NIAGARA POWER PROJECT

RELICENSING

FISH ENTRAINMENT AND MORTALITY STUDY

Volume 1: Public

Volume 2: Non-Internet Public

Volume 3: Critical Energy Infrastructure Information (CEII)
Do Not Release

Niagara Power Project
FERC No. 2216

Prepared for:

New York Power Authority

Prepared by:

Acres International Corporation

Copyright © 2005 New York Power Authority

August 2005

New York Power Authority

TABLE OF CONTENTS

EXECUTIVE SUMMARY ..... **vi**

ABBREVIATIONS ..... **ix**

1.0 INTRODUCTION **1-1**
1.1 Background 1-1
1.2 Objectives 1-2

2.0 PROJECT SETTING **2-1**
2.1 The Niagara River 2-1
2.2 Project Features 2-1
2.2.1 Intake Structures 2-1
2.2.2 Water Conduits 2-2
2.2.3 Forebay 2-2
2.2.4 Robert Moses Niagara Power Plant 2-2
2.2.5 Lewiston Pump Generating Plant and Lewiston Reservoir 2-3

3.0 FISH COMMUNITY AND HABITAT **3-1**
3.1 Upper Niagara River 3-1
3.2 Lewiston Reservoir 3-2

4.0 FISH ENTRAINMENT **4-1**
4.1 Review of Entrainment at Other Projects 4-1
4.1.1 Conventional Hydroelectric Projects 4-1
4.1.1.1 Similarity of Niagara Project to Sites Studied 4-2
4.1.1.2 Similarity of Fish Community 4-3
4.1.1.3 Summary of Entrainment at Other Projects 4-4
4.1.2 Pumped Storage Facilities 4-5
4.1.2.1 Case Studies 4-5
4.1.2.2 Applicability to the Niagara Project 4-7
4.2 Assessment of Potential Fish Entrainment 4-8
4.2.1 Niagara Power Project 4-8
4.2.2 Niagara Falls 4-12

5.0 FISH SURVIVAL **5-1**

Copyright © 2005 New York Power Authority

5.1 Review of Turbine Survival Studies 5-1
5.1.1 Overview of Francis Turbines 5-1
5.1.2 Overview of Potential Sources of Fish Mortality and Types of Injury Occurring during Turbine Passage 5-1
5.1.3 Generating Facilities 5-4
5.1.4 Pump Generation Facilities 5-7
5.2 Review of Fish Survival Over Large Falls 5-8
5.3 Turbine Survival at NPP 5-10
5.4 Fish Survival Over Niagara Falls 5-11

6.0 FISH BARRIERS 6-1
6.1 General Review and Assessment of Fish Barriers 6-1
6.1.1 Physical Barriers 6-1
6.1.1.1 Low-Velocity Fish Screens 6-2
6.1.1.2 High-Velocity Fish Screens 6-3
6.1.1.3 Angled Bar Racks 6-5
6.1.1.4 Louvers 6-6
6.1.1.5 Barrier Nets 6-8
6.1.2 Behavioral Barriers 6-9
6.1.2.1 Lights 6-9
6.1.2.2 Sound 6-10
6.1.2.3 Electrical Fields 6-11
6.1.2.4 Air Bubble Curtains 6-12
6.2 Applicability at Niagara Power Project 6-13
6.2.1 Maintaining Lewiston Reservoir Fishery 6-14
6.2.2 Fish Protection at Niagara River Intakes 6-26
6.2.3 Summary of Options for Fish Protection at the Niagara Project 6-29

7.0 LEWISTON RESERVOIR 7-1
7.1 Description 7-1
7.2 Fisheries 7-2
7.3 Fish Stranding 7-2
7.4 Habitat Alteration 7-3
7.4.1 Potential Opportunities 7-3
7.4.2 Potential Impediments 7-4

8.0 POTENTIAL BENEFITS OF ENTRAINMENT 8-1

Copyright © 2005 New York Power Authority

9.0 CONCLUSIONS **9-1**

REFERENCES **1**

TABLES

Table 3.1-1 ..... **3-5**

Fish Community Composition of the Upper Niagara River, New York and Ontario 3-5

Table 3.1-2 ..... **3-8**

Species Composition (%) of Adult and Juvenile Fish Caught or Observed in the Upper Niagara River 3-8

Table 3.2-1 ..... **3-10**

Results (No. and %) of Fish Surveys in the Lewiston Reservoir in 1975, 1982 and 1983 3-10

Table 3.2-2 ..... **3-11**

Fish Catch in the LewIston Reservoir During May, July, and October 2000 3-11

Table 4.2.1-1 ..... **4-14**

Estimated Flow Velocities at the NPP Intake Portals Under Different Flow Conditions 4-14

Table 4.2.1-2 ..... **4-15**

Comparison of the Fish Collections in the Upper Niagara River (Adults) and Lewiston Reservoir (Adults and Juveniles) 4-15

Table 4.2.1-3 ..... **4-17**

Comparison of the Fish Collections in the Upper Niagara River (Adults) and Lewiston Reservoir (Adults and Juveniles) 4-17

Table 5.3-1 ..... **5-14**

Average Turbine Survival for Francis Turbines 5-14

Table 6.2.1-1 ..... **6-31**

Applicability of Fish Barriers at the Lewiston Pump Generating Plant 6-31

Copyright © 2005 New York Power Authority

Table 6.2.1-2 6-33
Applicability of Fish Barriers and a Fish Bypass at the Robert Moses Niagara Power Plant 6-33

Table 6.2.2-1 6-34
Applicability of Fish Barriers at the Niagara River Intakes 6-34

FIGURES
(Following Tables)

Figure 1.1-1 1-4
Project Vicinity 1-4

Figure 3.1-1 3-12
Aquatic Habitat Features of the Grass Island Pool 3-12

Figure 3.2-1 3-13
Sampling Zones in Lewiston Reservoir 3-13

APPENDICES

Appendix A – Review of Fish Mortality Due to Turbine Passage 9

Appendix B – Photos 23

Photo 1 24
Rapids Upstream of American Falls 24

Photo 2 25
Currents to Approach Channel to American Falls 25

Photo 3 26
Entrance to American Falls Approach Channel 26

Copyright © 2005 New York Power Authority

Photo 4 ..... **27**
Rapids in Approach Channel of Horseshoe Falls 27

Photo 5 ..... **28**
Rock Rubble at Base of American Falls 28

Photo 6 ..... **29**
Rock Rubble at Base of American Falls 29

Photo 7 ..... **30**
Canadian Falls 30

Photo 8 ..... **31**
American Falls 31

Photo 9 ..... **32**
View of the Harmonica Structures of the NPP Intake during Construction 32

Copyright © 2005 New York Power Authority

EXECUTIVE SUMMARY

An assessment was done to determine the potential: 1) for young-of-the-year (YOY) and older fish to be entrained through the intakes and turbines of the Niagara Power Project (NPP) and 2) of various technologies to reduce entrainment and increase survival of fish entrained at the NPP.

The assessment of entrainment for YOY and older fish was based on the species composition, and the relative abundance of fish sampled in Lewiston Reservoir, and the expected rate of entrainment survival for those fish species was based on a review of the literature. A literature review was used because it was not feasible to conduct entrainment or turbine survival studies at NPP. It must be noted that applying results from other sites must be done with caution because the combination of operating parameters at NPP (e.g., head, flow, etc.) are substantially different from the plants where field data were collected.

It appears that YOY and small (<8 inches) fish make up the majority of fish entrained at other sites. During the night and on weekends, some of the water drawn through the NPP conduits is pumped into the reservoir of the Lewiston Pump-Generating Plant (LPGP) for use during periods of higher electrical demand. Comparison of fish catches in the upper Niagara River with those in the Lewiston Reservoir suggests that small forage fish may not be entrained to the same extent that occurs at other hydroelectric plants. However, differences in habitats sampled in the river and reservoir, the relative limitations of electrofishing (which is generally employed to capture small fish) in the deep water of the reservoir and possible diurnal (day versus night) differences in entrainment rates of small forage fish may account for some of the observed catch differences between the upper Niagara River and Lewiston Reservoir. Notwithstanding possible differences in diurnal entrainment rates in larger fish, northern pike, rainbow trout, smallmouth bass, and yellow perch appear to be entrained more often than would be expected based on catches in the river and reservoir. Similarly, species with relatively small territories, such as black and white crappie, bluegill, pumpkinseed and largemouth bass and those associated with the bottom (brown bullhead, white sucker and goldfish) appear to be less susceptible to entrainment.

Copyright © 2005 New York Power Authority

Entrainment of small fish at the NPP intakes on the upper Niagara River is likely due, in part, to downstream transport by strong water currents. Therefore, if small fish are not entrained into the NPP intakes, strong water currents are likely to transport most of them downriver to the American Falls. Survival of small fish over the American Falls is likely to be near 0% due to the long falling distance and impact with the hard surface (e.g., boulder field) at the base of the falls.

In tests conducted at other hydroelectric plants, immediate survival of fish passed through a turbine can range from 0 to 100%. On average, however, immediate survival through vertical Francis turbines is about 75%. Survival through turbines is generally more dependent on fish size than fish species, with higher survival among smaller fish. Since there have been no survival tests conducted at sites with similar characteristics to NPP, estimates of turbine survival at NPP cannot be made.

Entrainment of fish at the NPP intakes has led to the establishment of an important urban/suburban fishery in the Lewiston Reservoir, particularly a spring fishery for yellow perch. Entrainment also has enhanced bird watching and sport fishing opportunities in the tailrace of RMNPP because fish, alive or dead, released in the tailrace attract game fish and fish-eating birds.

Downstream passage technologies were evaluated to address the biological effectiveness and engineering feasibility of constructing them at the NPP. Physical barriers that could exclude fish from the NPP facilities are not considered feasible, from an engineering perspective, due to the large size of the NPP facilities and the amount of ice and debris (aquatic vegetation) in the upper Niagara River. Behavioral devices, such as strobe lights and sound, have not been shown to be effective in excluding most fish species typical of the upper Niagara River from intakes. Additionally, behavioral devices mounted on the intakes are not likely to be effective because velocities near the intakes are higher than those where behavioral devices have successfully been deployed. For those species where behavioral devices would be effective, the number of fish passing over the American Falls might increase. Reducing entrainment could decrease the number of fish recruited to Lewiston Reservoir and the number of fish transported into the tailrace of RMNPP.

Copyright © 2005 New York Power Authority

The bottom topography of Lewiston Reservoir could theoretically be altered for the purpose of increasing the number of fish retained. However, these alterations are not likely to measurably increase fish retention without substantially increasing the amount of water unavailable for power production. Moreover, it is possible that Lewiston Reservoir may not be able to support a larger fish community if additional fish are retained.

Copyright © 2005 New York Power Authority

ABBREVIATIONS

Agencies

EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
FPC	Federal Power Commission
NYSDEC	New York State Department of Environmental Conservation
NYSDOS	New York State Department of State
OMNR	Ontario Ministry of Natural Resources
USACE	United States Army Corps of Engineers

Units of Measure

cfs	cubic feet per second
cm	centimeter
El.	elevation
fps	feet per second
ft	feet/foot
GW	gigawatt

Copyright © 2005 New York Power Authority

hp	horsepower
Hz	hertz, cycles per second
k	kilo (prefix for one thousand)
km	kilometer
kV	kilovolt
m	meter
m	milli (prefix for one-thousandth)
M	mega (prefix for one million)
MVA	megavolt-ampere
MW	megawatt
RPM	Revolutions per minute

Environmental

SAV	submerged aquatic vegetation
YOY	Young-of-year

Miscellaneous

FSCR	First Stage Consultation Report

Copyright © 2005 New York Power Authority

GIP	Grass Island Pool
LPGP	Lewiston Pump Generating Plant
MIS	Modular Inclined Screen
NGO	Non-Government Organization
NMPC	Niagara Mohawk Power Corporation
NPP	Niagara Power Project
NRCS	Niagara River Control Structure
NYPA	New York Power Authority
OPG	Ontario Power Generation
RBR	Richard B. Russell Pump Generation Plant
RMNPP	Robert Moses Niagara Power Plant
SAB	Sir Adam Beck Generating Station
STS	Submerged Traveling Screen

Copyright © 2005 New York Power Authority

1.0 INTRODUCTION

The New York Power Authority (NYPA) is engaged in the relicensing of the Niagara Power Project in Lewiston, New York. The present operating license of the plant expires in August 2007. As part of its preparation for the relicensing of the Niagara Project, NYPA is developing information related to the ecological, engineering, recreational, cultural, and socioeconomic aspects of the Project. The Scope of Services outlined here relates to this information-gathering effort.

1.1 Background

The 1,880 MW (firm capacity) Niagara Power Project (NPP) is one of the largest non-federal hydroelectric facilities in North America. The Project was licensed to the Power Authority of the State of New York (now the New York Power Authority) in 1957. Construction of the Project began in 1958, and electricity was first produced in 1961.

The project has several components. Twin intakes are located approximately 2.6 miles above Niagara Falls. Water entering these intakes is routed around the Falls via two large low-head conduits to a 1.8-billion-gallon forebay, lying on an east-west axis about 4 miles downstream of the Falls. The forebay is located on the east bank of the Niagara River. At the west end of the forebay, between the forebay itself and the river, is the Robert Moses Niagara Power Plant (RMNPP), NYPA's main generating plant at Niagara. This plant has 13 turbines that generate electricity from water stored in the forebay. Head is approximately 300 ft. At the east end of the forebay is the Lewiston Pump Generating Plant (LPGP). Under non-peak-usage conditions (i.e., at night and on weekends), water is pumped from the forebay via the plant's 12 pumps into the 22-billion-gallon Lewiston Reservoir, which lies east of the plant. During peak usage conditions (i.e., daytime Monday through Friday), the pumps are reversed for use as generators, and water is allowed to flow back through the plant, producing electricity. The forebay, therefore, serves as headwater for the RMNPP and tailwater from the LPGP. South of the forebay is a switchyard, which serves as the electrical interface between the Project and its service area. For purposes of generating electricity from Niagara Falls, two seasons are recognized: tourist season and

Copyright © 2005 New York Power Authority

non-tourist season. By the 1950 Niagara River Water Diversion Treaty, at least 100,000 cfs must be allowed to flow over Niagara Falls during tourist season (April 1 – October 31) daytime and evening hours, and at least 50,000 cfs at all other times. Canada and the United States are entitled by international treaty to produce hydroelectric power with the remainder, sharing equally.

Water level fluctuations in the Chippawa-Grass Island Pool (in the upper Niagara River) are limited by an International Joint Commission directive to 1.5 ft per day. It is important to note that water level fluctuations in both the upper and lower Niagara River may be caused by a number of factors other than operation of the NPP. These may include wind, natural flow and ice conditions, and operation of power plants on the Canadian side of the river.

Water level fluctuations in the lower Niagara River (upstream of the RMNPP tailrace) from all causes can be as great as 12 ft per day. Most of this daily fluctuation is due to the change in the treaty-mandated control of flow over Niagara Falls. Water level fluctuations downstream of the RMNPP tailrace are much less. The average daily water level fluctuation 1.4 miles downstream of the RMNPP tailrace, during the 2002 tourist season, was approximately 1.5 ft.

Operation of the NPP can result in water level fluctuations in the Lewiston Reservoir of 8-18 ft per day and as much as 36 ft per week.

The investigation area includes the upper Niagara River, the falls, the Project between the NYPA intakes on the upper Niagara River and the RMNPP, and Lewiston Reservoir (Figure 1.1-1).

1.2 Objectives

This report addresses six related objectives that have been developed by NYPA in consultation with the resource agencies and other stakeholders to the Niagara Project relicensing. Together, these six objectives provide information for the NEPA requirements and future settlement negotiations. The objectives are as follows:

Copyright © 2005 New York Power Authority

- Estimate the survival rate of young-of-the-year (YOY) and older fish entrained through: (1) the LPGP, and (2) the RMNPP;
- Compare the survival rate of fish passing over Niagara Falls with the survival rate of YOY and older fish entrained through LPGP or RMNPP;
- Discuss the likelihood that YOY and older fish in the Niagara River are entrained through the Project intakes on the upper Niagara River;
- Discuss the beneficial uses of entrained fish below the Project for bird and sport fish populations;
- Incrementally assess the feasibility (based on biological effectiveness and engineering considerations) and cost (as necessary) of designing, installing, and maintaining: (1) physical or behavioral barriers to reduce the numbers of YOY and older fish entrained through the Project intakes on the upper Niagara River, LPGP during pumping and generating modes, and the RMNPP, and (2) a fish bypass at the RMNPP; and
- Assess the need for and the feasibility of creating refuge habitats in the Lewiston Reservoir to help retain fish and to reduce the likelihood of fish being stranded at low water levels.

Copyright © 2005 New York Power Authority

Non-Internet Public (NIP) information has been removed from the following page(s).

This material is contained in:
Volume 2
Section: Fish Entrainment and Mortality Study

FIGURE 1.1-1

PROJECT VICINITY

[NIP – General Location Maps]

Copyright © 2005 New York Power Authority

2.0 PROJECT SETTING

2.1 The Niagara River

The NPP is located on the east bank of the lower Niagara River (Niagara County, New York), approximately four miles downstream of Niagara Falls. The 37-mile-long Niagara River connects Lakes Erie and Ontario, forming the boundary between the State of New York and the Province of Ontario, Canada. Flowing generally from south to north, the river (technically a strait) is the principal outlet for four of the five Great Lakes, a drainage area of 263,700 square miles. The Niagara River is navigable from Lake Erie to the Upper Rapids above Niagara Falls. Below the Falls, it is navigable from the mouth at Lake Ontario to just upstream of the Niagara Power Project tailrace by conventional watercraft, and upstream to the Whirlpool by specialized watercraft.

Average flow in the Niagara River is 212,300 cfs. From its head at Lake Erie to its mouth at Lake Ontario, the river falls approximately 326 ft. This steep descent and the relatively high and consistent flows create an ideal situation for hydropower generation.

2.2 Project Features

The NPP is comprised of: (1) two intake structures on the upper Niagara River, (2) two underground water conduits, (3) a forebay for storage of water used in the production of electric power, (4) the RMNPP, (5) the LPGP, (6) Lewiston Reservoir, and (7) a switchyard.

2.2.1 Intake Structures

Twin intakes, located 2.6 miles upstream of Niagara Falls, are the site of entry of Niagara River water into the system. Each underwater reinforced-concrete structure is 700 ft long and contains 48 vertical-slot openings (see Photo 9). Each slot opening is about 12 ft wide, and the 48 slots range in height from 13 to 26.5 ft. The intakes are situated sequentially along the northern shore of the river,

Copyright © 2005 New York Power Authority

parallel to the main flow. The tops of the openings lie 13-26 ft below the river surface. Each intake has an associated gate structure, approximately 55 ft wide by 100 ft high. Each structure contains two sets of slots: one for a 400-ton vertical wheeled gate, approximately 49 ft wide by 68 ft high, and the second for segmented bulkheads (stoplogs) that can be used in emergencies in place of the gate. The gates are not used to regulate water diversion into the conduits but only to dewater the conduits for inspection or repair.

2.2.2 Water Conduits

The two underground conduits run generally northward from the intakes under the City of Niagara Falls to the southeast corner of the forebay, a distance of about 4.3 miles. Each reinforced concrete conduit has a flow area 46 ft wide by 66.5 ft high. The conduits have a combined capacity of approximately 110,000 cfs and no diversion or control mechanisms (Photo 9).

