.00%	0
Striped bass	1.08%	2.17	0.83%	0.85
Striped x white bass hybrid	0.00%	0	0.09%	0.09
Threadfin shad	19.02%	38.33	37.19%	37.77
Warmouth	0.00%	0	0.07%	0.07
White bass	0.00%	0	0.54%	0.55
White catfish	0.25%	0.5	1.04%	1.05
White crappie	2.89%	5.83	0.77%	0.78
White perch	1.16%	2.33	24.69%	25.07
Yellow perch	0.83%	1.67	0.09%	0.09
Total CPUE		**201.49**		**101.55**

Table 2-5

Percent composition and CPUE of fishes collected by electrofishing (fish/h) and gillnets (fish/24-h set) in Tuckertown Reservoir.

	Electrofishing		Gillnets	
Species	%Comp	CPUE	%Comp	CPUE
Black crappie	0.91%	4.25	6.83%	5.43
Blue catfish	0.00%	0	0.02%	0.02
Bluegill	51.19%	240.13	0.76%	0.6
Channel catfish	0.37%	1.75	8.95%	7.11
Common carp	2.56%	12	0.94%	0.75
Creek chubsucker	0.00%	0	0.06%	0.05
Flathead catfish	0.00%	0	1.14%	0.91
Gizzard shad	6.16%	28.88	7.45%	5.92
Golden shiner	0.43%	2	0.06%	0.05
Green sunfish	0.40%	1.88	0.00%	0
Largemouth bass	4.74%	22.25	0.78%	0.62
Longnose gar	0.00%	0	0.18%	0.14
Pumpkinseed	0.45%	2.13	0.14%	0.11
Quillback	0.00%	0	0.06%	0.05
Redbreast sunfish	0.13%	0.63	0.00%	0
Redear sunfish	0.85%	4	0.00%	0
Redhorse sp. (*Moxostoma*)	0.00%	0	0.02%	0.02
Satinfin shiner	0.03%	0.13	0.00%	0
Shorthead redhorse	0.08%	0.38	0.46%	0.37
Silver redhorse	0.03%	0.13	0.06%	0.05
Striped bass	0.00%	0	1.66%	1.32
Striped x white bass hybrid	0.00%	0	0.06%	0.05
Threadfin shad	28.83%	135.25	44.78%	35.6
Warmouth	0.75%	3.5	0.26%	0.21
White bass	0.03%	0.13	0.32%	0.25
White catfish	0.00%	0	0.16%	0.13
White crappie	0.40%	1.88	0.60%	0.48
White perch	0.88%	4.13	24.20%	19.24
Yellow perch	0.80%	3.75	0.04%	0.03

Table 2-6

Percent composition and CPUE of fishes collected by electrofishing (fish/h) and gillnets (fish/24-h set) in Narrows Reservoir.

	Electrofishing		Gillnets	
Species	**%Comp**	**CPUE**	**%Comp**	**CPUE**
Black crappie	0.10%	0.25	0.94%	0.51
Blue catfish	0.00%	0	1.06%	0.57
Blueback herring	0.00%	0	0.14%	0.08
Bluegill	33.23%	83.38	0.23%	0.12
Brown bullhead	0.55%	1.38	0.06%	0.03
Channel catfish	0.60%	1.5	5.89%	3.16
Common carp	1.30%	3.25	0.26%	0.14
Creek chubsucker	0.00%	0	0.03%	0.02
Flat bullhead	0.50%	1.25	1.20%	0.64
Flathead catfish	0.05%	0.13	0.31%	0.17
Gizzard shad	19.63%	49.25	7.00%	3.76
Golden shiner	0.15%	0.38	0.00%	0
Green sunfish	0.30%	0.75	0.00%	0
Largemouth bass	6.58%	16.5	1.11%	0.6
Pumpkinseed	0.85%	2.13	0.14%	0.08
Redbreast sunfish	4.24%	10.63	0.06%	0.03
Redear sunfish	1.59%	4.0	0.11%	0.06
Shorthead redhorse	0.10%	0.25	0.66%	0.35
Snail bullhead	0.80%	2.0	0.83%	0.44
Striped bass	0.10%	0.25	8.15%	4.37
Striped x white bass hybrid	0.00%	0	0.40%	0.21
Sunfish (hybrid)	0.05%	0.13	0.00%	0
Threadfin shad	13.35%	33.5	3.17%	1.7
Warmouth	0.60%	1.5	0.26%	0.14
White bass	0.00%	0	1.23%	0.66
White catfish	2.54%	6.38	3.60%	1.93
White crappie	0.45%	1.13	0.29%	0.15
White perch	1.49%	3.75	62.75%	33.67
Yellow perch	10.86%	27.25	0.11%	0.06
Total CPUE		**250.92**		**53.65**

Table 2-7

Percent composition and CPUE of fishes collected by electrofishing (fish/h) and gillnets (fish/24-h set) in Falls Reservoir.

