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CLAYTOR HYDROELECTRIC PROJECT FISH ENTRAINMENT AND IMPINGEMENT ASSESSMENT

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Claytor Hydroelectric Project
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Table of Contents

Page

List of Figures

Page

List of Tables

1.0 INTRODUCTION AND BACKGROUND

The purpose of this report is to evaluate the potential for fish entrainment and impingement at the Claytor Hydroelectric Project (No. 739). Appalachian Power Company (Appalachian) is in the process of relicensing the Project using the Integrated Licensing Process (ILP) as defined by the Federal Energy Regulatory Commission (FERC). The ILP process involves many participants or stakeholders, including government agencies, local governments, non-governmental organizations (NGOs), the public, and other interested parties. Stakeholders were solicited for input on project-related issues that needed to be addressed during relicensing.

An initial step was preparation and submittal of a Pre-Application Document that identified issues for study. Meetings with stakeholders and a work group guided study plan preparation during summer 2006. A revised study plan was developed in October 2006, and approved by FERC letter in November 2006.

This report addresses the likelihood of impingement, entrainment, and turbine mortality at the Claytor Project within a comprehensive review of relevant biological and physical factors at the project. The overall approach to this assessment is, for three tasks, to review existing literature relative to the species of management interest in the Project reservoir, and evaluate the potential for entrainment, impingement, and turbine mortality of fishes relative to Project facilities and structures. The three literature-based tasks are:

1. Review swim speed and intake avoidance behavior literature for the identified fish species of principal management interest.
2. Review existing evidence of impingement and entrainment problems associated with the current operating regime.
3. Review other projects of similar design for impingement and entrainment problems and perform a comparative analysis to the Claytor Project.

A fourth task represents a field component that will measure intake velocity profiles at various reservoir locations during maximum and “most efficient” hydraulic capacities. The field measurements and analyses will be used to establish threshold velocities relative to individual key species’ burst swimming ability identified in the initial literature-based task listed above.

Via the study plan development process, eleven fish taxa have been identified as the basis for analysis in this report: juveniles and adults of striped bass, striped bass hybrids, gizzard shad, largemouth bass, smallmouth bass, spotted bass, white bass, walleye, black crappie, bluegill, and alewife. The Virginia Department of Game and Inland Fish (VDGIF) manages the reservoir’s fisheries.

2.0 PROJECT DESCRIPTION AND GENERAL APPROACH

The Claytor Project consists of a single conventional hydroelectric development located on the New River in southwestern Virginia (Figure 2-1). The Claytor Project dam is located at river mile (RM) 252. Claytor Lake, the project reservoir, is a sinuous, riverine impoundment 21.7 miles long with a surface area of 1,810 hectares (4,472 acres) at a normal full pool of 1,846 ft NGVD (AEP 2006). Claytor Lake features one long, narrow tributary arm (Peak Creek) and several smaller tributary creek embayments located mainly in the lower half of the lake. Claytor Lake is located near Radford, Virginia and was impounded in 1939. More detailed information is provided below.

2.1 CLAYTOR LAKE DESCRIPTION AND CHARACTERISTICS

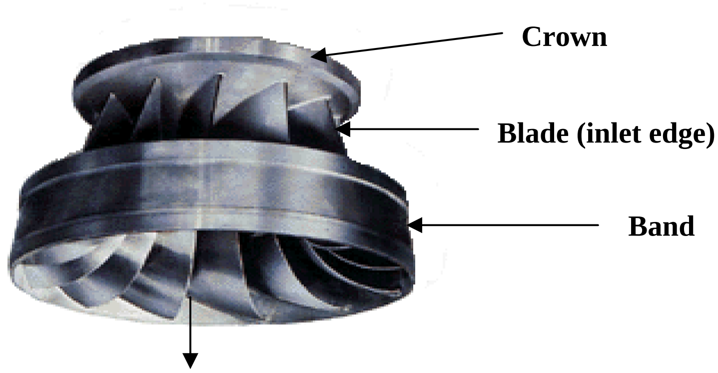
Claytor Lake covers 4,472 acres with a maximum and mean depth of 115 ft and 49 ft, respectively (Table 2-1). Lake depth at the dam is reported at 124 ft. The main lake shoreline is rocky and steep-sided. Shallow littoral areas are limited and generally confined to coves and lake areas upstream of Lighthouse Bridge (Figure 2-1) (Kohler et al. 1986; Rash 2003; Copeland 2004). Normal daily and weekly fluctuations in water surface elevation due to generation are less than 1 ft and 2 ft, respectively (Appalachian 2006). A fall drawdown of 5 ft is scheduled annually to permit shoreline landowners to access and repair dock supports, etc.

Claytor Lake is considered moderately eutrophic (Copeland 1999), or nutrient enriched (Appalachian 2006). Temperature and dissolved oxygen stratification occurs in summer, and is particularly strong during summers with low inflow. Water quality monitoring near Claytor Dam shows that dissolved oxygen depletion by late summer typically occurs between depths of 5 to 10 m (16-33 ft) to the bottom (Appalachian 2006).

2.2 PROJECT FACILITIES

The Claytor Project powerhouse contains four Francis-type generating units each with a maximum and “most efficient” hydraulic capacity of 2,500 and 2,000 cfs, respectively (Table 2-1). Normal operating head (rated net head) is 116 ft (Table 2-2). The submerged intakes for the four units extend from 14 ft to 61 ft below the surface at normal full pool (Table 2-1; Figure 2-2). Each unit is screened by 0.5 in bar racks with 4.0 in clear spacing (Table 2-1). An historical reference photo is also provided for additional perspective showing the relationship among the intake area, spillway section, and lake bottom (Figure 2-3).

Francis turbine runners (example below) consist of a series of vertically arranged, curved, fixed metal blades. Claytor turbine runners have 15 blades, or “buckets”. Water under high to moderately high pressure flows down through the blades and makes the turbine spin. Water flow from the intakes is delivered to the turbine through the penstock and is controlled by wicket gates (Claytor has 18 wicket gates) that surround the runner. Index testing determines the best wicket gate setting (percent opening, or most efficient setting) to deliver the optimum output. Water exits the turbine through a draft tube to the tailrace. Major parts of the runner are labeled in the figure below.



The approach velocity at the submerged intakes was estimated from calculations shown on the original project drawings. Estimated approach velocity in front of the trash racks, where fish initially encounter the project intakes, was calculated as 1.5 ft/s (Table 2-1). Velocity at the racks (located several feet inside the maximum intake opening) was calculated as approximately 2.4 ft/s. Water velocity accelerates during passage past the bar racks and through the penstocks as the penstock cross-sectional area further decreases. Additional intake velocity data obtained from planned field studies is discussed in Section 3.2.

The calculated intake velocity information shown in Table 2-1 reflects data that were unavailable during study plan preparation. At that time an engineering analysis of intake flows was planned to augment the field intake velocity studies. The discovery of the project drawings that contained intake velocity estimates meant that the engineering analysis was no longer necessary. Thus, the engineering analysis portion of the study plan was dropped.

2.3 FISH POPULATIONS AND MANAGEMENT SPECIES

Fisheries data for Claytor Lake were summarized for the Pre-Application Document by Copeland (2005). At least 24 native and introduced taxa characterize the known fish assemblage, although numerous additional species (e.g., minnows and darters) likely occur but are undocumented since sampling locations and sampling gear generally targets game fish for management assessments (Copeland 2005). Game species include largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieu*), spotted bass (*M. punctulatus*), striped bass (*Morone saxatilis*), striped bass hybrids (*M., chrysops* x *M. saxatilis*), crappie (*Pomoxis* spp. mostly black crappie, *P. nigromaculatus*), and walleye (*Sander vitreus*). Striped bass, hybrid striped bass, and walleye historically have been maintained through stocking. Recent (since 2001) stocking densities for striped bass have been about 13 to 17 fingerlings per acre, whereas hybrid striped bass stocking density has been 7.5 fish per acre over the same period. Walleye stocking was discontinued in 1996, then resumed in 2004 (Appalachian 2006). Various sunfishes (*Lepomis* spp.) and catfishes, including channel catfish (*Ictalurus punctatus*) and flathead catfish (*Pylodictis olivaris*) are also abundant.

The principal forage species include introduced gizzard shad (*Dorosoma cepedianum*) and alewife (*Alosa pseudoharengus*), in addition to young and smaller individuals of other species such as crappie and bluegill. Alewife was introduced concurrently with striped bass as pelagic forage in the late

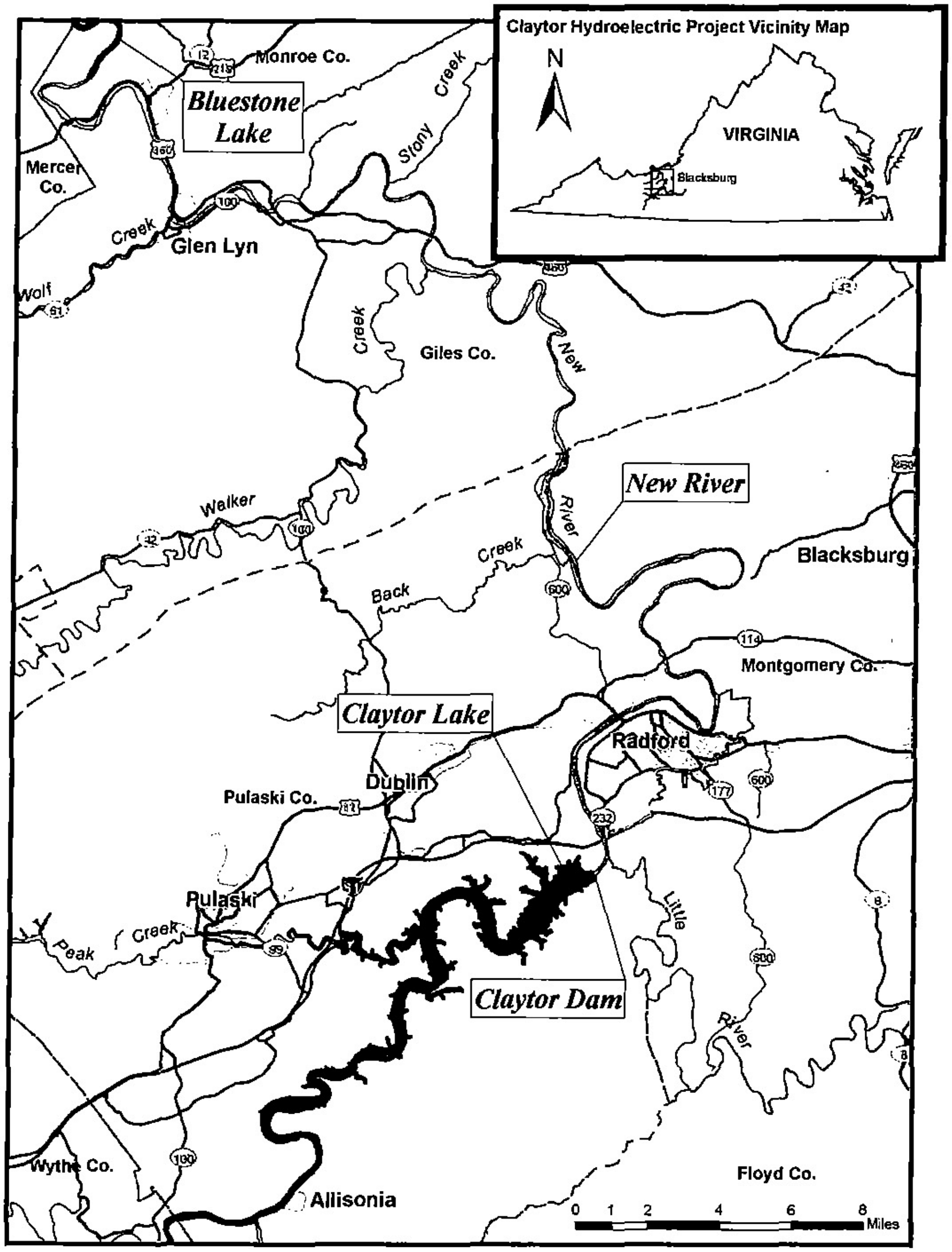


Figure 2-1. Claytor Hydroelectric Project location in Virginia.

Table 2-1. Reservoir and intake characteristics of the Claytor Hydroelectric Project.

Development	Surface Area-full pond (acres)	Maximum and (mean) depth-ft	Normal Full Pond Elevation[1] (ft)	Intake Elevations[1]			Unit Intake Width (ft)[3]	Individual Unit[3] Screened Area (sq ft)	Trash Rack Bars		Number of Units Operating	Design Hydraulic Capacity (cfs)	Normal[2] Operating Discharge (cfs)	Approach Velocity (ft/s)[4]
				Top (ft)	CL (ft)	Bottom (ft)			Width (in)	Clear Spacing (in)				
Claytor Project	4,472	115 (49)	1,846.00	1,832.00	1,808.50	1,785.00	34.0	1,598.0	0.5	4.0	1	2,500	2,000	1.50
							34.0	1,598.0			2	2,500	2,000	1.50
							34.0	1,598.0			3	2,500	2,000	1.50
							34.0	1,598.0			4	2,500	2,000	1.50
Project Totals								**6,392.0**				**10,000**	**8,000**	

Notes:

1. All elevations are USGS datums.
2. Normal hydraulic capacity (turbine discharge) at most efficient point (MEP).
3. Each unit has two intake bays, each 17 ft wide x 47 ft high.
4. Calculated velocity in front of racks at intake plane.

Table 2-2. Physical and hydraulic characteristics of turbines at Claytor Hydroelectric Project.

Unit Number	Turbine Type	Design Head (ft)	Individual Unit Design Flow (cfs)	No. of Blades/ Buckets	Runner Diameter (ft)	Runner Speed (rpm)
1, 2	Vertical Francis	116	2,000	15	10.9	138.5
3, 4	Vertical Francis	116	2,000	15	11.2	138.5

Notes:
1. Design flow (turbine discharge) at most efficient point (MEP).
2. Runner diameter (ft) at inlet.

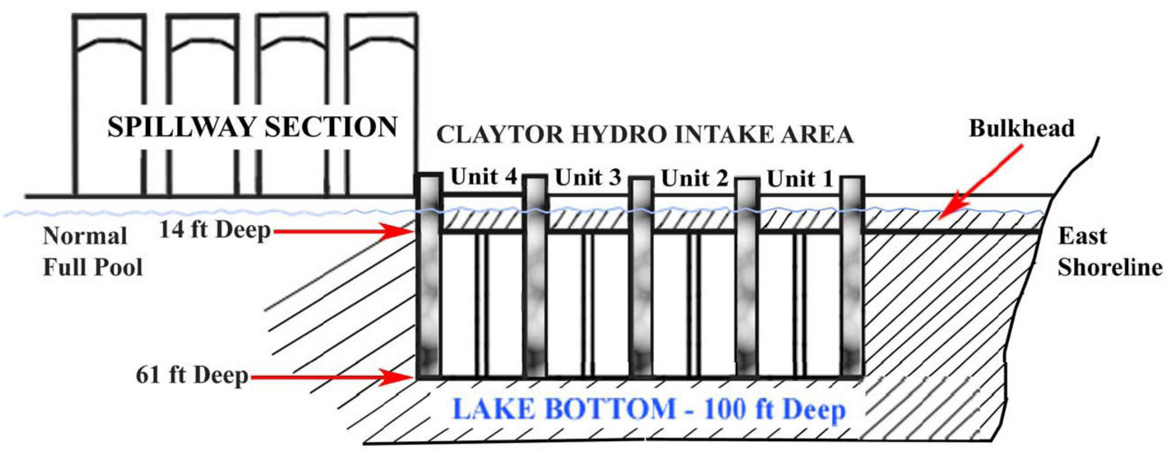


Figure 2-2. Representative drawing of Claytor Hydro Project intake area.