2.2.3 Forebay

The approximately 71-acre forebay serves as the headwater for RMNPP and receptor of tailwater from LPGP. Constructed in rock, it is unlined, and measures approximately 4,200 ft long, by 500 ft wide, by 110 ft deep. Depth of water in the forebay varies between 35 and 80 ft, depending upon operating conditions. The forebay's large volume (approximately 1.8 billion gallons) enables it to function as a surge basin when flows in the conduits change or when sudden load acceptance or rejection occurs in the plants.

2.2.4 Robert Moses Niagara Power Plant

The RMNPP, located at the western end of the forebay, contains 13 individually controlled generating units in a 1,100-ft-long concrete structure located at the base of the gorge wall. The intakes are oriented parallel to the flow of water from the forebay. Twin portal intakes (i.e., total of 26 intake portals for the 13 generating units), each equipped with individual trashracks, steel head gates and fixed hoist machinery, supply water to 13, 462-ft long steel penstocks leading to each turbine. The intake block, with its top deck at El. 585 ft and including the intake and penstock transition sections, is founded

Copyright © 2005 New York Power Authority

on rock at El. 585 ft. The penstocks, each encased in reinforced concrete founded on the rock face of the gorge, are inclined 48.5º and range in diameter from 28.5 ft at the intake to 21 ft at the turbine. Water from the forebay discharges from each unit through an individual draft tube into a short tailrace channel, perpendicular to the flow of the lower Niagara River. The average head is about 300 ft. The one-inch trashracks are on six inch centers, and are deployed to control ice and debris only on units 1, 2 and 13 from November through April, and the bottom third of the trashracks are deployed on all units from May through October.

The power plant consists of 13 Francis (vertical) type turbine generating units (El. 263 ft). In 1990, NYPA began a program designed to upgrade the generating units at the RMNPP. The new turbines will operate with improved efficiency and with increased peak capacity. The added peak capacity from the upgraded turbines will permit the water stored in the Lewiston Reservoir to generate more electricity at times of peak demand. To date, eight units have been upgraded from the original nameplate capacity of 167 MVA, 150 MW at 0.9 power factor to 215 MVA, 194 MW at 0.9 power factor. As a result of the upgrades, the peak capacity of the units will be increased from approximately 175 MW to 200 MW. When the upgrade is complete, efficiency improvements of 1-2% are expected to result in an overall increase in firm capacity of approximately 35 MW. The total hydraulic capacity of the RMNPP will be increased from 102,000 cfs to 115,000 cfs (approximately 8,850 cfs per turbine). Each of the turbines in the power plant, following upgrading, will generate 273,000 horsepower (hp) at 120 revolutions per minute (rpm).

2.2.5 Lewiston Pump Generating Plant and Lewiston Reservoir

The LPGP is located at the eastern end of the forebay and the western end of Lewiston Reservoir. Its purpose is to pump water from the forebay into Lewiston Reservoir during periods of low electricity demand, generally at night and on weekends, and to generate electricity from the release of water in Lewiston Reservoir during periods of peak demand.

Drawdown of Lewiston Reservoir generally occurs weekly and daily. The drawdown is about the same from Monday through Friday, with partial refilling at night (for a net daily drawdown of 6-7 ft).

Copyright © 2005 New York Power Authority

Total refilling of Lewiston Reservoir generally occurs on weekends. Therefore, the reservoir is generally at maximum capacity on Monday morning, while it is at a minimum level on Friday evening. Operation of the NPP can result in water level fluctuations in the Lewiston Reservoir of 8-18 feet per day, and as much as 36 feet per week.

Lewiston Reservoir is about 1,900 acres in area and comprised of a 6.5-mile-long rock-filled dike with impervious clay core. The dike is anchored to each end of a 1,000-ft-long concrete plant intake structure. At its maximum surface elevation (El. 658 ft), water in the reservoir is about 42 ft deep, and at its minimum (El. 620 ft), just over 3 ft.

The intakes of each of LPGP generating units (i.e., the intakes from the Lewiston Reservoir) consist of twin intake portals (inverts at El. 570 ft), each equipped with a gate slot. Each portal may be closed with a steel gate, utilizing the associated hoisting mechanism. The intake channel in the reservoir is bounded on the bottom by a 3 ft thick concrete apron, which slopes from the floor of the reservoir (El. 570 ft) to El. 618 ft approximately 100 ft upstream from the intakes. Each intake discharges to a penstock (about 170 ft long), ranging in diameter from 24 ft at the upper end to 18 ft at the lower end, leading to the generation turbines in the powerhouse.

The LPGP consists of 12 Francis reversible type pump turbines, each connected to a motor-generator unit, which can be used to either pump water into Lewiston Reservoir for storage, or to generate electricity, utilizing water released from the reservoir, depending on energy demand and water supply. As a generator, each unit can produce 20 MW at 28,000 hp, with a rated net head of 75 ft. Units spin at 112.5 rpm each, with a rated hydraulic discharge capacity of 3,500 cfs as a generator. Therefore, the total rated discharge capacity of LPGP is 42,000 cfs as a generator, with a total power generation nameplate capacity of 330 MW under normal flow conditions and 240 MW under low flow conditions.

The draft tubes of the turbine units act as intakes during pumping mode and are provided with gates. Each unit, as a pump, can generate 37,500 hp, with a net head of 85 ft, and has a pumping capacity of 3,400 cfs, for a total pumping capacity of 41,000 cfs. The intakes of the pumps are oriented perpendicular to the flow exiting the conduits.

Copyright © 2005 New York Power Authority

3.0 FISH COMMUNITY AND HABITAT

3.1 Upper Niagara River

The upper Niagara River supports a warm/cool water fish community with coldwater species (rainbow and brown trout) present in the fall, winter and spring periods (Kleinschmidt Associates 2002). Carlson (2001) reported 92 species of fish in the upper Niagara River since the late 1800s. Table 3.1-1 provides a list of species collected or observed in the upper Niagara River in the 1920s, between 1960 and 2000, and in 2001. The coldwater salmonid species are maintained primarily through stocking programs in Lake Erie and its tributaries.

A survey of the fish community in the upper Niagara River was conducted in 2001 (Kleinschmidt Associates 2002). Fish were collected by backpack and boat mounted electrofishing, fyke and trap netting, and seining, and were observed by SCUBA divers. The surveys ranged from Strawberry Island downstream to the north end of Grand Island. A total of 46 species were collected or observed in the upper Niagara River during May, July and September (Table 3.1.2). Emerald shiner, rainbow smelt, and suckers accounted for approximately 80% of the fish collected or observed. Sport fish collected or observed included black crappie, largemouth bass, muskellunge, northern pike, smallmouth bass, white crappie, and yellow perch. No walleye or salmonids were collected or observed.

No surveys have been conducted in the Grass Island Pool (GIP) downstream of Grand Island. However, given the current velocities in the area (average channel velocities are generally 2+ fps), it is likely that the fish community is dominated by riverine, benthic fish such as dace, sculpin, darter and sucker. Where some structure exists and along the natural or rip-rap protected river banks, there should be species such as rock bass and smallmouth bass. Pelagic species, such as alewife, are likely to be uncommon except in isolated special habitats or as drift from Lake Erie into the Niagara River.

Fish habitat has been described in URS et al. (2005a) and Goodyear et al. (1982). The upper Niagara River contains numerous shoals, with many near Grand Island. These shoals are important

Copyright © 2005 New York Power Authority

habitat for species such as rainbow (steelhead) and brown trout (during the winter), muskellunge, smallmouth bass, various panfish (crappies, rock bass and sunfish), as well as a number of Cyprinid species. The shoals at the south end of Grand Island, bounded by Strawberry and Motor Islands, and those near Navy Island at the north end of Grand Island are known as muskellunge spawning areas. Shoals along the west side of Grand Island are spawning areas for smallmouth bass and rock bass. Substrate along these shoals consist of rock, gravel, sand, and mud and often contain extensive areas of submerged aquatic vegetation (SAV). Other important spawning and nursery areas include the streams on Grand Island and those on the Canadian side of the river for northern pike and various bait fish.

The New York State Department of State (NYDOS) identified three significant coastal fish and wildlife habitats in the upper Niagara River that are relevant to this study. These are the Buckhorn Island Wetlands, at the northwest tip of Grand Island; the Strawberry Island-Motor Island Shallows, at the southeast end of Grand Island; and the Grand Island Tributaries, including Gun, Spicer, Woods and Big Six Mile Creeks. Each of these areas provides significant spawning and nursery habitat for several families of fish including esocids, centrarchids, and cyprinids.

The NPP intakes are located on the east side of the Grass Island Pool (GIP), which is relatively wide and deep (generally > 6 ft) with strong currents (generally > 2 fps) and little vertical structure (Figure 3.1-1). Water levels in the GIP are in part controlled by the Niagara River Control Structure (NRCS) and are limited to a daily fluctuation as measured at the Material Dock gauge, of 1.5 feet. In the immediate vicinity of the intakes, the bottom has been excavated to a depth of about 20 ft. The shoreline is highly altered with rip-rap and areas that are supported with sheet piling. With the exception of the Carborundum Reef, located downstream and offshore from the NPP intakes, the area is devoid of SAV. Due to its strong currents, and its lack of vertical structure and vegetative cover, the GIP is not considered prime fish habitat.

3.2 Lewiston Reservoir

Fish stocks in the Lewiston Reservoir appear to be maintained principally by entrainment of fish through the intakes in the upper Niagara River and subsequently through LPGP. There are no streams

Copyright © 2005 New York Power Authority

flowing into the reservoir. The fish in the reservoir have been surveyed for NYPA in June 1975, November 1982, May and July 1983 and May, July and October 2000 (Environnement Illimité, Inc. 2001). Sampling was conducted along eight transects, seven of which covered the entire sloped dike perimeter, and the eighth sampled the open water of the reservoir (Figure 3.2-1). A total of 39 fish species have been collected from the reservoir (Tables 3.2-1 and 3.2-2). Yellow perch or yellow perch and rock bass have dominated the catch in each of the sampling sessions.

Spawning habitat in the reservoir is limited. The reservoir (when full) consists of relatively deep open water surrounded by steep sided (dropping vertically about 45 feet over a linear distance of about 200 feet), rip-rap shoreline. The reservoir experiences a weekly cycle of filling and drawdown, with the lower portions of the dike and reservoir bottom (i.e., the portion below El. 620 ft) remaining consistently submerged. At maximum drawdown (El. 620 ft), only about 10% of the gross storage capacity remains in the reservoir, and areas of the bottom are exposed. Water levels are generally highest on Monday morning and lowest on Friday afternoon.

The reservoir bottom is relatively flat with little structure. Much of the reservoir underlying substrate is rock and gravel that is uniformly covered by 6 to 10 in. of fine-grained sediment. Substrates in the northeast corner and along the eastern end of the reservoir consist of primarily of clay, mud, muck and silt (TVGA and C&C 2002). These areas are generally dewatered late in the week. Due to the depth of the reservoir, SAV growth is limited to isolated patches. The only isolated pools observed were along the south and northeast reservoir berms, where there is excess rock forming narrow “troughs” where water is retained during drawdown. Some fish were observed in these troughs by the study team during a site visit late in the week. Water eventually drains from these troughs and some fish are stranded.

Larval fish were sampled in the reservoir from May through August 1983 (NYPA 1984). Smelt was the most abundant species in May and June, while cyprinids (minnows) and centrarchids (sunfish and bass) were most common in July. Spawning likely occurs in the Lewiston Reservoir only on a very limited basis with adult populations maintained primarily by the transport of fish from the upper Niagara River into the reservoir through the conduits and the Lewiston Pump Generating Plant (NYPA 1984).

Copyright © 2005 New York Power Authority

Studies have found evidence of only very limited spawning activity in the reservoir by yellow perch and rock bass (Ecological Analysts 1984).

Copyright © 2005 New York Power Authority

TABLE 3.1-1

FISH COMMUNITY COMPOSITION OF THE UPPER NIAGARA RIVER, NEW YORK AND ONTARIO

Common Name	Scientific Name[1]	Circa[2] 1927	1960-2000[2]	2001
American Brook Lamprey	*Lampetra appendix*		X[3]	
Sea Lamprey	*Petromyzon marinus*		X	
Lake Sturgeon	*Acipenser fulvescens*	X	X	
Longnose Gar	*Lepisosteus osseus*	X	X	X
Bowfin	*Amia calva*		X	X
Mooneye	*Hiodon tergisus*		X	
American Eel	*Anguilla rostrata*	X	X	X
Alewife	*Alosa pseudoharengus*	X	X	X
Gizzard Shad	*Dorosoma cepedianum*		X	X
Central Stoneroller	*Campostoma anomalum*	X	X	
Goldfish	*Carassius auratus*		X	X
Lake Chub	*Couesius plumbeus*		X	
Satinfin Shiner	*Cyprinella analostana*	X	X	
Spotfin Shiner	*Cyprinella spiloptera*	X	X	X
Common Carp	*Cyprinus carpio*	X	X	X
Striped Shiner	*Luxilus chrysocephalus*	X	X	
Common Shiner	*Luxilus cornutus*	X	X	X
Redfin Shiner	*Lythrurus umbratilis*	X	X	
Hornyhead Chub	*Nocomis biguttatus*	X	X	X
River Chub	*Nocomis micropogon*	X	X	
Golden Shiner	*Notemigonus crysoleucas*	X	X	X
Emerald Shiner	*Notropis atherinoides*	X	X	X
Bridle Shiner	*Notropis bifrenatus*		X	
Blackchin Shiner	*Notropis heterodon*	X		X
Blacknose Shiner	*Notropis heterolepis*	X	X	
Spottail Shiner	*Notropis hudsonius*	X	X	X
Sand Shiner	*Notropis stramineus*	X	X	
Mimic Shiner	*Notropis volucellus*	X	X	
Bluntnose Minnow	*Pimephales notatus*	X	X	X
Fathead Minnow	*Pimephales promelas*	X	X	
Blacknose Dace	*Rhinichthys atratulus*		X	
Longnose Dace	*Rhinichthys cataractae*	X	X	
Rudd	*Scardinius erythrophthalamus*		X	X
Creek Chub	*Semotilus atromaculatus*	X	X	X
Fallfish	*Semotilus corporalis*		X	

Copyright © 2005 New York Power Authority

TABLE 3.1-1 (CONT.)

FISH COMMUNITY COMPOSITION OF THE UPPER NIAGARA RIVER, NEW YORK AND ONTARIO

Common Name	Scientific Name(1)	Circa 1927(2)	1960-2000(2)	2001
Quillback	*Carpiodes cyprinus*		X	X
White Sucker	*Catostomus commersonii*	X	X	X
Lake Chubsucker	*Erimyzon sucetta*	X		
Northern Hog Sucker	*Hypentelium nigricans*	X	X	X
Silver Redhorse	*Moxostoma anisurum*	X	X	X
Black Redhorse	*Moxostoma duquesnei*		X	
Golden Redhorse	*Moxostoma erythrurum*		X	
Shorthead Redhorse	*Moxostoma macrolepidotum*	X	X	X
Greater Redhorse	*Moxostoma valenciennesi*		X	X
Black Bullhead	*Ameiurus melas*		X	
Yellow Bullhead	*Ameiurus natalis*		X	
Brown Bullhead	*Ameiurus nebulosus*	X	X	X
Channel Catfish	*Ictalurus punctatus*	X	X	
Stonecat	*Noturus flavus*	X	X	
Tadpole Madtom	*Noturus gyrinus*		X	X
Brindled Madtom	*Noturus miurus*		X	X
Grass Pickerel	*Esox americanus vermiculatus*	X	X	
Northern Pike	*Esox lucius*	X	X	X
Muskellunge	*Esox masquinongy*	X	X	X
Central Mudminnow	*Umbra limi*	X	X	X
Rainbow Smelt	*Osmerus mordax*		X	X
Coho Salmon	*Oncorhynchus kisutch*		X	
Rainbow Trout/ Steelhead	*Oncorhynchus mykiss*		X	X
Chinook Salmon	*Oncorhynchus tshawytscha*		X	
Brown Trout	*Salmo trutta*		X	
Lake Trout	*Salvelinus namaycush*		X	
Trout Perch	*Percopsis omiscomaycus*	X	X	
Burbot	*Lota lota*		X	
Brook Silverside	*Labidesthes sicculus*	X	X	X
Banded Killifish	*Fundulus diaphanus*	X	X	X
Brook Stickleback	*Culaea inconstans*	X	X	X
Threespine Stickleback	*Gasterosteus aculeatus*	X		X

Copyright © 2005 New York Power Authority

TABLE 3.1-1 (CONT.)

FISH COMMUNITY COMPOSITION OF THE UPPER NIAGARA RIVER, NEW YORK AND ONTARIO

Common Name	Scientific Name[1]	Circa 1927[2]	1960-2000[2]	2001
Nine-spine Stickleback	*Pungitius pungitius*		X	
Mottled Sculpin	*Cottus bairdii*	X	X	X
White Perch	*Morone americana*		X	X
White Bass	*Morone chrysops*	X	X	X
Rock Bass	*Ambloplites rupestris*	X	X	X
Green Sunfish	*Lepomis cyanellus*		X	
Pumpkinseed	*Lepomis gibbosus*	X	X	X
Bluegill	*Lepomis macrochirus*		X	X
Smallmouth Bass	*Micropterus dolomieu*	X	X	X
Largemouth Bass	*Micropterus salmoides*		X	X
White Crappie	*Pomoxis annularis*		X	X
Black Crappie	*Pomoxis nigromaculatus*		X	X
Greenside Darter	*Etheostoma blennioides*		X	
Rainbow Darter	*Etheostoma caeruleum*	X	X	
Iowa Darter	*Etheostoma exile*	X	X	X
Fantail Darter	*Etheostoma flabellare*		X	
Johnny Darter	*Etheostoma nigrum*	X	X	X
Yellow Perch	*Perca flavescens*	X	X	X
Logperch	*Percina caprodes*	X	X	X
Sauger	*Sander canadensis*	X	X	
Walleye	*Sander vitreus*	X	X	X
Blue Pike	*Sander vitreus glaucus*	X	X	
Freshwater Drum	*Aplodinotus grunniens*	X	X	X
Hybrid Carp x Goldfish	*NA*		X	
Round Goby	*Neogobius melanostomus*		X	

Notes:

1. Common and scientific names of fishes after American Fisheries Society, Special Publication 29, 2004.
2. Fish community composition of the Niagara River, circa 1927 and 1960-2000, based on Greeley (1929), NMPC (1977), and Carlson (2001), respectively.
3. Fish species listed in each source are indicated with an X. Lists include species present in the Niagara River only as migrants, species found either upstream or downstream of the Falls, and species found in the Lewiston Reservoir.

   2001 data from Kleinschmidt Associates (2002).