	Electrofishing		Gillnets	
Species	**%Comp**	**CPUE**	**%Comp**	**CPUE**
Black crappie	0.00%	0	0.72%	0.1
Blue catfish	0.21%	0.25	12.80%	1.84
Blueback herring	0.00%	0	1.45%	0.21
Bluegill	36.19%	43.25	1.21%	0.17
Channel catfish	3.35%	4.0	10.14%	1.46
Common carp	1.46%	1.75	0.48%	0.07
Eastern mosquitofish	0.21%	0.25	0.00%	0
Flathead catfish	0.21%	0.25	3.14%	0.45
Gizzard shad	9.21%	11.0	13.04%	1.88
Golden shiner	0.21%	0.25	0.00%	0
Green sunfish	1.88%	2.25	0.00%	0
Largemouth bass	12.34%	14.75	1.69%	0.24
Pumpkinseed	0.21%	0.25	0.00%	0
Redbreast sunfish	12.34%	14.75	0.24%	0.03
Redear sunfish	1.46%	1.75	0.24%	0.03
Shorthead redhorse	0.00%	0	3.38%	0.49
Smallmouth buffalo	0.21%	0.25	0.00%	0
Striped bass	0.00%	0	0.72%	0.1
Sunfish (hybrid)	0.21%	0.25	0.00%	0
Threadfin shad	0.21%	0.25	0.00%	0
Warmouth	10.67%	12.75	0.97%	0.14
White catfish	7.53%	9.0	8.70%	1.25
White crappie	0.00%	0	0.48%	0.07
White perch	1.05%	1.25	40.34%	5.81
Yellow perch	0.84%	1.0	0.24%	0.03
Total CPUE		**119.5**		**14.4**

Table 3-1

Reservoir fish species of interest for the entrainment/mortality assessment of the four developments comprising the Yadkin Hydro Project. Bold text denotes NCWRC management species that were also ranked as abundant as determined by 2000 field sampling.

	Yadkin Project Developments			
Basis for Inclusion	**High Rock**	**Tuckertown**	**Narrows**	**Falls**
Relative Abundance in Fish Community*	threadfin shad	threadfin shad	white perch	white perch
	gizzard shad	bluegill	bluegill	bluegill
	white perch	white perch	gizzard shad	gizzard shad
	bluegill	gizzard shad	threadfin shad	white catfish
	black crappie	channel catfish	yellow perch	**largemouth bass**
	channel catfish	**black crappie**	**largemouth bass**	channel catfish
	largemouth bass	**largemouth bass**	**black crappie**	blue catfish
NCWRC Management Target	striped bass	striped bass	striped bass	black crappie
River Basin Restoration Target	American shad	American shad	American shad	American shad
	river herring	river herring	river herring	river herring
	American eel	American eel	American eel	American eel

* Fish listed in rank order of abundance as determined by Progress Energy sampling in 2000; see text.

Table 3-2

Average entrainment densities for Yadkin Project fish species of interest from EPRI (1997) entrainment database. Annual density shown as fish per million cubic feet of water.

	Small Fish (< 8 inches)			Medium Fish (8-15 inches)			Large Fish (>15 inches)		
Species/surrogates	**No. Sites Present**	**Annual Density**	**Entrainment Potential**	**No. Sites Present**	**Annual Density**	**Entrainment Potential**	**No. Sites Present**	**Annual Density**	**Entrainment Potential**
Alewife[1]	3	34.057	High	3	0.078	Moderate-High	3	0.0	None
Gizzard shad[2]	10	15.668	High	10	0.220	High	10	0.0047	Moderate
Yellow perch	41	1.632	High	41	0.006	Moderate	41	0	Low
Bluegill[3]	36	0.925	Moderate-High	36	0.005	Moderate	36	0.0000	Low
Black crappie	30	0.400	Moderate-High	30	0.013	Moderate-High	30	0.0000	Low
Channel catfish[4]	18	0.631	Moderate-High	18	0.033	Moderate-High	18	0.002	Low-Moderate
Brown bullhead[5]	30	0.111	Moderate-High	30	0.025	Moderate-High	30	<0.001	Low
Largemouth bass	34	0.118	Moderate-High	34	0.002	Low-Moderate	34	0.0032	Moderate
White perch	4	0.224	Moderate-High	4	0.183	High	4	<0.001	Low
White bass[6]	4	0.003	Low	4	0.042	Moderate-High	4	0	Low
American eel	9	<0.001	Low	9	0.005	Moderate	9	0.0710	Moderate-High

