

ALABAMA POWER COMPANY

COOSA AND WARRIOR RIVER PROJECTS

E11 – Impingement, Entrainment, and Turbine Mortality Study Progress Report III

October, 2002

Prepared by:

KLEINSCHMIDT ASSOCIATES
Energy and Water Resource Consultants

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PROGRESS REPORT III**

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1.0 INTRODUCTION

Stakeholders of the Coosa and Warrior Relicensing Teams have identified fish impingement, entrainment, and turbine mortality as an issue to address during relicensing of the Coosa (FERC No. 2146 – Weiss, Neely Henry, Logan Martin, Lay, and Bouldin), Mitchell (FERC No. 82) and Jordan (FERC No. 618) Projects (Coosa River Projects), and the Warrior Project (FERC No. 2165 – Smith and Bankhead). Therefore, the E11 Issue Action Group (IAG) was formed to identify methods to address this issue.

The IAG met on January 30, 2002 to discuss potential methods to address the issue and agreed to evaluate the potential magnitude of fish impingement, entrainment, and turbine mortality using a combination of existing entrainment and turbine mortality literature and site-specific information. On March 7, 2002, APC distributed the Draft E11 Entrainment Study Plan (Study Plan). The IAG met on March 12, 2002 to discuss the proposed methodology outlined in the draft Study Plan. The IAG members indicated that, after some minor changes, the Study Plan was acceptable (E11 IAG Meeting Notes, March 12, 2002).

On May 15, 2002, APC distributed the “E11 – Impingement, Entrainment, and Turbine Mortality Study Progress Report” (Progress Report I) to IAG members. The IAG met on May 22, 2002 to review Progress Report I and to discuss how to execute the study plan to the satisfaction of IAG members. Specifically, IAG members requested seasonal estimates of the family/genus and size composition of the entrainment estimate (E11 IAG Meeting Notes, May 22, 2002).

On July 11, 2002, APC distributed the “E11 – Impingement, Entrainment and Turbine Mortality Study Progress Report II” (Progress Report II) to IAG members. The IAG met on July 16, 2002 to discuss Progress Report II and provide recommendations on how to proceed with

entrainment analysis. Members agreed that the entrainment estimate should include a family/genus level summary of results (E11 IAG Meeting Notes, July 16, 2002).

This report addresses the specific comments received at the May and July 2002 meetings and represents a summary of the study progress since the issuance of the Progress Report II.

2.0 *STUDY PROGRESS*

2.1 Impingement

Analysis of potential impingement at the projects will require several inputs: trash rack spacing, intake velocity, and species-size composition. Trash rack spacing and intake velocities have been provided by APC. Fish species and size composition estimates are currently being developed based on comments from IAG members.

Once all of these inputs are developed, intake velocities and trash rack spacing will be compared with the swimming speeds and body widths of fish species at the projects to determine which species and sizes of fish, if any, are susceptible to impingement. This qualitative analysis may be supplemented by plant operator observations, as stated in the Study Plan.

2.1 Entrainment

2.2.1 Entrainment Database

At the May 22, 2002 meeting, IAG members agreed that the average annual and seasonal entrainment rates from the 9-study database should be used to estimate the number of fish entrained at the Projects.

2.2.3 Calculation of the Entrainment Estimate

Step 1 – Total number of fish entrained by month

The estimated total number of fish entrained monthly by each project was presented in Progress Report II. The estimate was calculated by multiplying the appropriate seasonal fish entrainment rate from the 9-study database by the average monthly volume of water passed through the turbines.

At the July 16, 2002 meeting, Andy Sheppard (APC) noted that the flow data used to produce the estimate was inaccurate in that it did not account for the effects of upgrades at Mitchell in 1985, nor did it reflect the effects of minimum flows at Jordan.

APC has provided revised turbine flow data for Mitchell which was calculated using records from 1985 through 2000.

Revised data for Jordan presented a dilemma. Operations at Jordan began in 1926 and at Bouldin in 1967. In 1975, the Bouldin Dam earth embankment was breached rendering the plant inoperable until repairs were completed in 1980. APC has been operating Jordan Dam under minimum flow requirements since the late 1960's. Modifications to these requirements have been made over the years, with the most recent being implemented in May 2000. This minimum flow requirement varies from 2,000 cfs to 10,000 cfs, depending on the time of year.

Normal operating procedures call for passing Jordan Lake inflow first through the Bouldin Powerhouse, except for the minimum flows APC is required to maintain through Jordan. Flows in excess of the combined minimum flow at Jordan and turbine capacity of Bouldin (27,600 cfs) are discharged through the Jordan powerhouse to the extent of its capacity (19,700 cfs). Flows in excess of the two projects' combined turbine capacity are discharged through the Jordan Spillway.

As minimum flow requirements increase the average monthly turbine flows through Jordan, turbine flows through Bouldin are consequently decreased. While using the period of record that includes the most current typical operations at Jordan and Bouldin might seem warranted, it would likely exclude the hydrologic and associated generation variability that is experienced over a longer period of record, potentially skewing the entrainment estimate.

To solve this dilemma, we propose that average monthly turbine flows for the period of 1981 through 2000 be used to estimate entrainment. While this period of record will not completely reflect the current typical operations at Jordan and Bouldin individually, it should reflect typical combined operations of the two projects. This period of record would include the continuous, simultaneous operation of Jordan and Bouldin (since it was repaired and operations resumed in 1981) and should also generally reflect the effect of minimum flow requirements at Jordan.

The proposed turbine flow data for Jordan and Bouldin and the revised turbine flow data for Mitchell and are provided in Table 1. Based on these revised turbine flow data, the estimates of the total number of fish entrained by month were recalculated and are presented in Table 2.

Step 2 – Total number of fish entrained by season

The estimated total number of fish entrained by each project for each season was revised based on the revised turbine flow information (see Step 1) and is presented in Table 3.

Step 3 – Number of entrained fish within each family/genus-group by Season

Step 4 – Number of entrained fish within each 25mm (1-inch) length-group for each family/genus-group by season

At the July 16, 2002 IAG meeting, it was noted that the entrainment database did not include freshwater drum, which are present in every project reservoir except Lewis Smith. Members agreed that this species was important and warranted a search for additional studies at sites where freshwater drum entrainment occurred.

Three studies in which freshwater drum were entrained were obtained. These studies were conducted at the Minetto development of the Oswego Project (FERC No. 2474), the Townsend Dam Project (FERC No. 3451), and the New Martinsville Project (FERC No. 3206). After review, it was determined that data from two of the three studies, Minetto and Townsend, are acceptable for use in the entrainment estimate. Brief summaries of these two studies are provided in Appendix A of this report.

The New Martinsville study was deemed unacceptable due to high rates of net intrusion by downstream fish resulting from the use of partial-flow discharge netting. Previous review by RMC Environmental Services, Inc., found that the New Martinsville study methods were essentially flawed and that attempts to correct for net intrusion likely resulted in entrainment estimates that were off by several orders of magnitude (RMC, 1994).

Entrainment Database Composition

At the May 22 and July 16, 2002 IAG meeting, members discussed the need to further examine fish species composition in the entrainment database. The IAG agreed that some method of grouping fish species by family and/or genus should be devised.

A comparison of fish species listed in the entrainment database versus those present in project reservoirs is presented in Table 4. Fish species were sorted by family/genus group including an indication of percent relative abundance. It is notable that there are many species of fish present in the project reservoirs that are not present in the entrainment database and vice-versa. However, at the family/genus group level, there appears to be good agreement. Additionally, fish species from the entrainment database were grouped according to their classification as game fish, forage fish, and other species in Table 5.

Based on comments received at the May 22, 2002 IAG meeting (E11 IAG Meeting Notes, May 22, 2002), the seasonal family/genus and size composition percentage of the entrainment database has been organized and is presented in tables 6 through 11. According to the Study Plan, this family/genus and size composition percentage will be applied to the estimated number of fish entrained to complete the final steps of the fish entrainment estimate.