Copyright © 2005 New York Power Authority

TABLE 3.1-2

SPECIES COMPOSITION (%) OF ADULT AND JUVENILE FISH CAUGHT OR OBSERVED IN THE UPPER NIAGARA RIVER

Common Name	Grass Island	Woods Creek	Burnt Ship Ck.	Buckhorn East	Big Six Mile Ck.	Gun Creek	Spicer Creek	Strawberry Island	Motor Island	Tonawanda Creek	All Sites
Longnose Gar					0.0						0.00
Bowfin					0.0				0.0		0.00
Alewife					0.7			0.0			0.09
Gizzard Shad								0.0	0.0		0.00
Goldfish	1.4	0.9		0.4	0.2	3.0	0.5				0.26
Spotfin Shiner				0.1							0.01
Carp	0.3	0.5		0.1	0.6	1.7	0.1	0.0	0.8		0.20
Common Shiner	22.7	1.2	0.7	2.0	3.9	7.1	1.3	0.1	0.1		2.32
Hornyhead Chub				0.2							0.03
Golden Shiner	0.1	4.3	0.0	0.1	3.2	2.5	0.8				0.69
Emerald Shiner	0.3	33.0	86.7	39.9	75.0	44.1	81.6	57.9	25.5	3.0	54.60
Blackchin Shiner			0.7								0.02
Spottail Shiner	10.4	5.1	0.3	36.4	5.9	12.5	0.6	0.4	4.0		6.91
Shiners		0.2	0.1						0.3		0.02
Bluntnose Minnow	1.0	1.9	1.9	5.5	1.0	1.1	2.6	0.9	0.2		1.70
Minnow	4.6	1.6	3.2	0.0			0.1		6.3		0.71
Rudd	0.1			0.0							0.01
Creek Chub		0.2		0.1							0.01
Quillback							0.0				0.00
White Sucker	1.0	4.2	0.0	3.3	0.2	5.1	0.5	0.1	0.5		0.83
Northern Hog Sucker	0.0			0.0				0.1			0.04
Sucker	53.6	0.9	3.2	4.9	0.0		5.0	18.1	56.0		15.18
Silver Redhorse	0.0	0.6		0.2	0.1	0.3			0.0		0.11
Shorthead Redhorse		0.7		0.1	0.0	0.5	0.0	0.0			0.06
Greater Redhorse				0.0	0.0						0.01
Brown Bullhead	1.2	2.9	0.1	0.1	1.5	7.1	0.5	0.0	0.5		0.55
Tadpole Madtom		0.1				0.6					0.01

Copyright © 2005 New York Power Authority

TABLE 3.1-2 (CONT.)

SPECIES COMPOSITION (%) OF ADULT AND JUVENILE FISH CAUGHT OR OBSERVED IN THE UPPER NIAGARA RIVER

Common Name	Grass Island	Woods Creek	Burnt Ship Ck.	Buckhorn East	Big Six Mile Ck.	Gun Creek	Spicer Creek	Strawberry Island	Motor Island	Tonawanda Creek	All Sites
Brindled Madtom				0.0							0.00
Northern Pike	0.5	0.3			0.1	0.1			0.1		0.06
Pike	0.0								0.0		0.00
Muskellunge	0.2	0.1	0.1		0.0	0.1	0.3	0.0	1.6		0.11
Central Mudminnow			0.1			0.3	0.2				0.02
Rainbow Smelt	0.2	0.0		0.0		0.1		21.0	0.1		10.27
Brook Silverside		2.1			1.3	0.1		0.4			0.47
Banded Killifish	0.3	0.0	0.7	0.3		0.1	0.3	0.2	0.2		0.21
Mottled Sculpin				0.1					0.0		0.01
White Perch		0.0									0.00
Rock Bass	0.9	11.5		1.2	0.9	10.2	2.4	0.0	0.8		1.11
Pumpkinseed		12.6		0.1	0.4	1.6	0.7	0.0	0.0	39.4	0.69
Bluegill		0.8	0.1	0.0	0.5	0.5	0.2	0.0			0.13
Sunfish		4.5									0.19
Smallmouth Bass	0.5	0.0		0.2	0.1		0.0	0.1	0.2		0.11
Largemouth Bass	0.8	6.4	1.1	3.9	2.4	6.0	1.4	0.4	0.9		1.54
Bass								0.0			0.00
White Crappie		0.0		0.0	0.2		0.2				0.04
Black Crappie		2.0			1.4		0.1	0.0			0.28
Crappie		1.1									0.04
Iowa Darter	0.0			0.3			0.0			57.6	0.07
Johnny Darter	0.0	0.0		0.6			0.2	0.1	0.8		0.16
Yellow Perch	0.1	0.3			0.1		0.0	0.0	0.3		0.05
Logperch				0.0	0.2						0.03
Freshwater Drum					0.1				0.0		0.01
Unidentified					0.1	0.1	0.3	0.0	0.1		0.03
Total Number	3108	2232	2155	7064	6938	630	3269	26239	2019	33	53687

Note: From Kleinschmidt Associates (2002). Gear utilized included backpack and boat-mounted electrofishing, fyke and trap nets, and SCUBA diver observations.

Copyright © 2005 New York Power Authority

TABLE 3.2-1

RESULTS (NO. AND %) OF FISH SURVEYS IN THE LEWISTON RESERVOIR IN 1975, 1982 AND 1983

Common Name	June 1975	November 1982	May 1983	July 1983
Sea Lamprey	1 (<1)			
American Eel	1 (<1)		1 (<1)	
Alewife	28 (1)			1 (<1)
Gizzard Shad			2 (<1)	
Goldfish	1 (<1)			
Lake Chub				1 (<1)
Carp	43 (1)			
Common Shiner	2 (<1)		1 (<1)	
Spottail Shiner	90 (2)	11 (4)	10 (1)	
White Sucker	287 (7)	34 (12)	72 (4)	20 (3)
Shorthead Redhorse	8 (<1)	3 (1)	13 (1)	6 (1)
Brown Bullhead	1 (<1)			
Northern Pike	1 (<1)		1 (<1)	
Muskellunge	1 (<1)		1 (<1)	
Rainbow Smelt	2 (<1)	18 (7)	4 (<1)	
Coho Salmon	1 (<1)		1 (<1)	
Rainbow Trout	1 (<1)	1 (<1)	3 (<1)	2 (<1)
Brown Trout	5 (<1)			
Trout-Perch	4 (<1)			
White Bass	4 (<1)	7 (3)		
Rock Bass	230 (5)	71 (25)	626 (33)	241 (42)
Pumpkinseed	53 (1)		1 (<1)	10 (2)
Smallmouth Bass	9 (<1)	1 (<1)	15 (1)	35 (6)
White Crappie	1 (<1)			
Johnny Darter	1 (<1)		2 (<1)	
Yellow Perch	3444 (81)	123 (44)	1103 (59)	233 (40)
Logperch	3 (<1)	5 (2)	10 (1)	22 (4)
Walleye	1 (<1)			
Freshwater Drum	20 (1)	1 (1)	3 (<1)	5 (1)
Carp x Goldfish			1 (<1)	

Note: From URS et al. (2005a)
Gear utilized included trap netting, gill netting, trawl netting, and boat-mounted electrofishing.

Copyright © 2005 New York Power Authority

TABLE 3.2-2

FISH CATCH IN THE LEWISTON RESERVOIR DURING MAY, JULY, AND OCTOBER 2000

Common Name	May		July		October		Total	
	No.	%	No.	%	No.	%	No.	%
American Eel					1	0.4	1	0.1
Alewife	4	0.8	3	0.9	1	0.4	8	0.8
Carp	18	3.6	25	7.8	22	1.0	65	6.2
Common Shiner	12	2.4					12	1.1
Golden Shiner	1	0.2					1	0.1
Emerald Shiner	50	10.1			3	1.3	53	5.1
Spottail Shiner	17	3.4	3	1.0	1	0.4	21	2.0
Bluntnose Minnow	1	0.2					1	0.1
Quillback					1	0.4	1	0.1
White Sucker	1	0.2	9	2.8	4	1.7	14	1.3
Silver Redhorse			2	0.6			2	0.2
Shorthead Redhorse	5	1.0	2	0.6	1	0.4	8	0.8
Greater Redhorse	1	0.2	1	0.3			2	0.2
Brown Bullhead			1	0.3			1	0.1
Channel Catfish					1	0.4	1	0.1
Northern Pike	28	5.6	25	7.8	38	16.5	91	8.7
Muskellunge	1	0.2					1	0.1
Rainbow Smelt	1	0.2	6	1.9	2	0.9	9	0.9
Rainbow Trout	3	0.6	4	1.2	2	0.9	9	0.9
White Bass	1	0.2	6	1.9			7	0.7
Rock Bass	61	12.3	122	37.9	95	41.1	278	26.5
Pumpkinseed	5	1.0			7	3.0	12	1.1
Smallmouth Bass	12	2.4	22	6.8	23	10.0	57	5.4
Largemouth Bass	1	0.2			1	0.4	2	0.2
Black Crappie			4	1.2			4	0.4
Johnny Darter			45	14.0			45	4.3
Yellow Perch	266	53.6	27	8.4	18	7.8	311	29.7
Logperch	7	1.4	11	3.4	5	2.2	23	2.2
Freshwater Drum			4	1.2	5	2.2	9	0.9
Total	496		322		231		1049	

Note: From Environnement Illimité, Inc. 2001.
Gear utilized included trap netting, gill netting, trawl netting, and boat-mounted electrofishing.

Copyright © 2005 New York Power Authority

Non-Internet Public (NIP) information has been removed from the following page(s).

This material is contained in:
Volume 2
Section: Fish Entrainment and Mortality Study

FIGURE 3.1-1

AQUATIC HABITAT FEATURES OF THE GRASS ISLAND POOL

[NIP – General Location Maps]

Copyright © 2005 New York Power Authority

FIGURE 3.2-1

SAMPLING ZONES IN LEWISTON RESERVOIR

[NIP – General Location Maps]

Copyright © 2005 New York Power Authority

4.0 FISH ENTRAINMENT

4.1 Review of Entrainment at Other Projects

A review of available documents and literature was conducted to assess the relevance of the fish community and habitat information presented above with regard to entrainment at the NPP. The results of this review are presented in the following sections.

4.1.1 Conventional Hydroelectric Projects

Entrainment and survival of fish passing through hydroelectric turbines have been investigated for many years (Bell 1991; Eicher 1987), but most of these earlier studies focused on the passage survival of anadromous species, particularly salmon and steelhead trout. However, beginning in the late-1980's and into the mid-1990's, several fish entrainment studies were conducted at hydroelectric projects throughout the northeastern, midwestern, and southeastern U.S., primarily involving "resident," non-anadromous species. These studies were mostly associated with the FERC relicensing of the "Class of 1993" projects, which consisted of 157 projects whose licenses expired at the end of 1993. Most of the projects where entrainment studies were conducted were located in Michigan, Wisconsin, and New York, but studies were also conducted at projects in Minnesota, Ohio, Kentucky, Pennsylvania, West Virginia, South Carolina, and Georgia. The results of these several entrainment studies have been filed with FERC under their separate docket numbers, but three reviews summarizing the results of these studies have been published: EPRI (1992), FERC (1995), and EPRI (1997).

EPRI (1992) summarized the results of entrainment studies conducted through 1991. Because the significant number of studies conducted from 1992 through 1996 is not reported in this review, we will focus our discussion on the results reported by FERC (1995) and EPRI (1997).

Copyright © 2005 New York Power Authority

FERC (1995) summarized the results of entrainment studies completed through 1993, but only included studies conducted using hydroacoustics, intake netting, or tailrace netting, and where there was a reasonable level of confidence in the entrainment estimate. FERC did not include sites that were "geographically isolated" (outside of the main groupings of projects in the Northeast, Midwest, and Southeast) and did not include any pumped storage projects. The objective of FERC (1995) was to review recent entrainment studies to identify trends that would potentially allow entrainment to be assessed at hydro projects without extensive studies, or to provide a basis for suggesting improvements in future studies.

EPRI (1997) is a turbine entrainment and survival database that includes many of the studies reported in FERC (1995) and additional studies completed through 1996. The objective of the EPRI database is similar to FERC (1995), to provide a compilation of entrainment and survival studies that would allow others to utilize these data to evaluate entrainment at unstudied sites. The EPRI entrainment database includes only studies that were conducted using full-flow tailrace netting, in which the entire outflow from one or more generating units is sampled. No hydroacoustic studies are included. The turbine passage survival database includes only studies with paired releases of treatment fish (those that pass through the turbine) and control fish (those that are released below the turbine), using either full-flow turbine netting or balloon tag retrieval methods. The database did not include any survival estimates based on passive netting of naturally entrained fish, or estimates derived from radio telemetry or PIT tagging methods. EPRI (1997) does not include any interpretation of results (as FERC 1995 did), but instead simply provides the data along with ancillary information such as the site characteristics, unit type and characteristics, and other notes/observations recorded during the studies.

4.1.1.1 Similarity of Niagara Project to Sites Studied

None of the sites reported in FERC (1995) or EPRI (1997) were equal in size (generating or hydraulic capacity) to the NPP. The 45 studies reported on by FERC (1995) were at projects ranging in size from 0.56 MW to 102 MW, with hydraulic capacities from 360 cfs to 35,598 cfs. Most of the sites,

Copyright © 2005 New York Power Authority

however, were less than 5 MW, with hydraulic capacities less than 3,000 cfs.[1] The EPRI (1997) entrainment database includes test data from 43 sites, while the turbine passage survival database includes test data from 51 different turbines. The 43 entrainment sites had total hydraulic capacities ranging from 270 to 60,000 cfs, but only the Richard B. Russell Project in South Carolina, at 60,000 cfs, was similar in size to any of NPP facilities. The Russell Project, which is owned and operated by the U.S. Army Corps of Engineers, also has pump-generating units, similar to the LPGP. The other 42 projects have hydraulic capacities less than 7,500 cfs. Of the 51 turbines reported on in the survival database, only one site had vertical Francis units with a hydraulic capacity similar in size to any of the Niagara units. The Holtwood Project, Susquehanna River, Pennsylvania, has units with a capacity of 3,500 cfs, but the head is about 55 ft, lower than any of the units at Niagara. All the other vertical Francis units in the database have capacities less than 2,450 cfs, and most are less than 2,000 cfs.

Another dissimilarity of the previously-studied sites to NPP is that most (if not all) of the studied sites are conventional hydroelectric stations where the powerhouse is integral to a dam on a mainstem river or reservoir, or is located on a forebay or power canal. At Niagara, with the river shoreline intakes, Niagara River fish have the option of bypassing the intakes by staying in the main river flow. Once fish enter the Niagara forebay, however, they would be susceptible to entrainment into either the LPGP or the RMNPP, similar to other hydroelectric stations.

4.1.1.2 Similarity of Fish Community

Because many of the projects previously studied are located in the Great Lakes drainage of Michigan and Wisconsin, and in New York, there are similarities in the fish communities between many

[1] The total capacity of the Niagara River intakes is 110,000 cfs, although the average diversion is 50,000 cfs in the summer daytime period and 70,000 cfs in the winter daytime period. The LPGP has a total rated generating capacity of 42,000 cfs and a total power generation nameplate capacity of 330 MW at normal flow conditions and 240 MW at low flow conditions, while the RMNPP has a total hydraulic capacity of 102,000 cfs and an installed plant capacity of 2,538 MW (based on currently completed upgrades). Each unit at the LPGP is 20 MW with a hydraulic capacity of 3,400 cfs, while each unit at the RMNPP will have peak capacity of 200 MW when the upgrades are completed and a hydraulic capacity of 7,850 cfs.

Copyright © 2005 New York Power Authority

of the studied sites and the Niagara River. Many of the studied sites have warmwater/coolwater resident fish communities with similar species composition to the upper Niagara River.

4.1.1.3 Summary of Entrainment at Other Projects

EPRI (1992), FERC (1995), and EPRI (1997) reported a wide range in entrainment rates at the projects where studies were conducted. Possibly because of this variability, FERC (1995) found few statistically significant relationships between entrainment rates and the size or design of projects, flow rate, and other physical variables. FERC (1995), however, stated that much of the variability may be due to the variety of study designs and sampling methods used in the studies reviewed, and that it still may be appropriate to apply entrainment rates observed at studied projects to other projects within the same watershed. Although entrainment rates observed for specific species was also variable, FERC (1995) found some consistent trends for the same species, particularly within the same drainage. For example, for warmwater/coolwater species, entrainment is normally low during the winter months and higher during the spring/summer/fall months. At sites where large numbers of clupeids occur in the project reservoir, episodic high entrainment events may occur as dense schools of clupeids periodically enter the intake area. High entrainment rates for clupeids often occur during the winter period, probably due to low water temperature stress and the weakened condition of the fish. This is particularly the case for reservoirs with high populations of gizzard shad or threadfin shad.

Other general characterizations of fish entrainment made by EPRI (1992) and FERC (1995), with the caveat that entrainment is variable from site to site, include:

- Entrainment is relatively low (less than 20 fish/hour) for most resident warmwater/coolwater fish communities;

Copyright © 2005 New York Power Authority

- Over 90% of the fish entrained are young-of-year (YOY) or juvenile fish less than 200 mm (8 in.) in length, and at many sites 90% are less than 100 mm (4 in.) long;[2] and
- Larger gamefish species comprise a very low percentage of the total fish entrained.[3]

The higher catch of YOY and juvenile fish and lower catch of larger fish may be explained by either that there are simply higher numbers of YOY/juvenile fish in a typical fish population, that there is a density-dependent mechanism that results in a downstream movement of juvenile life stages that are "surplus production" seeking vacant habitat, avoidance by larger fish with greater swimming speed relative to smaller fish, or that many of the projects studied had trashracks that may physically exclude the much larger fish but allow most fish to pass through and enter the turbines.

The above generalizations, particularly with respect to the entrainment rate of 20 fish per hour, may not apply to NPP as all of the sites studied had flow rates that were much lower than NPP. It should also be noted that the intakes at NPP do not have bar racks.

4.1.2 Pumped Storage Facilities

4.1.2.1 Case Studies

The EPRI (1992), FERC (1995), and EPRI (1997) reviews included only one pumped storage project, the 200-MW Mt. Elbert Pumped Storage Project, Twin Lakes, Colorado.[4] Fish and opossum

[2] Using the EPRI (1997) database, for the 43 projects included in the database, fish less than 100 mm (4 in.) comprised 90% of the entrainment.
[3] In the EPRI (1997) database, fish larger than 200 mm (8 in.) comprised less than 1% of the entrainment.
[4] EPRI (1997) included data on the Richard B. Russell Project, which has four pump-generating units and four conventional units, but the database does not identify whether entrainment sampling occurred in any of the pump-generating units. If any of those units were sampled, the data are not identified as to whether collections occurred during the pumping or generating cycles.

Copyright © 2005 New York Power Authority

shrimp entrainment was monitored using partial recovery tailrace and intake nets. For both fish and opossum shrimp (which may be indicative of fish early life stages), the entrainment during the pumping cycle was several times that of the generation cycle, as follows:

Species	Pumping	Generating
Opossum shrimp	2.38 – 17.19/m^3	0.05 – 1.21/m^3
Various fish species[1]	14.92/million m^3 (fish > 150 mm in length)[2]	1.52/million m^3 (fish > 150 mm in length)[2]

Notes: [1] Rainbow trout, lake trout, kokanee salmon, longnose sucker, and white sucker.

[2] 150 mm = 5.9 in.