Footnotes (also see text):

1) alewife representative of blueback herring, American shad
2) gizzard shad representative of threadfin shad
3) bluegill representative of other sunfishes
4) channel catfish representative of blue catfish
5) brown bullhead representative of white catfish
6) white bass surrogate for striped bass

Table 3-3

Size composition of entrainment catch by bar rack spacing (after Winchell *et al.* 2000).

Clear Spacing (inches)	N	Average Composition (%) by Size Class (inches): 0 to 4	4 to 8	8 to 15	15 to 30	> 30	Representative Development
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	All Yadkin Developments*
All	**39**	**71.3**	**22.9**	**5.3**	**0.5**	**0.0**	

* Range of rack clear spacing 4.125-5.625 inches.

Table 3-4

Fish survival rates for different turbine types and fish sizes (after Winchell *et al.* 2000).

Turbine Type	Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size-mm (in)	Average Immediate Survival-all species (%) N	Minimum	Maximum	Mean	Survival Potential**	Representative Developments/Units
Radial-flow (Francis)	<250	440-1,600	<100 (3.9)	13	85.9	100	**93.9**	**High**	High Rock Units 1-3
		370-1,600	100-199 (3.9-7.8	19	74.8	100	**91.6**	**High**	Narrows Units 1-4
		370-2,450	200-299 (7.9-11.8)	18	59.0	100	**86.9**	**Moderate**	Falls Unit 1
		440-1,600	300+ (11.8+)	14	36.1	100	**73.2**	**Low**	
Axial-flow*	<300	636-1,203	<100 (3.9)	3	94.1	98.0	**95.4**	**High**	Tuckertown Units 1-3
		636-21,000	100-199 (3.9-7.8	10	89.8	97.5	**94.8**	**High**	Falls Unit 2 and 3
		636-2,200	200-299 (7.9-11.8)	5	77.4	97.4	**87.2**	**Moderate**	
		1,203-2,200	300+ (11.8+)	2	86.8	100	**93.4**	**High**	

* Includes Kaplan, fixed-blade propeller, bulb, and tube turbines
** Qualitative survival rating: High = 90-100%; Moderate = 80-89.9%; Low = <80%.

Table 3-5

Empirical turbine passage survival rates (%) at sites with Kaplan/propeller turbines for diadromous fishes targeted for Yadkin/PeeDee River basin restoration.

Species	Small <8 in	Medium 8-15 in	Large >15 in	Station(reference)	Notes
Alewife	89.0			Fourth Lake, NS (1)	
	92.8			Herrings, NY (2)	Reported as "clupeids", known to be alewife
Average survival	***90.9***				
American shad	89.1			Hadley Falls, MA (3)	
	94.9			Conowingo, MD (4)	
	97.3			Hadley Falls, MA (4)	
	97.8			Safe Harbor, PA (5)	Unit 8, mixed flow turbine
	98.0			Safe Harbor, PA (5)	Unit 7, Kaplan turbine
	98.9			Safe Harbor, PA (5)	Unit 8, mixed flow turbine
	100.0			Hadley Falls, MA (3)	
Average survival	***96.6***				
Blueback herring	96.0			Crescent, NY (6)	
Average survival	**96.0**				
Overall average clupeid survival by size	**95.4**				
American eel			63.0	Raymondville, NY (7)	
			73.5	St. Lawrence-FDR, NY (8)	88-h post-test value
			76.1	Beauharnois, QC (9)	
Average survival			***70.9***		

References: 1) Ruggles 1990; 2) KA 1996a; 3) Mathur et al. 1994; 4) RMC 1994a; 5) Heisey et al. 1992; 6) Mathur et al. 1996a; 7) KA 1995a; 8) NAI 1997; 9) Desrochers 1995.

Table 3-6

Empirical turbine passage survival rates (%) at sites with Francis turbines for diadromous fishes targeted for Yadkin/PeeDee River basin restoration.