2.3 Turbine Mortality

Studies from the turbine mortality database have been divided based on whether they were performed at sites with propeller or francis-type turbines. The sites were sorted based on several characteristics including station head, runner diameter, and runner speed. This data is presented in tables 12 through 14 for propeller-type turbines, and tables 15 through 17 for francis-type turbines. Each of these tables includes the site characteristics of the Coosa and Warrior projects. Note that the Mitchell project appears in both the propeller and francis tables, because the newer turbines at that site are propeller turbines and the single remaining original turbine is a francis turbine.

Additionally, information on each turbine mortality study is provided in tables 18 and 19. The study information contained in the tables includes (where available) species type tested, size class/range tested, number of fish tested (test and control), and survival results. The study information is sorted by species type tested.

Table 1. Average monthly turbine flow in million cubic feet (mcf)

Site (period of record)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Weiss (1964 – 2000)	35,299	32,688	39,024	32,612	24,286	15,158	13,611	11,857	10,824	13,876	17,945	26,344
N. Henry (1966 – 2000)	40,084	35,637	41,593	33,463	25,365	16,488	14,891	12,749	11,613	14,391	20,280	28,877
Logan Martin (1964 – 2000)	47,519	44,227	52,776	40,927	29,683	18,508	16,148	13,432	12,318	17,161	22,640	33,784
Lay (1964 – 2000)	48,881	45,551	53,517	43,023	31,144	20,621	17,889	14,740	13,556	18,143	23,359	34,749
Mitchell (1985 – 2000)*	52,856	53,849	62,859	40,919	27,878	22,131	21,020	14,248	13,662	20,662	28,256	37,179
Jordan (1981 – 2000)**	39,591	35,431	41,467	32,984	29,399	17,774	14,424	12,414	11,222	15,790	17,413	28,382
Bouldin (1981 – 2000)**	43,146	43,957	48,211	34,892	22,355	17,539	16,161	11,514	9,854	14,640	22,557	35,237
Smith (1961 – 2000)	5,343	5,919	7,320	6,775	4,690	3,685	3,560	3,606	2,921	1,649	1,897	3,997
Bankhead (1963 – 2000)	19,552	18,634	20,527	16,537	10,953	6,983	6,432	5,218	4,487	3,167	5,889	13,663

*revised to reflect increased turbine flow resulting from upgrade

**revised to reflect minimum flows and Bouldin outage

[Source: APC 2002, unpublished data, as modified by Kleinschmidt]

Table 2. Monthly Estimated Total Number of Fish Entrained for the Warrior and Coosa River Projects

Site	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Weiss	161,318	149,382	238,438	199,257	148,386	84,279	75,674	65,927	39,722	50,924	65,858	120,391	1,399,555
N. Henry	183,185	162,863	254,131	204,461	154,981	91,674	82,793	70,884	42,621	52,816	74,428	131,967	1,506,805
Logan Martin	217,162	202,118	322,464	250,065	181,364	102,905	89,783	74,679	45,206	62,980	83,087	154,394	1,786,209
Lay	223,386	208,170	326,987	262,870	190,288	114,654	99,465	81,957	49,749	66,586	85,729	158,805	1,868,646
Mitchell	241,551	246,091	384,069	250,016	170,332	123,049	116,872	79,221	50,141	75,829	103,701	169,907	2,010,780
Jordan	180,932	161,917	253,364	201,532	179,629	98,825	80,200	69,021	41,184	57,949	63,904	129,704	1,518,161
Bouldin	197,175	200,882	294,570	213,189	136,587	97,519	89,856	64,019	36,163	53,727	82,784	161,035	1,627,506
Smith	24,417	27,051	44,724	41,398	28,656	20,486	19,794	20,048	10,721	6,051	6,962	18,268	268,576
Bankhead	89,354	85,158	125,419	101,043	66,921	38,826	35,760	29,013	16,468	11,622	21,613	62,441	683,638

**Table 3. Seasonal Estimated Total Number of Fish
Entrained at the Warrior and Coosa River Projects**

Site	WINTER	SPRING	SUMMER	FALL
Weiss	431,090	586,081	225,880	156,504
N. Henry	478,015	613,573	245,351	169,865
Logan Martin	573,674	753,893	267,368	191,273
Lay	590,361	780,146	296,076	202,064
Mitchell	657,550	804,418	319,141	229,671
Jordan	472,553	634,525	248,046	163,037
Bouldin	559,092	644,346	251,394	172,675
Smith	69,736	114,778	60,328	23,734
Bankhead	236,952	293,383	103,599	49,703

Table 4. A comparison of fish species listed in the entrainment database versus those present in project reservoirs*

Family	%	Common Name	%	Weiss	N. Henry	L. Martin	Lay	Mitchell	Jordan/Bouldin	Smith	Bankhead	Database	
Anguillidae	0.00	American eel	0.00									x	
Aphredoderidae	0.01	pirate perch	0.01									x	
Atherinidae	0.01	brook silverside	0.01						x	x	x	x	
Catastomidae	6.01												
	5.08	Alabama hog sucker							x	x	x		
		blue sucker							x				
		creek chubsucker	0.04						x	x	x	x	
		northern hog sucker	0.18									x	
		smallfin redhorse	1.55									x	
large	0.90	striped jumprock	3.31									x	
		black redhorse	0.03	x	x	x	x	x	x	x	x	x	
		blacktail redhorse		x	x	x	x	x	x	x	x		
		golden redhorse							x	x	x		
		quillback	0.09									x	
		shorthead redhorse	0.29									x	
		silver redhorse	0.42									x	
		smallmouth buffalo		x	x	x	x	x					
		spotted sucker		x	x	x	x	x	x	x	x		
		white sucker	0.10									x	
Centrarchidae	24.53												
crappie	1.32	black crappie	1.19	x	x	x	x	x	x	x	x	x	
		white crappie	0.13	x	x	x	x	x	x	x	x	x	
sunfishes	22.77	blackbanded sunfish	0.00									x	
		bluegill	16.99	x	x	x	x	x	x	x	x	x	
		bluespotted sunfish	0.01										x
		dollar sunfish	0.13							x	x	x	x
		flier		x	x								
		green sunfish	0.00	x	x	x	x	x	x	x	x	x	x
		longear sunfish		x	x	x	x	x	x	x	x	x	
		orangespotted sunfish		x	x	x	x	x					
		pumpkinseed	0.00										x
		red spotted sunfish								x	x	x	
		redbreast sunfish	4.47			x	x	x	x	x	x	x	x
		redear sunfish	1.13	x	x	x	x	x	x	x	x	x	x
		shadow bass		x	x					x	x	x	
		warmouth	0.04	x	x	x	x	x	x	x	x	x	x
Micropterus	0.44	Coosa bass	0.00									x	

Table 4. A comparison of fish species listed in the entrainment database versus those present in project reservoirs*

Family	%	Common Name	%	Weiss	N. Henry	L. Martin	Lay	Mitchell	Jordan/Bouldin	Smith	Bankhead	Database
		largemouth bass	0.18	x	x	x	x	x	x	x	x	x
		reдеye bass	0.05					x	x	x	x	x
		smallmouth bass	0.21									x
		spotted bass	0.00	x	x	x	x	x	x	x	x	x
Clupeidae	39.54	gizzard shad	12.15	x	x	x	x	x	x	x	x	x
		blueback herring	3.95									x
		threadfin shad	23.44	x	x	x	x	x	x	x	x	x
Cyprinidae	4.97											
small	3.91	Alabama shiner							x	x	x	
		blacknose dace							x	x	x	
		blacktail shiner		x	x	x	x	x	x	x	x	
		bluntnose minnow							x	x	x	
		bullhead minnow							x	x	x	
		burrhead shiner							x	x	x	
		clear chub							x	x	x	
		coastal shiner	0.00									x
		creek chub	0.04						x	x	x	x
		Dixie chub							x	x	x	
		dusky shiner	0.00									x
		Eastern silvery minnow	0.04									x
		emerald shiner							x	x	x	
		fathead minnow	0.11									x
		fieryblack shiner	0.47									x
		goldfish		x	x	x	x					
		mimic shiner							x	x	x	
		pretty shiner							x	x	x	
		pugnose minnow							x	x	x	
		rifle minnow							x	x	x	
		rosyface chub	0.00									x
		rough shiner							x	x	x	
		sailfin shiner	0.00									x
		sandbar shiner	0.65									x
		silverstripe shiner							x	x	x	
		spottail shiner	1.43									x
		steelcolor shiner								x	x	
		striped shiner							x	x	x	
		thicklip chub	0.10									x