Other pumped storage projects where entrainment/mortality studies have been conducted (but were not reported in any of the above reviews) include the Ludington Pumped Storage Project on Lake Michigan and the Northfield Mountain Pumped Storage Project, Connecticut River, Massachusetts. The 1,872-MW Ludington Project went into operation in 1973 and uses Lake Michigan as its lower reservoir. Significant mortality of large salmonids and other species from Lake Michigan, primarily during the pumping phase, was documented by several studies funded by the licensee, and filed with FERC. As described in further detail in Section 6.1, as a result of a 1996 settlement agreement, a seasonal barrier net was installed by the licensee in Lake Michigan, to prevent fish from entering the project intakes during the peak period of fish activity (the summer months).

The Northfield Mountain Pumped Storage Project is located on a reach of the Connecticut River that is used seasonally by several anadromous species, including Atlantic salmon, American shad, and river herring. The 1,000-MW project was constructed in the 1970's by Northeast Utilities, and, while the company has investigated fish entrainment and mortality at the site, its efforts have focused almost exclusively on salmon and shad. Several studies using radio telemetry and partial recovery nets have been conducted to determine the impact of the project on salmon smolts and juvenile shad migrating past

Copyright © 2005 New York Power Authority

the site, and some testing has been done with barrier nets (see Section 6.1). Evidence of entrainment and mortality during the pumping phase was collected, but actual entrainment and mortality rates were not determined (Robert Stira, Northeast Utilities, to Peter Foote, The Louis Berger Group, Inc., personal communication, October 15 and 22, 2003). The effects of the project on the resident warmwater/ coolwater fish community have not been studied in detail.

4.1.2.2 Applicability to the Niagara Project

The three pumped storage projects described above are all dissimilar in design/location to LPGP. Mt. Elbert is located on a large lake (Twin Lakes) in Colorado, Ludington is located on the shoreline of Lake Michigan, and Northfield Mountain is located on a much smaller river than the Niagara. The fish communities at the three projects are also unlike the Niagara River. At both Mt. Elbert and Ludington, there are large salmonid populations, while at Northfield, although the resident fish community is similar to the Niagara (a warmwater/coolwater community), the focus of studies has been only on the anadromous species. An important finding of the studies at both Mt. Elbert and Ludington, and from anecdotal information at Northfield Mountain, however, is that it appears more entrainment typically occurs during the pumping cycle than the generating cycle. These two facilities along with the LPGP are diurnal with regard to pumping. The pumping cycles occur at night, and as a result may skew the entrainment, since fish are more susceptible at night to entrainment. Moreover, since some fish die during the pumping cycle, then fewer fish may be present to be entrained during generation, however, there are also habitat differences that may result in retention in these pump storage reservoirs. If these findings are applicable to NPP, then many of the fish entering the Niagara forebay from the river, immediately downstream of LPGP, may be entrained at the LPGP and pumped up to the Lewiston Reservoir.

Copyright © 2005 New York Power Authority

4.2 Assessment of Potential Fish Entrainment

4.2.1 Niagara Power Project

Physical processes of fish entrainment at the intakes of NPP are a function of the probability that fish encounter the flow field and how they react to it.

As discussed in Section 3.1, the area near the intakes has been excavated and contains little structure, and given that the currents in that area of the river are relatively high (average channel velocities are generally 2+ fps, URS et al. 2005b), prime fish habitat for most species is likely limited. The local resident fish community in the GIP is probably dominated by riverine benthic fish such as dace, sculpin, darter, sucker, and the recently introduced round goby. Given the probable fish community in the GIP and the relatively high current velocities, "cruising behavior" would not occur frequently. Rather, fish will remain close to cover and within small ranges or territories. Consequently, the likelihood of contact with the NPP intakes for GIP resident fish is small. Fish may enter the GIP due to migratory behavior, density dependent movements or as drift in the strong currents. These fish probably include pelagic species and YOY that cannot maintain their position in the strong river currents and would likely be more susceptible to entrainment in the intakes.

Once a fish encounters the flow field of the NPP intakes, their ability to avoid entrainment is determined by the fish's behavioral responses to changes in current velocity and its swimming ability. Most fish species are positively rheotactic (i.e., they orient themselves to face upstream against the current). Many mature gamefish typical of the upper Niagara River can generally swim against currents of 2.5 fps or more and have burst speeds greater than 3.25 fps (Pope undated).

Table 4.2.1-1 provides the estimated flow velocity, calculated on the basis of the cross-sectional area of the intake openings, at the intakes utilizing long-term average minimum and maximum flows in the Niagara River during tourist and non-tourist seasons when either 100,000 cfs or 50,000 cfs must be maintained over the falls. For the average river flow of 212,300 cfs, the average velocity at the portals of

Copyright © 2005 New York Power Authority

each of the intakes would be 5.9 fps during tourist flows and 8.5 fps during non-tourist flows. For the extreme river flow occurrences, average velocities could be as low as 2.8 fps during the tourist season in extremely low river flow years and as high as 11.6 fps when river flow was high enough to meet the maximum design capacity of the conduits. These velocity estimates would likely decrease quickly away from the portals, depending on river flow and other factors. We have conservatively estimated that velocities would decrease by half 20 ft away from the portals, but this could only be verified by field studies.

Velocities experienced by fish approaching the intakes would increase from the ambient river velocity (average channel velocities are generally 2+ fps) to a velocity of 3 to 4 fps 20 ft from the portals and then to a maximum velocity calculated at the intake portals of 5.9 or 8.5 fps under average flow conditions, depending on season. Consequently, fish with maximum sustained swimming speeds of less than 1 to 2 fps (e.g., YOY and small fish) would likely seek cover in preferred low velocity habitat well upstream of the NPP intakes. Those fish with maximum sustained swimming speeds of less than 2 fps that did not seek cover upstream of the NPP intakes would not likely be capable of moving back upstream out of GIP. These latter fish would be susceptible to entrainment into the intakes or to passage over the falls.

Mature gamefish with maximum sustainable swimming speeds above ambient GIP currents and that would more likely be "cruising" within the GIP, may be likely to come in contact with the intakes and the power flow as a result of this behavior. Their ability to avoid entrainment is dependent on their ability to perceive the acceleration in velocity and their swimming capability to avoid the power flow when their maximum sustainable swimming speed is approached (i.e., when they can only maintain position). The maximum sustainable swimming speeds of four Niagara River species (Pope undated) are as follows:

- northern pike 2.3 fps
- walleye 3.3 fps
- white sucker 3.3 fps

Copyright © 2005 New York Power Authority

- rainbow trout 4.3 fps

If these species did not respond to the acceleration in velocity until they could only maintain position in the flow, they would be relatively close to the intakes. Although burst speeds of some of these species are relatively high, they can be maintained for only short duration (generally less than 10 seconds), likely not enough time to escape the power flow if they have approached too close. Consequently, if larger, stronger swimming fish do not detect and respond to the change in velocity well before they approach their maximum sustainable swimming speed, they would be susceptible to entrainment.

Once fish have been entrained into the conduits, they are transported to the forebay where they may eventually be entrained through the turbines of RMNPP, most likely during the day, or through the pump turbines of LPGP at night. Assuming there are no species dependent differences between entrainment at the two facilities and that there are not substantial differences among species mortality rates during pumping at LPGP, the composition of fish in the reservoir should be a reflection of those species most frequently entrained from the upper Niagara River. Table 4.2.1-2 compares data of catches in the upper Niagara River in May, July and September 2001 with those in the Lewiston Reservoir in May, July and October 2000. The comparison is made between adult fish from the river and juvenile and adult fish from the reservoir. Although electrofishing for YOY and small forage fish was conducted in both areas, the depth of the reservoir made collection of YOY and forage fish by electrofishing less effective. Small forage fish (including minnows, darters, sculpins, etc.) comprised about 95% of catches in the upper Niagara River and only 16% in the reservoir catches. The under representation of small forage fish in the reservoir sampling may be due to the difficulty of catching these species by electrofishing in the reservoir, diurnal differences in entrainment rates for these species (water is pumped into the reservoir mostly during the night) or the likelihood that small fish find cover in low velocity habitats upstream of the GIP and do not frequently come in contact with the power flow.

This comparison of percent composition, excluding small forage fish (Table 4.2.1-3) indicates that some species are more common in the reservoir than would be expected if the intakes sampled fish at random from the upper river. Using a criterion of a greater than 5% difference in the contribution of a

Copyright © 2005 New York Power Authority

particular species in the reservoir compared to the upper river, the species that may be more susceptible to entrainment include:

- yellow perch
- northern pike, and
- smallmouth bass.

These fish are normally associated with cover and would have difficulty maintaining position in the water column in the ambient GIP currents. The relatively high proportion of smallmouth bass, northern pike and yellow perch in the reservoir suggests that there may be some structural habitat upstream of the intakes from which they stray and are entrained into the power flow. Yellow perch are known to make large movements associated with spawning in the spring (Scott and Crossman 1979), and smallmouth bass have pronounced nocturnal behavior that would make them more susceptible to entrainment during pumping at LPGP, which occurs primarily at night.

Entrainment of large numbers of yellow perch may be related to spring spawning runs as the number of yellow perch collected in the reservoir was highest in the spring (Tables 3.2-1 and 3.2-2). However, at the Huntley Plant (Sartor Associates 1977), although yellow perch were more commonly impinged in the spring and summer, the data does not suggest that impingement of yellow perch at that plant was associated with spring spawning migrations.

Another potential reason for relatively high numbers of these species in the reservoir is that these species are more likely to be entrained through LPGP or that they suffer less mortality during pumping than other species. However, there are no plausible reasons that these species would be more susceptible to entrainment at LPGP and the literature suggests that fish length is a far more important factor in determining the rate of turbine mortality than fish species.

Rainbow trout and white bass, although relatively uncommon in the reservoir (approximately 1%) were absent from the catches in the upper river and may also be susceptible to entrainment.

Copyright © 2005 New York Power Authority

Conversely, the species composition of the reservoir suggests that some species have low susceptibility to entrainment due to their absence or relatively low abundance in the reservoir. The species whose contribution to the catch in the upper Niagara River that was greater than 5% of the difference in contribution to the reservoir include:

- brown bullhead,
- pumpkinseed,
- white sucker, and
- largemouth bass.

In addition, white crappie, bluegill and goldfish comprised 1 to 4% of the catch in the river but were not collected in the reservoir. Most of these species are benthic or relatively sedentary and would not often come in contact with the intakes.

Generally, the results of this comparison are consistent with the theories presented earlier in this section. One theory held that relatively strong swimming fish, such as rainbow trout, are more likely to be active in the GIP and susceptible to entrainment. They may approach closer to the intakes before the currents exceed their maximum sustainable swimming speed, and then have less opportunity for an avoidance response. The second was that benthic or sedentary fish, such as white sucker and many of the centrarchids, are more likely to have found cover upstream of the GIP and are thus less susceptible to entrainment.

4.2.2 Niagara Falls

As discussed in the previous section, the currents in the GIP are such that only larger, strong swimming fish or fish strongly associated with the bottom are resident or can enter and leave the GIP. Poorer swimming or smaller non-benthic fish species (e.g., <7 inches) that enter the GIP north of Navy and Grand Islands likely cannot swim back upstream. These fish would be susceptible to entrainment in the NPP intakes, the Sir Adam Beck (SAB) intakes or the SAB Power Canal at Chippawa. Small, weakly

Copyright © 2005 New York Power Authority

swimming fish entering the GIP from the Chippawa channel are likely more susceptible to entrainment by the SAB intakes and/or passage over the Horseshoe Falls, while those fish entering the GIP from the Tonawanda channel are likely more susceptible to entrainment by the NPP intakes and/or passage over the American Falls. Larger, strong swimming fish (e.g., sport fish) can likely maintain their position in the GIP and swim upstream in the river and would be less susceptible to passage over the falls.

There are some refugia available for fish entrained in the flow over the falls or through the various power conduits (i.e., NPP and SAB). These include, immediately upstream and downstream of closed gates at the Niagara River Control Structure (NRCS), Dufferin Islands on the Canadian side of the river (fish must go through the control gates at the end of the SAB ice acceleration channel), Lyon's Creek on the Welland River east of the SAB Power Canal and the Welland River west of the SAB Power Canal. These refugia, however, would not likely be readily available to fish located on the east side of the river or in the approach channel of the American Falls, since these fish would require lateral movement across at least half the river (about 0.5 miles) to reach the refugia. The approach channel of the American Falls, where most fish on the east side of the river would likely be entrained, provides little or no refuge other than limited low-velocity pockets in the rapids, particularly during the tourist season when higher flows pass down this channel (see photos at end of the report).

Stronger swimming fish may also be carried in the currents of the falls flow downstream of the NRCS or in the approach channels to the falls on both sides of Goat Island. Rainbow trout (steelhead) may be able to maintain their position downstream of the NRCS, as they are often caught by shore anglers immediately downstream of the NRCS and in the Horseshoe Falls approach channel near the outflow of Dufferin Islands in the spring and fall (G.T. Haymes, Acres International, Ltd., personal observation 2003).

Copyright © 2005 New York Power Authority

TABLE 4.2.1-1

ESTIMATED FLOW VELOCITIES AT THE NPP INTAKE PORTALS UNDER DIFFERENT FLOW CONDITIONS

	Average	Maximum	Minimum
River Flow	212,300 cfs	277,900 cfs	152,600 cfs
Power Flow			
Tourist[1]	112,300 cfs	177,900 cfs	52,600 cfs
Non-Tourist[1]	162,300 cfs	227,900 cfs	102,600 cfs
Flow Through Each Intake[2]			
Tourist	28,075 cfs	44,475 cfs	13,150 cfs
Non-Tourist	40,575 cfs	55,000 cfs[4]	25,650 cfs
Average Velocity at Intake[3]			
Tourist	5.9 ft/s	9.4 ft/s	2.8 ft/s
Non-Tourist	8.5 ft/s	11.6 ft/s	5.4 ft/s

Notes:

1. Tourist (scenic) flows are 100,000 cfs over the falls 8 a.m. – 10 p.m. April 1 – September 15 and 8 a.m.- 8 p.m. September 16 – October 31; non-tourist flows of 50,000 cfs the rest of the time.
2. Assumes 50-50 split between NYPA and OPG and equal distribution of flow between the two NPP intakes.
3. Based on calculated open area of 4,754.4 ft^2 for each NPP intake.
4. Maximum design capacity of each conduit.

Copyright © 2005 New York Power Authority

TABLE 4.2.1-2

COMPARISON OF THE FISH COLLECTIONS IN THE UPPER NIAGARA RIVER (ADULTS) AND LEWISTON RESERVOIR (ADULTS AND JUVENILES)

Common Name	Upper Niagara River[1]		Lewiston Reservoir[2]	
	No.	%	No.	%
Longnose Gar	1	0.0		
Bowfin	2	0.0		
American Eel			1	0.1
Alewife	1	0.0	8	0.8
Gizzard Shad	2	0.0		
Goldfish	65	0.2		
Spotfin Shiner	6	0.0		
Carp	95	0.3	65	6.2
Common Shiner	1241	3.3	12	1.1
Hornyhead Chub	17	0.0		
Golden Shiner	369	1.0	1	0.1
Emerald Shiner	29286	77.9	53	5.1
Blackchin Shiner	15	0.0		
Spottail Shiner	3475	9.2	21	2.0
Shiners	10	0.0		
Bluntnose Minnow	885	2.4	1	0.1
Minnow	1	0.0		
Rudd	3	0.0		
Creek Chub	8	0.0		
Quillback	1	0.0	1	0.1
White Sucker	196	0.5	14	1.3
Sucker	1	0.0		
Northern Hog Sucker	1	0.0		
Silver Redhorse	22	0.1	2	0.2
Shorthead Redhorse	23	0.1	8	0.8
Greater Redhorse	3	0.0	2	0.2
Brown Bullhead	269	0.7	1	0.1
Channel Catfish			1	0.1
Tadpole Madtom	5	0.0		
Brindled Madtom	1	0.0		
Northern Pike	29	0.1	1	0.1
Muskellunge	3	0.0	1	0.1
Central Mudminnow	10	0.0		
Rainbow Smelt	3	0.0	9	0.9

Copyright © 2005 New York Power Authority

TABLE 4.2.1-2 (CONT.)

COMPARISON OF THE FISH COLLECTIONS IN THE UPPER NIAGARA RIVER (ADULTS) AND LEWISTON RESERVOIR (ADULTS AND JUVENILES)

Common Name	Upper Niagara River[1]		Lewiston Reservoir[2]	
	No.	%	No.	%
Rainbow Trout			9	0.9
Brook Silverside	252	0.7		
Banded Killifish	123	0.3		
Brook Stickleback	13	0.0		
Mottled Sculpin	5	0.0		
White Perch	1	0.0		
White Bass			7	0.7
Rock Bass	500	1.3	278	26.5
Pumpkinseed	209	0.6	12	1.1
Bluegill	55	0.1		
Smallmouth Bass	22	0.1	57	5.4
Largemouth Bass	136	0.4	2	0.2
Bass	2	0.0		
White Crappie	20	0.1		
Black Crappie	35	0.1	4	0.4
Iowa Darter	39	0.1		
Johnny Darter	71	0.2	45	4.3
Yellow Perch	28	0.1	311	29.7
Logperch	16	0.0	23	2.2
Pike	1	0.0		
Freshwater Drum	6	0.0	9	0.9
Unidentified	1	0.0		
Total	37585	100.0	1049	100.0

Notes: From Environnement Illimité, Inc. (2001) and Kleinschmidt Associates (2002).

[1]Gear utilized included backpack and boat-mounted electrofishing, fyke and trap nets, and SCUBA diver observations.

[2]Gear utilized included boat-mounted electrofishing, fyke and trap nets, and an otter trawl.

Copyright © 2005 New York Power Authority

TABLE 4.2.1-3

COMPARISON OF THE FISH COLLECTIONS IN THE UPPER NIAGARA RIVER (ADULTS) AND LEWISTON RESERVOIR (ADULTS AND JUVENILES)

Common Name	Upper Niagara River		Lewiston Reservoir	
	No.	%	No.	%
Longnose Gar	1	0.1		
Bowfin	2	0.1		
American Eel			1	0.1
Alewife	1	0.1	8	0.9
Gizzard Shad	2	0.1		
Goldfish	65	3.7		
Carp	95	5.5	65	7.3
Rudd	3	0.2		
Quillback	1	0.1	1	0.1
White Sucker	196	11.2	14	1.6
Northern Hog Sucker	1	0.1		
Sucker	1	0.1		
Silver Redhorse	22	1.3	2	0.2
Shorthead Redhorse	23	1.3	8	0.9
Greater Redhorse	3	0.2	2	0.2
Brown Bullhead	269	15.4	1	0.1
Channel Catfish			1	0.1
Tadpole Madtom	5	0.3		
Brindled Madtom	1	0.1		
Northern Pike	29	1.7	91	10.2
Muskellunge	3	0.2	1	0.1
Pike	1	0.1		
Rainbow Smelt	3	0.2	9	1.0
Rainbow Trout			9	1.0
White Perch	1	0.1		
White Bass			7	0.8
Rock Bass	500	28.7	278	31.1
Pumpkinseed	209	12.0	12	1.3
Bluegill	55	3.2		
Smallmouth Bass	22	1.3	57	6.4
Largemouth Bass	136	7.8	2	0.2
Bass	2	0.1		
White Crappie	20	1.1		
Black Crappie	35	2.0	4	0.4
Yellow Perch	28	1.6	311	34.8
Freshwater Drum	6	0.3	9	1.0
Unidentified	1	0.1		
Total:	1743	100	893	100

Note: From Environnement Illimité, Inc. (2001) and Kleinschmidt Associates (2002).