1960s (Kohler et al. 1986). Gizzard shad were introduced by anglers in the late 1980s (Copeland 1999).

Recreational fishing for the three black bass species in Claytor Lake comprised 58% of the 330,000 angler hours expended in the most recent creel survey (Copeland 2000). Angling for *Morone* spp. formed nearly 10% of targeted effort, followed by effort for catfishes (7%) and panfish (5%). Angler catch was dominated by bluegill, followed by the three black basses. Angler harvest was also principally bluegill, followed by channel catfish and black crappie. In terms of retention rate, however, anglers favored channel catfish (81%), walleye (73%), and flathead catfish (67%).

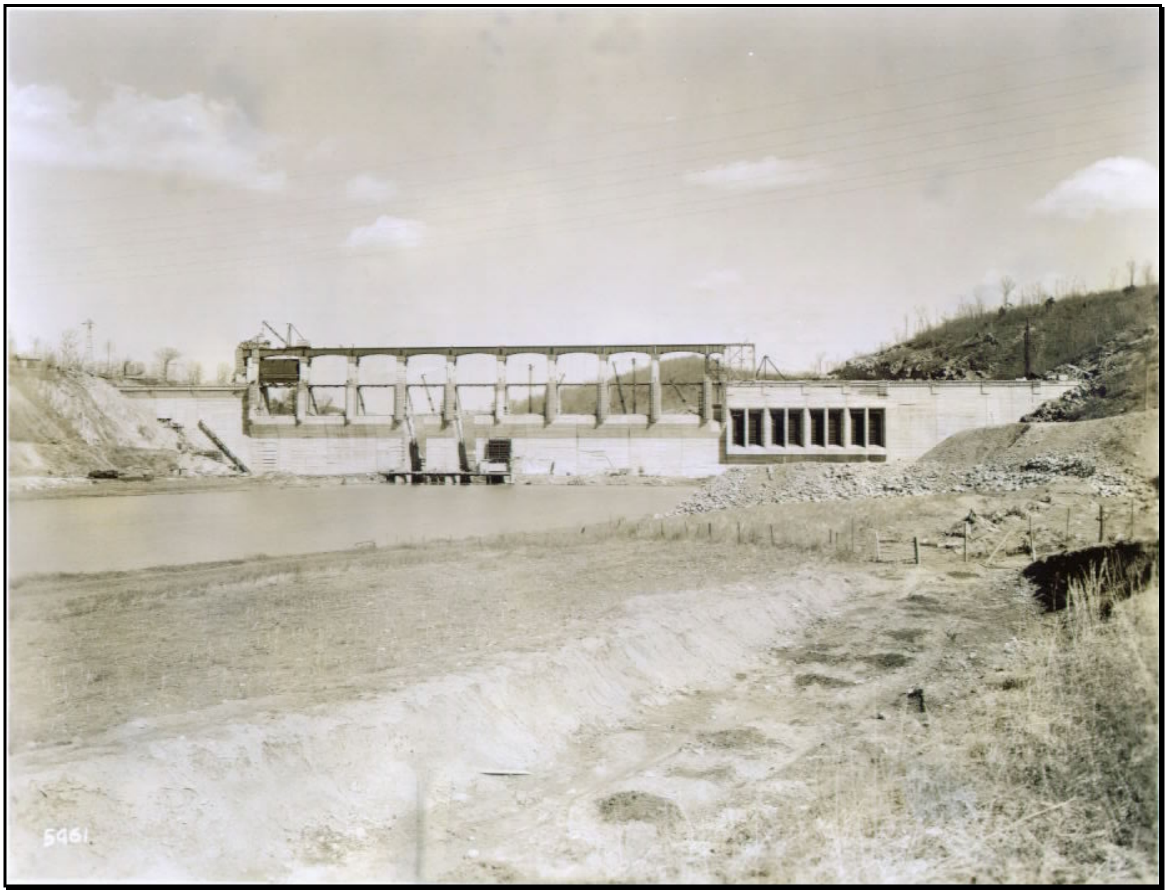


Figure 2-3. Reference photo of Claytor intakes and spillway area during project construction.

2.4 SPECIES OF SPECIAL CONCERN

No rare, threatened, or endangered fish species are known from Claytor Lake (Appalachian 2006).

2.5 CURRENT EVIDENCE OF ENTRAINMENT AND IMPINGEMENT PROBLEMS

2.5.1 Brief Description of Operations

The Claytor Project is operated primarily to provide peaking power, particularly during the cooler months from mid-October through mid-April. During the warmer months from mid-April through mid-October, considered the prime recreation season, peaking is voluntarily limited (pool levels are maintained within 1 ft of full pool) to stabilize river levels for water-based recreation in the New River downstream of the dam. Additionally, water levels in the lake during 15 April to 15 June are maintained between 1,844 ft and 1,846 ft (full pond) to promote fish reproduction in shallow shoreline areas.

2.5.2 Evidence of Entrainment and Impingement Problems

Direct evidence of fish emigration out of Claytor Lake is limited to 1) capture by anglers and biologists of adult striped bass and striped bass hybrids in dam tailwaters and New River reaches further downstream (Copeland 1999; Kilpatrick 2003), 2) establishment of alewife in Bluestone Lake at least 100 km downstream of Claytor Lake (Kohler 1982), and 3) capture of moribund alewife during passage through turbine penstocks (Boaze and Lackey 1974). Gizzard shad were also noted as emigrants out of Claytor Lake into the New River and downstream reservoirs by Bonds (2000). Among these lines of evidence, alewife clearly are subject to turbine entrainment due to passage through penstocks noted by investigations during the 1970s (e.g., Boaze 1972). For the other species, evidence is indirect since timing and routes of travel (turbine route or spill) have not been established.

Survival of stocked striped bass during passage out of Claytor Lake has resulted in consistent sport fishing captures in the tailrace (primarily) as well as for a considerable distance downstream of the Project. However, radio telemetry and conventional tagging efforts by Kilpatrick (2003) were unable to determine whether striped bass caught in the tailrace were entrained as juveniles or adults, or the emigration route utilized by either life stage. Kohler et al. (1986) speculated that striped bass in Claytor Lake were susceptible to entrainment (= “emigration”) due to comparatively short water retention times. Alewife in Claytor Lake are prone to die-offs during cold winters (Kohler and Ney 1981) and become susceptible to turbine entrainment as they lose swimming ability in cold water (Boaze and Lackey 1974).

Impingement of fishes on project structures (trash racks) has not been noted. Given the wide bar rack spacing (4-inch) and submerged intake depth (14 ft at top), fish impingement would be unlikely. Fish lacking the swimming ability to avoid the intakes would be expected to pass through the bar racks and not be impinged upon them. See Section 3.0 (below) for information on fish swimming capabilities.

3.0 SWIM SPEED LITERATURE REVIEW AND FIELD VELOCITY DATA

3.1 FISH SWIM SPEEDS

Avoidance of fish entrainment and impingement problems at water intakes is related to fish size and swimming performance (Castro-Santos and Haro 2005). We conducted a literature review of swim speed information for eleven fish species that inhabit the Claytor Hydro Project reservoir. The purpose was to compare available swim performance data for these species to in-situ measurements of current velocity obtained proximal to the project's intakes (see Sections 3.2 and 3.3).

Nine Claytor Lake fish species evaluated for swim performance represent the principal targets of fisheries management efforts by VDGIF as well as the focus of angler interest , including juvenile and adult striped bass and hybrid striped bass, largemouth bass, smallmouth bass, spotted bass, white bass, walleye, bluegill, and black crappie. Gizzard shad, alewife, and young bluegill and other *Lepomis* (sunfish) represent the principal forage for these game species.

Three swim speed modes are generally recognized for fishes. Sustained swim speed is that maximum speed sustainable indefinitely, or for at least 200 min (Beamish 1978). Prolonged swim speed represents continuous, faster swimming that ultimately results in fatigue after at least 20 seconds. Laboratory testing of prolonged swim speeds for specific time intervals, frequently related to an expected or required time required to pass through fishways or culverts, results in estimates of critical swim speed (U), accompanied by a time stamp (e.g., $Ucrit_2$ = maximum prolonged speed for 2 min). Burst, or sprint swim speeds, results in fatigue after no more than 15-20 seconds or less (Beamish 1978; Bell 1991). Burst or sprint swim speeds (also startle, fast-start, or dart) are the fastest attainable, and are also those generally associated with fish well-being or survival (Beamish 1978; Wardle 1980), as they are also related to a fish's ability to capture prey, avoid predators, or in the present case, avoid water intake velocities or structural elements. Among the three swim speed modes, burst swim speed is harder to quantify in a laboratory, and, thus, fewer burst swim speed studies with adequate sample sizes are available (Castro-Santos and Haro 2005).

Utilization of burst swim speed to avoid water intakes also implies the ability to use additional sensory mechanisms to properly detect and orient to the intake. Available stimuli near an intake, in addition to the physical structure, include turbulence, flow acceleration, pressure changes, sound, etc. (Castro-Santos and Haro 2005). The ability to utilize available cues to avoid intake structures or flow fields may be compromised by darkness or turbidity, for example, or reduced swimming ability as water temperatures approach or exceed cold water tolerances.

The swim performance data in Table 3-1 clearly identify two trends for any given species. First, the swimming speed of larger juveniles or adult fish is faster than smaller juveniles. Second, water temperature also plays a role, and swim speed for several species appears maximized at approximately 20-30°C, typical late spring to fall ambient water body conditions. A reduction in swimming ability of 50% may occur at water temperatures outside a preferred range (ASCE 1995). Typically, reduced swimming ability only becomes a concern at water intakes in temperate latitudes as winter approaches.

Swim speeds determined in the laboratory are typically measured by a distance rate, e.g., feet/sec, for a given fish length range or measure of length central tendency (mean, median). However, in

Table 3-1. Reported swimming speed of fishes for the Claytor Hydroelectric Project

Species	Life Stage	Fish Size	SWIM SPEED-feet per second-ft/s Max. Sustained	Prolonged or Critical	Burst or Startle	Literature Source-Comments-Clarification
Striped bass	juv	1 in	0.83			Kerr 1953, cited in Clay 1961
	unknown				12-18L/sec	Kerr 1953, cited in Hocutt 1973.
	juv	1-3 in	~1.9			from Figure 88 in Clay 1961--100% swimming @ 10 minutes.
	juv	32-63 mm FL	0.6-1.2			Tatham 1970-draft report; empirical data, 75 & 80F; 3 ppt salinity
	juv	50mm SL		1.91-1.98		2-min critical swim speed, U-crit: Young and Cech 1993.
	fry	0.5 in			0.6	est. from Bell 1991; dart speed maintained for 7.5 sec;
	fry	1 in			1.0	est. from Bell 1991; dart speed maintained for 7.5 sec;
	juv	2 in			2.0	est. from Bell 1991; dart speed maintained for 7.5 sec;
	juv	5 in			5.0	est. from Bell 1991; dart speed maintained for 7.5 sec;
Striped bass	adult	554 FL			14.9*	Haro et al. 2004; @ 17.2C; upstream into fishway-max V tested
Hybrid striped bass	**No swim speed studies located in literature.**					
Gizzard shad	juv	25-50 mm	0.75			Not available
	juv	N/A	2.8**			max water velocity with HSI = 0.1; Williamson and Nelson 1985.
	adult	250-350mm TL			8.0*	measured water velocity at ConoWest Lift-does not exclude adults
Largemouth bass	juv	150mm	0.79 @ 10C			Beamish 1970 in Carlander 1977
		150mm	1.57 @ 30C			
	juv	250 mm	1.51 @ 10C			
		250mm	2.07 @30C			
	juv	75-85mm	1.21-1.34			Dahlberg et al. 1968 in Carlander 1977
	juv	52-64mm TL	0.50 @ 30C	1.63		Hocutt 1973; at 30C;--critical speed was max of tests from 15-35C.
	juv	52-64mm TL		8.08L/sec		Hocutt 1973; at 30C; same study--relative swim speed.
	juv	93-128mm		1.60 (see comments)		U-crit 2 min = 3.5-3.8 BL/s; 15-19C; Kolok 1991
		"		0.92 (see comments)		U-crit 2 min = 2.2 BL/s; 5C; Kolok 1991
	juv	52-64 mm		1.64		Farlinger and Beamish 1977 (cited in Beamish 1978); critical @ 25C
	juv	102 mm		1.50		Farlinger and Beamish 1977 (cited in Beamish 1978); critical @ 25C
	juv	100 mm		1.15		Otto and Rice 1974 (cited in Beamish 1978); critical @ 10C
	fry	20-22mm		0.78-1.02		Larimore and Deuver 1968 (cited in Beamish 1978); prolonged @10-30C.
	juv	57mm		1.01		Larimore and Deuver 1968 (cited in Beamish 1978); prolonged @20C
	lg juv	150-270 mm		1.80-2.17		Beamish 1970 (cited in Beamish 1978); prolonged at 10-30C.
Smallmouth bass	fry	20-25mm		≤0.89		Larimore and Deuver (1968) cited in Carlander 1977 & Houde 1969
	fry	14mm		13-19L/sec		relative prolonged speed; Larimore and Deuver (1968)
	fry	14mm		0.60-0.87		range of prolonged speed; Larimore and Deuver (1968)
	juv	91-93mm		1.3-1.8		Critical swim speed, 2-min U-crit @ 13-23C range; Webb 1998.
	adult	262-378mmTL		1.6-3.9		Critical swim speed, U-crit-10 min @ 15-20C; Bunt et al. 1999.
Spotted bass	**No swim speed studies located in literature.**					

(continued)

Table 3-1. (Continued)

Species	Life Stage	Fish Size	SWIM SPEED-feet per second-ft/s Max. Sustained	Prolonged or Critical	Burst or Startle	Literature Source-Comments-Clarification
White bass	adult	313mm TL		3.94		critical swim speed; U-crit-10 min; Tunink 1975; Schmulbach et al. 1981; both cited in Wilcox et al. 2004.
Walleye	fry	12mm TL	0.16			18.3C; Houde 1969
	fry	20mm TL	0.25			13C; Houde 1969
	juv	80mm FL		1.24		Jones et al. 1974; critical swim speed @18-20C for 10-min
	lg. juv	317mm FL			11.0*	Haro et al. 2004; @ 10.3C; able to enter fishway at this V (max tested)
	adult	380mm FL		2.74		Jones et al. 1974; critical swim speed @ 18-20C for 10-min
	juv	160mm FL			6.02	Fast-start or startle speed; calc. from formula in Peake et al. 2000.
	adult	350mm FL			7.20	Fast-start or startle speed; calc. from formula in Peake et al. 2000.
	adult	570mm FL			8.57	Fast-start or startle speed; calc. from formula in Peake et al. 2000.
Alewife	juv	2.5-3 in			~3.0	est. from Bell 1991; dart speed maintained for 7.5 sec;
	adult	250mm TL			11.5-16.4	range of burst swim speed in fishway; Dow 1962 cited in Beamish 1978.
	adult	235mm FL			11.2*	Haro et al. 2004; @ 11.2C; able eto enter fishway at this V (max tested)
Herring (spp. ?)	fry	0.8 in			1.0	est. from Bell 1991; dart speed maintained for 7.5 sec;
	adult	6-11 in	~5.0		~6.7	est. from Bell 1991; dart speed maintained for 7.5 sec;
Bluegill	juv	25-40 mm FL	0.3-0.75			Schuler 1968; S/max = minimal swim speed in natural environment; most tests ≥ 60F.
	juv	39-44 mm FL	0.48-0.52			King 1969; S/max = minimal swim speed in natural environment; 79-85F.
	juv	51-54 mm		0.92		tested at 21C; Beamish 1978
	adult	203 mm TL	1.0			Deng et al. 2004
	adult	unknown	0.98			Drucker and Lauder 1999
	adult	100-150 mm TL		1.22		Critical swim speed for 10-min; Gardner et al. 2006
	adult	153 mm TL			4.3	Webb 1978; final velocity measured after 9-sec burst over short distance
Black crappie	**No swim speed studies located in literature.**					
Black crappie	juv	78 mm TL	0.5L/sec***			Assumed foraging swim speed, slower than sustained (Chick and Van Den Avyle 2000)
White crappie	juv	55-100 mm FL	0.50-0.75			S/max speed likely minimal sustained; 70-83F; Schuler 1968.
	juv	75-81 mm FL	0.54-0.61			S/max speed likely minimal sustained; 76-79F; King 1969.
	juv	77 mm SL		0.52		U-crit 60 min @ 25C; Smiley and Parsons 1997.
	juv	77 mm SL		0.18		U-crit 60 min @ 5C; Smiley and Parsons 1997.