Table 4. A comparison of fish species listed in the entrainment database versus those present in project reservoirs*

Family	%	Common Name	%	Weiss	N. Henry	L. Martin	Lay	Mitchell	Jordan/Bouldin	Smith	Bankhead	Database	
medium	1.04	whitefin shiner	1.07									x	
		yellowfin shiner	0.00									x	
		golden shiner	0.77	x	x	x	x	x	x	x	x	x	
		largescale stoneroller								x	x	x	
large	0.28	bluehead chub	0.27						x	x	x	x	
		carp	0.28	x	x	x	x	x	x	x	x	x	
Esocidae	0.00	chain pickerel	0.00	x	x	x	x	x	x	x	x	x	
		redfin pickerel	0.00									x	
Fundulidae		blackspotted topminnow							x	x	x		
Ictaluridae	19.29												
small	0.21	margined madtom	0.21									x	
		speckled madtom	0.00						x			x	
medium	12.10	tadpole madtom	0.00									x	
		frecklebelly madtom								x	x		
		freckled madtom									x	x	
		black bullhead	0.01	x	x	x	x	x	x	x	x	x	x
		brown bullhead	1.13	x	x	x	x	x					x
		flat bullhead	0.57										x
large	6.98	yellow bullhead	0.00						x	x	x	x	
		snail bullhead	7.51										x
		white catfish	2.88	x	x	x	x	x					x
		flathead catfish	0.01	x	x			x	x	x	x	x	x
		channel catfish	6.97	x	x	x	x	x	x	x	x	x	x
		blue catfish		x	x	x	x	x	x				
Lepisosteidae	0.00	longnose gar	0.00	x	x	x	x	x	x	x	x	x	
		spotted gar		x	x	x	x	x	x	x	x		
Moronidae	0.68												
medium	0.68	white perch	0.36									x	
		white bass	0.32	x	x	x	x	x	x	x	x	x	
large	0.01	striped bass	0.00	x	x	x	x	x	x	x	x	x	
		hybrid striped bass	0.01	x	x	x	x	x	x				x
Percidae	4.74												
small	0.54	bandfin darter								x	x		
		blackbanded darter	0.00						x	x	x	x	
		blackside darter							x	x	x		
		Christmas darter	0.00										x
		dusky darter									x	x	

Table 4. A comparison of fish species listed in the entrainment database versus those present in project reservoirs*

Family	%	Common Name	%	Weiss	N. Henry	L. Martin	Lay	Mitchell	Jordan/Bouldin	Smith	Bankhead	Database	
medium large	4.20 0.00	goldstripe darter							x	x	x		
		logperch		x									
		Mobile logperch				x	x	x	x	x	x	x	
		piedmont darter	0.37										x
		redfin darter								x	x	x	
		river darter								x	x	x	
		rock darter								x	x	x	
		seagreen darter	0.02										x
		speckled darter								x	x	x	
		essellated darter	0.15										x
		Tuskaloosa darter									x	x	
		Warrior darter									x	x	
		yellow perch	4.20										x
walleye	0.00			x	x	x	x	x	x		x		
Petromyzontidae		chestnut lamprey							x	x	x		
		southern brook lamprey							x	x	x		
Poeciliidae	0.00	mosquitofish	0.00	x	x	x	x	x	x	x	x	x	
Salmonidae	0.00	rainbow trout	0.00							x	x	x	
Sciaenidae	0.5**	freshwater drum	0.5**	x	x	x	x	x	x		x	x	

NOTES

Fish families/genus-groups are grouped together as indicated by the shading

Fish that are listed in **bold** print are not present in the 9-site database, but are present in one or more project reservoirs

Percentages less than 0.005 appear as 0.00

*Based on ADCNR reservoir management reports

**Based on two additional studies (see Progress Report III, section X.X)

Table 5. Gamefish and forage fish composition within the entrainment database

	%	%
Gamefish species		39.2
sunfish	22.6	
catfish	9.9	
percids	4.2	
crappie	1.3	
moronids	0.7	
micropterans	0.4	
drum	0.1	
Forage fish species		39.5
threadfin shad	23.4	
gizzard shad	12.2	
blueback herring	4.0	
Other fish species		21.3

Table 6. Seasonal family/genus group composition from the entrainment database

Family/genus group	Winter	Spring	Summer	Fall	Annual
Anguillidae	0.00	0.00	0.00	0.00	0.00
Aphredoderidae	0.00	0.01	0.00	0.03	0.01
Atherinidae	0.00	0.04	0.00	0.00	0.01
Catastomidae	2.48	12.62	2.90	6.04	6.01
Sunfish	3.74	20.26	36.64	35.69	24.08
Micropterans	0.09	0.55	0.79	0.33	0.44
Clupeidae	73.40	35.20	17.42	32.13	39.54
Cyprinidae	0.47	5.41	8.65	6.45	5.24
Esocidae	0.00	0.00	0.00	0.00	0.00
Ictaluridae	14.48	12.92	32.59	17.17	19.29
Lepisosteidae	0.00	0.00	0.00	0.00	0.00
Moronidae	0.95	0.71	0.02	1.05	0.68
Percidae	4.40	12.28	1.05	1.24	4.74
Poeciliidae	0.00	0.00	0.00	0.00	0.00
Salmonidae	0.00	0.00	0.00	0.00	0.00
Scianidae	0.00	0.21	1.58	0.44	0.56

Table 7. Annual size composition of fish family/genus groups in the entrainment database (by percent)

Family/Genus	1 in. 0-25 mm	2 26-50	3 51-75	4 76-100	5 101-125	6 126-150	7 151-175	8 176-200	9 201-225	10 226-250	10 - 12 251-300	12 - 16 301-400	16 - 20 401-500	20 - 24 501-600	24 - 28 601-700	28 - 32 701-800	32 - 36 801-900
Anguillidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.6	57.1	14.3	0.0	0.0	0.0
Aphredoderidae	0.0	20.5	74.4	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Atherinidae	8.1	43.2	35.1	10.8	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catastomidae	0.0	0.0	2.3	0.5	0.0	3.1	1.5	9.3	16.5	8.8	25.3	28.5	3.3	0.8	0.0	0.0	0.0
Lepomids/sunfish	0.1	12.3	26.0	20.8	10.0	4.7	15.0	5.2	3.9	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Micropterus	0.1	14.9	6.4	4.3	0.1	0.0	0.0	20.0	3.3	3.3	4.6	27.7	15.3	0.0	0.0	0.0	0.0
Clupeidae	0.0	10.2	14.6	17.0	18.0	20.7	9.6	2.1	2.5	1.4	1.0	2.2	0.7	0.0	0.0	0.0	0.0
Cyprinidae	0.0	13.3	46.2	29.7	2.9	0.3	0.8	1.3	0.6	0.0	0.0	1.1	1.3	2.2	0.2	0.1	0.0
Esocidae	0.0	0.0	31.8	50.0	9.1	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ictaluridae	0.0	8.4	10.9	16.2	16.3	5.2	12.7	6.2	2.9	1.8	13.3	5.2	0.0	0.8	0.0	0.0	0.0
Lepisosteidae	0.0	0.0	0.0	0.0	25.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0
Moronidae	0.0	0.0	0.1	1.4	6.4	15.8	12.5	7.0	6.3	1.3	13.0	19.1	15.1	2.1	0.0	0.0	0.0
Percidae	4.8	14.2	54.0	1.5	1.6	4.1	1.4	2.6	1.5	0.1	0.1	0.0	0.0	14.3	0.0	0.0	0.0
Poeciliidae	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salmonidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Scianidae	0.2	0.2	20.1	20.1	1.2	1.2	1.6	1.6	2.4	2.4	22.2	22.2	4.1	0.6	0.0	0.0	0.0

Table 8. Winter Size Composition of Entrained Fish by Family/Genus Group from the Study Database (by percent)