Table excludes small forage species.

Copyright © 2005 New York Power Authority

5.0 FISH SURVIVAL

5.1 Review of Turbine Survival Studies

5.1.1 Overview of Francis Turbines

Both RMNPP and LPGP utilize vertical Francis turbines to generate power. Francis turbines tend to dominate hydroelectric installations in the eastern and upper Midwest areas of the United States (Becker et al. 2003) and are more often installed at higher head facilities than Kaplan turbines. A Francis turbine generally consists of a spiral tube to deliver water to the turbine, a series of wicket gates, stay vanes and adjustable guide vanes to direct flow radially inwards towards the impeller, which causes it to rotate, and a draft tube at the outlet of the turbine to direct flow back to the river.

5.1.2 Overview of Potential Sources of Fish Mortality and Types of Injury Occurring during Turbine Passage

Becker et al. (2003) indicated that fish are exposed to a variety of unnatural stresses during turbine passage. Therrien and Bourgeois (2000) identified four possible causes of fish injury and/or mortality during turbine passage:

- Contact with turbine parts resulting in injury due to strike (collision with turbine component or object in flow), abrasion (rubbing against turbine component or object in flow) or grinding (when a fish is drawn into small clearances between moving parts).
- Sudden acceleration or deceleration of up to 30 times, resulting in turbulence and shear forces that could tear fish to pieces.
- Variation in pressure, either positive or negative, of up to three times reference pressure, potentially causing a hemorrhage or rupture of the swim bladder. The usual pattern of

Copyright © 2005 New York Power Authority

pressure changes during passage includes an increase during entrainment, rapid decrease during passage into the turbine, and increase during discharge.

- Cavitation, caused by collapse or implode of gas bubbles in a liquid, which could result in various injuries to fish.

Cada (2001) also identified turbulence (irregular motions of the water) as a potential cause of localized injuries or disorientation.

Factors found to affect abrasion include flow discharge and velocity, number of turbine blades and blade spacing, and flow passage geometry (USACE 1995, cited in Odeh 1999). Areas of the turbine that may result in grinding include between:

- the leading edge of the turbine and the hub,
- the blades and the throat ring,
- the wicket gates and stay vanes, and
- the wicket gates and the distributor ring.

The probability of a fish striking turbine components is generally dependant on the size of the fish, the number of turbine blades, blade spacing, turbine speed, flow velocity, and discharge as well as other factors (Odeh 1999). The probability of striking a turbine blade has been calculated using the parameters for specific turbine units (Therrien and Bourgeois 2000). Turnpenny 1998, (cited in Therrien and Bourgeois 2000) found that for low head facilities (i.e., <100 ft), the predominant cause of injury or mortality was contact with turbine components. Therrien and Bourgeois (2000) stated that the probability of a fish coming into contact with turbine parts, and therefore their susceptibility to injury or mortality, is higher for larger fish. Turnpenny 1998, (cited in Therrien and Bourgeois 2000) found that the probability of a fish coming into contact with turbine parts is related, at least in part, to fish weight, and impacts on the possibility of a fish being swept away from the blade by the moving water in the turbine.

Copyright © 2005 New York Power Authority

The highest values of shear stress observed with turbines are generally found at or close to the interface between the flow and solid objects such as vanes and wicket gates (Odeh 1999). Injuries due to shear stress are generally related to fish species, fish size and the manner in which a fish enters the shear stress zone (USACE 1995, cited in Odeh 1999). Larger fish have been shown to have a lower probability of sustaining an injury due to shear effects (Franke et al. 1997, cited in Therrien and Bourgeois 2000). As reviewed in Odeh (1999), Franke et al. (1997) found that the shear stress threshold value was approximately 450 ft/s/ft, with values above this value believed to result in mortality.

External injuries caused by contact with turbine parts or due to shear forces resulting from velocity changes include fractures, severances, isthmus tearing, contusions, lacerations, abrasion, scaling, torn gill covers and eye lesions (Therrien and Bourgeois 2000). Loss of external mucous from the fish's surface may also be harmful by facilitating an increased incidence of fungal infections (Turnpenny 1998 in Therrien and Bourgeois 2000).

The probability of fish sustaining damage due to pressure changes is dependant on the amount and rate of change of pressure exerted on the fish, as well as the individual species of fish (Odeh 1999). Perch and bass are generally more susceptible to changes in pressure than salmon or trout, due to physiological differences in their ability to vent gases from the swim bladder (Odeh 1999). Odeh (1999) found that pressure increases during passage may be anywhere from a 2-4 fold over normal water pressure. Mortality during a rapid pressure decrease generally results from a corresponding increase in the volume of gases in the fish's bloodstream and swim bladder. Becker et al. (2003) identified that internal dissolved gases could be up to 130% of saturation, and that this supersaturation may also exacerbate trauma induced by rapid pressure changes. Franke et al. 1997, (cited in Odeh 1999) found that pressure related damage to fish is a significant source of mortality at facilities with heads greater than approximately 100 ft, while Larinier and Dartiguelongue 1989 (cited in Therrien and Bourgeois 2000) indicated that heads greater than 60 ft resulted in higher risk of injury.

Cavitation, resulting from collapse of bubbles in the water, can result in production of shock waves, noise, vibration, pressure fluctuation, erosion damage to solid surfaces and loss of efficiency or flow capacity (Odeh 1988 and Tullis 1989, cited in Odeh 1999). Damage due to cavitation often results

Copyright © 2005 New York Power Authority

from release of high-pressure shock waves or high velocity microjets (Tullis 1989, cited in Odeh 1999). Although potentially very damaging, the effects of cavitation are only experienced in close proximity to their origin – typically, very near the back side of the turbine blade. Furthermore, cavitation is more common at very inefficient turbine settings that do not occur very frequently.

Pressure changes and cavitation may result in internal injuries such as eye bulging, external and internal hemorrhages, rupture of the swim bladder and gaseous embolism (Therrien and Bourgeois 2000).

The stress and other physical impacts associated with turbine passage, which could result in weakening, disorientation and changes in survival behavior, may also make fish more susceptible to predation or disease (Therrien and Bourgeois 2000). For example, gas bubble disease severely disables the functioning of the fish's lateral line, resulting in decreased predator and object avoidance, and potentially, increased mortality as a result (Popper and Carlson 1998, cited in Therrien and Bourgeois 2000).

5.1.3 Generating Facilities

The following section is a summary of the results of a literature search conducted in order to review fish turbine passage survival studies that have been conducted at other hydroelectric facilities (Appendix A). Section 4.1 provides a general overview of fish entrainment and mortality reviews conducted to date, and this section and Appendix A provide more detailed information.

Fish passage and associated turbine mortality is an important consideration when determining the effects of a hydroelectric facility on fish communities. Fish passing through turbines experience a variety of unnatural stresses including contact with turbine components (resulting in abrasion, striking, or grinding), shear forces due to sudden acceleration/deceleration, variation in pressure or cavitation due to implosion of entrained gas bubbles. Fish can sustain a number of different internal or external injuries that may result in direct mortality or may lead to conditions that result in indirect mortality due to

Copyright © 2005 New York Power Authority

predation or disease (e.g., weakening, disorientation, altered survival tendency behavior, loss of protective mucous, etc.).

Turbine mortality associated with different types of turbines (e.g., Francis, Kaplan, propeller types) has been extensively studied over the past two decades. EPRI 1997 is the most comprehensive summary database of mortality studies. The database was compiled by Alden Research Laboratory Inc. The goal of this production was to compile the results of representative turbine mortality studies in order to provide a predictive tool to estimate turbine mortality at unstudied facilities without necessitating costly and time-consuming field studies. The database presents the results of studies conducted at 51 individual turbines throughout the United States. This study was reviewed to determine the type and quality of information contained within the database, to determine its applicability for predicting turbine mortality associated with NPP facilities. A total of 20 studies within the database involved Francis (vertical) turbines similar to those found at NPP. However, the physical characteristics (e.g., average head, rated flow, rated power and rotational speed) were generally significantly different from those found at the NPP. Physical characteristics of turbines and hydroelectric facilities are one of the primary determinants of fish passage mortality and as such, the applicability of the studies within the database for predicting mortality associated with fish passage at NPP is very limited.

Stone and Webster also conducted a Fish Entrainment and Mortality Review (EPRI 1992), which summarized the results of 33 studies that examined fish passage at turbines throughout the U.S., as well as one in Canada. The overall mortality estimate for fish passage through Francis turbines was 20%, but EPRI indicated that the information contained within the review did not seem to be sufficient to determine predictive correlations between turbine types and fish size classes. Several of the studies associated with Francis turbines exhibited high control mortality, which affects the reliability of the mortality data and inflates the turbine mortality estimate (Winchell et al. 2000).

Many other fish passage and turbine mortality studies have been conducted in the United States. Projects reviewed for this study included the Tapoco Hydroelectric Project and the Cowlitz River Project, as well as others, although none had a suite of characteristics that exactly matched those at NPP.

Copyright © 2005 New York Power Authority

However, the results of the many studies reviewed, but not necessarily all, do identify several general trends associated with fish passage and turbine mortality. These trends include:

- Fish size, turbine type, turbine rotational speed and turbine size each affected fish survival in a predictable manner, while species of fish did not result in any obvious difference in survival probability.
- Survival was typically higher for smaller fish (i.e., <8 in.). Larger fish tended to show higher incidence of observable physical injury, therefore likely indicating a higher probability of striking parts of the turbine.
- Lower rotational speeds (i.e., <250 rpm) typically resulted in decreased mortality.
- Maximum fish survival tends to be associated with units operating at peak efficiency. Increased mortality outside this range may be due to impacts associated with increased cavitation in the turbine or the result of a narrower clearance between wicket gates at lower (i.e., inefficient) wicket gate settings. Greater wicket gate opening has also been associated with increased mortality, possibly due to smaller clearance between leading edges and runners.
- Plant head is generally not correlated with fish mortality for a given type of turbine. The influence of head may be overstated in several studies due to the fact that Francis turbines are used more often at higher head installations. That is, increased mortality may have been due to turbine type, rather than increased plant head, as described below.
- Survival rates for Francis turbines were more variable than those observed for other turbine types (e.g., Kaplan). Some sites with Francis turbines show high rates of survival for all sizes of fish, therefore indicating the relative importance of site characteristics and not just turbine type. Francis turbines tend to have more closely spaced internal components, which tends to negatively affect survival probability, particularly for larger fish. Number of wicket gates and stay vanes may also affect survival probabilities.

Copyright © 2005 New York Power Authority

5.1.4 Pump Generation Facilities

The following section summarizes the information reviewed as part of the background literature review of pump generation facilities and associated fish turbine/pump passage mortality.

Richard B. Russell Pump Generation Plant (RBR)

The RBR, owned by the USACE, is located on the Savannah River on the Georgia-South Carolina border, situated between two other federally owned power projects (Hartwell on the upstream side and J. Strom Thurmond on the downstream side). The project was initially constructed in 1984 and consisted of four 82-MW Francis turbine generating units. In 1994, four pump turbines, each rated for 80 MW were installed in the powerhouse to provide pump storage generating capacity to the facility. Each pump can pass a rated flow of 7,500 cfs from the tailwater (J. Strom Thurmond Lake) to the reservoir during pumping operations. Similarly, during generation, each of the eight units in the powerhouse can pass up to 7,500 cfs.

Prior to the installation of the new turbines, environmental concerns associated with the upgraded capacity and function of the powerhouse (e.g., fish entrainment due to pumpback operations), were identified. Nestler et al. (1999a) indicate that the pumping phase of a pumped storage operation generally results in significantly higher entrainment than the conventional generation phase, although this is highly dependant upon specific site characteristics (e.g., intake locations, habitat conditions, flows, etc.). In order to assess the potential effects of fish entrainment from the downstream reservoir and the upstream forebay of the facility, a study, *The Richard B. Russell Fish Entrainment* Study, was initiated in 1986 (Nestler et al. 1999b). Extensive monitoring and analyses were undertaken prior to and following installation of the pump turbines in order to accurately predict, mitigate and monitor their effect on surrounding fish communities.

The study found that during pumping operations, fish were more likely to be entrained because of more suitable habitat conditions in the tailrace, compared to conditions found in the reservoir during

Copyright © 2005 New York Power Authority

generation. It was also observed that species that congregated in the tailrace area during the spawning period were more susceptible to entrainment and turbine mortality. Turbine survival rates were computed based on the results of entrainment studies. Passage survival ranged from 0 to 100% depending on species and water temperature, but the author did not elaborate on differences in the survival results. The predominant species entrained into the system during pumping were clupeids (i.e., threadfin shad and blueback herring).

Ludington Pumped Storage Plant

The Ludington pumped storage plant, owned by Consumers Power Company and Detroit Edison Company, is located in the state of Michigan, on the eastern shore of Lake Michigan, 8 km south of the Town of Ludington. The facility is capable of pumping up to 66,510 cfs of water from Lake Michigan up 360 ft to a 340-hectare reservoir for later use in the station's generating facility. During low demand periods, the facility is used to pump water from Lake Michigan for storage in the reservoir. During higher energy demand periods, water is drawn from the reservoir, through the project's turbines and discharged back to the lake. It was recognized that pumping operations had the potential to result in entrainment of fish into the pump and subsequent mortality or sustained injuries (Guilfoos et al. 1995). Particular species of concern include salmonids (Chinook and coho salmon, rainbow, brown and lake trout), yellow perch, rainbow smelt, alewife and bloater chub. Significant mortality of large salmonids and other species from Lake Michigan was documented by a number of studies and filed with FERC.

5.2 Review of Fish Survival Over Large Falls

The question of fish survival over Niagara Falls is one that has not previously been investigated. To our knowledge, no field studies have ever been conducted to determine fish survival over Niagara Falls, although some survival studies have been conducted at natural falls in the Pacific Northwest (Bell and DeLacey 1972). However, more information is available for fish survival over spillways, and this information is used to address the question of survival over Niagara Falls.

Copyright © 2005 New York Power Authority

While fish passage over natural falls has not been assessed, passage over spillways associated with a number of large dams has been investigated, primarily to provide a comparison to turbine passage. Factors that may inflict damage to fish and affect the survival rate associated with passage over a spillway include:

- Height of the structure, size of the fish and impact velocity
- Abrasion against and the roughness of the spillway surface during passage
- Physical characteristics of the landing zone (deep pool versus stilling basin blocks or other energy dissipation devices)
- Hydraulic characteristics of the landing zone/plunge pool (depth, shear stresses, turbulence, nitrogen super-saturation, etc.)

Mortality rates can vary greatly from one location to another, with a number of the large dams on the Columbia River (Bonneville, McNary and John Day), with approximately 100 ft high spillways, ranging from 0 to 4%. However, passage of juvenile salmonids over a 30 m (98 ft.) high spillway at the Lower Elwha dam (on the Elwha River) results in 37% mortality (Marmulla 2001). Passage over a spillway structure may or may not result in direct mortality, however, indirect or latent mortality may occur as a result of gas super-saturation, increased susceptibility to predation (due to momentary stunning or disorientation) and/or general exhaustion or weakening associated with passage (Clay 1995).

Height, Size of Fish and Impact Velocity

The terminal velocity of a falling object is a function force (gravity), mass (weight) and drag (air resistance). Also height of the fall determines whether the object reaches its terminal velocity, i.e., when force equals drag. Studies of fish passing over a spillway indicate that the height of the spillway and the size (weight) of the fish both affect the terminal impact velocity of a free-falling fish. Complete survival of Atlantic and Pacific salmon smolts (6-7 in. length) has been found to occur at structures 12 to 40 m in height (39-131 ft), while complete survival of adults (24 in. in length) only occurs at structures approximately 13 m (43 ft) or less. Even at structures up to almost 300 ft in height, 98% survival has been noted for salmonid smolts (Therrien and Bourgeois 2000). Small fish (smolts) reached a terminal free-fall velocity of 52 fps at a height of 100 ft. (Bell and DeLacey 1972), while larger, heavier fish had

Copyright © 2005 New York Power Authority

terminal velocities in excess of 190 fps. Thus height and fish size are both factors affecting fish survival over spillways.

Physical Abrasion During Passage

Various types of spillway configurations result in different flow paths for the water. While free-fall spillways have their own considerations, Ogee type spillways, which result in more or less constant water/concrete contact, may increase the potential for external injuries, such as stripping of the external mucous membrane, de-scaling, and/or tearing of tissues (Clay 1995). Damage to the external mucous membrane may not be perceived as a significant direct injury, secondary fungal infections as a result of these injuries may ultimately lead to mortality of the fish (Therrien and Bourgeois 2000).

Physical and Hydraulic Characteristics of the Landing Zone

Landing zones below the spillway that provide appropriate physical and hydraulic characteristics optimize fish survival. Direct contact with physical structures within the landing zone (energy dissipation devices, river bed or banks, etc.) can lead to significant mortality. Researchers have studied plunge pool characteristics and have indicated that the pool depth be a minimum of 3 ft, that it be equal to a quarter of the head, and contain a volume of 350 ft^3 for every cubic meter (35 cubic ft) of flow (Odeh and Orvis 1988 in Therrien and Bourgeois 2000). Hydraulic characteristics of the landing zone are equally important as shearing effects and rapid pressure changes can lead to disorientation and/or internal damage that may increase susceptibility to predation. Rapid and deep submersion into the plunge pool can also lead to nitrogen super-saturation (Clay 1995).

5.3 Turbine Survival at NPP

Turbine survival estimates at many hydroelectric facilities have been based on experimental tests in which fish are injected into the penstock and collected in the tailrace in nets. In the case of NPP, the severity of the currents in the lower Niagara River eliminates the potential for conducting such tests due

Copyright © 2005 New York Power Authority

to safety factors. The potential for survival of fish through the turbines of the RMNPP and LPGP can be surmised only based on experimental tests at other sites.

We examined the survival data in the EPRI database for all vertical Francis turbines in order to determine the average immediate and latent (24 and 48 h) survival of fish passing through turbines (Table 5.3-1). In examining the data, any survival estimate that exceeded 100% (i.e., more control than test fish died) was given a value of 100. Cases of high control mortality masked the effects of turbine passage, but the survival of fish was likely high, but lower than 100%. Average fish survival for all tests conducted on Francis turbines was 76.3% immediately after passage and survival after 24 and 48 hours was 73.8 and 70.8%, respectively. There was a slight difference in survival among seasons, with lowest survival in the summer, when water temperature was highest, and among species groups with salmonids having the highest mortality. Centrachids and percids, which include rock bass and yellow perch (the most common species in the Lewiston Reservoir), had the highest survival, approximately 80%.

It must be noted that applying average survival estimates from other sites must be done with caution because the combination of operating parameters at NPP (e.g., head, flow, etc.) are substantially different from the plants where field data were collected.

It was not possible to estimate turbine survival at LPGP during pumping mode, based on average survival at other sites, as too few studies were conducted on fish survival at pump-storage facilities. However, it is likely that the probability of a fish hitting the moving parts of the units during pumping mode would be similar to that during generation and thus survival should be similar to that during the generating phase, although entrainment may be higher during the pumping phase (see Section 4.1-2).