* Values cited represent measured current velocities (V) that fish were able to negotiate at a fishway entrance.
** Estimated from HSI curve in source literature.
***Assumed swim speed, not from laboratory test.

recognition of the role of fish size in swim performance, much information on burst swim speed may also be expressed as fish body lengths/sec (L/sec), termed “relative burst speed”. Smaller sized fish typically have a higher relative swim speed (more body lengths per second) than larger fish, even though the absolute swim speed of larger fish is faster.

The data listed in Table 3-1 include studies specifically designed to measure one or more component of swim speed or performance, as well as other studies, typically more recent, that measure swim speed in relation to one or more variables, such as temperature changes, dissolved oxygen levels, etc. Where a temperature range or specific test temperature is provided, these are indicated. For others with a range provided, the maximum swim speed attained was listed along with the appropriate temperature. Where other conditions were tested, such as physically-conditioned fish versus non-conditioned fish, the data from non-conditioned fish were used as they best represent wild fish (Young and Cech 1993). Few studies were noted that tested fish with an objective of developing a water intake design, or tested vs intake design criteria (e.g., Tatham 1970; Hocutt 1973). In general, the comments or clarifications provided in Table 3-1 identify any information deemed useful to assist interpretation of the test result.

For several species in Table 3-1, a listed burst swim speed was based upon successful upstream passage through a maximum water velocity at an actual or simulated fishway entrance, without an accompanying estimate of the actual swim speed attained (e.g, data for three species from Haro et al. 2004; adult gizzard shad data). We interpreted these data to represent a minimum estimate of burst swim speed for the species considered.

3.1.1 Striped bass

Burst swim speed estimated for juvenile striped bass ranged from 2.0 to 5.0 ft/s, depending on fish length (Table 3-1). Fingerling striped bass stocked by VDGIF in Claytor Lake in June typically measure 25-50-mm TL (average about 41 mm), or 1 to 2-inches (Rash 2003; Copeland 2005). Thus, the burst swim speed shortly after stocking would approximate 2.0 ft/s, based upon data provided in Bell (1991). As the stocked juveniles grew to 5 in TL during their first year, estimated burst swim speed would increase to 5.0 ft/s.

No estimates were found of actual burst swim speed for adult striped bass. However, Haro et al. (2004) tested the ability of comparatively small adult striped bass (mean FL = 554 mm, appropriate for an adult male striped bass) to enter a simulated fishway and pass upstream (the test flume is well described) over a range of current velocities. The maximum current velocity tested in the flume was 14.9 ft/s. We interpreted that this value represents a minimum burst swim speed for adult striped bass, since test fish were able to penetrate 5 to 6-m into the test flume.

3.1.2 White bass x striped bass hybrids

Hybrid striped bass are stocked later in the season and at a larger size than striped bass, typically in late summer or early fall at approximately 3 in TL or longer (Rash 2003; Copeland 2005). Thorough searching revealed no available swim performance data for hybrid striped bass in the published literature. Given their comparability in habits with juvenile striped bass (Rash 2003), plus acknowledged greater hardiness and fighting ability as adults (Gleason 1982) relative to striped bass, their swimming ability should approach or be comparable to that of striped bass. Therefore, as stocked 3-in fingerlings, burst swim speed is likely between 2.0 to 5.0 ft/s, based on data in Bell

(1991). Similarly, an adult hybrid striped bass measuring 554 mm FL, as for striped bass cited in Haro et al. (2004) above, may be able to achieve a burst swim speed near 14.9 ft/s. This estimated swim speed for adult striped bass, however, is substantially higher than the burst swim speed estimated for adult white bass (7.9 ft/s), typically the male parent in the cross (see Section 3.7 below). As a result, a reasonable approximation of adult burst swim speed for hybrid striped bass would be the mid-point of the two estimates, or approximately 11.4 ft/s.

An estimated swim speed near 11 ft/s for larger striped bass hybrids also appears reasonable based on numerous captures of a wide size range of yearling and older hybrid striped bass in a Maryland fishway (see Section 3.3 below). Water velocities at the fishway entrance are typically maintained near 8 ft/s to attract adult alosids.

3.1.3 Gizzard shad

We located no estimates of burst swim speed for either juvenile or adult gizzard shad. However, gizzard shad represent the most common species caught in a fishway located at Conowingo Dam on the Susquehanna River in Maryland. Fishway entrance current velocities have been measured historically to assist in capture of American shad, the primary target species. Measured current velocities of 8 ft/s represented no barrier to adult gizzard shad (estimated TL = 250-350mm) passage into the fishway entrance. We interpreted that this value represents a minimum burst swim speed for adult gizzard shad. A burst swim speed estimate for juvenile gizzard shad would likely be less than 8 ft/s, based upon information in Table 3-1 and trends for other species actually tested.

Two behavioral factors related to gizzard shad must also be acknowledged. First, gizzard shad are a schooling species. Schooling behavior confers enhanced survival (through presumably better swimming ability) as opposed to swimming as individuals (Boyd and Parsons 1998). Because of this schooling behavior, gizzard shad are prone to entrainment in large numbers. Second, gizzard shad are affected by low water temperatures (Williamson and Nelson 1985). During cold winters gizzard shad become increasingly moribund as water temperatures decline below 14°C (56°F), and die-offs of juveniles and adults occur at or below 3.3°C (38°F). Thus, the swimming ability of either life stage, and the ability to avoid entrainment, may be compromised during colder winters.

3.1.4 Largemouth bass

Although a common test animal in swim speed studies, we located no estimates of burst swim speed for either life stage of largemouth bass, perhaps because largemouth bass are not typically thought of as riverine nor a common user of fishways, often a stimulus for burst or sprint swim speed testing. The study by Hocutt (1973) tested juvenile largemouth bass swim speed for a proposed water intake on a reservoir. A range of studies cited in Table 3-1 identified critical swim speed for small juvenile largemouth bass (52-102 mm) of approximately 1.01-1.64 ft/s, within a temperature range of 15-30°C. Prolonged swim speeds of large juveniles to perhaps small adults (150-270 mm) were faster, within the range of 1.80-2.17 ft/s. These speeds are faster than typical water intake design criteria used on reservoirs or rivers where intakes are usually oriented parallel to flow.

Burst swim speed for juveniles would be faster than either of these estimated for prolonged or critical swim speed (above). Bell (1991) estimated that prolonged (= sustained in his terminology) swim speed was 50 % to 70 % of dart (burst) speed. Applying Bell's "50% criteria", an estimate of burst swim speed for small (52-102 mm) and large juvenile (150-270 mm) largemouth bass would be from

3.2 to 4.3 ft/s. Burst swim speed for adult (e.g., ≥ 305 mm) largemouth bass would be expected to be faster than for the larger juveniles.

3.1.5 Smallmouth bass

No studies of burst swim speed for smallmouth bass were located. Several studies that developed estimates of prolonged swim speed were identified and reported in Table 3-1. The maximum prolonged swim speed for juvenile smallmouth bass up to 93 mm long was 1.8 ft/s. A maximum critical swim speed (subset of prolonged swim speed) estimated for adult smallmouth bass up to 378-mm TL was 3.9 ft/s. Again using the "50% criteria" from Bell (1991), a maximum estimate of burst swim speed for juvenile smallmouth bass is 3.6 ft/s, and 7.8 ft/s for adult smallmouth bass.

3.1.6 Spotted bass

No estimates of swim speed for spotted bass were located in the fisheries literature. Spotted bass prey preferences and diets are similar to smallmouth bass, but spotted bass habitat preferences are considered intermediate between their congeners (Jenkins and Burkhead 1993). It is reasonable to assume that swim speeds may also be intermediate between those estimated for largemouth and smallmouth bass.

A minimal estimate of burst swim speed for juvenile largemouth bass is 3.2 ft/s, and approximately 3.6 ft/s for juvenile smallmouth bass. Therefore, an intermediate estimate of burst swim speed for juvenile spotted bass would be approximately 3.5 ft/s.

A minimal estimate of burst swim speed for small adult largemouth bass is 4.3 ft/s. Burst swim speed for adult smallmouth bass was estimated to be 7.8 ft/s. A reasonable estimate of burst swim speed for adult spotted bass would be approximately 6 ft/s, the midpoint of swim speeds estimated for the congeners.

3.1.7 White bass

No studies of burst swim speed for white bass were located. One estimate of the critical swim speed for adult (313 mm TL) white bass was 3.94 ft/s (Table 3-1), in reference to upstream passage of white bass through Mississippi River Corps of Engineers dams (Wilcox et al. 2004). Using the "50% criteria" from Bell (1991), an estimate of burst swim speed for adult white bass would be approximately 7.9 ft/s. The burst swim speed for juvenile white bass would likely be less than 7.9 ft/s due to their smaller size.

3.1.8 Walleye

Walleye swim speed information was comparatively abundant for walleye sizes ranging from larval (12-20 mm TL) to large adults (570 mm FL). However, burst swim speed data or estimates were available only for juveniles and adults larger than 160-mm FL (Table 3-1).

Peake et al. (2004) tested the burst swim speed of walleye by startling (tail-touching) walleye in a holding tank and measuring their movement rate by video. The term "fast-start performance" was assumed synonymous with burst swim speed, and was found to increase linearly with fish size. The estimates of burst swim speed ranged from 6.02 ft/s for 160-mm FL walleye to 8.57 ft/s for 570-mm FL walleye, and were calculated from the regression equation "Speed (m/s) = 1.53 + 1.90*(fish FL in m)". Tabulated data were converted to English units in Table 3-1.

Haro et al. (2004) tested walleye swimming ability to enter a simulated fishway entrance, and walleye were able to enter the test flume at current velocities up to 11.2 ft/s, the highest velocity tested for walleye. As for the striped bass (Section 3.1 above) tested in the same apparatus, 11.2 ft/s may be assumed to represent a minimum burst swim speed for large juvenile walleye that averaged 317-mm FL.

Since loss of small juvenile walleye due to entrainment is often more of a concern than loss of adults, information from Bell (1991) may be applied to data for larval walleye (Houde 1969) to develop a rough estimate of burst swim capability for very small walleye approximating the fingerling size commonly stocked (typically 1-2 inches; Copeland 2005). Bell (1991) estimated that a fish's cruising (= sustained) speed may be 15-20% of the dart (burst) swim speed. Houde (1969) reported a sustained swim speed of 0.25 ft/s for 20-mm TL walleye (Table 3-1). Thus, a conservative estimate of newly-stocked walleye fingerling burst swim speed would be approximately 1.25 ft/s. Similarly, a burst swim speed of approximately 2.5 ft/s may be estimated for somewhat larger juveniles of 80-mm FL, based on the 10-min critical swim speed estimate of 1.24 ft/s (Table 3-1) reported by Jones et al. (1974) and application of the Bell (1991) "50% criteria".

3.1.9 Alewife

Burst swim speeds for juvenile and adult alewife are reported in Table 3-1. The burst swim speed for juvenile alewife (2.5-3 inch; 64-76-mm) was approximately 3 ft/s. Two comparable estimates of burst swim speed were available for adult alewife (235-mm FL; 250-mm TL), both generated in studies of alewife upstream passage in fishways. Dow (1962) estimated a range of burst swim speeds in a fishway of 11.5 to 16.4 ft/s. Haro et al. (2004) tested adult alewife passage in a test flume that simulated a fishway entrance. The maximum water velocity tested at the flume entrance for successful ascent of adult alewife was 11.2 ft/s, which may represent a minimum estimate of burst swim speed.

The burst swim speed estimates derived from Dow (1962) and Haro et al. (2004) were based on typical lengths of adult anadromous alewife. However, adults in land-locked populations such as in Claytor Lake are usually smaller. Further, in Claytor Lake the bulk of alewives are Age-0 or Age-1 fish. Mean TL of alewife at the end of the first growing season may range from 130-160 mm TL, but late-spawning cohorts can be much smaller (Nigro and Ney 1982). Thus, for the bulk of alewives in Claytor Lake, the pertinent swim speed would probably be somewhat less than 11.2 ft/s. Additionally, landlocked alewife are especially susceptible to loss of swimming ability in cold water, so seasonal effects (further loss of swim speed and lethargy in winter) must also be considered.

3.1.10 Bluegill

Swim speed studies of both juvenile and adult bluegill were located. Bluegills are not considered strong swimmers, although tested juveniles oriented well to current (Schuler 1968). Bluegill body morphology is better suited for maneuverability than for fast swim speed (Deng et al. 2004). Sustained swim speeds of 0.3 to 0.75 ft/s were reported for young of year bluegill at typical summer water temperatures by Schuler (1968) and King (1969). Adult sustained swim speed was faster, about 1.0 ft/s (Drucker and Lauder 1999; Deng et al. 2004). Prolonged swim speed of young of year bluegill at 21°C was 0.92 ft/s (Beamish 1978). Critical swim speed of bluegill tested for 10 min, considered sufficient for culvert passage, was 1.22 ft/s, although fish size was not specified (Gardner et al. 2006). The burst swim speed of adult bluegill was estimated at 4.3 ft/s, attained over a 9-sec test period using high speed photography (Webb 1978). However, this speed was reported as a final velocity calculated from an acceleration rate, and may represent a faster speed than might be estimated by more conventional test methods.