Species	Small <8 in	Medium 8-15 in	Large >15 in	Station(reference)	Notes
Alewife	80.0			Minetto, NY (1)	
Average survival	***80.0***				
American shad	83.5			Holtwood, PA (2)	Unit 3, double runner
	89.4			Holtwood, PA (2)	Unit 10, single runner
	94.7			Vernon, VT/NH (3)	
Average survival	***89.2***				
Blueback herring	92.7			Columbia, SC (4)	
		95.3		Stevens Creek, SC (5)	
Average survival	***92.7***	***95.3***			
Overall average alosid survival by size	***88.1***				
American eel			76.9	Minetto, NY (1)	
			84.2	Beauharnois, QC (6)	
			91.1	Luray, VA (7)	Unit 2
Average survival			***84.1***		

References: 1) KA 1995c; 2) RMC 1992c; 3) NAI 1996a; 4) NAI 1999; 5) RMC 1994e; 6) RMC 1995; 7) Desrochers 1995.

Table 4-1

Comparison of factors that may influence entrainment or survival rates at Yadkin Project developments.

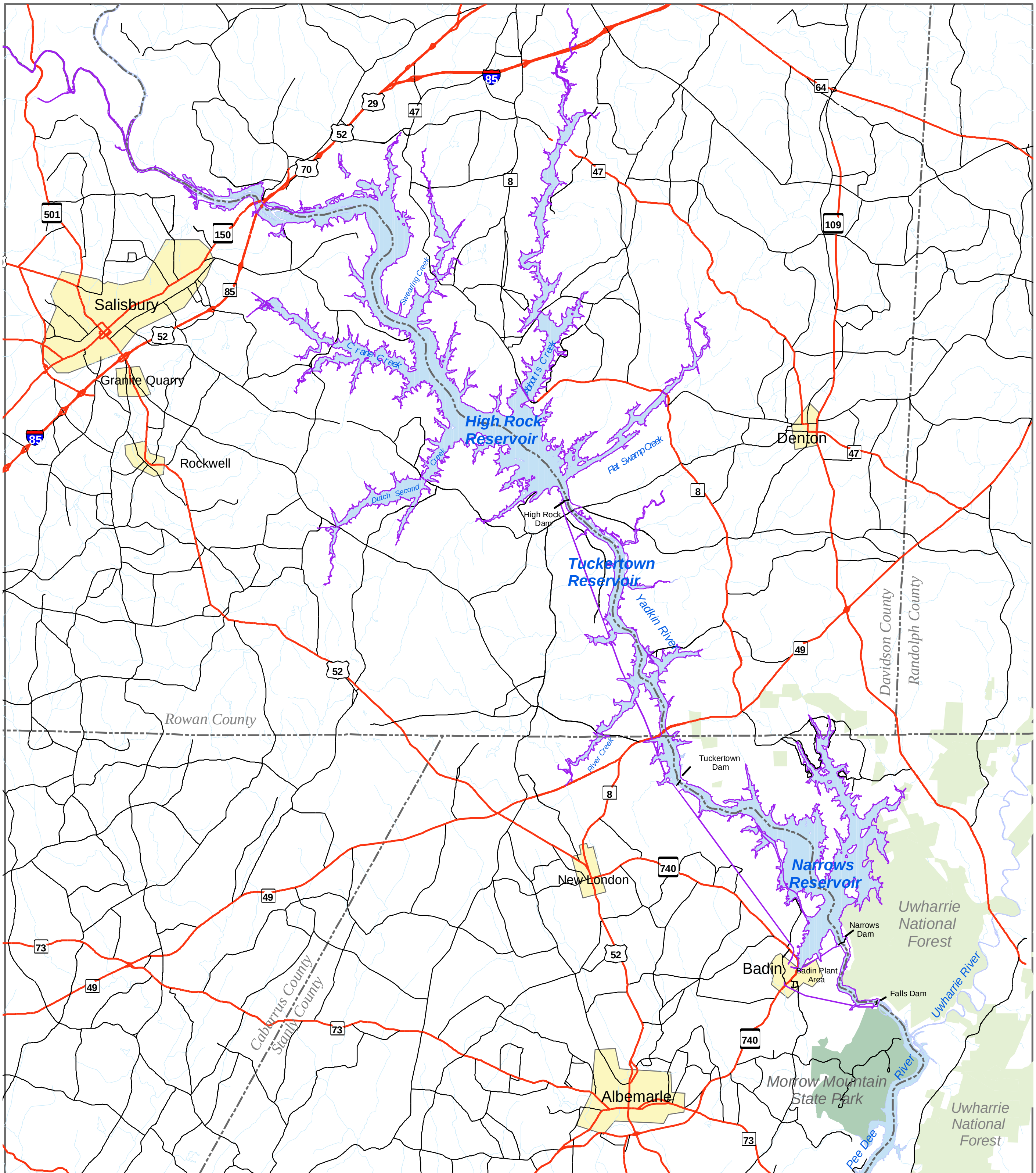
Influence Factors	High Rock	Tuckertown	Narrows	Falls
Entrainment rates				
Intake adjacent to shoreline	No	No	No	Yes
Intake location in littoral zone	No	No	No	No
Abundant littoral zone fishes (no. species)	Yes	Yes	Yes	Yes
Abundant littoral zone fishes (no. individuals)	Yes	Yes	Yes	Yes
Abundant clupeids	Yes	Yes	Yes	Yes
Obligatory migrants	No	No	No	No
Intake depth-ft (at top, full pond)	18	32.5	31.1	7
Winter drawdown	Yes	No	No	No
Normal hydraulic capacity (cfs)	7,800	8,025	8,200	7,500
Approach velocity (ft/s, normal operation)	1.95	2.33	2.93	2.11
Water quality factor	No	No	No	No
Risk of entrainment*	**High/ Moderate-High**	**High/ Moderate-High**	**High/ Moderate-High**	**High/ Moderate-High**
Survival rates				
Turbine type	Francis	Kaplan	Francis	Francis (1) Propeller (2)
High turbine speed	No	No	No	No
Survival rates of small fish (<8 in)	High	High	High	High
Pressurized intake tunnel	No	No	Yes	No
Risk of mortality	**Low**	**Low**	**Low**	**Low**