Family/Genus	1 in. 0-25 mm	2 26-50	3 51-75	4 76-100	5 101-125	6 126-150	7 151-175	8 176-200	9 201-225	10 226-250	10 - 12 251-300	12 - 16 301-400	16 - 20 401-500	20 - 24 501-600	24 - 28 601-700	28 - 32 701-800	32 - 36 801-900
Anguillidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aphredoderidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Atherinidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catastomidae	0.0	0.0	5.6	0.4	0.0	0.0	2.3	13.3	3.9	11.6	32.8	30.0	0.0	0.0	0.0	0.0	0.0
Lepomids/sunfish	0.0	4.1	26.2	18.5	12.3	11.5	19.9	3.2	3.2	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
Micropterans	0.0	0.0	0.0	24.1	0.0	0.0	0.0	0.0	25.0	25.0	12.0	0.0	13.9	0.0	0.0	0.0	0.0
Clupeidae	0.1	26.8	7.4	14.1	17.9	18.2	7.0	3.8	0.6	0.0	1.9	1.9	0.5	0.0	0.0	0.0	0.0
Cyprinidae	0.0	23.8	25.7	32.2	5.8	4.2	4.2	1.0	1.7	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0
Esocidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ictaluridae	0.0	5.8	5.1	15.8	25.1	6.7	9.5	15.4	4.8	8.1	3.4	0.2	0.0	0.0	0.0	0.0	0.0
Lepisosteidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Moronidae	0.0	0.0	0.0	18.6	0.0	4.7	0.0	0.0	0.0	25.0	0.0	26.8	25.0	0.0	0.0	0.0	0.0
Percidae	0.0	0.3	69.2	7.3	5.3	0.9	0.2	0.1	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0
Poeciliidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salmonidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scianidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 9. Spring Size Composition of Entrained Fish by Family/Genus Group from the Study Database (by percent)

Famliy/Genus	1 in. 0-25 mm	2 26-50	3 51-75	4 76-100	5 101-125	6 126-150	7 151-175	8 176-200	9 201-225	10 226-250	10 - 12 251-300	12 - 16 301-400	16 - 20 401-500	20 - 24 501-600	24 - 28 601-700	28 - 32 701-800	32 - 36 801-900
Anguillidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	66.7	0.0	0.0	0.0	0.0
Aphredoderidae	0.0	33.3	33.3	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Atherinidae	11.1	55.6	25.9	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catastomidae	0.0	0.0	3.6	0.5	0.0	0.0	3.2	9.0	4.5	35.1	7.6	29.0	6.1	1.5	0.0	0.0	0.0
Lepomids/sunfish	0.0	7.7	42.6	28.1	11.0	3.3	4.2	2.2	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Micropteraans	0.0	16.7	3.3	10.0	3.3	0.0	0.0	0.0	8.3	8.3	0.0	41.7	8.3	0.0	0.0	0.0	0.0
Clupeidae	0.1	10.4	14.8	12.1	6.8	35.2	3.3	3.1	4.7	2.1	0.4	6.0	0.9	0.0	0.0	0.0	0.0
Cyprinidae	0.0	16.1	38.6	21.7	7.0	5.2	4.4	1.2	1.0	0.0	0.0	0.0	3.2	1.5	0.0	0.0	0.0
Esocidae	0.0	0.0	50.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ictaluridae	0.2	7.7	20.6	10.6	15.6	3.2	28.0	5.6	3.0	1.6	3.7	0.0	0.2	0.0	0.0	0.0	0.0
Lepisosteidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Moronidae	0.0	0.0	0.1	2.6	13.5	6.7	8.6	1.5	0.1	0.2	1.0	30.1	31.3	4.4	0.0	0.0	0.0
Percidae	6.7	28.9	50.0	6.1	4.3	3.1	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Poeciliidae	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salmonidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scianidae	0.0	0.0	0.0	0.0	2.1	2.1	0.0	0.0	4.5	4.5	39.2	39.2	8.4	0.0	0.0	0.0	0.0

Table 10. Summer Size Composition of Entrained Fish by Family/Genus Group from the Study Database (by percent)

Family/Genus	1 in. 0-25 mm	2 26-50	3 51-75	4 76-100	5 101-125	6 126-150	7 151-175	8 176-200	9 201-225	10 226-250	10 - 12 251-300	12 - 16 301-400	16 - 20 401-500	20 - 24 501-600	24 - 28 601-700	28 - 32 701-800	32 - 36 801-900
Anguillidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0	25.0	0.0	0.0	0.0
Aphredoderidae	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Atherinidae	0.0	0.0	66.7	22.2	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catastomidae	0.0	0.0	6.4	0.4	0.0	8.5	2.6	10.3	4.3	21.8	18.4	27.1	0.0	0.0	0.0	0.0	0.0
Lepomids/sunfish	0.2	4.2	37.3	38.1	8.3	3.6	6.0	1.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Micropterus	1.2	45.1	15.4	3.7	0.0	0.0	0.0	0.0	16.7	16.7	0.0	0.0	1.2	0.0	0.0	0.0	0.0
Clupeidae	0.0	2.0	38.9	14.2	3.6	10.5	6.8	3.1	2.6	2.4	7.2	7.2	1.4	0.0	0.0	0.0	0.0
Cyprinidae	0.0	14.4	44.4	19.9	3.2	3.8	4.7	2.6	0.2	0.0	0.0	3.8	2.7	0.0	0.3	0.0	0.0
Esocidae	0.0	0.0	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ictaluridae	0.0	5.1	6.9	23.0	28.2	4.7	5.4	6.2	3.2	1.7	14.9	0.6	0.0	0.1	0.0	0.0	0.0
Lepisosteidae	0.0	0.0	0.0	0.0	50.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Moronidae	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0
Percidae	0.0	4.2	71.6	13.3	7.1	3.3	0.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Poeciliidae	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salmonidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Scianidae	0.5	0.5	16.2	16.2	0.5	0.5	0.9	0.9	2.8	2.8	26.3	26.3	3.8	1.9	0.0	0.0	0.0

Table 11. Fall Size Composition of Entrained Fish by Family/Genus Group from the Study Database (by percent)

Species	1 in. 0-25 mm	2 26-50	3 51-75	4 76-100	5 101-125	6 126-150	7 151-175	8 176-200	9 201-225	10 226-250	10 - 12 251-300	12 - 16 301-400	16 - 20 401-500	20 - 24 501-600	24 - 28 601-700	28 - 32 701-800	32 - 36 801-900
Anguillidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aphredoderidae	0.0	9.4	87.5	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Atherinidae	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catastomidae	0.0	0.0	6.0	0.6	0.0	0.0	1.8	9.8	5.1	15.8	32.4	28.6	0.0	0.0	0.0	0.0	0.0
Lepomids/sunfish	0.1	12.0	23.5	20.0	7.7	4.9	16.5	3.0	6.9	3.7	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Microptera	0.0	0.0	0.0	8.1	0.0	0.0	0.0	25.0	12.5	12.5	25.0	4.1	12.8	0.0	0.0	0.0	0.0
Clupeidae	0.0	18.3	15.6	5.4	8.1	10.5	16.8	9.6	5.4	2.5	5.4	2.0	0.5	0.0	0.0	0.0	0.0
Cyprinidae	0.0	24.8	20.0	30.5	8.1	4.2	4.2	1.9	1.5	0.0	0.0	0.0	1.9	0.0	2.0	1.0	0.0
Esocidae	0.0	0.0	0.0	0.0	66.7	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ictaluridae	0.0	10.8	7.3	7.2	27.5	18.8	8.4	9.0	3.2	4.4	0.6	2.8	0.0	0.0	0.0	0.0	0.0
Lepisosteidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Moronidae	0.0	0.0	0.0	0.0	0.0	0.0	27.1	18.4	8.0	4.0	9.2	33.3	0.0	0.0	0.0	0.0	0.0
Percidae	0.0	0.0	68.8	3.4	13.4	11.4	2.4	0.0	0.1	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Poeciliidae	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salmonidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scianidae	0.0	0.0	44.1	44.1	1.1	1.1	3.8	3.8	0.0	0.0	0.9	0.9	0.2	0.0	0.0	0.0	0.0

Table 12. Kaplan/propeller-type turbine mortality database, sorted by runner speed