3.1.11 Black crappie

No swim speed studies for black crappie were located. However, the swim speed studies of closely related white crappie reviewed below suggested that black crappie may represent the poorest swimmers of the species considered herein.

Juvenile white crappie 55 to 100 mm FL were able to swim at between 0.50 to 0.75 ft/s in tests at typical summer water temperatures (Schuler 1968; King 1969). However, their behavior in the test apparatus suggested poor orientation to current, as many fish tended to drift passively even at low water velocities. Investigators also noted that the swim performance of 80-mm long white crappie was similar to that of 40-mm long bluegill.

The critical swim speed of juvenile white crappie was estimated at 0.52 ft/s at 25°C, but was substantially lower (0.18 ft/s) when tested at 5°C, a typical winter water temperature in Virginia (Smiley and Parsons 1997). No studies of burst swim speed for white crappie were located. Based on the conservative application of the “50% criteria” from Bell (1991), an estimate of white crappie burst swim speed would be 1.0 to 1.5 ft/s. Based on white crappie as an appropriate surrogate, it is likely black crappie swim speeds would be similar.

3.2 FIELD STUDY OF INTAKE VELOCITY

Water current measurements were taken in front of the Claytor Project intakes on April 14, 2008. The intake current data were taken at two flow rates and compared to existing engineering calculations of intake velocity taken from original project drawings. These data were then compared to the swim speed information developed in Section 3.1.

3.2.1 Field Methods

A boat-mounted 300 kHz Acoustic Doppler Current Profiler (ADCP) connected to a laptop PC was used to acquire water current measurements in both horizontal and vertical dimension. The ADCP data system was operated in concert with a differential global positioning system (GPS) that fed data to the ADCP and a navigation software package on a separate PC. The navigation package provided accurate position updates each second. All data systems were clock-synchronized to enable accurate X-Y positioning during data processing.

Data were collected for five transect types at two flow conditions. A discharge of 10,000 cfs represented all four units at maximum output. The 2,000 cfs condition represented one unit at MEP flow. The five transect types included:

- Fixed station vertical profiles in front of each intake; position maintained for approximately 4 minutes.
- Tangential transects run parallel to the intake structure face. Four transects were run per flow, each further away from the intakes.
- Normal transects run perpendicular to each intake, starting near the intake. A pair of transects was run for each intake (each intake has two bays).

- Transects run parallel to the log boom.
- Two far-field transects, approximately 0.5-mile and one mile uplake from the intakes.

A log boom running diagonally uplake from Unit 4 that intercepts surface debris interfered with boat movements during tangential and normal transect runs. Figures in the accompanying full report show the location of the log boom. Transects were completed by positioning the boat outside the log boom to continue data collection. The breaks in positional data are also shown on report figures.

Approach velocity data could not be obtained closer than approximately 40 feet from the intake wall. The ADCP transducers are angled 20° from vertical and signals propagate downward as a cone-shape. The 40-foot distance permitted data acquisition without interference by acoustic reflections off the dam face.

Additional details of the ADCP and GPS data systems are provided in the accompanying field study report prepared by Ocean Data Technologies, Inc.. The full report describes data processing steps, and presents all the data in tabular or graphical detail. The study report also includes all electronic data files on compact disk. Study results are summarized below in tabular fashion for the fixed station profiles, and by representative graphics for both types of near-dam transects. These transects represent the zones of influence for fish entrainment. Results for the log boom and uplake transects are provided in the separate field study report.

3.2.2 Results

All fixed-position profiles were taken at 38 to 75 feet in front of the intakes. The maximum velocities measured at the 10,000 cfs flow condition were 0.60 ft/s to 0.68 ft/s in the upper half of the intake in front of Unit 3 (Table 3-2). Directional data for the fixed profiles in front of Units 1-3 also depict flows heading directly toward the intakes (i.e., at about 45° heading). Current velocities for the single unit MEP flow of 2,000 cfs provided by Unit 4 were substantially less, but also occurred at depths nearest the upper intake elevation (Table 3-3). Current directionality among all profiles at 2,000 cfs was decidedly weaker and inconsistent. Recall that the calculated velocity at the intake face was 1.5 ft/s (Section 2.2). Flow acceleration toward the protective bar racks and potential effects on fish thus occurs mainly within a comparatively short distance in front of the Claytor project intakes.

The results of the tangential and normal transects agreed well with the fixed profile data. Each figure depicts current velocity and flow direction by color code with an accompanying color legend adjacent to the right axis. Figure 3-1 shows the parallel transect closest to the intakes at the 10,000 cfs flow. The maximum velocity was less than 1.5 ft/s, most of the transect contained velocities less than 1.0 ft/s, and the highest velocity component occurred in front of Unit 3. The current velocities further upstream at 10,000 cfs, and along all tangential transects at 2,000 cfs were substantially less. Similarly, for the normal transects the current velocity was highest at the portion of each transect nearest the intake wall. Figure 3-2 shows the highest velocities at 10,000 cfs in front of Unit 2, with velocity decreasing progressively with distance up-lake, as you would expect. In the vertical aspect, both sets of transect profiles showed that current velocities were highest in the upper portion of the intake profile, as also noted for fixed station data. Flow direction at 10,000 cfs was strongest in the North-East quadrant (toward the intakes). The normal transects also show flow directionality weakening with distance up-lake from the intake.

Table 3-2. Speed and direction values for each fixed station profile. CL = approx. centerline.

10,000 cfs Flow Rate

Location ID	Intake 1: F110		Intake 2: F210		Intake 3: F310		Intake 4: F410	
Duration	4.21 min		3.92 min		4.45 min		4.98 min	
Depth (feet)	Speed ft/sec	Direct (deg)	Speed ft/sec	Direct (deg)	Speed ft/sec	Direct (deg)	Speed ft/sec	Direct (deg)
10.1	0.33	28.6	0.44	54.0	0.53	70.7	0.42	100.0
16.6	0.35	34.9	0.47	50.0	0.60	56.6	0.46	88.7
23.2	0.37	38.3	0.46	54.3	0.68	56.4	0.41	85.9
29.7	0.40	38.9	0.46	47.2	0.65	43.4	0.38	78.9
36.3	0.39	36.2	0.52	51.4	0.60	45.0	0.42	84.3
42.9-CL	0.37	36.3	0.37	59.9	0.48	63.8	0.41	94.6
49.4	0.27	44.0	0.42	62.9	0.43	70.7	0.31	109.4
56.0	0.20	61.0	0.41	58.9	0.38	57.2	0.33	85.1
62.5	0.20	54.0	0.23	63.5	0.20	77.0	0.17	119.9
69.1	0.11	57.4	0.11	98.0	0.20	79.4	0.18	121.0
75.7	0.12	81.4	0.18	100.9	0.28	82.4	0.16	114.2
82.2	0.14	74.1	0.18	144.2	0.19	122.8	0.14	206.8
88.8	0.06	241.2	0.29	134.9	0.19	107.4	0.10	198.8
95.3	0.04	259.3	0.32	101.7	0.43	105.3	0.25	245.9

Table 3-3. Speed and direction values for each fixed station profile. CL = approx. centerline.

2,000 cfs Flow Rate

Location ID	Intake 1: F12		Intake 2: F22		Intake 3: F32		Intake 4: F42	
Duration	3.68 min		3.68 min		3.68 min		4.27 min	
Depth (feet)	Speed ft/sec	Direct (deg)	Speed ft/sec	Direct (deg)	Speed ft/sec	Direct (deg)	Speed ft/sec	Direct (deg)
10.1	0.08	55.3	0.11	45.2	0.06	45.8	0.20	98.4
16.6	0.06	331.0	0.12	13.1	0.04	36.5	0.17	50.0
23.2	0.16	322.9	0.09	336.1	0.05	57.6	0.08	18.3
29.7	0.08	292.9	0.09	215.6	0.10	58.2	0.07	290.6
36.3	0.04	228.8	0.03	31.6	0.07	20.4	0.05	101.3
42.9-CL	0.07	323.3	0.03	124.3	0.09	356.9	0.11	21.2
49.4	0.01	45.0	0.18	49.6	0.10	87.8	0.08	328.4
56.0	0.05	306.0	0.11	50.5	0.22	131.2	0.07	236.6
62.5	0.06	331.7	0.15	2.3	0.13	172.2	0.07	4.1
69.1	0.07	202.8	0.10	169.3	0.16	138.8	0.02	293.1
75.7	0.04	114.6	0.08	179.8	0.01	100.8	0.09	342.0
82.2	0.09	202.3	0.05	117.3	0.12	90.2	0.08	334.9
88.8	0.14	176.6	0.07	57.2	0.21	110.1	0.01	276.8
95.3	0.09	179.5	0.15	101.2	0.23	85.2	0.07	27.8

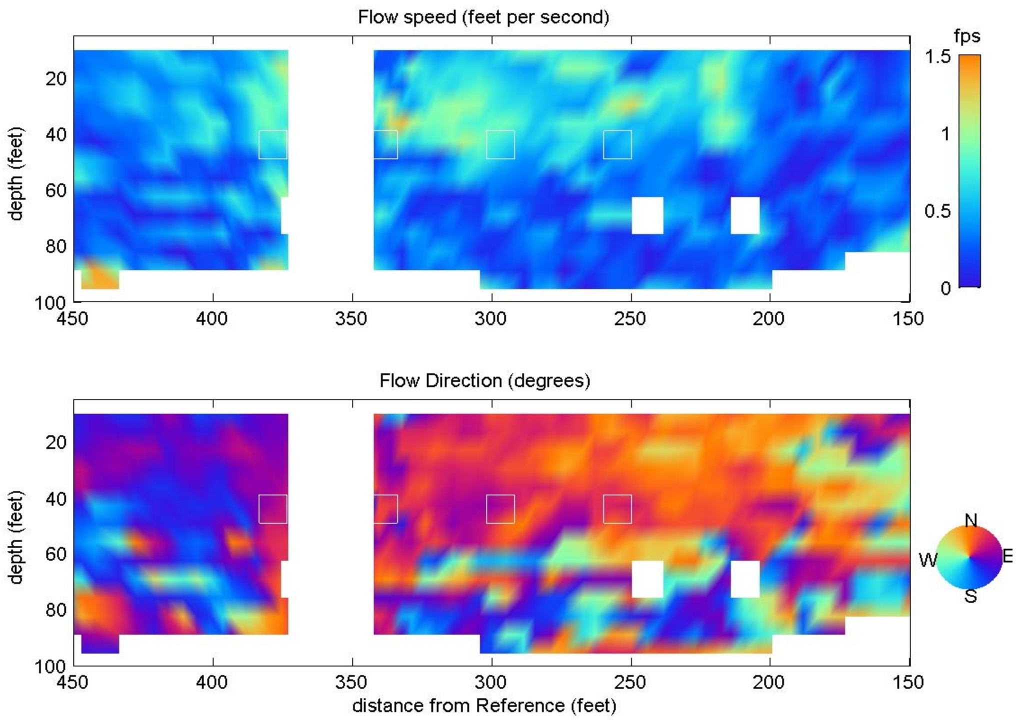


Figure 3-1. (T110) Color-contour section for tangential line (parallel transect) approximately 40 feet off the intake wall for 10,000 cfs condition. Box outline = intake centerline 44 feet deep.

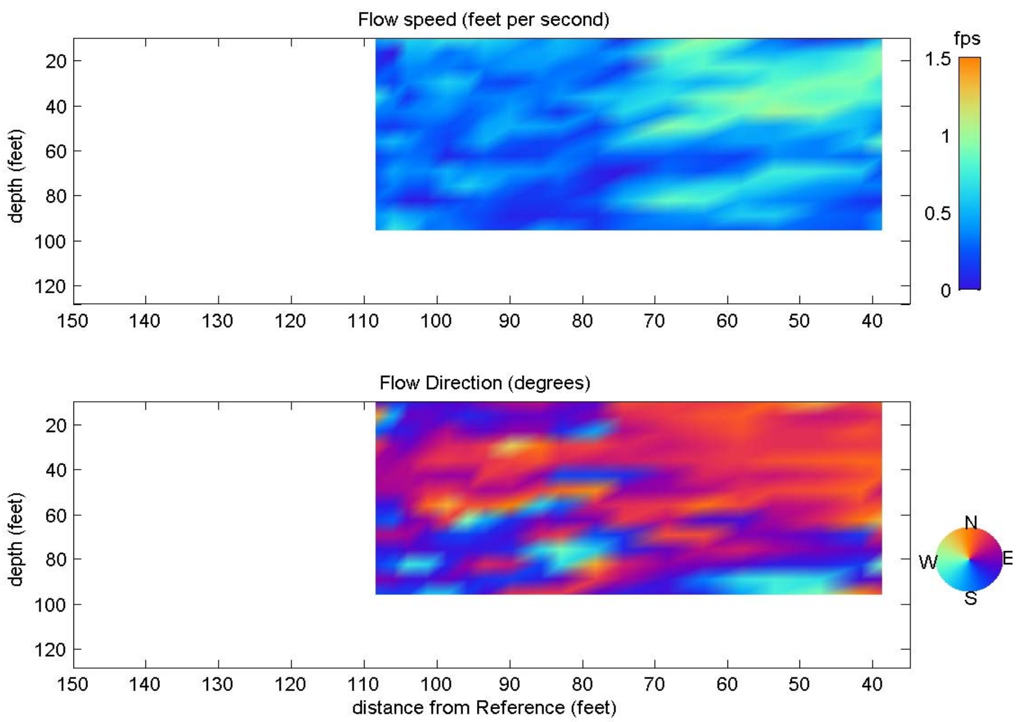


Figure 3-2. (N2A10). Color-contour section for normal line (perpendicular transect) in front of Unit #2 for the 10,000 cfs condition. Distance refers to distance from the face of the intake wall. Intake centerline is 44 feet deep.

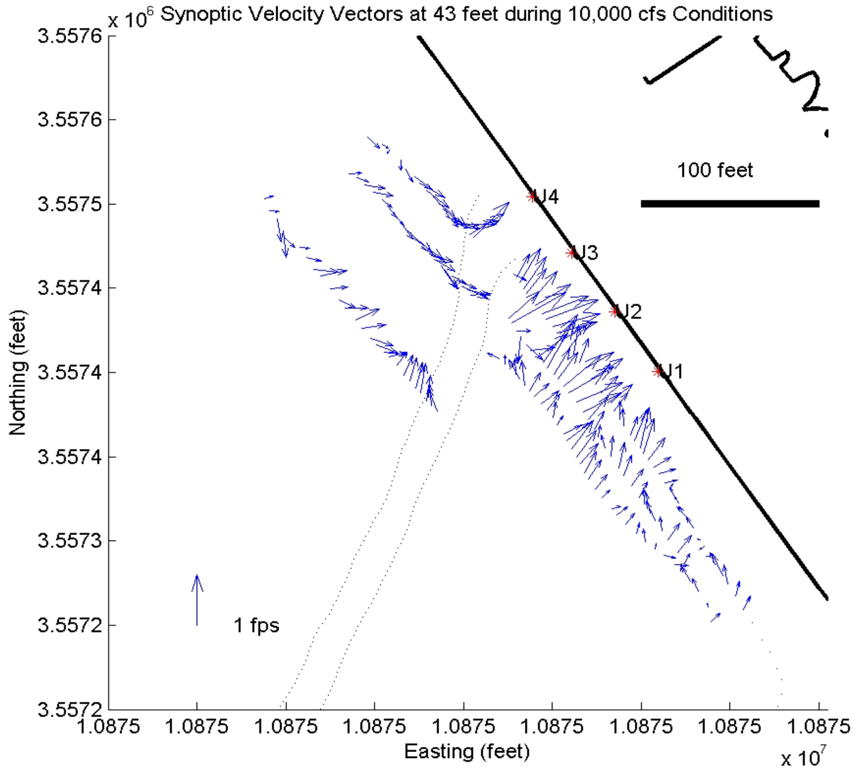


Figure 3-3. (T10-43) Synoptic velocity vectors 43 feet below the surface during the 10,000 cfs condition. Intake bays are labeled U1, U2, etc. Scale arrow in lower left represents the length of a 1 ft/s vector. . ...