5.4 Fish Survival Over Niagara Falls

Information presented in Section 5.2 can be used to provide a professional opinion on fish survival over Niagara Falls. As noted in Section 4.0, many small, weakly swimming fish entering the GIP are likely incapable of moving upstream against the currents in the GIP. Consequently, those fish

Copyright © 2005 New York Power Authority

that are not entrained by the NPP intakes may pass over the American Falls, on the north side of the river, or Horseshoe Falls, on the south side of the river. It is most likely that fish that are on the north side of the river are entrained in the flow of the American Falls. Depending on the path taken, the outcome may be considerably different (i.e., fish passing over the American Falls will not likely survive while those entrained may end up in the Lewiston Reservoir or may survive passage through the turbines at RMNPP).

The American Falls is the most likely route of passage over Niagara Falls for small fish on the east side of the river downstream of the NPP intakes. Downstream of the NPP intakes, flow vectors are essentially parallel with the shoreline (NYPA 1998), with the result that small fish that are incapable of swimming against the currents of the GIP would pass into the channel leading to these falls. Currents in the channel approaching the American Falls along the east side of Goat Island are extreme (see photos at end of report), and any fish entering the channel would not likely avoid passage over the American Falls.

The drop over the American Falls is estimated at approximately 175 ft. However, as noted in the photos, the landing zone is a boulder field with no appreciable pools or water depth, which is located at approximately one-half of the overall falls elevation. The remainder of the passage to the river would be made through a series of mini-waterfalls and underground passages that would impose additional physical and hydraulic stresses. Thus, the degree of direct or indirect mortality associated with the passage over these falls could reasonably be expected to approach 100%.

It should be noted that fish sufficiently strong to move laterally in the downstream flow and thus avoid the approach channel to the American Falls may continue to move downstream once they enter the approach channel to the Horseshoe Falls, on the west side of Goat Island.

Similar to the American Falls, the Horseshoe Falls drop is a free-fall, which in this case is approximately 165 ft. Given this height and anticipated terminal velocities, one would expect some moderate level of mortality for larger fish and some minimal level of mortality for small fish (<10%). While somewhat obscured by mist in the photograph, the water depth at the base of most of the falls is considerable and has been estimated to be as deep as the falls is high. Using the factors noted in Section

Copyright © 2005 New York Power Authority

5.2), one would anticipate that the survival rate for most fish passing over the Horseshoe Falls is relatively good, although large fish would be expected to suffer higher mortality.

Copyright © 2005 New York Power Authority

TABLE 5.3-1

AVERAGE TURBINE SURVIVAL FOR FRANCIS TURBINES

	Immediate Survival			24 Hour Survival			48 Hour Survival		
	Average	**SE**	**N**	**Average**	**SE**	**n**	**Average**	**SE**	**n**
All Tests	76.3	1.5	309	73.8	1.8	211	70.8	1.6	303
Season									
Spring	78.0	2.7	63	72.6	3.4	54	67.3	3.5	62
Summer	72.7	3.4	56	68.1	4.3	26	65.9	3.6	56
Fall	76.4	2.2	163	68.1	4.3	26	72.2	2.3	163
Species Group									
Centrarchids	79.6	3.1	89	79.1	3.9	65	74.5	3.5	87
Coarse	73.4	2.0	127	71.2	2.1	105	68.4	2.2	126
Salmonids	68.2	5.1	39	57.8	9.0	11	66.2	5.5	36
Percids	79.2	4.7	28	70.9	7.6	14	74.1	5.0	28

Source: EPRI (1997) Database

SE – standard error of the mean
n – sample size (i.e., number of tests)
centrarchids – bluegill, sunfish, largemouth bass, bluegill X green sunfish hybrid
coarse – white sucker, bullhead, fathead minnow, creek chub, golden redhorse, shorthead redhorse
salmonids – rainbow trout, brook trout, brown trout, Atlantic salmon
percids – yellow perch, walleye

Copyright © 2005 New York Power Authority

6.0 FISH BARRIERS

This section of the report includes a description of fish barriers or fish protection measures that were considered for the NPP. Section 6.1 is a general review of measures that have been used at other projects throughout North America, with a general physical description of each measure, an analysis of whether the measure has been biologically effective, and a discussion of factors to consider for construction and operation and maintenance (O&M). Section 6.2 is a more detailed assessment of which fish protection measures might have some applicability to the NPP, considering the potential alternatives for managing fish protection in the project area. The more detailed assessment only examines those measures that would potentially be biologically effective at the project, and that could be feasible to engineer, construct, and operate.

6.1 General Review and Assessment of Fish Barriers

6.1.1 Physical Barriers

Physical barriers have been the most common method for preventing fish and other organisms from entering the intakes of hydroelectric and thermal generating stations and other types of water intakes. The design concept is to deploy a structure (usually a screen or bar rack) that allows water to pass through, but has a clear space between the screen or rack elements small enough to physically exclude a target size range of fish or other organism. Velocity through the structure, however, must be low enough so that the target species or size group can avoid being impinged on the structure. Additionally, there are behavioral aspects associated with physical barriers, where fish may avoid passing through confined spaces, even though that space may be large enough for the fish to pass through.

EPRI (1986) and FERC (1995) summarize the types of physical barriers that have been deployed at hydroelectric intakes, or have the potential to be deployed. EPRI (1986) describes six types of physical barriers: bar racks, traveling and stationary screens, rotary drum screens, infiltration intakes, cylindrical wedge-wire screens, and barrier nets. FERC (1995) describes five types of physical barriers that have

Copyright © 2005 New York Power Authority

been installed at hydroelectric stations: low-velocity fish screens, high-velocity fish screens, close-spaced and angled bar racks, louvers, and barrier nets. Many of the descriptions in EPRI (1986) may be more applicable to intakes with smaller flow volumes, and, in fact, several of the facilities described are used primarily at thermal power stations and industrial intakes. Therefore, our description of physical barriers will follow the general categories used by FERC (1995).

6.1.1.1 Low-Velocity Fish Screens

These types of screens have been widely deployed in the western U.S., where they are a generally accepted and well-proven measure. They include fixed screens constructed of several types of material (wire mesh, punch-plate, wedgewire), rotary drum screens, or vertical or horizontal traveling screens. Screen mesh size is usually small (less than 0.5 in.), and the approach velocity is less than 0.5 feet per second (fps). Fixed screens usually require a cleaning mechanism to remove accumulated river debris, while rotary drum screens include self-cleaning mechanisms. Vertical or horizontal traveling screens may also be self-cleaning or are often equipped with a screen-washing system.

Biological effectiveness of low-velocity screens is usually high for all species, but a major limitation is that these types of screens can generally be used at only small hydroelectric stations or other intakes with relatively low flow volumes, such as agricultural water diversions (i.e., irrigation canal intake structures). For example, vertical traveling screens are typically used for relatively shallow diversions with volumes of only 100 to 500 cfs (ASCE 1995), although multiple screens can be grouped together to provide a higher volume diversion. Rotary drum screens, which are most commonly used in irrigation canals in the western U.S., may be used for diversions of up to 3,000 cfs, but are also limited to a shallow intake depth (as occurs in an irrigation canal) (ASCE 1995). These types of screens are a well-known technology, having been used for many years at a variety of intakes. An important O&M consideration, however, is that the typically small mesh sizes create the potential for collection of debris, and screen washing systems are a necessity. Screen washing systems usually also require a fish return system, since fish are often collected off the screens, along with any debris, and must be flushed back to the water body to prevent mortalities.

Copyright © 2005 New York Power Authority

6.1.1.2 High-Velocity Fish Screens

High-velocity screens are a "newer" technology that includes designs that are "experimental" and some that have been successfully deployed at operating hydroelectric stations. These include designs such as submerged traveling screens (STS), the Eicher screen, and Modular Inclined Screen (MIS).

The STS has been installed at several mainstem Columbia and Snake River projects since the late-1970s. It is a partial screen that extends at an angle into the turbine intake, to take advantage of the behavior of those species of juvenile salmon and steelhead that remain close to the intake ceiling when passing downstream through a hydro station. The STS is designed for placement inside the intakes (downstream of the trashrack) of large hydro stations.[5] The screen is usually about 20 ft long by 20 ft wide, and consists of a continuous polyester mesh that rotates around a perforated plate (ASCE 1995). The rotating mesh acts to flush off any impinged fish or debris. The fish are typically diverted into an intake gatewell or another collection channel to be bypassed around the dam. This type of screen, however, has only been used for anadromous salmonids at Columbia and Snake River projects, and diversion efficiencies have been fair to good, at about 40 to 80%, although extended length screens of up to 40 ft have been tested, to improve diversion efficiency (ASCE 1995). Some level of fish mortality may also occur during the use of STSs, via fish impingement and abrasion on the screens, and additional abrasion and injuries associated with passage through the fish bypass system. The STS has not been used or tested with resident warmwater/coolwater fish species, but the diversion efficiency would likely be low, because these species may be found throughout the water column.

Installation of an STS requires upstream gatewell slots, and major structural modifications would be required if an existing hydro station is not equipped with gatewell slots of the correct dimensions. O&M requirements would also be significant, in maintaining the functioning of this large traveling, but submerged screen. In rivers with high debris loads (leaves, aquatic vegetation, woody debris), significant effort may be required to keep the screen clean. Frazil icing could become a problem if STSs were

[5] For example, STSs have been installed at the 1,093-MW Bonneville Dam, 2,160-MW John Day Dam, and 980-MW McNary Dam, on the lower Columbia River.

Copyright © 2005 New York Power Authority

installed at projects with winter icing conditions (none have been installed to date in projects with severe icing conditions). High debris or ice loads would affect the proper functioning of the screen, could increase fish impingement on the screen or increase fish diversion under the screen (and into the turbines), and potentially result in structural damage to the screen (if loadings are too high).

The Eicher screen is designed to be placed inside a turbine penstock or pipeline and is mounted on a pivot shaft to allow the screen to be tilted for cleaning. The screen is oriented at a shallow angle to the flow (<20°), and fish are diverted to a bypass at the top of the penstock/pipeline. The screen is typically constructed of aluminum wedgewire, with a clear spacing between elements as small as 2 mm. Testing of this screen in both laboratory and prototype installations has shown that it can be highly efficient in fish diversion (greater than 95%), with high fish survival (greater than 95%), at penstock velocities of 4 to 8 fps. This screen has been deployed at two west-coast hydroelectric stations (the 15-MW Sullivan Plant, Willamette River, Oregon, and 24-MW Puntledge River Project, British Columbia), for the diversion of anadromous salmonids (ASCE 1995). The volume of flow screened at the Sullivan plant is 425 cfs. No east-coast applications are known (other than experimental), nor are there any reported applications with warmwater/coolwater resident species. However, because the screen "filters" the entire water passage, it is probable that resident fishes would be efficiently diverted, although agencies have expressed concerns about the use of the Eicher screen with smaller, weaker-swimming fish.

Engineering considerations for an Eicher screen include the requirement for placement in a pipeline-type conduit, and providing for a fish bypass conduit. O&M requirements should be less than other types of screens, because the screen can be pivoted for cleaning, although cleaning is an important requirement, since experience has shown that increased debris loads result in higher injury to fish. Head losses may be significant across the screen (up to 2 ft), and flow distribution into the hydro unit may also be affected by the backflushing/cleaning cycle (ASCE 1995). Frazil icing in the winter could also become a problem and result in screen blockage and even higher head losses.

The MIS is an experimental design that is also made of wedgewire and uses the pivoting inclined screen concept of the Eicher screen. It is different from the Eicher screen in that it is designed as a rectangular module that could be installed at intakes outside of the turbine penstock or pipeline. During

Copyright © 2005 New York Power Authority

prototype testing by Alden Research Laboratory at the Green Island Hydroelectric Project, Hudson River, both diversion efficiency and fish survival was high for a variety of anadromous and riverine species at tested velocities ranging from 2 to 10 fps (as presented by the U.S. Fish and Wildlife Service during a 2000 workshop on fish passage and bypass facilities in Hadley, MA). The MIS, however, has not been permanently installed at any hydroelectric station since the Alden testing. Because of the experimental nature of the MIS, and since it has not been installed at any operating hydroelectric project, there is no design, construction, or operational experience to report. It is expected that O&M requirements would be similar to the Eicher screen, although maintenance could be somewhat easier because the MIS would be installed outside of a pipeline or penstock. Because the MIS uses a relatively narrow spacing between screen elements, it is also expected that cleaning would be a primary O&M item to maintain the proper functioning of the screen. Frazil icing or river ice loading could also become a problem during the winter season.

6.1.1.3 Angled Bar Racks

Angled bar racks are probably the most commonly recommended and deployed fish protection/passage measure in the northeastern and midwestern U.S. in recent years. In a 1993 survey of FERC licensed projects with fish protection measures, 38% of the projects (total of 32 projects) had angled bar racks (Cada and Sale 1993). In a more recent survey, the 8 northeastern U.S. states were reported to have a total of 36 bar rack installations, including 17 in New York State (Amaral 2003). Most of these installations are at small to medium-sized hydroelectric projects. The largest project in New York with angled bar racks is the Hudson Falls Project on the Hudson River, with a generating capacity of 36.1 MW and a total hydraulic capacity of 7,500 cfs.

Angled bar racks are usually installed upstream of the turbine intakes and the conventional trashracks. They may also serve as trashracks and are typically installed at an angle to the flow (usually 45°), with the vertical bars oriented perpendicular to the plane of the rack, and the spacing between the bars of 1 in. Maximum allowable approach velocity (per U.S. Fish and Wildlife Service criteria) is 2 fps, measured 1 ft upstream of the intake, and the bar rack is often associated with a fish bypass. Some field testing of the fish diversion efficiency of angled bar racks has occurred, and indicates efficiencies of from

Copyright © 2005 New York Power Authority

20 to 100%. Most field testing of efficiency has been with Atlantic salmon and juvenile *Alosa* species, but laboratory testing has indicated that efficiencies for riverine resident species may be less than 60% (Amaral 2003). Construction of angled bar racks may require major project renovations, depending on whether a new support structure or other intake modifications are required (for existing projects), or whether the bar rack can be substituted for an existing trashrack, as part of normal maintenance. For new unconstructed projects, angled bar racks may be designed as an integral part of the intake structure. O&M may be significant during periods of high river debris, requiring a rack cleaning system, similar to a conventional trashrack. Frazil ice or river ice loads may also be a problem during the winter months, requiring measures to prevent icing and clogging of the racks, or removal of the bar racks during the winter season.

A variation of the narrow-spaced bar rack is the trashrack overlay, which is a narrow-spaced (1 in. or less) screening material placed over an existing trashrack, usually seasonally, to prevent fish from entering an intake during periods of high or increased fish activity. Trashrack overlays have been used at several projects in New York State. Installation usually requires little construction, and O&M requirements are likely similar to angled bar racks, with some increase in rack cleaning activities and considerations for icing in the winter months. Information on the effectiveness of trashrack overlays has not been reported, but may be similar to angled bar racks. One difference, however, would be that trashrack overlays usually are placed on existing trashracks that are perpendicular to the flow, and there would be no "guiding effect" as occurs with angled bar racks.

6.1.1.4 Louvers

Louvers are a widely used fish passage technology that was initially developed in the 1950's, primarily for the passage of juvenile anadromous salmonids (Clay 1995). Louvers are similar to angled bar racks, but the louver bars are arranged perpendicular to the flow, with the louver array angled at about 15 to 30° to the flow. Spacing between the louver bars can vary from 1 in. to 12 in., depending on the species, and approach velocity should be less than 3 fps (ASCE 1995). Louvers actually operate more as a behavioral device, by creating hydraulic conditions that are sensed by approaching fish, and elicit an avoidance response. The bypass velocities should be 1.5 to 2 times the approach velocity. Because

Copyright © 2005 New York Power Authority

louvers depend on controlled hydraulic conditions, they must be placed in a power canal or forebay with relatively stable hydraulic conditions. Guidance efficiencies have ranged from 40% to more than 90%, for anadromous species, but no effectiveness studies have been reported for riverine resident species. Laboratory studies, however, have indicated potential guidance efficiencies of up to 80% for a range of other species (Amaral 2003).

Louvers have not been widely deployed nationwide in recent years, although louver arrays have been installed in the Holyoke Canal System, associated with the Holyoke Project, on the Connecticut River, at the Vernon Project on the Connecticut River, Garvins Falls Project on the Merrimack River, Eastman Falls Project on the Pemigiwasset River, and Gardner Falls Project on the Deerfield River. Available information on some of these facilities is summarized as follows:

Project	Louver Type	Flow Volume Screened (cfs)	Species Tested	Guidance Efficiency
Holyoke Canal	Partial depth (about 9 ft)	7,000	Salmon smolt Juvenile *Alosa*	80 – 95%
Vernon	Partial depth (about 15 ft)	13,000	Salmon smolt	74 – 76%
Garvin Falls	Not known	--	Salmon smolt	88%

(Sources: Amaral 2003; Warner 2003)

Construction of louver arrays at hydroelectric projects usually does not require major renovations of existing facilities, because louvers are placed in a canal or forebay. Construction, however, may require shutdown of the project, so that the often large structure that supports the louver array can be installed in the dry (for example, the Holyoke Canal array is 440 ft long). Louvers also require construction of a bypass conduit to return the fish to the river, and depending on the project site, may also be a major structure (the bypass pipeline at Holyoke is 600 ft long). O&M considerations would be similar to angled bar racks, with the need to provide a cleaning mechanism, and possibly measures to deal with frazil ice or river ice loads during the winter months, if the array is left in place. For anadromous species, louvers may be removed during the non-migration season.

Copyright © 2005 New York Power Authority

6.1.1.5 Barrier Nets

Barrier nets may be considered a relatively "low-technology" method of preventing fish from entering intakes, and have been used at both steam-electric and hydroelectric projects. With a barrier net, the intake area is cordoned off with a net that has a mesh sized to the target species and size groups to be excluded. The mesh size should also be of a size that does not "gill" other non-target species, which would result in loading the net with dead fish. A few successful applications of barrier nets at steam-electric stations were reported by EPRI (1986) and FERC (1995). These included: the Bowline Station, Hudson River; J.P. Pulliam Plant, Green Bay, WI; Dallman Station, Lake Springfield, IL; J.R. Whiting Plant, MI; and Chalk Point Station, Patuxent River, MD. The deployments were considered successful if impingement on the station's intake screens (which were cordoned off by the barrier net) was reduced. For some species, impingement was reduced by 80 to 90%. Conditions required for successful deployment at all these stations included both low flow velocity through the net (less than 0.5 fps) and low debris loads.

Barrier net deployments reported for hydroelectric projects include: the Pine River Project, WI: Northfield Mountain Pumped Storage Project, Connecticut River, MA; and Ludington Pumped Storage Project, Lake Michigan. At the Pine River Project, a small run-of-river project, the net was deployed from 12 to 18 in. below the water surface, to allow for debris to pass over the net. Entrainment rates downstream of the net were reduced from 92 to 70% (FERC 1995). At Northfield Mountain, several different layouts of partial and full barrier nets were tested at the river intake structure (the lower reservoir). Some successful diversion of salmon smolts away from the intake was observed, although there were some difficulties in maintaining the nets in place, with several instances of nets tearing out of their anchors. Measured water velocities through the net ranged from 0.7 to 2.0 fps. The largest barrier net application is at the 1,872-MW Ludington Pumped Storage Project on Lake Michigan, where a 2.5-mile-long net is installed in the lake around the project intakes during the summer months. The net is placed outside of the areas of higher flow velocity from the project. The effectiveness of the net has been reported to be from 30 to 84%, although has improved in recent years to efficiencies exceeding 90% for some species (FERC 1995). The net, however, requires continuous maintenance by a full-time contractor during its deployment to maintain its integrity. It is removed from the lake from fall through spring,

Copyright © 2005 New York Power Authority

because of the difficulty in maintaining it over the stormy winter season (when fish abundance is normally lower).