Station	Designed Turbine Flow (cfs)	Number of Blades	Runner Speed (rpm)	Head (ft)	Runner Diameter (in)	Fish Groups Tested
Annapolis, NS	14,287	-	50	22	267	clupeids
Safe Harbor, PA (Unit 8)	9,200	7	75	55	242	clupeids
Neely Henry, AL	9,200	4	81.8	35	256	n/a
Mitchell, AL	10,459	5	85.7	57.4	266	n/a
Weiss, AL	8,750	5	90	49	232	n/a
Logan Martin, AL	10,000	5	90	56	250	n/a
Greenup Dam, OH (Vanceburg)	11,890	5	90	30	283	warmwater
Safe Harbor, PA (Unit 7)	8,300	5	109	55	222	clupeids
Thornapple, WI	700	6	120	15	110	warmwater
Raymondville, NY	1,640	6	120	21	131	warmwater
Conowingo, MD	10,000	6	120	90	225	clupeids
Hadley Falls, MA	4,200	5	128	52	170	clupeids
Lawrence, MA	4,500	3	128.6	29	145	warmwater
Lay, AL	5,519	8	128.6	81	175	n/a
Herrings, NY	1,200	-	138	19	113	warmwater
Bouldin, AL	9,334	6	138.5	117	205	n/a
Crescent, NY	1,520	5	144	27	108	clupeids
Chalk Hill, MI-WI	1,330	4	150	29	102	warmwater
Townsend Dam, PA	1,500	3	152	16	113	warmwater
Marshall, NC	1,250	-	212	31	149	warmwater
Craggy Dam, NC	600	4	229	21	69	warmwater
Twin Branch, IN	411	4	241	21.4	NA	warmwater

Table 13. Kaplan/propeller-type turbine mortality database, sorted by head

Station	Designed Turbine Flow (cfs)	Number of Blades	Runner Speed (rpm)	Head (ft)	Runner Diameter (in)	Fish Groups Tested
Thornapple, WI	700	6	120	15	110	warmwater
Townsend Dam, PA	1,500	3	152	16	113	warmwater
Herrings, NY	1,200	-	138	19	113	warmwater
Raymondville, NY	1,640	6	120	21	131	warmwater
Craggy Dam, NC	600	4	229	21	69	warmwater
Twin Branch, IN	411	4	241	21.4	NA	warmwater
Annapolis, NS	14,287	-	50	22	267	clupeids
Crescent, NY	1,520	5	144	27	108	clupeids
Lawrence, MA	4,500	3	128.6	29	145	warmwater
Chalk Hill, MI-WI	1,330	4	150	29	102	warmwater
Greenup Dam, OH	11,890	5	90	30	283	warmwater
Marshall, NC	1,250	-	212	31	149	warmwater
Neely Henry, AL	9,200	4	81.8	35	256	n/a
Weiss, AL	8,750	5	90	49	232	n/a
Hadley Falls, MA	4,200	5	128	52	170	clupeids
Safe Harbor, PA (Unit 8)	9,200	7	75	55	242	clupeids
Safe Harbor, PA (Unit 7)	8,300	5	109	55	222	clupeids
Logan Martin, AL	10,000	5	90	56	250	n/a
Mitchell, AL	10,459	5	85.7	57.4	266	n/a
Lay, AL	5,519	8	128.6	81	175	n/a
Conowingo, MD	10,000	6	120	90	225	clupeids
Bouldin, AL	9,334	6	138.5	117	205	n/a

Table 14. Kaplan/propeller-type turbine mortality database, sorted by runner diameter

Station	Designed Turbine Flow (cfs)	Number of Blades	Runner Speed (rpm)	Head (ft)	Runner Diameter (in)	Fish Groups Tested
Craggy Dam, NC	600	4	229	21	69	warmwater
Chalk Hill, MI-WI	1,330	4	150	29	102	warmwater
Crescent, NY	1,520	5	144	27	108	clupeids
Thornapple, WI	700	6	120	15	110	warmwater
Townsend Dam, PA	1,500	3	152	16	113	warmwater
Herrings, NY	1,200	-	138	19	113	warmwater
Raymondville, NY	1,640	6	120	21	131	warmwater
Lawrence, MA	4,500	3	128.6	29	145	warmwater
Marshall, NC	1,250	-	212	31	149	warmwater
Hadley Falls, MA	4,200	5	128	52	170	clupeids
Lay, AL	5,519	8	128.6	81	175	n/a
Bouldin, AL	9,334	6	138.5	117	205	n/a
Safe Harbor, PA (Unit 7)	8,300	5	109	55	222	clupeids
Conowingo, MD	10,000	6	120	90	225	clupeids
Weiss, AL	8,750	5	90	49	232	n/a
Safe Harbor, PA (Unit 8)	9,200	7	75	55	242	clupeids
Logan Martin, AL	10,000	5	90	56	250	n/a
Neely Henry, AL	9,200	4	81.8	35	256	n/a
Mitchell, AL	10,459	5	85.7	57.4	266	n/a
Annapolis, NS	14,287	-	50	22	267	clupeids
Greenup Dam, OH (Vanceburg)	11,890	5	90	30	283	warmwater
Twin Branch, IN	411	4	241	21.4	NA	warmwater

Table 15. Francis-type turbine mortality database, sorted by runner speed.

Station	Designed Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Diameter (in)	Fish Groups Tested
Minetto, NY	1,500	16	72	17	139	Warmwater
Vernon, VT/NH	1,834	15	74	34	156	Warmwater
Stevens Creek, SC	1,000	14	75	28	135	Warmwater
Centralia, WI (Unit 2)	510		90	20	28	Warmwater
Alcona, MI	615	16	90	43	100	Warmwater
Grand Rapids, WI (U 1,2,4 comb)	645		90			Warmwater
Mitchell, AL	4,791	17	90	70	178	n/a
Alcona, MI	1155 -1660	16	90		100	Warmwater
Holtwood, PA(U10/single runner)	3,500	16	94.7	62	149.5	Clupieds
Holtwood, PA	3,500	16	95	55	164	Clupieds
Peshtigo, WI (Unit 4)	460		100	13	80	Warmwater
Jordan, AL	4,655	15	100	90	178	n/a
Holtwood, PA (U3/double runner)	3,500	17	102.8	62	112	Clupieds
Bankhead, AL	10,338	6	102.8	68	232.5	n/a
E. J. West, NY	2,700	15	113	63	131	Warmwater
Seton Creek, BC	4,500		120	150	114	Warmwater
Potato Rapids, WI (Unit 1)	500		123	17	84	Warmwater
Potato Rapids, WI (Unit 2)	440		135	17	80	Warmwater
Shasta, WA	3,200	15	138.5	380	184	Warmwater
Shasta, WA	3,200	15	138.5		184	Warmwater
Lewis Smith, AL	5,700	15	138.5	210	186	n/a
Rogers, MI (units 1 & 2)	383	15	150	39	60	Warmwater
Grand Rapids, WI (Unit 2)	645		150	28	58	Warmwater
Five Channels, MI	675	16	150	36	55	Warmwater
Five Channels, MI	1034 -1167	16	150		55	Warmwater
Sandstone Rapids, WI			150	42	87	Warmwater
Hardy, MI (Unit 2)	510	16	163.6	100.2	83.75	Warmwater
Luray, VA	369	12	164	18	62.75	Angulidae
Columbia, SC	833	14	164	28	64	Warmwater
Grand Rapids, WI (Unit 4)	926		180	28	72	Warmwater
Caldron Falls, WI (Unit 1)			226	80	72	Warmwater
Prickett, MI	326		257	54	53.5	Warmwater
Highley, NY	675	13	257	46	48	Warmwater
Bond Falls, MI	450		300	210		Warmwater
Hoist, MI	300		360	142		Clupieds
Colton, NY	497	19	360	265	59	Warmwater
Centralia, WI (Unit 1)	510					Warmwater
Centralia, WI	variable			15.5		Warmwater
Finch Pruyn, NY (Unit 4)				9-16	41	Warmwater
Finch Pruyn, NY (Unit 5)				9-16	41	Warmwater
Herrings, NY						Warmwater
High Falls, WI (Unit 5)						Warmwater
Raymondville, NY						Warmwater

Table 16. Francis-type turbine mortality database, sorted by head.