The tangential transect data were also used to generate synoptic velocity vectors (arrows) that depict regional flow fields in front of and near the intakes. The vectors point in the direction of the flow and are scaled to current speed (ft/s). Figure 3-3 shows the flow vectors 43 feet deep near the intake centerline at 10,000 cfs. Current flow generally follows a consistent path toward the intakes for Units 1-3. However, flow toward Unit 4 runs parallel to the dam before bending sharply toward the intake. Similar vector direction and speed occurred at the 23-foot depth corresponding to the upper portion of the intakes, but were notably slower at 69 feet deep (see report).

3.3 FIELD VELOCITIES VS FISH SWIMMING CAPABILITIES

Results of field velocity studies near Claytor Lake Dam described above combined with engineering calculations of at-rack intake velocity (Section 2.2) generally depict acceleration of the near-dam water mass from about 75 ft up-lake directly toward the intakes. Intake velocities appeared highest in the upper water column, from about the intake centerline (44 ft deep) to approximately 10 ft deep. In this reach, the water current increases from ≤ 0.5 ft/s to 1.5 ft/s. Velocity was notably less in deeper areas near the intakes. This summarization of intake velocities is shown with summarized fish swim speed information in Table 3-4.

The review of fish swimming ability clearly identified the juvenile period as the life stage most vulnerable to entrainment. However, by mid-to-late summer, larger juveniles of most species are capable of escaping the at-rack velocity of 1.5 ft/s. The exceptions would likely be limited to crappie and late-spawned bluegill. These species are primarily littoral zone residents, however, and therefore generally reside away from the intake area that is located more than 200 ft offshore. Larger juveniles and adults have the swimming ability to avoid intake flow velocities, even during full generation (10,000 cfs).

Newly stocked striped bass and walleye (if stocked) at < 2 inches long are also vulnerable to intake velocities. Although stocked in off-channel areas such as coves, an early summer spate might displace stocked juveniles from typical rearing areas and transport numbers of young downstream toward the intake area, potentially leading to higher losses of stocked fish to the New River downstream of the dam.

Swim performance for several species listed in Table 3-4 was poorer in colder water, as detailed in Table 3-1. For example, swim test results for white crappie at 5°C showed one-third the swimming ability compared to tests conducted at 25°C. Juvenile largemouth bass were also poorer swimmers in cold water. Other species such as alewife and gizzard shad become moribund or succumb at low water temperatures. In either instance, reduction or loss of swimming ability and the behavioral response necessary to avoid intake flows can lead to increased episodes of fish entrainment.

Table 3-4. Comparison of Claytor Lake intake velocity data and synthesis of fish swim speed information.

Velocity Estimate Type	Approach Velocity (ft/s)
Engineering drawing-at rack	1.5
ADCP fixed profile @ 10,000 cfs	0.60-0.68
ADCP fixed profile @ 2,000 cfs	≤ 0.2
ADCP tangential and normal profiles	< 1.5 cfs

Species	Life Stage	Size (in)	Burst Swim Speed (ft/s)
Striped bass	Juv	2 - 5	2.0 - 5.0
	Adult	21.8	14.9
Hybrid striped bass	Swim speed intermediate between striped bass and white bass		
Gizzard shad	Juv		N/A
	Adult		8.0
Largemouth bass	Juv	2 - 4	3.2
	Juv	5.9 - 10.6	4.3
	Adult		N/A
Smallmouth bass	Juv		3.6
	Adult		7.8
Spotted bass	Swim speed intermediate between largemouth bass and smallmouth bass		
White bass	Juv		N/A
	Adult		7.9
Walleye	Juv	~1	1.25
	Juv	3.1	2.5
	Juv	6.3	6.02
	Juv	12.5	11.0
	Adult	22	8.57
Alewife	Juv	2.5 - 3	~3.0
	Adult	9.3	11.2
Bluegill	Juv	2	1.8
	Adult	4 - 6	2.4
	Adult	6	4.3
Crappie	Juv	~3	~1-2

Original swim speed data shown in Table 3-1. Absent a fish size or size range, no specific test was conducted; estimates were derived as described in text.

4.0 COMPARATIVE ANALYSIS OF SIMILAR PROJECTS

Selected project data in Table 2-1 were compared to comparable project data available in the EPRI (1997) database to provide some perspective on the subsequent analyses herein, particularly the potential for entrainment. The EPRI (1997) analysis examined fish entrainment for 43 sites including turbines of both Francis and Kaplan/propeller configurations. The sites represented in the EPRI database are listed in Table 4-1.

The Claytor Project is large compared to the 43 sites reviewed by EPRI. Based on plant capacity (8,000 cfs is the MEP combined flow for the four units at Claytor; see Table 2-1), only one site (Richard B. Russell) exceeded the plant capacity of the Claytor Hydro Project. Further, only one site approached the MEP plant flow capacity (Minetto). Similarly, the MEP flow for an individual turbine unit at Claytor Project (2,000 cfs) was exceeded by only three sampled units. Most (31) sampled units discharged less than 1,000 cfs.

Trash rack spacing for the 43 projects examined by EPRI (1997) is also listed in Table 4-1. Most projects (all but four) had rack spacing narrower than the 4-inch spacing at the Claytor Project. Some sampled sites featured rack spacing as narrow as 1-inch. However, a subsequent examination of rack spacing and fish entrainment catch performed on EPRI (1997) data by Winchell et al. (2000) found that rack clear spacing had little effect on fish entrainment, particularly on the size of fish entrained (Table 4-2).

Table 4-1. Location, hydraulic capacity and trash rack spacing of 43 sites included in the EPRI database.

Site Name	State	River	Total Plant Capacity (cfs)	Average Capacity of Sampled Units (cfs)	Clear Trash Rack Spacing (in)
Belding	MI	Flat	416	208	2
Bond Falls	MI	W.B. Ontonagon	900	450	3
Brule	WI	Brule	1,377	458	1.62
Buzzard's Roost	SC	Saluda	3,930	1,310	3.625
Caldron Falls	WI	Peshtigo	1,300	650	2
Centralia	WI	Wisconsin	3,640	550	3.5
Colton	NY	Raquette	1,503	450	2
Crowley	WI	N.F. Flambeau	2,400	1,200	2.375
E. J. West	NY	Sacandaga	5,400	2,450	4.5
Feeder Dam	NY	Hudson	5,000	1,000	2.75
Four Mile Dam	MI	Thunder Bay	1,500	500	2
Gaston Shoals	SC	Broad	2,211	837	1.5
Grand Rapids	MI/WI	Menominee	3,870	739	1.75
Herrings	NY	Black	3,610	1,203	4.125
High Falls	NY	Beaver	900	300	1.81
Higley	NY	Raquette	2,045	682	3.63
Hillman Dam	MI	Thunder Bay	270	270	3.25
Hollidays Bridge	SC	Saluda	4,396	370	unknown
Johnsonville	NY	Hoosic	1,288	644	2
Kleber	MI	Black	400	200	3
Lake Algonquin	NY	Sacandaga	750	750	1
Luray	VA	S.F. Shenandoah	1,477	369	2.75
Minetto	NY	Oswego	7,500	1,500	2.5
Moshier	NY	Beaver	660	330	1.5
Ninety-Nine Islands	SC	Broad	4,800	584	1.5
Ninth Street Dam	MI	Thunder Bay	1,650	550	1
Norway Point Dam	MI	Thunder Bay	1,775	575	1.69
Potato Rapids	WI	Peshtigo	1,380	500	1.75
Raymondville	NY	Raquette	1,640	1,640	2.25
Richard B. Russell	GA/SC	Savannah	60,000	7,200	8
Saluda	SC	Saluda	812	227	unknown
Sandstone Rapids	WI	Peshtigo	1,300	650	1.75
Schaghticoke	NY	Hoosic	1,640	410	2.125
Shawano	WI	Wolf	850	850	5
Sherman Island	NY	Hudson	6,600	1,650	3.125
Thornapple	WI	Flambeau	1,400	700	1.69
Tower	MI	Black	404	202	1
Townsend Dam	PA	Beaver	4,400	2,200	5.5
Twin Branch	IA	St. Joseph	3,200	600	3
Warrensburg	NY	Schroon	1,350	1,350	unknown
White Rapids	MI/WI	Menominee	3,994	1,225	2.5
Wisconsin River Division	WI	Wisconsin	5,150	431	2.19
Youghiogheny	PA	Youghiogheny	1,600	800	10

Table 4-2. Size composition of entrainment catch by bar rack spacing (after Winchell et al. 2000).

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

* Bar rack clear spacing = 4.0 inches.

5.0 ENTRAINMENT ASSESSMENT

5.1 CHARACTERISTICS AND BEHAVIOR OF SELECTED FISHES

In evaluating entrainment susceptibility and effects, the eleven target species (juvenile and adults of striped bass, hybrid striped bass, gizzard shad, largemouth bass, smallmouth bass, spotted bass, white bass, walleye, alewife, bluegill, and black crappie) were considered separately. Following are brief life history accounts for each of the species considered in this study, with emphasis on their distribution within Claytor Lake.

5.1.1 Striped Bass

Striped bass is a significant recreational species in Claytor Lake, accounting for approximately 10% of angler effort during 1998-1999, the most recent creel survey period (Copeland 2004). The population is maintained by stocking 1 to 2-inch fingerlings during June of each year. Stocking densities since 2001 have been about 13 to 17 fingerlings per acre. Fingerlings were stocked during 2001 and 2002 in two or three coves throughout Claytor Lake, including coves in lower-, mid-, and up-lake areas (Rash 2003).

Juvenile striped bass rapidly disperse from stocking sites, residing primarily in shallow littoral areas with open sand-bottom habitat (Van Den Avyle and Higginbotham 1979; Rash 2003). Stocked juvenile striped bass quickly become piscivorous at about 120 mm in mid-summer, growing fast enough to successfully exploit young-of-year (YOY) alewives. Rash (2003) was most successful capturing YOY striped bass at lower lake littoral areas, which also corresponded to lower-lake habitats favored by spawning alewife, particularly along the north shore downstream of Claytor Lake State Park (Nigro and Ney 1982). Striped bass young likely follow alewife movements from littoral spawning areas to more pelagic, off-shore areas later in fall as water temperatures cool. Yearling striped bass move back onshore in spring, again exploiting YOY alewives. It is likely juvenile striped bass remain in close proximity to favored alewife food sources until the thermal requirements of mature striped bass intervene during the hottest periods.

The distribution of older striped bass in Claytor Lake is water temperature and/or food supply driven. Large striped bass actively seek the coolest water available when water temperatures become warmer than preferred (Cheek et al. 1985). Coutant (1985) defines suitable summer habitat for adult striped bass as having water temperatures between 18 and 25°C, and DO concentrations at least 2-3 mg/L. As a result, striped bass in Claytor Lake are distributed much more broadly during fall through spring, but tend to be restricted to the deeper reaches in the lower one-third of the lake in summer. The deeper reaches provide required cooler water temperatures that are unavailable in the shallower upper areas. Net uplake movements of adults occur in fall and spring, as large striped bass either leave thermal refugia as water temperatures cool or stage for spawning migrations to lake headwaters, respectively.

Although adult striped bass occupy lower lake habitats at depths similar to powerhouse intakes, little evidence of transport out of Claytor Lake exists for the larger specimens. More likely, downstream movement out of Claytor Lake occurs during the period shortly after stocking when juveniles (fingerlings) are rapidly dispersing from the stocking locations.

5.1.2 Striped bass x white bass hybrids

Hybrid striped bass fingerlings stocked during late summer maintain the fishery in Claytor Lake. Hybrids are larger (3 to 5 inches) than striped bass at the time of stocking, but due to the time of year are unable to exploit YOY alewives and gizzard shad that have grown too large to ingest. YOY hybrids feed primarily on young *Lepomis* when they became piscivorous at approximately 120 mm (Rash 2003). Hybrid juveniles preferred open, sandy littoral habitats, similar to young striped bass, with similar thermal niches (Rash 2003). Seasonally, YOY hybrids moved offshore in December, and back on-shore in March-April, similar to striped bass movements (and alewives).

Adult hybrids exhibit the same general within-lake seasonal movement patterns as striped bass, but in a given reach may occupy slightly different areas either horizontally or vertically (Kilpatrick 2003). Vertical separation occurs in summer due to the warmer water temperature tolerances of hybrids which allow them to exist higher in the water column. Horizontal separation within a 700-m reach was noted as both groups staged prior to moving uplake for the spawning run.

Hybrids were stocked due to the belief they were less prone than striped bass to emigrate downstream. Hybrids have become established in dam tailwaters, although little evidence exists to suggest when or at what size movement out of the lake occurs. One adult hybrid moved to dam tailwaters between February and April 2002, possibly exiting during a period of high inflow (Kilpatrick 2003). However, most hybrids probably exit as juveniles during their first year during post-stocking dispersal, based on prior experience with hybrids in a large hydroelectric reservoir (Normandeau Associates, in-file data).

5.1.3. Gizzard shad

The spatial distribution of gizzard shad in Claytor Lake generally overlaps that of alewives, the other clupeid forage species, due to generally similar mesotrophic characteristics throughout the lake (Bonds 2000). Gizzard shad are primarily residents of shallow, littoral habitats. Standing stock estimates in 1997, ten years after they became established, revealed that gizzard shad comprised 35% of littoral fish biomass based in cove rotenone samples (Small 2002). However, overall abundance is regarded as low compared to more eutrophic reservoirs.

Gizzard shad in Claytor Lake spawn in the spring, beginning in mid-May around the same time as alewives (Small 2002). Peak larval densities were attained in late June, and larval captures ceased in early August. YOY gizzard shad appear in fish diets at about 20 mm in mid to late summer; Age 1 shad are eaten only in spring before the new cohort is available. First-year growth in Claytor Lake is rapid, and YOY reach a mean length of 155 mm TL at Age 1, larger than Age 1 gizzard shad in other similar reservoirs (Bonds 2000). The rapid growth of young-of-year gizzard shad in Claytor Lake limits their usefulness as prey for piscivorous young of predators, and for the most part their contribution as forage to predator populations other than for the largest adults is as Age-0 fish, as commonly observed elsewhere (e.g., Ney et al. 1988). Young gizzard shad provide the main forage for striped bass and hybrid striped bass in late summer and fall, and represent a secondary forage species (after alewives) for walleye (Bonds 2000).