Based on experience to date, successful deployment of barrier nets at both steam-electric and hydroelectric projects depends on two important variables: low water velocity and low debris loads. If either of these variables is not met, there is a high likelihood of unsuccessful operation of the net, which could mean either low fish diversion effectiveness or loss of the net.

6.1.2 Behavioral Barriers

Behavioral barriers are typically non-structural methods used to modify fish behavior so that they avoid intake areas, or are guided to safe bypass routes. Many of these barriers have been tested experimentally in the field, with variable results, and some types of behavioral barriers have been successively used at both hydroelectric and steam generating stations. The most commonly deployed or tested behavioral barriers have been lights, sound, and electrical fields. Other methods that have been tested, but are usually considered highly experimental at hydroelectric projects, include air bubble curtains and hanging chains. Sources of information on behavioral barriers are EPRI (1986) and FERC (1995), unless indicated otherwise.

6.1.2.1 Lights

Lights have been used to both repel fish away from an intake, and to attract fish to a fish bypass. Strobe lights are used to repel fish away from an intake, and have been successfully tested with two anadromous species. A strobe light array was deployed at the York Haven Project on the Susquehanna River, Pennsylvania, and was successful in repelling juvenile American shad away from the turbine intakes and into a sluiceway bypass. Strobe lights have also been used at the Weldon Project on the Penobscot River, Maine, to repel Atlantic salmon smolts away from turbine intakes and toward the fish bypasses. Strobe lights have also been shown to cause an avoidance response with American eel, alewife, gizzard shad, menhaden, spot, and white perch at both hydro and thermal station intakes. Testing at the University of Iowa found that bluegill, channel catfish, juvenile walleye, and hybrid bass avoided strobe

Copyright © 2005 New York Power Authority

lights, but largemouth bass had no reaction (ASCE 1995). Successful testing with other resident coolwater/warmwater species that occur in the Niagara River has not been reported. To date, strobe lights have been deployed only experimentally at hydroelectric projects, so there is no long-term operational experience with strobe lights. Installation of strobe lights, however, should not require a major engineering effort or major construction, other than mounting the lights and providing an electrical supply. Some underwater construction may be required. O&M requirements should also be minimal, other than light replacement and cleaning to prevent bio-fouling.

Mercury lights, which are believed to attract fish, could be useful in attracting fish away from an intake and into an area with a bypass, and have been tested in both the laboratory and in the field. Species that have demonstrated attraction to mercury lights include several estuarine species, alewife, smelt, gizzard shad, white bass, and "shiners" (*Notropis* sp.). Mercury lights were tested at the Ludington Pumped Storage Project and were found to attract resident species. Testing at the University of Iowa, however, found that largemouth bass, channel catfish and walleye were repelled by mercury lights, while hybrid bass and bluegill showed no response (ASCE 1995). Mercury lights have sometimes been used in combination with other devices to improve the efficiency of those devices. For example, mercury lights have been placed in the vicinity of a pump for collection of fish. At the Fort Halifax Project, Sebasticook River, Maine, a mercury light was placed immediately over a fish bypass system for alewife, but it has not been reported whether the light improved passage through the bypass.

As with strobe lights, mercury lights have only been deployed experimentally, but installation would not likely require a major engineering effort, and O&M requirements would likely be minimal. One disadvantage of lights is that they are most effective at night, so could provide protection at intakes for only the nighttime hours, allowing fish to enter the intakes during the daylight hours.

6.1.2.2 Sound

Sound generators have been used to both repel and attract fish at water intakes, but most applications at power plants have been to repel fish. Two types of sound technology have been used: poppers, which create a high-energy acoustic output (a "pop") to startle fish and cause an avoidance

Copyright © 2005 New York Power Authority

response, and sound generating transducers, which create frequencies and amplitudes that also cause an avoidance response in fish. Both types of sound systems have been used with some success at thermal plant intakes, and in laboratory tests, but only sound generators have had some applications at hydro plants.

The use of high frequency sound generators at the James A. FitzPatrick Nuclear Power Plant on Lake Ontario was successful in reducing the impingement of alewife at the intakes by 81 to 87% (Ross et al. 1993; 1996). Permanent sound generator systems have also been installed at the Point Beach and Cook Nuclear Stations on Lake Michigan (Guida et al. 2003). The same technology was used experimentally at the Benton Falls and Fort Halifax Hydroelectric Projects on the Sebasticook River, Maine, at the Lawrence Hydroelectric Project, Merrimack River, Massachusetts, and at Bonneville Dam, Columbia River. Permanent installations of a sound deterrent system are in place at the NYPA Crescent and Vischer Ferry Hydroelectric Projects, Mohawk River, NY, to prevent blueback herring from entering the unit intakes. Sound at a frequency of 125 kHz has been found to be effective in the deterrence of clupeids (American shad, alewife, blueback herring) (Guida et al. 2003). FERC (1995) also reported some success in deterring Chinook salmon and steelhead smolts, but there is little evidence that sound devices will effectively work with the coolwater/warmwater species that occur in the Niagara River.

Sound deterrence systems that have been deployed were easy to install and operate, with minimal O&M requirements, and have had high reliability (Guida et al. 2003).

6.1.2.3 Electrical Fields

Electrical fields have been used or experimented with for many years at both thermal and hydroelectric plants, to prevent fish from entering an intake, or to guide fish to a bypass. The objective is to provide an electrical field that is strong enough to cause an avoidance response in fish, but not strong enough to stun or incapacitate the fish. Typically, an installation consists of placing (often hanging) electrodes across an intake area, to prevent fish from entering the area. Electrical fields have also been used to block the upstream migration of fish, but most applications have attempted to prevent fish from entering an intake. EPRI (1986) reports that the electrical barrier placed at the intake of the Connecticut

Copyright © 2005 New York Power Authority

Yankee Nuclear Power Plant on the Connecticut River, was successful in reducing the impingement of catfish and American eels, although the system was not used on a permanent basis. At hydro stations, electrical fields have been used to guide fish to a fish bypass (salmon and steelhead at the Chandler Canal diversion, Yakima River, Washington), or to prevent downstream migrating American shad adults from entering a "dead-end" canal system (Holyoke Project, Connecticut River, Massachusetts). At Chandler, guidance efficiencies were relatively high, but decreased with increasing water velocities in the canal. At Holyoke, the guidance efficiency of the electrical barrier was not evaluated.

Another somewhat unique application of electric fields was also implemented at Holyoke, where a bypass system was developed for adult shad at a canal hydro station where significant impingement of downstream migrating adult shad had occurred over many years. An electrical DC shocker array was set up at the entrance to a fish bypass, and any fish that entered the field was stunned and then swept into the bypass, which discharged downstream of the canal system. Large numbers of adult shad were successfully bypassed using this system, with up to 142,000 bypassed in 1980.

As with other behavioral barriers, electric field barriers have mostly been deployed only experimentally, so there is little operational experience with this device. Installation, however, would not likely require a major engineering effort and O&M requirements should also be minimal. One negative aspect of electric fields is that it could be considered a safety issue for humans, and care would be required to make sure that areas where electric fields are used are not accessible to anglers or other recreationalists.

6.1.2.4 Air Bubble Curtains

The objective of an air bubble curtain is to elicit an avoidance response by fish based on visual or tactile (i.e., lateral line) cues, or as a result of the noise of the air bubbles. The typical installation consists of a diffuser pipe (usually on the bottom of an intake or water passage) with compressed air creating a dense curtain of bubbles. This technology was tested both in the laboratory and in the field in the 1960's and 1970's, primarily for use in steam electric generating station intakes. Laboratory testing with rainbow smelt and alewife, at water velocities ranging from 0.5 to 2.0 fps, showed some reduction in

Copyright © 2005 New York Power Authority

entrainment behind the bubble curtain, with no decrease in effectiveness at the highest velocity tested (2 fps). Air bubble curtains were field tested at the Indian Point Nuclear Station on the Hudson River, the Quad-Cities Station on the Mississippi River, the Prairie Island Nuclear Station on the Mississippi River, and the Monroe Station on Lake Erie. Species tested included: white perch, striped bass, alosids, gizzard shad, crappie, freshwater drum, carp, silver chub, white bass, yellow perch, and walleye. None of the field power plant tests showed that air bubble curtains were successful in reducing entrainment, and no permanent installations were implemented. Although testing at power plant intakes was not successful, air bubble curtains have been successfully used in the fishing industry to divert Atlantic herring into fish traps, and confine roundfish in sea cages. An air bubble curtain was also used successfully to reduce the movement of alewife into the Milwaukee River, Wisconsin, and Canadian testing has shown that air bubble curtains in conjunction with strobe lights may improve the diversion efficiency (EPRI 1986).

Air bubble curtains would be relatively easy to deploy, but long-term operational experience with power plant applications is not known because none have been permanently installed. Potential operational problems could include clogging of the air diffuser by rust or river born debris, which could be minimized by use of stainless steel diffusers and continued debris removal in the vicinity of the device. Fish diversion efficiency would depend on the pattern of the bubbles, which would be affected by air volume flow rate, water velocity, and distance from the intake, as well as probable differences in behavior among species. At higher intake velocities, the air bubble curtain should be placed farther from the intake to avoid air entrainment, which could reduce the effectiveness of the curtain and may negatively affect the performance/efficiency of pumps or power generation equipment downstream of the intakes.

6.2 Applicability at Niagara Power Project

To assess the applicability of various fish protection measures at the NPP, we first considered the alternatives for managing fish protection in the project area. NYSDEC and the Tuscarora Environment Department indicated that maintaining the fishery in Lewiston Reservoir should be an important objective. Under this alternative, fish entrainment from the Niagara River and passage into Lewiston Reservoir should be maintained, along with some method to improve the residence time of fish in the reservoir, by preventing or slowing down their entrainment and passage through the LPGP during the

Copyright © 2005 New York Power Authority

generation cycle. Part of this alternative would also include fish protection at the RMNPP, along with a bypass conduit to allow fish to return to the Niagara River downstream of the project.

A second alternative that was considered was to entirely prevent fish entrainment into the NPP by providing fish protection at the Niagara River intakes. This would potentially offer maximum fish protection by preventing fish from entering project facilities, but would be contrary to the NYSDEC and Tuscarora Environment Department's objective to maintain the fishery in Lewiston Reservoir. If most fish were prevented from entering the power conduits, the "supply" of fish to the reservoir would be interrupted, and with the minimal natural production that is believed to occur in the reservoir, the fishery would likely decline.

Both of these alternatives, however, were assessed, for the detailed assessment of fish protection alternatives at the NPP.

6.2.1 Maintaining Lewiston Reservoir Fishery

Under this alternative, fish would continue to be entrained through the Niagara River intakes, and pumped into Lewiston Reservoir, with the objective to retain these fish in Lewiston Reservoir. Thus, no fish protection would be required at the river intakes, and none on the forebay side of the LPGP, although measures would be required at the reservoir side to discourage fish entrainment through the station during generation. However, any measures on the reservoir side must allow fish passage into the reservoir during pumping.

Potential Designs for the LPGP

Fish protection measures at the Lewiston Reservoir side of the plant (to prevent entrainment during the generation cycle) must meet the following design criteria:

- Allow fish to pass into the reservoir during pumping;

Copyright © 2005 New York Power Authority

- Operate at a maximum water depth of 40 ft, with a maximum reservoir fluctuation of nearly 40 ft;

- Operate at a total station discharge of 42,000 cfs;

- Potentially operate through all seasons and in a variety of adverse weather conditions (high winds, freezing conditions); and

- Effectively deter the warmwater/coolwater reservoir fish community from entering the station intakes.

The first criterion, that fish be allowed to pass into the reservoir, would eliminate most standard physical barriers, because any structural barrier on the reservoir side of the LPGP would also prevent fish from passing into the reservoir during pumping. Fish could still be entrained from the forebay, but would be blocked by the "back side" of the structure. This would eliminate most standard applications of low-velocity and high-velocity screens, angled bar racks, and louvers (although louvers would also not be suitable at LPGP because there is no canal with stable hydraulic conditions in which to place louvers).

The only way that any of the above structural barriers could be employed would be if they could be removed during the pumping cycle, and put back in place prior to and during the generating cycle (on a daily basis). This design requirement would eliminate angled bar racks because it would be infeasible to raise and lower a structure that would be perhaps 1,000 feet long and up to 40 ft deep. Only low-velocity or high-velocity screens could be considered, although low-velocity screens would be eliminated based on the estimated velocities in the intake portals of 5 fps. At LPGP there are gate or stoplog slots on the reservoir intake side of the station, which would be potential locations for installing fish screens that could be lowered and raised, depending on the operational cycle. The only high-velocity screen design discussed above that would potentially fit into the gate slots would be the STS, which has never been tested with warmwater/coolwater fish species. The STS has been used only with anadromous salmonids and works on the principle that fish remain close to the intake ceiling during passage. Such behavior has

Copyright © 2005 New York Power Authority

not been demonstrated for warmwater/coolwater species, and thus an STS may not be effective in diverting resident fish in Lewiston Reservoir.

The only other potential screen design that could be placed in the gate slots (and raised and lowered on a daily basis) would be narrow-spaced trashracks. These, however, would not be feasible both biologically and for operational reasons. With an existing intake velocity of 5 fps (which is already higher than the maximum screen approach velocity of 2 fps recommended by the natural resource agencies), placing a narrow spaced trashrack into the water passage would further reduce the size of the passage and result in even higher velocities between the racks, which would increase the potential for fish impingement mortality due to the narrower space between the bars. Operationally, there would be a high potential for debris and aquatic vegetation loading (which is why the LPGP currently operates with no trashracks), which would further increase velocities and the potential for fish impingement. Heavy debris loading could also cause severe head losses and unit shutdowns if the trashracks became clogged and restricted flow into the units. Another operational problem would be the physical process of raising and lowering multiple trashracks for the 12 generating units on a timely basis between the pumping and generating cycles (a period of only a few hours, at most). The LPGP has only one gantry crane for the intakes, so additional cranes or other equipment to quickly raise and lower the trashracks would be required.

One high-velocity screen design that could be considered at the LPGP (although not at the intakes) would be an Eicher screen, which would have the ability to tilt, allowing free fish passage during pumping, and then, after tilting into place, screening during generation. The only possible location to place an Eicher screen would be in the penstocks upstream of the unit. These penstocks range in diameter from 24 ft at the upper end to 18 ft at the lower end. At a unit hydraulic capacity of 3,500 cfs, the velocity at the head of the penstock would be about 7.7 fps, rising to 13.8 fps at the lower end. The maximum penstock velocity would be higher than the maximum reported operational velocity for Eicher screens (8 fps). This would also require the largest Eicher screens ever designed, and would involve placement of a screen in a tapering-geometry penstock. Available information reviewed on Eicher screens indicate that applications to date have not been in tapering-geometry penstocks. Major construction would also be required to install the fish bypass conduit at the roof of the penstocks, because the penstocks at the LPGP are encased in concrete for their entire length. In addition, even if a fish

Copyright © 2005 New York Power Authority

bypass was installed, fish would then have to be pumped back to the reservoir, because of the location of the penstocks downstream of the reservoir. This would also require operating Eicher screens in an unconventional mode, by tilting and maintaining the screens in an intermediate position, to allow free fish passage during pumping. Construction and operation of Eicher screens at the LPGP would be outside the limits of any previous applications, and combined with the unknown as to whether the screens would work effectively with warmwater/coolwater resident species, it would not be advisable to attempt such an installation.

The only other physical barrier that could be considered at the LPGP would be a barrier net. This net, however, would require an operation not attempted at any other site where barrier nets have been placed. That is, the net would have to be raised or lowered at least once per day to allow fish to enter the reservoir during pumping and then placed in a "blocking mode" during generation. Although the precise placement of a barrier net in Lewiston Reservoir has not been determined (it would depend on the water velocities and pattern entering the station), a net at least 3,000 ft long and 40 ft deep would be required. The net would need to be placed in the reservoir at a point where velocities through the net would be less than 0.5 fps (based on experience elsewhere), and without a study of velocity patterns in the reservoir, we can only estimate where the net might be deployed. Assuming a net of this size, this would be one of the largest ever deployed. The Ludington Pumped Storage Project barrier net on Lake Michigan is about the same depth, and is longer (2.5 miles), but is maintained in place during the summer months, and is not raised and lowered on a daily basis. Barrier nets used at other projects have experienced some water level fluctuations, although not as high as 30 to 40 ft on a weekly basis, as would occur at Lewiston Reservoir.

Water level fluctuations, however, may not be the critical design constraint at Lewiston, since the net could rise and fall with the water level. The critical constraint would be the requirement to raise and lower the net on a daily basis to allow fish passage during pumping. A mechanism would need to be designed to allow such an operation, or, as an alternative, a manpower-intensive manual method would be required. Any mechanism for raising and lowering the net would require that a structure be built in the reservoir, to maintain the position of the net, and to provide the mechanics for raising and lowering the net. This structure would need to be the same length as the net (3,000 ft) and more than 40 ft high (assuming a free-standing structure). Alternatively, a floating structure could be attempted, although it would require an anchoring system to maintain the structure in place. Any floating structure, however,

Copyright © 2005 New York Power Authority

would be exposed to the strong winds and wave action that are common on the reservoir, particularly during the fall, winter, and spring period. Other operational problems would be related to the amount of ice and floating debris or vegetation that could be intercepted by the net, and the effects of wind and wave action on the net itself. Based on conversations with NYPA personnel (Norm Stessing, Operations Superintendent, NYPA, to Peter Foote, Louis Berger, personal communication, October 3, 2003), there are currently no trashracks at the LPGP because of past problems with heavy accumulation of vegetation and debris on the trashracks that had initially been installed, resulting in clogging and severe head losses. It is also likely that the net could not be deployed during the winter months due to icing conditions, so the net would only be in place, offering fish protection, part of the year. Because of the high debris loads and several unknowns regarding the feasibility of deploying such a net, a full-scale application of a barrier net would not be advisable at the LPGP.

For the behavioral barriers reviewed in Section 6.1, strobe lights and sound generators are likely the only options that could be considered at LPGP. Electric fields were judged to be too experimental and untested, to be considered at the project. Bubble curtains were also considered, but based on previous field testing at steam generating stations, installation at LPGP would not be successful. These field tests, which included species that also occur in the Niagara River, were generally not effective in reducing fish entrainment, and bubble curtains were never installed as permanent fish protection devices. Since testing at the intakes to steam generating stations (which are typically much smaller than hydro station intakes) was unsuccessful, it is unlikely that air bubble curtains would be effective at an intake as large as LPGP. Because of the high velocity of the LPGP intakes (5 fps), the diffuser pipes would have to be placed upstream of the intakes within the reservoir in areas with lower velocities (higher velocities will disrupt the bubble curtain). Although the precise location of where the diffuser pipes could be placed can not be determined at this time, it is likely that the bubble curtain would have to be at least 1,000 to 1,500 ft long. Placing the bubble curtain in the reservoir (instead of in the confines of the intakes) would also expose it to wind and wave action. The combination of previous unsuccessful testing of bubble curtains and the scale that would be required at LPGP indicates that bubble curtains should not be attempted at LPGP.