Station	Designed Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Diameter (in)	Fish Groups Tested
Peshtigo, WI (Unit 4)	460		100	13	80	Warmwater
Centralia, WI	variable			15.5		Warmwater
Potato Rapids, WI (Unit 2)	440		135	17	80	Warmwater
Potato Rapids, WI (Unit 1)	500		123	17	84	Warmwater
Minetto, NY	1,500	16	72	17	139	Warmwater
Luray, VA	369	12	164	18	62.75	Angulidae
Centralia, WI (Unit 2)	510		90	20	28	Warmwater
Grand Rapids, WI (Unit 2)	645		150	28	58	Warmwater
Columbia, SC	833	14	164	28	64	Warmwater
Grand Rapids, WI (Unit 4)	926		180	28	72	Warmwater
Stevens Creek, SC	1,000	14	75	28	135	Warmwater
Vernon, VT/NH	1,834	15	74	34	156	Warmwater
Five Channels, MI	675	16	150	36	55	Warmwater
Rogers, MI (units 1 & 2)	383	15	150	39	60	Warmwater
Sandstone Rapids, WI			150	42	87	Warmwater
Alcona, MI	615	16	90	43	100	Warmwater
Highley, NY	675	13	257	46	48	Warmwater
Pricket, MI	326		257	54	53.5	Warmwater
Holtwood, PA	3,500	16	95	55	164	Clupieds
Holtwood, PA(U10/single runner)	3,500	16	94.7	62	149.5	Clupieds
Holtwood, PA (U3/double runner)	3,500	17	102.8	62	112	Clupieds
E. J. West, NY	2,700	15	113	63	131	Warmwater
Bankhead, AL	10,338	6	102.8	68	232.5	n/a
Mitchell, AL	4,791	17	90	70	178	n/a
Caldron Falls, WI (Unit 1)			226	80	72	Warmwater
Jordan, AL	4,655	15	100	90	178	n/a
Hardy, MI (Unit 2)	510	16	163.6	100.2	83.75	Warmwater
Hoist, MI	300		360	142		Clupieds
Seton Creek, BC	4,500		120	150	114	Warmwater
Bond Falls, MI	450		300	210		Warmwater
Lewis Smith, AL	5,700	15	138.5	210	186	n/a
Colton, NY	497	19	360	265	59	Warmwater
Shasta, WA	3,200	15	138.5	380	184	Warmwater
Finch Pruyn, NY (Unit 4)				9-16	41	Warmwater
Finch Pruyn, NY (Unit 5)				9-16	41	Warmwater
Grand Rapids, WI (U 1,2,4 comb)	645		90			Warmwater
Five Channels, MI	1034 -1167	16	150		55	Warmwater
Centralia, WI (Unit 1)	510					Warmwater
Shasta, WA	3,200	15	138.5		184	Warmwater
Alcona, MI	1155 -1660	16	90		100	Warmwater
Herrings, NY						Warmwater
High Falls, WI (Unit 5)						Warmwater
Raymondville, NY						Warmwater

Table 17. Francis-type turbine mortality database, sorted by runner diameter

Station	Designed Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Diameter (in)	Fish Groups Tested
Centralia, WI (Unit 2)	510		90	20	28	Warmwater
Finch Pruyn, NY (Unit 4)				9-16	41	Warmwater
Finch Pruyn, NY (Unit 5)				9-16	41	Warmwater
Highley, NY	675	13	257	46	48	Warmwater
Prickett, MI	326		257	54	53.5	Warmwater
Five Channels, MI	675	16	150	36	55	Warmwater
Five Channels, MI	1034 -1167	16	150		55	Warmwater
Grand Rapids, WI (Unit 2)	645		150	28	58	Warmwater
Colton, NY	497	19	360	265	59	Warmwater
Rogers, MI (units 1 & 2)	383	15	150	39	60	Warmwater
Luray, VA	369	12	164	18	62.75	Angulidae
Columbia, SC	833	14	164	28	64	Warmwater
Grand Rapids, WI (Unit 4)	926		180	28	72	Warmwater
Caldron Falls, WI (Unit 1)			226	80	72	Warmwater
Potato Rapids, WI (Unit 2)	440		135	17	80	Warmwater
Peshigo, WI (Unit 4)	460		100	13	80	Warmwater
Hardy, MI (Unit 2)	510	16	163.6	100.2	83.75	Warmwater
Potato Rapids, WI (Unit 1)	500		123	17	84	Warmwater
Sandstone Rapids, WI			150	42	87	Warmwater
Alcona, MI	615	16	90	43	100	Warmwater
Alcona, MI	1155 -1660	16	90		100	Warmwater
Holtwood, PA (U3/double runner)	3,500	17	102.8	62	112	Clupieds
Seton Creek, BC	4,500		120	150	114	Warmwater
E. J. West, NY	2,700	15	113	63	131	Warmwater
Stevens Creek, SC	1,000	14	75	28	135	Warmwater
Minetto, NY	1,500	16	72	17	139	Warmwater
Holtwood, PA(U10/single runner)	3,500	16	94.7	62	149.5	Clupieds
Vernon, VT/NH	1,834	15	74	34	156	Warmwater
Holtwood, PA	3,500	16	95	55	164	Clupieds
Jordan, AL	4,655	15	100	90	178	n/a
Mitchell, AL	4,791	17	90	70	178	n/a
Shasta, WA	3,200	15	138.5	380	184	Warmwater
Shasta, WA	3,200	15	138.5		184	Warmwater
Lewis Smith, AL	5,700	15	138.5	210	186	n/a
Bankhead, AL	10,338	6	102.8	68	232.5	n/a
Hoist, MI	300		360	142		Clupieds
Bond Falls, MI	450		300	210		Warmwater
Centralia, WI (Unit 1)	510					Warmwater
Grand Rapids, WI (U 1,2,4 comb)	645		90			Warmwater
Centralia, WI	variable			15.5		Warmwater
Herrings, NY						Warmwater
High Falls, WI (Unit 5)						Warmwater
Raymondville, NY						Warmwater

Table 18. Summary of mortality studies performed at sites with Kaplan/propeller type turbines

Station	Sampling Method	Species Tested	Avg. Fish Length (mm)	Est. Percent Survival
Annapolis, NS	Radio telemetry	American shad	Adult	53.7
Conowingo, MD	HI-Z Turb'N Tag	American Shad	125	94.9
Hadley Falls, MA	Radio telemetry	American Shad	560	78.2
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	82	97.3
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	82	100.0
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	82	89.1
Safe Harbor, PA (Unit 7)	HI-Z Turb'N Tag	American Shad	424	89.7
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	424	87.0
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	118	97.8
Safe Harbor, PA (Unit 7)	HI-Z Turb'N Tag	American Shad	118	98.0
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	118	98.9
Morrow, MI	Full discharge netting	Black Crappie	Adult/YOY	74.0
Crescent, NY	HI-Z Turb'N Tag	Blueback Herring	91	96.0
Chalk Hill, MI-WI	HI-Z Turb'N Tag	Bluegill	103	97.0
Chalk Hill, MI-WI	HI-Z Turb'N Tag	Bluegill	153	98.0
Craggy Dam, NC	HI-Z Turb'N Tag	Bluegill	100	96.0
Craggy Dam, NC	HI-Z Turb'N Tag	Bluegill	155	86.0
Morrow, MI	Full discharge netting	Bluegill	Adult/YOY	70.0
Twin Branch, IN	Full discharge netting	Bluegill	126	94.7
Morrow, MI	Full discharge netting	Brown Bullhead	Adult	97.0
Thornapple, WI	Full discharge netting	Bullheads & Catfish	-	91.9
Herrings, NY	Full discharge netting	Centrarchid	<100	98.3
Herrings, NY	Full discharge netting	Centrarchid	175	97.3
Herrings, NY	Full discharge netting	Centrarchid	>250	93.2
Herrings, NY	Full discharge netting	Centrarchid	<100	95.0
Herrings, NY	Full discharge netting	Centrarchid	100-250	96.4
Herrings, NY	Full discharge netting	Centrarchid	>250	92.5
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	180	93.0
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	180	90.0
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	277	81.0
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	277	93.0
Herrings, NY	Full discharge netting	Clupeids	<100	92.8
Raymondville, NY	Full discharge netting	Eel	625	63.0
Morrow, MI	Full discharge netting	Largemouth Bass	Adult	81.0
Townsend Dam, PA	HI-Z Turb'N Tag	Largemouth Bass	217	96.8
Townsend Dam, PA	HI-Z Turb'N Tag	Largemouth Bass	102	100.0
Townsend Dam, PA	HI-Z Turb'N Tag	Largemouth Bass	217	86.0
Thornapple, WI	Full discharge netting	Minnow/Dace/Darter	-	97.1
Thornapple, WI	Full discharge netting	Panfish & Y. Perch	-	93.5
Herrings, NY	Full discharge netting	Percid	<100	91.1
Herrings, NY	Full discharge netting	Percid	<100	94.9
Herrings, NY	Full discharge netting	Percid	100-250	98.2
Herrings, NY	Full discharge netting	Percid	>250	96.2
Morrow, MI	Full discharge netting	Pumpkinseed	Adult/YOY	90.0
Morrow, MI	Full discharge netting	Redhorse	Adult	71.0
Marshall, NC	Partial netting	Resident	-	92.3
Morrow, MI (EPRI)	Full discharge netting	Resident	-	92.1
Thornapple, WI	Full discharge netting	Small/Largemth Bass	-	97.4