Gizzard shad apparently are routinely transported out of Claytor Lake to the New River and reservoirs downstream (Bonds 2000). Gizzard shad will succumb or become moribund at prolonged water temperatures below about 3°C (37°F) (see review in Williamson and Nelson 1985). Young gizzard shad typically pass out of temperate reservoirs during fall and early winter as their lower temperature threshold is approached and swimming ability is reduced or lost. The loss of swimming ability creates their susceptibility to entrainment, and as a result fall/winter gizzard shad entrainment peaks are typical in reservoirs where they are abundant (FERC 1995).

5.1.4 Largemouth bass

Largemouth bass currently comprise about 30% of the three black bass species in Claytor Lake as determined by electrofishing (Copeland 2004). However, the angler catch of largemouth bass was equal to the combined catch of the other two black bass species in the most recent creel survey (Copeland 2004). Largemouth bass electrofishing catch rates increased during 1992 to 1998 in Claytor Lake. Based on VDGIF electrofishing samples over the same period, largemouth bass spatial population densities are comparatively even among upper, mid, and lower lake reaches. Abundance is highest in off-channel coves, including Peak Creek, the major tributary arm. Largemouth bass growth is good and condition is excellent (Copeland 1999). Bluegill and crayfish dominated the diet of largemouth bass in all seasons, but alewives and gizzard shad can be important seasonal diet components (Bonds 2000). Reliance on bluegill identifies largemouth bass as mainly littoral zone inhabitants.

Largemouth bass spawn in spring and build nests in shallow, littoral zone habitats typically associated with cover objects. Adults guard the young after hatching, and young bass remain in shallow, protected habitats such as coves and flooded tributary mouths following cessation of parental care. Adults typically establish home ranges during the summer into fall. Largemouth bass are generally considered inactive during winter (Cooke et al. 2003). Strong orientation to cover and preference for shallower, off-channel habitats generally limits largemouth bass exposure to entrainment through water intakes.

5.1.5 Smallmouth bass

Smallmouth bass are most abundant in lower and mid-lake areas, which afford an abundance of steeper, rocky shoreline habitats (Copeland 1999; 2004). Throughout most of the 1990s overall smallmouth bass abundance (electrofishing CPUE) was about equal to that of largemouth bass. The representation of smallmouth bass in the 1998-1999 sport fishing survey was 38% of the total black bass catch (Copeland 1999). Crayfish and bluegill dominated the smallmouth bass diet (Bonds 2000).

Smallmouth bass spawn in spring and build nests associated with littoral zone cover, and guard their young after hatching. Young bass remain in shallow, protected habitats following cessation of parental care. After spawning, adult smallmouth bass may move about within a variable-sized home range in summer. Smallmouth bass may move from littoral areas in late fall to winter aggregations associated with cover in deep water (Langhurst and Schoenike 1990). Although more abundant in downlake areas of Claytor Lake, the numerous protected coves combined with smallmouth bass preferences for shallow littoral habitats would tend to isolate most young smallmouth bass, typically the life stage most vulnerable to entrainment, from the submerged, offshore-sited intake structures located in the lower lake.

5.1.6 Spotted bass

Spotted bass are the most abundant of the black bass species in Claytor Lake based on electrofishing CPUE (Copeland 1999). Spatially, spotted bass abundance is highest in the upper portion of the lake. Its habitat requirements, intermediate between those of largemouth and smallmouth bass (Miller

1975; Jenkins and Burkhead 1993), and higher tolerance for turbidity (Trautman 1981, in Jenkins and Burkhead 1993) conform to the more riverine character and higher turbidity of upper Claytor Lake. Seasonal movements to deeper lake areas (offshore) in winter may occur based on accounts in Miller (1975).

Spotted bass formed 12% of the black bass catch during the 1998-1999 creel survey (Copeland 1999). Adult dietary components strongly favored crayfish with some bluegill, similar to smallmouth bass (Bonds 2000).

Spotted bass construct nests on firm bottom at depths to 20 ft when water temperatures near 60°F (Jenkins and Burkhead 1993). A wide variety of firm bottom types are acceptable, but nearby cover is also important (Miller 1975; Vogele 1975). Young aggregate in schools while guarded by the male, then gradually disperse at about 30 mm (Vogele 1975). The occurrence of most spotted bass in up-lake areas, tight schooling aided by parental care, and strong association with cover may make the species less prone to entrainment at the most vulnerable juvenile stage.

5.1.7 White bass

White bass are highly fecund, mobile, pelagic predators that move to reservoir headwaters or tributary rivers to spawn in spring. Claytor Lake white bass abundance is considered low (Copeland 2004), possibly due to competition from hybrid striped bass or predation on larvae by alewives (Kohler 1980, cited in Bauer 2002). In Claytor Lake spawning success and dominant white bass year classes occur during Aprils with high run-off (DiCenzo and Duval 2002). Poor or missing year classes result from springs with low reservoir inflow. Spawning occurs on the open-water surface and the eggs are demersal and adhere to the bottom. Young prefer shallow water over harder bottom, but remain in littoral zones only during early life stages (Horrall 1962, in Becker 1983). When in littoral habitat the young prefer sandy substrates, similar to striped bass and hybrid striped bass.

Larval white bass utilize a diurnal vertical migration to slow downstream transport from high-current spawning areas (Starnes et al. 1983). This mechanism may effectively permit young white bass to grow to a larger size with higher swim performance capability before reaching Claytor Dam intakes, thereby reducing susceptibility to entrainment during the most vulnerable life stage.

Following spawning in the upper reaches of Claytor Lake, most adults would likely move downstream to the main body of the reservoir. The summer-fall spatial distribution of larger white bass would likely mimic prey movements. White bass are schooling, aggressive pelagic predators that favor clupeid prey where they co-exist. White bass would likely follow schools of YOY alewives and gizzard shad, the dominant pelagic prey in Claytor Lake. White bass were heavy consumers of alewives prior to gizzard shad introduction (Boaze and Lackey 1974). During summer, white bass were found primarily within the top 6 m (20 ft) of the water column (Tibbles 1956, in Becker 1983). During the rest of the year they were found in deeper waters. White bass remain active during winter (Cooke et al. 2003).

Larger white bass respond to seasonal prey movements, and since they remain active during winter could be susceptible to fall/winter entrainment as discussed below for walleye. White bass will follow clupeid schools (alewives in this case) throughout the upper 14 m (46 ft) of the water column (Boaze 1972).

5.1.8 Walleye

Claytor Lake walleye have received substantial management focus based on genetic characteristics in recent years. Prior to research recommendations to enhance the riverine walleye stock (Palmer 1999; Palmer et al. 2005), which may be native, walleye fry and fingerlings from largely lake sources were heavily stocked periodically since impoundment (Rosebery 1951; Copeland 1999), with the goal of establishing and maintaining a pelagic lake sport fishery. However, the principle sport fishery for walleye occurs in the New River upstream of Claytor Lake in spring during the spawning run. The lake sport fishery is negligible, representing less than 1% of total effort (Copeland 1999), likely due to the preference of adult walleye for deep, off-shore waters most of the year (Palmer 1999).

Adult walleye that mostly reside in the lower two-thirds of Claytor Lake move upstream during late February into early May to spawn in lake headwaters near Allisonia (Palmer 1999). Adults then return to pre-spawn home ranges in the lower lake that typically extend over 13 linear kilometers in size. The adults are considered nomadic within the home range, moving continually, likely in response to movements of alewife schools (Palmer et al. 2005). Alewife represents the preferred prey of walleye (Boaze and Lackey 1974; Bonds 2000).

Young walleye spawned in the New River likely drift downstream to rear in Claytor Lake. Young in other lakes are pelagic until they grow to slightly longer than 1 inch, then return to inshore rearing areas (Becker 1983). Dispersal of naturally produced young walleye (≤ 2 inches) to downstream tailwaters occurs at many reservoirs (FERC 1995). This is about the same size of stocked walleye. Movement of larger juvenile walleye out of reservoirs is also common in late fall and winter, often accompanied by increased inflows and shorter flushing times (FERC 1995; Jernejcic 1986). Larger walleye may also follow stressed prey such as cold-stressed clupeids to deeper reservoir areas thereby increasing susceptibility to entrainment into submerged water intakes (RMC 1992).

5.1.9 Alewife

Landlocked alewife were introduced during the 1960s, and along with introduced gizzard shad, comprise the main forage base for pelagic predators in Claytor Lake. Alewife spawn principally in littoral, lower-lake areas adjacent to their preferred, pelagic habitats (Nigro and Ney 1982). Alewife exhibit a protracted spawning period that extends approximately 13 weeks, beginning in early May and lasting until early August. Larvae consume zooplankton but also prey on larvae of other fishes (Kohler et al. 1986). Nigro and Ney (1982) documented a daily growth increment of 0.68-mm in Claytor Lake. The long growing season resulted in young attaining 155 mm at Age 1, a length beyond the capability of all but the largest predators to ingest.

Alewife seasonal distribution has been largely determined through gill netting and predator diet studies. Alewives in Claytor Lake are primarily pelagic-zone inhabitants, with highest densities in the lower lake (Nigro and Ney 1982). Mature fish move inshore in spring for spawning, then move back off-shore. Although regarded as pelagic zone fishes, alewives invade the littoral zone at night (Kohler and Ney 1981). Older alewife thermal requirements for cooler water temperatures (preferred 16-20°C; Coutant 1977, cited in Ney et al. 1988) effectively limit their distribution to deeper offshore portions of Claytor Lake, where they are available for large pelagic predators such as walleye and striped bass with similar thermal requirements. Younger alewife exhibit a more plastic thermal regime (preferred temperature up to 25°C; Stewart and Binkowski 1986, cited in Ney et al. 1988), and so may be more common than adults in shallower areas that are warmer.

Alewife can succumb to cold water temperatures in some winters (Boaze and Lackey 1974; Kohler et al. 1986). During such winters, alewife may initially seek warmer water and move to the deeper portions of lakes (RMC 1992). In Claytor Lake and elsewhere, this can result in large alewife schools proximal to submerged water intakes. The result is entrainment of large numbers of alewife, as well as predators such as walleye that follow the schools (Boaze and Lackey 1974; RMC 1992). .

5.1.10 Bluegill

Bluegill represents the principal panfish species caught and harvested in Claytor Lake (Copeland 1999). Bluegill catch was in excess of 108,000 fish, and more than 15,800 were harvested. Targeted panfish angling comprised 5% of overall effort.

Bluegills are primarily littoral zone residents. Spawning is protracted, occurring from May through at least August, and nests are constructed in shallows on sand or gravel. Upon leaving nests, bluegill larvae migrate to limnetic surface waters, returning to littoral areas at approximately 25 mm in length (Werner 1967). Young are planktivores (Jenkins and Burkhead 1993; Werner 1969), and themselves are the primary food of the black basses (Bonds 2000). In lower Claytor Lake, juvenile and adult bluegill abundance would likely be highest at the back of coves where habitat < 5 m deep is most common, as shown in Nigro and Ney (1982).

5.1.11 Black Crappie

Although both crappie species exist in Claytor Lake, black crappie was likely targeted for this assessment since they are the dominant crappie species in the lower lake where turbidity is less (Kohler et al. 1986). Black crappie ranked third (2,411 total) among harvested fishes during the most recent creel survey (Copeland 1999). Given the harvest magnitude and high retention, black crappie exploitation is considered low, and recruitment is consistent (Copeland 1999).

Black crappie are usually regarded as littoral zone residents, typically found in backwaters and other off-channel habitats, usually associated with in-water cover of some type. Historically, crappies were considered part of the pelagic predator assemblage in Claytor Lake (Kohler et al. 1986). Spawning occurs primarily in April in nests associated with cover (Jenkins and Burkhead 1993). Very young black crappie apparently undergo a migration from the spawning site to open limnetic habitat and then back to the littoral zone early in the first year, similar to bluegill (Werner 1967). Black crappie young represent a principal forage species for black basses which are also chiefly littoral zone inhabitants. In lower Claytor Lake, juvenile and adult black crappie abundance would likely be highest at the back of coves where cover and habitat < 5 m deep are most available, as shown in Nigro and Ney (1982).

5.2 REVIEW OF ENTRAINMENT RATES DEVELOPED BY EPRI (1997)

EPRI (1997) compiled fish entrainment data from the 43 selected sites listed in Table 4-1. As discussed above in Section 4.0, most of the sites were smaller than the Claytor Project in terms of individual unit size or plant capacity. Several projects were located in the south (seven), but only one project was located in Virginia (Luray). The compilation filtered site entrainment data through a range of 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 (< 8 inches), medium (8-15 inches), and large (> 15 inches) fish for most of the species considered for this assessment are summarized in Table 5-1. 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.

Table 5-1. Average entrainment densities for Claytor Hydro Project fish species of interest drawn from EPRI (1997) entrainment database. Annual density standardized and shown as number of fish per million cubic feet of water.

	Small Fish (< 8 inches)			Medium Fish (8-15 inches)			Large Fish (>15 inches)		
	No. Sites	Annual	Entrainment	No. Sites	Annual	Entrainment	No. Sites	Annual	Entrainment
Species/Surrogates	Present	Density	Potential	Present	Density	Potential	Present	Density	Potential
Alewife	3	34.057	High	3	0.078	Moderate-High	3	0.0	None
Gizzard shad	10	15.668	High	10	0.220	High	10	0.0047	Moderate
Bluegill	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
Walleye	29	0.120	Moderate-High	29	0.026	Moderate-High	29	0.002	Low-Moderate
Largemouth bass[1]	34	0.118	Moderate-High	34	0.002	Low-Moderate	34	0.0032	Moderate
Smallmouth bass[1]	34	0.090	Moderate	34	0.008	Moderate	34	0.0005	Low
White perch[2]	4	0.224	Moderate-High	4	0.183	High	4	0.0000	Low
White bass[2]	4	0.003	Low	4	0.042	Moderate-High	4	0.0	Low
Striped bass	NA								
Hybrid striped bass	NA								
Spotted bass	NA								

Footnotes (also see text):
NA = no sites in EPRI database reported this species in entrainment catch
[1] Potential surrogate species for spotted bass
[2] Potential surrogate species for striped bass and hybrid striped bass.

The entrainment densities and associated entrainment potential shown in Table 5-1 represent up to 36 sites per target 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 Claytor Project were represented in the EPRI (1997) database. As a result, we assumed that information deemed relevant for several species considered herein were represented by surrogate species included in the EPRI (1997) review. The surrogate species and the Claytor Project species they represent are listed as footnotes to Table 5-1.

As would be expected, small fish densities were substantially higher than for medium and large fish (Table 5-1). In fact, most field studies included in data compilations have shown that entrainment is highest for fish less than 4 inches (FERC 1995; Winchell et al. 2000). Alewife and gizzard shad generally have the highest potential for entrainment in reservoirs where they are abundant. For both clupeid species, entrainment density peaks occurred in either the fall or winter, typically when they become lethargic due to cold water temperatures. The potential for entrainment of small bluegill and black crappie, walleye, and largemouth bass was Moderate-High. Entrainment density for these species tended to be higher in summer (EPRI (1997) or fall (FERC 1995), suggesting dispersal of young as the primary factor. Smallmouth bass entrainment risk also was highest in summer, although the overall risk was rated as Moderate. The young of each of these species, particularly the centrarchids, are considered primarily littoral zone inhabitants.