* Clupeids/other species

Table 4-2

Cumulative survival rate summary for juvenile anadromous alosids and adult American eel at the Yadkin Project. Impact represents individuals lost from an initial cohort of 1,000 animals.

	Juvenile alosids						
	Survival			Survival		Survival	
Development	**Development Rate**	**Cumulative Rate**	**Impact**	**Cumulative Rate**	**Impact**	**Cumulative Rate**	**Impact**
High Rock	0.881	0.690	310				
Tuckertown	0.954			0.783	217		
Narrows	0.881					0.821	179
Falls	0.932	0.932	68				
	Adult American eel						
High Rock	0.841	0.376	624				
Tuckertown	0.709			0.447	553		
Narrows	0.841					0.630	370
Falls	0.749	0.749	251				



- Highways (CAS & USGS)
- Major Roads (CAS & USGS)
- Streams (USGS 100k)
- Counties
- Licensed FERC Boundary
- Dams
- Digitized from 1997 Gemini Map of Uwharrie National Forest

Regional Locus Map

Yadkin Project

N W E S

5 2.5 0 5 Miles

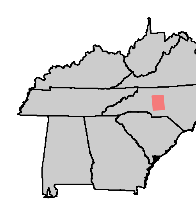


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FIGURE 2-1

7.0 GLOSSARY OF TERMS

Anadromous - fish born in freshwater that migrate early to saltwater for their rearing and adult phase, then return to freshwater to spawn.

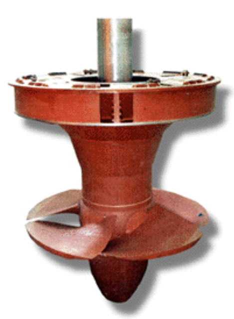
Catadromous - fish born in saltwater that migrate to freshwater for their rearing phase, then return to saltwater as adults to spawn

Diadromous - fish with a life history strategy that includes movement between fresh and saltwater (source: Armantrout, N.B., compiler. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland.

Entrainment - the passage of organisms such as fish through water intakes; at hydro stations fish pass into turbine intakes where they may be injured or killed (source: FERC 1995—one of the existing citations).

Francis Turbine - a type of turbine that consist of a series (typically 13-20) of vertically arranged curved metal blades. Water under very high to moderately high pressure flows down through the blades and makes the turbine spin. (see figure below – source: www.)

Kaplan Turbine – a type of turbine that has adjustable-pitch blades or propellers (typically 3-7) that allow the turbine to operate efficiently under relatively low water pressures. (see figure below – source: www.)



Littoral zone - shallow shore area generally less than 20 ft deep where light can usually penetrate to the bottom (source: Armantrout 1998 above).

Resident fish - freshwater fish species that use the river or stream for their entire life (also called "riverine" fish to denote that these fish do move within the waterbody).

Tailrace - channel of turbulent water exiting from a hydro turbine within the dam tailwater.