Table 18. Summary of mortality studies performed at sites with Kaplan/propeller type turbines
CONTINUED

Station	Sampling Method	Species Tested	Avg. Fish Length (mm)	Est. Percent Survival
Herrings, NY	Full discharge netting	Soft ray	<100	97.5
Herrings, NY	Full discharge netting	Soft ray	100-250	91.7
Herrings, NY	Full discharge netting	Soft ray	>250	85.1
Thornapple, WI	Full discharge netting	Suckers & Redhorse	-	93.4
Chalk Hill, MI-WI	HI-Z Turb'N Tag	W. Sucker/R. Trout	119	91.0
Chalk Hill, MI-WI	HI-Z Turb'N Tag	W. Sucker/R. Trout	261	97.0
Thornapple, WI	Full discharge netting	Walleye	-	97.6
Morrow, MI	Full discharge netting	White Sucker	Adult/YOY	67.0
Morrow, MI	Full discharge netting	Yellow Bullhead	Adult	92.0
Morrow, MI	Full discharge netting	Yellow Perch	Adult	78.0

Table 19. Summary of mortality studies performed at sites with Francis-type turbines

Station	Sampling Method	Species Tested	Avg. Fish Length (mm)	Est. Percent Survival
Minetto, NY (Unit 4)	Full Discharge Netting	American eel	547 – 705	93.6
Holtwood, PA (Unit 3 – double runner)	Full Discharge Netting	American shad	95 – 163	60.0
Columbia, SC	HI-Z Turb'N Tag	blueback herring	140	88.1
Stevens Creek, SC	Balloon tag	blueback herring	131 – 200	94.3
Alcona, MI	Full Discharge Netting	bluegill	58 – 154	90.0
Alcona, MI	Full Discharge Netting	bluegill	95 – 206	84.0
Grand Rapids, WI (Units 1,2, & 4 comb.)	Full Discharge Netting	bluegill	76	91.4
Grand Rapids, WI (Units 1,2, & 4 comb.)	Full Discharge Netting	bluegill	127	91.4
Grand Rapids, WI (Units 1,2, & 4 comb.)	Full Discharge Netting	bluegill	178	91.4
Hardy, MI (Unit 2)	Full Discharge Netting	bluegill	79 – 149	89.0
Hardy, MI (Unit 2)	Full Discharge Netting	bluegill	120 – 186	91.0
Minetto, NY (Unit 3)	Full Discharge Netting	bluegill	80 – 116	81.4
Rogers, MI (Units 1 & 2)	Full Discharge Netting	bluegill	46 – 155	96.0
Rogers, MI (Units 1 & 2)	Full Discharge Netting	bluegill	108 – 180	85.0
Peshtigo, WI (Unit 4)	Full Discharge Netting	catostomid	<152	93.9
Peshtigo, WI (Unit 4)	Full Discharge Netting	catostomid	>152	90.1
Potato Rapids, WI	Full Discharge Netting	catostomid	<152	78.0
Potato Rapids, WI	Full Discharge Netting	catostomid	>152	63.1
Sandstone Rapids, WI	Full Discharge Netting	catostomid	<152	75.0
Sandstone Rapids, WI	Full Discharge Netting	catostomid	>152	62.8
White Rapids, WI	Balloon tag	catostomid	<152	96.0
White Rapids, WI	Balloon tag	catostomid	>152	80.0
Hollidays Bridge, SC	balloon tag	catfish	152 – 228	100.0
Hollidays Bridge, SC	balloon tag	catfish	229 – 305	100.0
Hollidays Bridge, SC	balloon tag	catfish	152 – 228	93.0
Hollidays Bridge, SC	balloon tag	catfish	229 – 305	96.0
Ninety-Nine Islands, SC	balloon tag	catfish	152 – 228	89.0
Ninety-Nine Islands, SC	balloon tag	catfish	229 – 305	88.0
Ninety-Nine Islands, SC	balloon tag	catfish	152 – 228	100.0
Ninety-Nine Islands, SC	balloon tag	catfish	229 – 305	100.0
E.J. West, NY	Full Discharge Netting	centrarchiforms	small	72.0
E.J. West, NY	Full Discharge Netting	centrarchiforms	medium	85.0
E.J. West, NY	Full Discharge Netting	centrarchiforms	large	60.0
Five Channels, MI	Full Discharge Netting	centrarchiforms	72 – 189	94.0
Five Channels, MI	Full Discharge Netting	centrarchiforms	113 – 244	89.0
Peshtigo, WI (Unit 4)	Full Discharge Netting	centrarchiforms	<152	99.5
Peshtigo, WI (Unit 4)	Full Discharge Netting	centrarchiforms	>152	100.0
Potato Rapids, WI	Full Discharge Netting	centrarchiforms	<152	90.5
Potato Rapids, WI	Full Discharge Netting	centrarchiforms	>152	91.3
Sandstone Rapids, WI	Full Discharge Netting	centrarchiforms	<152	89.9
Sandstone Rapids, WI	Full Discharge Netting	centrarchiforms	>152	79.9
White Rapids, WI	Balloon tag	centrarchiforms	<152	97.0

Table 19. Summary of mortality studies performed at sites with Francis-type turbines
CONTINUED