Spotted bass were not represented among any of the EPRI (1997) source studies. Although their habitat requirements are intermediate between smallmouth bass and largemouth bass, spotted bass tend to be more abundant in upper Claytor Lake (see Section 5.1.6). Given this, the entrainment potential of young spotted bass is most likely no more than Moderate.

The entrainment potential of white bass was judged Low based on the limited EPRI (1997) data (Table 5-1). White bass young are typically produced in reservoir headwaters or tributary arms (DiCenzo and Duval 2002), which might account for their overall low entrainment rate.

Although in the same genus as striped bass, white bass alone as a surrogate for striped bass or hybrid striped bass may lead to an underestimate of entrainment potential for the young of these two stocked species. Stocked striped bass and, particularly, hybrid striped bass, are known to readily escape inland reservoirs and establish fisheries in downstream reaches, as has occurred in the New River and elsewhere (Van Den Avyle and Higginbotham 1979; Gleason 1982). As a result, white perch, another *Morone* species, was included to possibly bracket entrainment potential. Small white perch exhibited a Moderate-High entrainment potential rating based on the four studies that included white perch in EPRI (1997). Therefore, the entrainment potential of young striped bass and hybrid striped bass may be intermediate between white bass and white perch, and appropriately described as Moderate, given their acknowledged rapid dispersal from stocking sites in the mid-reservoir area (Rash 2003).

Although annual entrainment densities were substantially lower for all fish ≥ 8-15 inches except white bass, and only moderately lower for white perch, several species retained a qualitative potential rating of High or Moderate-High. These include gizzard shad, alewife, black crappie, walleye, white perch and white bass. In particular, use of the white perch entrainment rate to develop a representative rate for medium-sized striped bass and hybrids striped bass might be problematic.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 inches that are available for entrainment, including the *Morone* taxa, 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. For species like alewife and bluegill, fish >15 inches don't exist. The swimming ability of adults of most of the other species of interest (see Section 3.0) would be expected to preclude entrainment at the low prevailing approach velocities.

5.2.1 Projections of Entrainment Losses

The average annual entrainment densities shown in Table 5-1 were used with annual turbine flow data to extrapolate to estimates of fish lost from each reservoir due to turbine entrainment. A dry year and a wet year were selected by AEP to illustrate potential bounds for fish loss estimates. Annual Claytor turbine flow data were provided by Appalachian Power operations staff for a recent dry year (2007) and representative wet year (2003). Claytor turbine flow was 66.824 billion cubic feet of water in 2007 and 152.19 billion cubic feet of water in 2003. Turbine flow during a wet year was more than twice that in a dry year. Other factors that can affect the amount of generation in a year such as planned or unplanned outages for equipment repairs or upgrades are mentioned here but not considered further.

Estimated fish losses from Claytor Lake due to turbine entrainment without regard to variability in fish passage survival (discussed later in Section 5.4) are shown in Table 5-2. As expected, the prolific prey species alewife and gizzard shad dominate estimated entrainment losses. Projected game fish losses were substantially less. For all fishes, entrainment losses would generally be expected to be higher in years with higher precipitation and increased runoff that enables more generation. It is also important to note that fish losses are primarily of small fish, and that survival of these small fish is typically quite high (see Section 5.4).

Two *Morone* species, white bass and white perch, served as surrogates to develop bracketed estimates of striped bass and hybrid striped bass entrainment losses. This was done due to the lack of quantitative striped bass or hybrid striped bass entrainment data in available literature. The estimated losses in Table 5-2 were calculated by using white bass and white perch data each from four qualified projects reviewed by EPRI (1997). Juvenile white bass entrainment at these projects was low, whereas white perch entrainment was much higher. White bass young are produced in project headwaters, perhaps spatially isolated at their most vulnerable life stage by distance from turbine intakes. White perch are likely not as spatially isolated in reservoirs, and through natural reproduction can achieve high abundance leading to stunting in land-locked situations (e.g., Hergenrader and Bliss 1971, in Nebraska). The white perch in Nebraska also quickly propagated downstream. Additionally, studies at Richard B. Russell Project in South Carolina/Georgia estimated white perch entrainment (pump-back) more than 50 times higher than estimated for striped bass or striped bass hybrids (Nestler et al. 1998). Although striped bass and hybrid striped bass also establish fisheries downstream as noted for white perch, both species are stocked in Claytor Lake at controlled densities. Thus, entrainment of small striped bass and hybrid striped bass may be higher than shown for white bass, but almost certainly less than if white perch were used as the sole surrogate. Thus, to be conservative, the midpoint of the densities shown for white perch and white bass in Table 5-1 were used to estimate the losses in Table 5-2.

Higher losses of medium-sized white bass than smaller individuals, and (by surrogate) higher than expected losses of medium-sized striped bass and hybrid striped bass represent other apparent anomalies in Table 5-2. Striped bass and hybrid striped bass, largely due to the inclusion of white perch as a surrogate, also exhibited comparatively high entrainment densities of medium-sized fish.

Table 5-2. Estimated entrainment losses for Claytor Lake fish species of interest. Annual density standardized and shown as number of fish per million cubic feet of water.

DRY YEAR Species/surrogates	Small Fish (< 8 inches)		Medium Fish (8-15 inches)		Large Fish (> 15 inches)	
	Annual Density	Entrainment Losses	Annual Density	Entrainment Losses	Annual Density	Entrainment Losses
Alewife	34.057	2,275,830	0.078	5,212	0.0	0
Gizzard shad	15.668	1,047,001	0.220	14,701	0.0047	314
Bluegill	0.925	61,812	0.005	334	0.0000	0
Black crappie	0.400	26,730	0.013	869	0.0000	0
Walleye	0.120	8,019	0.026	1,737	0.002	134
Largemouth bass	0.118	7,885	0.002	134	0.0032	214
Smallmouth bass	0.090	6,014	0.008	535	0.0005	33
Spotted bass[1]	0.104	6,950	0.005	334	0.0018	120
Striped bass[2]	0.1135	7,585	0.1125	7,518	0.0005	33
Hybrid striped bass[2]	0.1135	7,585	0.1125	7,518	0.0005	33
White bass	0.003	200	0.042	2,807	0.0	0

WET YEAR Species/surrogates	Small Fish (< 8 inches)		Medium Fish (8-15 inches)		Large Fish (> 15 inches)	
	Annual Density	Entrainment Losses	Annual Density	Entrainment Losses	Annual Density	Entrainment Losses
Alewife	34.057	5,183,152	0.078	11,871	0.0	0
Gizzard shad	15.668	2,384,521	0.220	33,482	0.0047	715
Bluegill	0.925	140,776	0.005	761	0.0000	0
Black crappie	0.400	60,876	0.013	1,978	0.0000	0
Walleye	0.120	18,263	0.026	3,957	0.002	304
Largemouth bass	0.118	17,958	0.002	304	0.0032	487
Smallmouth bass	0.090	13,697	0.008	1,218	0.0005	76
Spotted bass[1]	0.104	15,828	0.005	761	0.0018	274
Striped bass[2]	0.1135	17,274	0.1125	17,121	0.0005	76
Hybrid striped bass[2]	0.1135	17,274	0.1125	17,121	0.0005	76
White bass	0.003	457	0.042	6,392	0.0	0

[1] Midpoint of largemouth bass and smallmouth bass density used to calculate potential losses of spotted bass.
[2] Midpoint of white perch and white bass density used to calculate potential losses of striped bass and hybrid striped bass.

Winchell et al. (2000), in his summarization of the EPRI (1997) entrainment database, suggested that despite best efforts to prevent tailrace net intrusion, some larger fish densities may have been affected by fish entering the net from downstream. The moderately high densities of medium-sized white bass and white perch likely reflect net intrusion, since peak entrainment catches of both species occurred in spring during the spawning period (EPRI 1997). Such higher entrainment densities of medium-sized fish are not only counterintuitive but opposite the data trends identified for other species in numerous field studies. In addition, the swimming abilities of 8-15 inch striped bass and hybrid striped bass are substantially better than the surrogate white perch, such that losses of striped bass and hybrid striped bass portrayed in Table 5-2 are probably overestimated.

5.3 BLADE STRIKE AND CAVITATION POTENTIAL OF EXISTING UNITS

Blade strike or contact with turbine structural elements is the most likely mode of injury or mortality for fishes passing through the turbines (e.g., Eicher Associates 1987). Other possible injury/mortality sources less likely to harm fish include shear forces and changes in pressure (e.g., Cada 1990). Changes in pressure within the turbine can result from cavitation. Cavitation potential is related to "plant sigma", which is related to the elevation (siting) of the turbine relative to minimum tailrace elevation. The risk of injury/mortality due to cavitation is addressed below. Additionally, for the more likely collisions with structural elements, the strike probability assessment using the Franke et al (1997) formula described below relates fish size (primarily) to water passage spaces in the turbine, and most likely predicts blade or mechanical strike potential.

5.3.1 Strike Probability using Predictive Model

The formula developed by Franke et al. (1997) grew out of efforts for the Department of Energy (DOE) to design more "fish-friendly" turbines. The formula calculates the probability (P) of blade strike by relating such turbine parameters as the number of buckets, runner diameter, and runner height to fish length and operating condition. Fish length and available passage space are the principal drivers of the output. The paramters of interest for the large Francis units at the Claytor Project are shown in Table 5-3. Other than manufacturer, the units differ only slightly in runner diameter (2.8%). For this exercise, eight representative fish lengths, two operating conditions, and two correlation factors were selected. The operating conditions were unit design flow (2,500 cfs) and MEP flow (2,000 cfs). The correlation factors used were 0.10 and 0.15; these are used to account for variability in strike potential and also to relate the output to empirical data available to the Franke study. Although the formula calculates a probability, in the present context it is more conventionally used in the formula Survival (S) = 1 – P, with results expressed as a survival percentage.

Table 5-3. Values of turbine parameters used in blade strike and survival estimates.

Parameter	Claytor Lake Turbines	
	Unit No. 1, 2	Unit No. 3, 4
Turbine type	Francis	Francis
No. blades/buckets	15	15
Max. turbine discharge (cfs)	2,500	2,500
Turbine discharge (cfs) at best efficiency	2,000	2,000
Runner diameter at inlet (ft)	8.8	9.0
Runner diameter at discharge (ft)	10.9	11.2
Runner height at inlet (crown) (ft)	6.3	6.3
Best turbine efficiency (%)	92	92
RPM	138.5	138.5
Head (ft)	116	116

The results applied to the Claytor units show that strike potential is low and expected survival is quite high for the mostly small fish likely to be entrained (Table 5-4). For example, at the MEP flow of 2,000 cfs and either unit type, predicted survival for small fish < 8 inches long (average of survival for 2, 4, and 6-inch fish) is 94% to 96%. The data also show that survival may be nearly as high for units operated at 2,500 cfs, and also that survival decreases as fish length increases. Both results conform to expectations. The water pathway is less turbulent at efficient flow, meaning smaller forces are acting on the fish, and larger fish are more likely to contact a turbine element in a confined space.

These modeled predictions may be compared to survival results determined in the field for similar sized fish (see Section 5.4 below). For comparison purposes, immediate survival results from field studies provide the most appropriate parallel, because these reflect fish condition immediately after turbine passage. The modeled data are generally quite similar to field study results and reflect the survival trends shown in Section 5.4 with particular reference to fish size.

5.3.2 Cavitation Potential

Cavitation occurs within the turbine environment. Most hydro plants are designed to minimize the likelihood of cavitation due to the costs of efficiency loss and the cost of repairs to turbine runners. Design issues or extreme operating conditions create sub-atmospheric pressures that typically damage metal turbine blades. Cavitation occurs in small areas of the runner, and damage to fish can result from intense shock waves emanating from collapsing bubbles or vapor pockets. Tests have shown, however, that the zone of cavitation is small, and fish passing through the turbine must be close to the shock wave to be damaged (Eicher Associates 1987; Cada 1990).

Operations staff were queried about cavitation damage to Claytor turbine runners, as a gauge of the potential for cavitation to damage fish during passage. Cavitation repairs are a minor occurrence at the Claytor Project; repairs are needed on about a decadal frequency (J. Thrasher, Appalachian, personal communication). As a result, fish injury or mortality due to the effects of cavitation would likely be minimal.

5.4 TURBINE PASSAGE SURVIVAL ASSESSMENT

5.4.1 EPRI (1997) Data

Fish size more so than species has emerged as the key decision variable for a given turbine type and operational characteristics (see also Franke et al. 1997). Winchell *et al.* (2000) summarized empirical turbine passage survival data reported in the EPRI (1997) database by turbine type and characteristics and fish size. The survival rates reported reflect trends from 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 survival data are reproduced herein for the studies representative of the four similar Francis turbines housed in the Claytor Project (Table 5-5). The four Claytor turbines are large (runner diameter about 11 ft, hydraulic capacity of 2,000 cfs at most efficient operation), and rotate slowly (138.5 rpm).

Immediate survival after passage was rated as High for two size groups of fish up to 7.8 inches (199 mm). Medium sized fish averaged 86.9% survival in 18 tests; risk was rated as Moderate. Survival was rated as Low (mean = 73.2%) for larger fish (> 11.8 inches). Survival declined a few percentage

Table 5-4. Predicted turbine passage survival at Claytor Project turbines based on the blade strike probability formula developed by Franke et al. (1997).

Units 1, 2			
Unit Flow-cfs	Correlation Factor	Fish Length-in	Survival (%)
2,000	0.1	2	98.1%
		4	96.3%
		6	94.4%
		8	92.6%
		10	90.7%
		12	88.8%
		18	83.3%
		24	77.7%
2,000	0.15	2	97.2%
		4	94.4%
		6	91.6%
		8	88.8%
		10	86.1%
		12	83.3%
		18	74.9%
		24	66.5%
2,500	0.1	2	98.0%
		4	95.9%
		6	93.9%
		8	91.8%
		10	89.8%
		12	87.8%
		18	81.7%
		24	75.6%
2,500	0.15	2	96.9%
		4	93.9%
		6	90.8%
		8	87.8%
		10	84.7%
		12	81.7%
		18	72.5%
		24	63.3%

Units 3, 4			
Unit Flow-cfs	Correlation Factor	Fish Length-in	Survival (%)
2,000	0.1	2	98.1%
		4	96.3%
		6	94.4%
		8	92.6%
		10	90.7%
		12	88.9%
		18	83.3%
		24	77.7%
2,000	0.15	2	97.2%
		4	94.4%
		6	91.6%
		8	88.8%
		10	86.1%
		12	83.3%
		18	74.9%
		24	66.6%
2,500	0.1	2	97.9%
		4	95.9%
		6	93.8%
		8	91.8%
		10	89.7%
		12	87.7%
		18	81.5%
		24	75.4%
2,500	0.15	2	96.9%
		4	93.8%
		6	90.8%
		8	87.7%
		10	84.6%
		12	81.5%
		18	72.3%
		24	63.1%

Table 5-5. Mean fish survival rates for Francis turbines and representative fish sizes in EPRI database (source: Winchell et al. 2000).

Turbine Type	Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size- mm (in)	Average Immediate Survival-all species (%)				Survival Potential**
				N	Minimum	Maximum	Mean	
Francis (radial-flow)	<250	440-1,600	<100 (3.9)	13	85.9	100	**93.9**	**High**
		370-1,600	100-199 (3.9-7.8	19	74.8	100	**91.6**	**High**
		370-2,450	200-299 (7.9-11.8)	18	59.0	100	**86.9**	**Moderate**
		440-1,600	300+ (11.8+)	14	36.1	100	**73.2**	**Low**
Turbine Type	**Runner Speed (rpm)**	**Hydraulic Capacity (cfs)**	**Fish Size- mm (in)**	**Average Survival (after 48 h)-all species (%)**				**Survival Potential****
				N	**Minimum**	**Maximum**	**Mean**	
Francis (radial-flow)	<250	440-1,600	<100 (3.9)	11	80.9	100	**90.4**	**High**
		370-2,450	100-199 (3.9-7.8	17	73.7	100	**87.8**	**Moderate**
		440-2,450	200-299 (7.9-11.8)	15	47.4	96.4	**80.4**	**Moderate**
		440-1,600	300+ (11.8+)	13	33.8	94.1	**66.8**	**Low**

** Qualitative survival rating: High = 90-100%; Moderate = 80-89.9%; Low = <80%.

points when fish were held for at least 48 h for delayed analysis, yet survival for all fish up to 3.9 inches remained High (Table 5-3).

5.4.2 Additional Empirical Survival Data

Empirical fish passage survival studies for species representative of those considered at the Claytor Project were examined to augment the EPRI survival data. Results were compiled from six additional sites with Francis turbines. Most of the turbine characteristics at the studied units bracketed those at Claytor Hydro Project, including number of runner buckets, runner speed (rpm) and runner diameter (Table 5-6). All were single-runner turbines except for those at Finch Pruyn (double and quad runner) and Holtwood Unit 3 (double). The operating head at each of the compiled studies was less when compared to the 116 ft of head at the Claytor Project. The species studied were either target species identified for the Claytor assessment (e.g., smallmouth bass, bluegill), or reasonable surrogates (Table 5-7). American shad and blueback herring were considered surrogates for alewife and gizzard shad due to similar shape and fragility. Fusiform fishes such as channel catfish, yellow perch, and suckers were considered surrogates for walleye and young striped bass due to comparable body shape. Mean size of fish tested ranged from 90 mm TL (bluegill) to 271 mm TL (smallmouth bass). Survival during turbine passage was determined using balloon tag technology (Heisey et al. 1992).

Survival of the large majority of species/sizes tested exceeded 90% (Table 5-7). These data agree with those summarized for Francis turbines in Section 5.4.1 above for the mostly small sizes of fish typically entrained. As discussed in Winchell et al. (2000) and elsewhere (e.g., Heisey et al.1996), there was little difference in survival rate among species tested. Survival was high for small and medium-sized fish of a variety of species.

5.4.3 Estimated Annual Fish Mortality

Compiled 48-h fish survival data in Table 5-5 were applied to estimated entrainment losses from Table 5-2 to estimate annual fish mortality due to turbine passage. Survival rates (S) for both groups of small fish (< 8 inches) were averaged. Survival rates for medium and large fish were those shown

Table 5-6. Site characteristics of empirical studies at Francis installations not reviewed in EPRI database. All studies performed using balloon tag technology.

Station/location	Turbine flow-cfs	No. buckets	Runner speed-rpm	Head-ft	Runner diameter-ft
Columbia, SC	833	14	164	28	5.33
Finch Pruyn, NY (Unit 4)	708	15	225	46	3.00
Finch Pruyn, NY (Unit 5)	836	15	225	46	3.00
Holtwood, PA (Unit 10)	3,500	16	94.7	62	12.46
Holtwood, PA (Unit 3)	3,500	17	102.8	62	9.33
Stevens Creek, SC	1,000	14	75	28	11.25
Vernon, VT/NH	1,834	15	74	34	13.00
White Rapids, WI	900	14	100	29	11.17

Table 5-7. Immediate (1-h) survival of representative fish species at Francis installations not reviewed in EPRI database. All studies performed using balloon tag technology.

Species	Station/location	Mean fish length-mm	Est. Percent Survival-1h
Smallmouth bass	Finch Pruyn, NY (Unit 4)	191	95
	Finch Pruyn, NY (Unit 4)	210	91
	Finch Pruyn, NY (Unit 4)	271	93
	Finch Pruyn, NY (Unit 5)	191	94
	Finch Pruyn, NY (Unit 5)	210	91
	Finch Pruyn, NY (Unit 5)	271	71
Bluegill	Stevens Creek, SC	122	95.4
	White Rapids, WI	90	95
	White Rapids, WI	155	100
Sunfishes (*Lepomis*)	Columbia, SC	106	95.9
Alosids			
American shad	Holtwood, PA (Unit 10)	125	89.4
	Holtwood, PA (Unit 3)	125	83.5
	Vernon, VT/NH	95	94.7
Blueback herring	Stevens Creek, SC	203	95.3
Fusiform shape			
Channel catfish	Columbia, SC	143	93.6
Spotted sucker/yellow perch	Stevens Creek, SC	165	98.3
White sucker	White Rapids, WI	112	100
	White Rapids, WI	204	93

for 7.9-11.8-inch fish and fish > 11.8 inches, respectively. Estimated entrainment losses were multiplied by the mortality rate (1-S) to estimate mortality.

Fish mortality in any given year would primarily be small alewife, gizzard shad, bluegill, and black crappie (Table 5-8). Comparatively little mortality for fish larger than 8 inches other than gizzard shad and alewife would be expected. As noted for the reasons discussed previously (use of white perch as one surrogate species for stocked striped bass and hybrid striped bass), the annual mortality losses estimated for medium-sized and larger striped bass and hybrid striped bass likely represent overestimates.

Table 5-8. Estimated annual mortality due to turbine passage for Claytor Lake fish species of interest. The source of mortality rates was Winchell et al. (2000).

Species/Surrogates	Small Fish (< 8 inches) Mortality Rate = 10.9%		Medium Fish (8-15 inches) Mortality Rate = 19.6%		Large Fish (> 15 inches) Mortality Rate = 33.2%	
	Dry Year	Wet Year	Dry Year	Wet Year	Dry Year	Wet Year
Alewife	248,065	564,964	1,022	2,327	0	0
Gizzard shad	114,123	259,913	2,881	6,562	104	237
Bluegill	6,738	15,345	65	149	0	0
Black crappie	2,914	6,636	170	388	0	0
Walleye	874	1,991	341	776	44	101
Largemouth bass	859	1,957	26	60	71	162
Smallmouth bass	656	1,493	105	239	11	25
Spotted bass[1]	758	1,725	65	149	40	91
Striped bass[2]	827	1,883	1,473	3,356	11	25
Hybrid striped bass[2]	827	1,883	1,473	3,356	11	25
White bass	22	50	550	1,253	0	0

[1] Annual mortality of spotted bass based on use of largemouth bass and smallmouth bass as surrogates; see Table 5-2.
[2] Annual mortality of striped bass and hybrid striped bass based on use of white bass and white perch as surrogates; see Table 5-2.

6.0 OVERALL ENTRAINMENT ASSESSMENT

The Claytor Hydro Project was assessed with respect to 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 6-1 may influence the risk of turbine passage entrainment or mortality. Among factors that can influence entrainment rates, this assessment examined the following:

Table 6-1. Comparison of factors that may influence entrainment or survival rates at Claytor Hydro Project.

Influence Factors	Claytor Project
Entrainment Rates	
Intake adjacent to shoreline	No
Intake location in littoral zone	No
Abundant littoral zone fishes (no. species)	Yes
Abundant littoral zone fishes (no. individuals)	Yes
Abundant clupeids	Yes
Obligatory migrants	No
Intake depth-ft (at top, full pond)	14
Winter drawdown	No
Normal hydraulic capacity (cfs)	8,000
Approach velocity (ft/s, normal operation)	≤ 1.5
Water quality factor	Yes
Risk of Entrainment	**High/ Moderate-High***
Survival Rates	
Turbine type	Francis
High turbine speed	No
Survival rates of small fish (<8 in)	Moderate-High
Pressurized intake tunnel	Yes
Risk of Mortality	**Low-Moderate**

* Mainly clupeids, alewives and young centrarchids

- 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/or alewife.
- 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. Herein, approach velocity is considered at the plane of the water intake opening.
- 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 relevant 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 (>100 ft) 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.

The Claytor project reservoir and turbines are examined below with respect to those unique features listed above that may affect fish entrainment or mortality.

The fish entrainment potential at the Claytor Hydro Project is rated Moderate to Moderate-High, principally due to abundant clupeids as well as numerous and abundant centrarchid species such as bluegill and crappie (see Section 5.1). Young alewife and gizzard shad (1.5 to 4 inches), as well as young bluegill and crappie (< 4 inches), typically form the bulk of entrainment catches where they are abundant in hydropower reservoirs (FERC 1995). Young clupeids form dense, large, open-water schools and both clupeid species in Claytor Lake tend to be susceptible to torpor due to 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 clupeids may also increase the risk of entrainment to those predatory species utilizing shad as prey. Young clupeids in fall and winter, including those stressed by cold water, may move to deeper waters of the reservoir seeking warmer water. Movements to the lower portions of the reservoir may increase exposure of alewife and gizzard shad and the predatory fishes that follow schools of these forage species to water proximal to the intakes, thus increasing the risk of entrainment. Boaze (1972) previously documented alewife winter entrainment due to cold stress.

In some reservoirs, such winter losses may be exacerbated by reduced reservoir volume during winter drawdown. Routine winter drawdown to increase storage does not occur at Claytor Lake, although brief fall drawdowns for shoreline structure maintenance or *ad hoc* drawdowns to accommodate expected high inflows do occur. Such occurrences, by their brief nature, would not likely increase entrainment risk substantially.

Young centrarchids such as bluegill and crappie 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 bluegill and black crappie shown in Table 5-1 are nowhere near the densities typical for clupeids, thus the rating “Moderate-High”. Although centrarchid entrainment can be substantial, Claytor Lake is moderately eutrophic and productive, and sustains large, diverse fish populations. Despite the “Moderate High” fish entrainment potential for several popular sport species (based on empirical studies elsewhere) Claytor Lake supports good recreational fishing for such species as bluegill and largemouth bass. The reservoir provides a “forage-rich” environment that supports these popular sport fisheries.

The Claytor Project intakes withdraw from moderately deep water. The intake ceiling is 14 ft below normal pool level, and extends to 61 ft deep; intake centerline is 37.5 ft below normal pool. 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, the Claytor Hydro intakes are removed from the limited littoral zone areas of the lake. The Claytor Hydro intakes are separated from the right (descending) shoreline by several hundred feet of bulkhead, and from the left shoreline by the extensive spillway section. Thus, relatively shallow water withdrawals (compared to near-dam pool depth) may be mediated by the distance from and limited area of littoral zones. The distance from and relatively low abundance of littoral areas is one of the prime factors that would be expected to limit entrainment and yield the overall risk profile of Moderate to Moderate-High.

Water quality is at most a seasonal deterrent to fish entrainment out of Claytor Lake. Years of low inflow result in dissolved oxygen depletion during warm months at depths below 5 to 10 m (16 to 33 ft), approximately equivalent to the upper portion of the intakes. Fish would avoid these areas of poor water quality and avoid potential entrainment through intakes at these depths. Avoidance of intake areas due to poor water quality would likely not occur during years or seasons of higher inflow or cooler temepratures when dissolved oxygen is also higher.

Water velocity at the project intakes is considered moderate as calculated on historical project drawings and determined by field studies. Intake area field studies identified intake velocities less than about 1.5 ft/s as close as 40 ft up-lake during full generation. Water velocities then increase toward the plane of the dam face to where intake openings are located (1.50 ft/s) and to the trash bar racks (2.40 ft/s). The withdrawal volume (normal full load discharges 8,000 cfs) is large. Although the larger water volumes would likely entrain more fish for a given entrainment rate, the comparatively low water velocities where fish might encounter withdrawal acceleration would mean that all but the poorest swimmers, such as young fish, could escape unless swimming ability (or behavioral avoidance) was compromised by cold water temperatures.

Claytor Project head is 116 ft, somewhat higher than the maximum head (100 ft) typically ascribed to low head hydro projects. The moderately high head pressurizes the penstocks, so that maximum pressure during operation is developed just in front of the turbine runners (44.5 psi; J. Thrasher, Appalachian, personal communication). Studies have shown that shallow water intakes and passage of fish acclimated to near normal atmospheric pressure enhances survival since entrained fish are not acclimated to deep water and high hydrostatic pressure and, thus, are not forced to equilibrate to rapid reductions to normal pressure when passed into a hydro station tailrace (Cada 1990; Franke et al. 1997). Most of the Claytor Lake fish would be expected to be entrained from impoundment surface layers (to approximately 30 ft deep), and the rapid transit time through the turbine (due to near-vertical fall of water) precludes the need for fish to make adjustments in swim bladder volume to accommodate pressure changes. Any injury or mortality due to the pressure changes experienced would be minimal (Cada 1990). A potential exception would be when fish acclimated to deep water, such as alewives seeking warmer water temperatures in late fall or winter or predator species following alewife schools, are inadvertently entrained. The sudden release to normal atmospheric pressure of the tailrace has caused decompression trauma elsewhere (RMC 1994). However, the lack of any history of such occurrences in the Claytor tailrace since alewife were introduced suggests this is not a common occurrence.

Four vertical Francis turbines are housed at the Claytor Project. All units are similar in size (large) and rotate slowly (138.5 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 5-5 supplemented by several additional empirical survival studies (Table 5-7), clearly identify high ($\geq$ 90%) survival of the mostly small fish that pass through project turbines. Thus, the risk to most fish passing through the turbines would be moderately Low.

7.0 CONCLUSIONS

Popular multi-species fisheries characterize the Claytor Hydro Project reservoir. Black basses, walleye, catfishes, and panfish naturally reproduce; these species are augmented annually with striped bass and hybrid striped bass fingerlings to take advantage of abundant clupeid prey species. Some level of fish entrainment was assumed prior to this investigation, particularly for the stocked predators and clupeid prey species, but entrainment was not believed to be a problem due to the mostly robust lake sport fisheries. Fish kills due to turbine passage are lacking. Swim speed information coupled with engineering calculations and field intake velocity measurements suggest small juvenile fishes, those less than 8 inches long, are the most vulnerable to entrainment. Larger individuals, principally the stocked predators, generally possess the swimming ability to avoid velocities near the intakes.

Entrained fishes would comprise mostly prey species such as alewife and gizzard shad. Entrainment of young sunfish such as bluegill and crappie is also likely, but moderated by intake separation from shorline littoral areas where they are typically most abundant. Stocked predators such as walleye, striped bass, and hybrid striped bass may be entrained as smaller juveniles, but older, larger fish are most likely to avoid entrainment through better swimming ability. The survival of the mostly small fish passing out of the lake would be expected to be high based on model calculations and evidence accumulated elsewhere for similar turbines and similar-sized fishes. Due to the inter-annual differences in water volume passed through the Claytor Project turbines, more than a factor of two, fish lost to the New River downstream would likely be higher in years with higher project inflows and annual discharge.

8.0 LITERATURE CITED

8.1 SWIM SPEED LITERATURE IN TABLE 3-1 AND SECTION 3.1

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