Station	Sampling Method	Species Tested	Avg. Fish Length (mm)	Est. Percent Survival
White Rapids, WI	Balloon tag	centrarchiforms	>152	80.0
Columbia, SC	HI-Z Turb'N Tag	channel catfish	143	92.5
Peshtigo, WI (Unit 4)	Full Discharge Netting	cyprinid	<152	93.9
Peshtigo, WI (Unit 4)	Full Discharge Netting	cyprinid	>152	90.1
Potato Rapids, WI	Full Discharge Netting	cyprinid	<152	78.0
Potato Rapids, WI	Full Discharge Netting	cyprinid	>152	63.1
Sandstone Rapids, WI	Full Discharge Netting	cyprinid	<152	75.0
Sandstone Rapids, WI	Full Discharge Netting	cyprinid	>152	62.8
White Rapids, WI	Balloon tag	cyprinid	<152	96.0
White Rapids, WI	Balloon tag	cyprinid	>152	80.0
Alcona, MI	Full Discharge Netting	golden shiner	65 – 129	81.0
Alcona, MI	Full Discharge Netting	golden shiner	101 – 188	85.0
Five Channels, MI	Full Discharge Netting	golden shiner	62 – 153	82.0
Five Channels, MI	Full Discharge Netting	golden shiner	111 – 207	85.0
Hardy, MI (Unit 2)	Full Discharge Netting	golden shiner	74 – 165	85.0
Hardy, MI (Unit 2)	Full Discharge Netting	golden shiner	113 – 204	89.0
Rogers, MI (Units 1 & 2)	Full Discharge Netting	golden shiner	70 – 114	54.0
Rogers, MI (Units 1 & 2)	Full Discharge Netting	golden shiner	103 -173	92.0
Peshtigo, WI (Unit 4)	Full Discharge Netting	ictalurid	<152	93.9
Peshtigo, WI (Unit 4)	Full Discharge Netting	ictalurid	>152	90.1
Potato Rapids, WI	Full Discharge Netting	ictalurid	<152	78.0
Potato Rapids, WI	Full Discharge Netting	ictalurid	>152	63.1
Sandstone Rapids, WI	Full Discharge Netting	ictalurid	<152	75.0
Sandstone Rapids, WI	Full Discharge Netting	ictalurid	>152	62.8
White Rapids, WI	Balloon tag	ictalurid	<152	96.0
White Rapids, WI	Balloon tag	ictalurid	>152	80.0
Hardy, MI (Unit 2)	Full Discharge Netting	largemouth bass	80 – 162	76.0
Minetto, NY (Unit 3)	Full Discharge Netting	largemouth bass	141 – 310	90.7
Minetto, NY (Unit 3)	Full Discharge Netting	largemouth bass	165 – 348	87.4
Minetto, NY (Unit 4)	Full Discharge Netting	largemouth bass	150 – 205	73.7
Minetto, NY (Unit 4)	Full Discharge Netting	largemouth bass	236 – 323	83.4
Rogers, MI (Units 1 & 2)	Full Discharge Netting	largemouth bass	74 – 139	77.0
Columbia, SC	HI-Z Turb'N Tag	Lepomids	107	95.9
E.J. West, NY	Full Discharge Netting	percoid	small	51.0
Five Channels, MI	Full Discharge Netting	percoid	<152	72.0
Five Channels, MI	Full Discharge Netting	percoid	>152	76.9
Peshtigo, WI (Unit 4)	Full Discharge Netting	percoid	<152	99.5
Peshtigo, WI (Unit 4)	Full Discharge Netting	percoid	>152	100.0
Potato Rapids, WI	Full Discharge Netting	percoid	<152	90.5
Potato Rapids, WI	Full Discharge Netting	percoid	>152	91.3
Rogers, MI (Units 1 & 2)	Full Discharge Netting	percoid	<152	91.8
Rogers, MI (Units 1 & 2)	Full Discharge Netting	percoid	>152	87.2
Sandstone Rapids, WI	Full Discharge Netting	percoid	<152	88.9

Table 19. Summary of mortality studies performed at sites with Francis-type turbines**CONTINUED**

Station	Sampling Method	Species Tested	Avg. Fish Length (mm)	Est. Percent Survival
Sandstone Rapids, WI	Full Discharge Netting	percid	>152	79.9
White Rapids, WI	Balloon tag	percid	<152	96.0
White Rapids, WI	Balloon tag	percid	>152	80.0
Finch Pruyn, NY (Unit 4)	Full Discharge Netting	smallmouth bass	<191	95.0
Finch Pruyn, NY (Unit 4)	Full Discharge Netting	smallmouth bass	191 – 229	91.0
Finch Pruyn, NY (Unit 4)	Full Discharge Netting	smallmouth bass	236 – 305	93.0
Finch Pruyn, NY (Unit 5)	Full Discharge Netting	smallmouth bass	<191	94.0
Finch Pruyn, NY (Unit 5)	Full Discharge Netting	smallmouth bass	191 – 229	91.0
Finch Pruyn, NY (Unit 5)	Full Discharge Netting	smallmouth bass	236 – 305	71.0
E.J. West, NY	Full Discharge Netting	soft ray	small	32.0
E.J. West, NY	Full Discharge Netting	soft ray	medium	71.0
E.J. West, NY	Full Discharge Netting	soft ray	large	68.0
Alcona, MI	Full Discharge Netting	spottail shiner	81 – 128	59.0
Rogers, MI (Units 1 & 2)	Full Discharge Netting	spottail shiner	58 – 174	73.0
Minetto, NY (Unit 4)	Full Discharge Netting	walleye	132 – 215	94.5
Minetto, NY (Unit 4)	Full Discharge Netting	walleye	135 – 210	95.7
Alcona, MI	Full Discharge Netting	white sucker	111 – 278	94.0
Alcona, MI	Full Discharge Netting	white sucker	161 – 395	90.0
Alcona, MI	Full Discharge Netting	white sucker	111 – 278	94.0
Alcona, MI	Full Discharge Netting	white sucker	161 – 395	90.0
Five Channels, MI	Full Discharge Netting	white sucker	81 – 241	89.0
Five Channels, MI	Full Discharge Netting	white sucker	225 – 442	71.0
Grand Rapids, WI (Units 1,2, & 4 comb.)	Full Discharge Netting	white sucker	76	91.4
Grand Rapids, WI (Units 1,2, & 4 comb.)	Full Discharge Netting	white sucker	127	91.4
Grand Rapids, WI (Units 1,2, & 4 comb.)	Full Discharge Netting	white sucker	178	91.4
Grand Rapids, WI (Units 1,2, & 4 comb.)	Full Discharge Netting	white sucker	229	91.4
Grand Rapids, WI (Units 1,2, & 4 comb.)	Full Discharge Netting	white sucker	292	91.4
Hardy, MI (Unit 2)	Full Discharge Netting	white sucker	96 – 237	77.0
Hardy, MI (Unit 2)	Full Discharge Netting	white sucker	137 – 375	64.0
Minetto, NY (Unit 3)	Full Discharge Netting	white sucker	114 – 215	99.1
Minetto, NY (Unit 3)	Full Discharge Netting	white sucker	177 – 280	81.5
Minetto, NY (Unit 4)	Full Discharge Netting	white sucker	70 – 111	90.7
Minetto, NY (Unit 4)	Full Discharge Netting	white sucker	71 – 105	74.0
Minetto, NY (Unit 4)	Full Discharge Netting	white sucker	141 – 260	89.3
Minetto, NY (Unit 4)	Full Discharge Netting	white sucker	212 – 285	87.4
Rogers, MI (Units 1 & 2)	Full Discharge Netting	white sucker	82 – 219	81.0
Rogers, MI (Units 1 & 2)	Full Discharge Netting	white sucker	162 – 413	86.0
Minetto, NY (Unit 3)	Full Discharge Netting	yellow perch	64 – 119	65.3
Minetto, NY (Unit 4)	Full Discharge Netting	yellow perch	51 – 93	85.4

APPENDIX A

Townsend Dam Entrainment Study Summary

Oswego River Project Entrainment Study Summary

1.0 TOWNSEND DAM ENTRAINMENT STUDY

1.1 Site Description

The Townsend Dam Project is located in Fallston and New Brighton, Pennsylvania on the Beaver River, an Ohio River tributary that has a drainage area of approximately 3,100 square miles. The Project has a rated head of 16 feet and operates in a run-of-river mode using two Kaplan (propeller turbines). The Beaver River fisher consists of a mixture of warm and coolwater species, including freshwater drum.

1.2 Study Description

Full recovery entrainment netting was performed on Unit 2 at the Townsend Dam Project. The unit was sampled for 24 hours three times per month in January – August 1992, July 1993, September – December 1993, and April 1994. Net efficiency tests resulted in relatively high efficiencies (94% to 97%). A total of 392,023 fish were collected during sampling. The entrainment sample was dominated by gizzard shad (99.4%). Freshwater drum comprised approximately 0.15% of the sample.

2.0 OSWEGO PROJECT ENTRAINMENT STUDY

2.1 Site Description

The Oswego Project is located in north-central New York State and is comprised of three developments: Fulton, Minetto, and Varick. The Oswego River originates just downstream of Oneida Lake at the confluence of the Seneca and Oneida Rivers. The Oswego River drainage area is approximately 5,100 square miles. The projects are operated as storage-and-release pulsing facilities. Entrainment netting was performed only at the Minetto site, which has a rated head of 17.3 ft and five horizontal Francis turbines with combined hydraulic capacity of 7,500 cfs.

2.2 Study Description

Full recovery entrainment netting was performed for a 48 hour duration on units 3, 4, and 5 at the Minetto development between May 1994 and April 1995 on a bi-weekly interval. Net efficiency tests were conducted on each unit and used to adjust entrainment netting data to provide total entrainment estimates for each unit. Data from the sampled units was used to estimate entrainment at the unsampled units (Units 1 and 2). A total of 3,519,061 fish were estimated as entrained at Minetto during the study. Gizzard shad were the dominant species, comprising 62% of all entrainment at the site. Freshwater drum were estimated to comprise less than 0.001%.