Both strobe lights and sound generators have shown some success in repelling anadromous species, particularly clupeids, but both systems have had mixed results or little testing with the warmwater/coolwater species that occur in the Lewiston Reservoir. Either system would need to be

Copyright © 2005 New York Power Authority

deployed near the intake portals on the reservoir side of the station, for maximum effectiveness. The top of these portals is at a depth of about 60 ft below full reservoir elevation. The strobe lights or sound transducers would need to be either mounted on the face of the intake portals, or alternatively could be mounted on a frame that would be lowered into the most upstream gate slot. Installing these devices on the face of the portals would involve underwater construction, because the reservoir is never drawn to a level that would expose the intake portals. Mounting the devices on a frame would have the advantage of being able to install the system "in the dry," and would also allow relatively easy access for maintenance (by pulling up the frame). The frame, however, would have to be designed to withstand the estimated velocities at the portals of 5 fps, and must also have clear spacing wide enough to allow river debris and fish to pass freely (during the pumping cycle). The relatively high velocities at the intake portals may also be a factor affecting the effectiveness of both lights and sound. Although previous applications of both technologies have occurred in the forebays of hydroelectric stations, velocities were likely less than 5 fps. It is unclear how higher velocities would affect effectiveness.

Although technically feasible to install either strobe lights or sound generators at LPGP, with minimal operational effects, there is no evidence that the majority of warmwater/coolwater species that occur in Lewiston Reservoir would respond to lights and sound. Additionally, lights would only provide protection from entrainment during nighttime hours, a period when LPGP is not generally generating electricity. Based on recent surveys, the most common species in Lewiston Reservoir are carp, emerald shiner, johnny darter, logperch, rock bass, smallmouth bass, spottail shiner, white sucker, and yellow perch. Northern pike also are known to occur in the reservoir and are a target species for the sport fishery, but few were taken in recent surveys (see Table 4.2.1-2). Test results involving strobe lights and sound are not known for these species, so the potential effectiveness of light and sound behavioral devices on these species is not known. For sound, other investigators have found that each species may have a specific frequency that is an effective deterrent. For example, noise centered at 125 kHz was found to be effective in deterring anadromous clupeids (Guida et al. 2003). The range of frequencies that may or may not be effective with the variety of species in the Niagara River has not been identified.

Table 6.2.1-1 summarizes the advantages and disadvantages of potential measures discussed for the LPGP.

Copyright © 2005 New York Power Authority

Potential Designs for the RMNPP

Part of this alternative would involve providing fish protection at the intakes to the RMNPP, along with a fish bypass, to allow any fish attempting to move out of the forebay through the RMNPP to safely bypass the station to the lower river. It should be noted, however, if fish protection and bypass facilities were to be installed at the RMNPP, it would likely be the largest project at which downstream fish passage facilities for resident warmwater/coolwater fishes had been attempted, and one of the largest projects where fish passage had been attempted for any species. At 2,538 MW[6] and a head of 300 ft, it is larger than any of the Columbia River projects where downstream fish passage facilities have been provided. The largest Columbia River project with fish passage is the John Day Dam with a capacity of 2,160 MW and a head of about 100 ft. All fish passage on the Columbia River, however, is provided for anadromous species, primary the several species of Pacific salmon and steelhead trout.

The primary design criteria for any fish protection and bypass measures at the RMNPP are:

- Operate at a maximum forebay water depth of 77 ft, and normal water depth of 66 ft, with a maximum forebay fluctuation of 17 ft;
- Operate at a total normal station discharge of 102,000 cfs, and maximum discharge of 115,000 cfs;
- Potentially operate through all seasons and in a variety of adverse weather conditions (high winds, freezing conditions);
- Effectively deter the warmwater/coolwater Niagara River fish community from entering the station intakes; and

[6] Installed plant capacity based on currently completed upgrades.

Copyright © 2005 New York Power Authority

- Provide a fish bypass with a capacity of up to 5% of powerhouse capacity (5,100 cfs) that would safely bypass fish to the lower Niagara River.[7]

The above noted criteria and the scale of the RMNPP essentially eliminates most of the fish protection options described in Section 6.1, as described below.

- *Low-velocity fish screens:* Since low-velocity screens typically operate at a velocity of 0.5 fps or less, they would not be feasible at RMNPP, where the estimated velocity at the intake portals is about 6 fps, and from 1.7 to 3.0 fps in the forebay at maximum generating capacity.

- *High-velocity fish screens:* These include the STS, which has only been used on Columbia River projects for anadromous salmonids, the Eicher screen, and the MIS. The STS would not be appropriate for use because it has been designed specifically for salmonids, rather than the warmwater/coolwater fish community in the Niagara River. The Eicher screen, which was considered and dismissed at the LPGP, would be even less feasible at RMNPP. The project scale is much larger than any previous application of the Eicher screen, and velocities within the penstocks (the only potential location for installation of Eicher screens) are estimated to range from 13.9 to 25.6 fps, much higher than the reported maximum operational velocity for Eicher screens (8 fps). The MIS, as noted above, has only been tested experimentally, and was not envisioned for projects as large as RMNPP.

- *Angled bar racks:* Angled bar racks should have a maximum approach velocity of 2 fps, and therefore would need to be placed upstream of the intake portals. At maximum

[7] The U.S Fish and Wildlife Service criteria for fish bypasses states that a bypass located next to perpendicular trashracks should equal 5% of station hydraulic capacity, but if angled racks (45 degrees to flow) are installed, the bypass volume may be reduced to 2-3% of capacity. The agency estimates that a bypass with 5% flow should be about 30% efficient (as presented during the 2000 Fish Passageways and Bypass Facilities East Workshop, U.S. Fish & Wildlife Service, Hadley, MA).

Copyright © 2005 New York Power Authority

generating capacity, we estimate that the velocities in the forebay would range from 1.7 to 3.0 fps, being lowest at the widest part of the forebay just upstream of the station. An angled bar rack in the forebay just upstream of the station would be over 1,000 ft long (at an angle of 45 degrees to the flow) and 80 ft deep, assuming a full depth bar rack that would operate at the full range of water levels. Along most of the angled bar rack, the velocities would approach or exceed the 2.0 fps criterion. This would be the largest angled bar rack structure ever constructed; the largest constructed to date in the Northeast is the 108-ft-long, 36-ft-deep Hudson Falls Project bar rack. Constructing a free-standing structure that large in the forebay would require shutting down the project and dewatering the forebay, resulting in a major loss of generation in the Northeast for the duration of the construction period, which could be up to a year. Operating such a structure, with 1-in. spaced racks, would also require a major O&M effort, because of the debris loading (and head losses) that would occur, and the potential frazil ice problems during the winter months. Angled bar racks would not be feasible at the RMNPP.

- *Trashrack overlays:* The RMNPP units have 6-in. spaced trashracks that are installed part of the year. Based on the pattern and timing of riverborne debris, the lower 1/3 of all intake portals have trashracks installed from May through October (leaving the upper 2/3 of the portals without racks). From November through April, Units 1, 2, and 13 (the shoreline units) have full trashracks installed, while the remaining units continue with 1/3 trashrack coverage. At a 6-in. clear spacing, most fish (except very large ones) would continue to pass through the racks and into the units. One-inch-spaced trashrack overlays would reduce the number of fish passing through the trashracks, but would not be feasible because of high intake portal velocities. We estimate that the velocity at the entrance to the portals would be about 6 fps at full generation. These velocities are more than three times the maximum approach velocity recommended at bar racks (2 fps), and would likely result in fish impingement and mortality on the racks. In addition, since most of the portals have only partial racks most of the year, fish would still be able to pass into the intakes through the open part of the portals.

Copyright © 2005 New York Power Authority

- *Louvers:* Full-depth louvers would have most of the same feasibility problems as described for the angled bar racks, although the louver structure would even be longer, perhaps up to 2,000 ft long, because of the shallower angle to flow required by louvers. A partial-depth floating louver could be considered (they have been used at other projects with anadromous species), but because the resident warmwater/coolwater species may be found throughout the water column, partial louvers would not be effective in diverting fish. A partial louver would also experience the same problems with debris loading and icing conditions as a full-depth louver or bar rack, and would also require a major O&M effort.

- *Barrier net:* A barrier net would not be feasible in the forebay because of high velocities and debris loading. The estimated velocities in the forebay of 1.7 to 3.0 fps at maximum capacity, are many times the maximum velocity of 0.5 fps often cited as the limit for operation of a barrier net.

- *Behavioral barriers:* As described for the LPGP, electrical fields and air bubble curtains would not likely be feasible at RMNPP, but strobe lights and sound generators could be considered. The same advantages and disadvantages for these devices, as discussed for LPGP, would also apply at RMNPP (see Table 6.2.1-1 and Table 6.2.1-2). Differences at RMNPP would be that there are some trashracks in the intake portals (none at LPGP), so any installation using the gatewell slots would have to consider the presence of the trashracks. The velocity at the portals is also slightly higher at RMNPP (6 fps versus 5 fps), and that would have to be considered in any application of strobe lights or sound generators. As with the LPGP, it would be technically feasible to deploy these devices at RMNPP, but questions remain as to the effectiveness of these devices with the resident warmwater/coolwater fish community because of the high velocities at the RMNPP intake portals.

- *Fish bypass.* As described above, none of the potential structural fish protection options would be feasible at RMNPP. Thus, per U.S. Fish and Wildlife Service criteria, if a fish

Copyright © 2005 New York Power Authority

bypass was installed at RMNPP, it should theoretically be sized for a capacity of 5% of the powerhouse capacity, or 5,100 cfs. Based on our assessment below, however, this may not be feasible. The typical fish bypass is a surface sluiceway gate near the end of the power station, often at the shoreline (minimum size of 3 ft wide and 2 ft deep, per U.S. Fish and Wildlife Service criteria), and at the downstream end of a screening structure, if present. Since a screening structure is not feasible at RMNPP, the only potential location for a bypass would be near the shoreline at one end of the station. At other hydro stations, ice or trash sluiceways are often used as fish bypasses, avoiding the need to construct a new structure, but at RMNPP there are no such sluiceways.

A fish bypass at RMNPP, however, if it were to meet the U.S. Fish and Wildlife Service criteria and pass a flow of 5,100 cfs, would be a major structure, many times larger than the minimum stated size of 3 ft by 2 ft. For example, at an entrance velocity of 4 fps,[8] the area of the bypass opening would need to be 1,275 sq ft, which would translate to an opening about 20 ft deep and 64 ft wide, or 30 ft deep and 43 ft wide. If we set the bypass flow at 1,000 cfs, which may be more reasonable,[9] and an entrance velocity of 4 fps, the bypass opening could be reduced to 20 ft deep by 13 ft wide, but still a relatively large structure. The final size of the bypass opening could be adjusted to any dimensions, although a deeper but narrower opening may be appropriate for resident species, because they may be distributed throughout the water column. A major constraint, however, on the design of any bypass opening would be the hydraulics of providing that amount of flow to the bypass. The intake and bypass conduit (pipe) must be designed so that the full amount of bypass flow is smoothly withdrawn from the forebay. A bypass flow of 1,000 cfs would require that the bypass opening be submerged, otherwise the full bypass flow might not be achieved, or there would be extensive turbulence and vortices at the entrance, which fish might avoid. If an 8-ft diameter pipe is used as the bypass conduit, the crown of the pipe would need to be submerged by about 25 ft below the water surface. A 12-ft diameter pipe would reduce the required

[8] U.S. Fish and Wildlife Service criteria state that the bypass entrance velocity should be greater than the local "ambient" velocity, but should be a gradual acceleration within the entrance, to reduce any fish avoidance reaction to the accelerating flow (as presented at the 2000 Fish Passageways and Fish Bypass Facilities East Workshop, U.S. Fish & Wildlife Service, Hadley, MA).

[9] Clay (1995) states that a bypass flow of 1% of powerhouse capacity may be suitable for "large diversions."

Copyright © 2005 New York Power Authority

submergence to about 15 ft below the water surface. The 17-ft water level fluctuation in the forebay would also have to be considered in the design. A submerged fish bypass entrance would be a non-standard design, unlike virtually all other fish bypasses installed in the Northeast. It may bypass some fish, since resident species are distributed throughout the water column, although the efficiency could not be estimated.

The design of the bypass conduit would also be a major consideration. We assume that a smooth pipe would be the conduit of choice, but the 300-ft head at the RMNPP would be a major factor that might make a fish bypass not feasible. At a diameter of either 8 or 12 ft, and an estimated length of 700 ft (from the forebay to the tailrace), the velocities at the discharge end of the pipe into the lower Niagara River would be in the range of 80 to 90 fps, much higher than recommended for a fish bypass system. Agency criteria are that the maximum impact velocity for fish discharged from a bypass pipe should be 35 to 40 fps, although there have been studies that show that fish may survive at higher impact velocities. Bell and DeLacy (1972) cite studies in which fish survival at heads over 250 ft ranged from 36 to nearly 100%, but depended on several factors, particularly the size of fish and whether or not the fish were within a column of water. In a drop of test fish from a helicopter at an altitude of 300 ft, smaller fish (less than 7 in. in length) had greater than 98% survival, 10 to 11-in. fish survival was 81%, and fish 12 to 15 in. long had a 20% survival. This indicates that at least some fish impacting the lower Niagara River at 80-90 fps would experience mortality, and would defeat the objective of safely bypassing fish around the station. The best way to reduce the impact velocity at the end of the bypass pipe would be to lengthen the pipe. For example, lengthening the pipe to 2,100 ft would reduce the velocity to about 50 to 60 fps, but this would still be higher than the agency criteria. Lengthening the pipe, however, to a point where impact velocities meet the agency criteria, may not be feasible, and would depend on the area/land available to install such a pipe.

Another agency criterion would apply to the depth of the plunge pool into which the pipe discharges. The criterion states that the depth should be 25% of the differential head between headwater and tailwater (as presented at the 2000 U.S. Fish & Wildlife Fish Passageways and Bypass Facilities East Workshop, Hadley, MA). At RMNPP, this required depth would be 75 ft. The depth of the lower Niagara River in the vicinity of the powerhouse is not known. Depths less than the criterion would

Copyright © 2005 New York Power Authority

increase the potential of fish to strike the river bottom and experience injury and mortality. This again would defeat the objective of safely bypassing fish around the station.

The above discussion indicates that a fish bypass at RMNPP may not be feasible from a biological and technical perspective (see Table 6.2.1-2). The other major consideration is the feasibility of constructing the bypass at RMNPP. This bypass would require a large submerged entrance immediately adjacent to the intakes, and a bypass conduit (probably 8 to 12 ft in diameter) that must pass through or around the station, under the highways that cross the station, and down the face of the station (or adjacent Niagara Gorge wall) to the Niagara River. Whether such a structure could even be designed at the RMNPP is not certain, and even if it could, this would be a major construction effort that would likely significantly disrupt project operations. Constructing the submerged entrance may require at least temporary drawdown of the forebay, and loss of generating capacity, while the remaining construction would require coordination with project operations and with the usage of the highways. Construction access could be a major issue, depending on the route of the bypass conduit. Once the bypass was built and operating, if a flow of 1,000 cfs (or more) was selected as the design flow, continued diversion of that flow would result in a significant loss of energy generation. Construction, operation and maintenance of a fish bypass could have major effects on the operation of the RMNPP, with minimal benefits likely to accrue in terms of entrainment survival.

6.2.2 Fish Protection at Niagara River Intakes

Under this alternative, the objective would be to prevent fish entrainment into the river intakes, and thus prevent fish from being exposed to any of the project facilities. As we described above, this would not meet the NYSDEC and Tuscarora Environment Department's objective of maintaining the fishery in Lewiston Reservoir; it would attempt to prevent fish from being exposed to potential mortality associated with passage through the LPGP and RMNPP, but it would potentially subject fish to mortality from passage over the Falls.

The Niagara River intakes are unique because of their design, orientation to the river, and size. The intakes consist of two 700-ft-long, shoreline harmonica structures, which each have a total of 48

Copyright © 2005 New York Power Authority

portals that range in size and depth below the river water level. The portals are about 12 ft wide and range in height from 13 to 26.5 ft., with a depth below water surface ranging from 13 to 26 ft. The largest portals are located on the upstream end of the intake, with a gradual downsizing of the portals in a downstream direction, with the entrance to the conduit tunnel at the downstream end. This was designed to provide a uniform flow of water through the intake portals and into the conduits. There are no control gates or structures on the intakes, other than closure gates for shutting down and inspecting the tunnel conduits. Niagara River waters enter the intakes essentially by "gravity flow," depending on the elevation of the forebay and water usage by the LPGP and RMNPP. Based on the size of the portals, the calculated average water velocity through the portals is 11.6 fps, at the maximum hydraulic capacity (55,000 cfs per tunnel). However, we estimate that the velocity quickly diminishes at small distances from the intake face, decreasing to an estimated average approach velocity of about 5 fps (at maximum capacity) at a distance of about 20 feet in front of the intake face. The average river velocity in this reach of the Niagara River (the Grass Island Pool) is reported to be 2.3 fps (Norm Stessing, NYPA, to Peter Foote, Louis Berger, personal communication, October 3, 2003). There are no trashracks of any type on the intakes, primarily because of heavy loading of aquatic vegetation, particularly during the summer and fall months.

Based on the design of the intake structures and the ambient conditions described above, with relatively high river velocities, high intake velocities, and heavy aquatic vegetation loads, most of the options for fish protection described in Section 6.1 would not be feasible for deployment at the Niagara River intakes, as discussed below.

- *Low-velocity fish screens:* Since low-velocity screens typically operate at a velocity of 0.5 fps or less, they would not be feasible at the river intakes, where the estimated velocity at the intake portals is about 12 fps at full capacity, and the average river velocity is 2.3 fps.

- *High-velocity fish screens:* These include the STS, the Eicher screen, and the MIS. The STS would not be appropriate for use because of the warmwater/coolwater fish community in the Niagara River, and because the STS would need to be deployed in the

Copyright © 2005 New York Power Authority

tunnel conduits, a type of installation that has never been attempted before with the STS. The Eicher screen, which was considered and dismissed at the LPGP and RMNPP, would be even less feasible at the river intakes. The hydraulic capacity of the conduits is much higher than any previous application of the Eicher screen, the shape of the conduits (rectangular, with an arched ceiling) is not appropriate for use of an Eicher screen, and velocities within the conduits (estimated to be 14 fps at maximum capacity) are higher than the reported maximum operational velocity for Eicher screens (8 fps). The MIS, as noted previously, has only been tested experimentally, and was not envisioned for intakes as large as on the Niagara River.

- *Angled bar racks:* Angled bar racks should have a maximum approach velocity of 2 fps, and therefore would need to be placed in the river at some distance from the intake portals. The river, however, has an average velocity of 2.3 fps at this location. Although the average river velocity is slightly higher than the design velocity for angled bar racks, if an angled bar rack was designed for the river intakes, it would have an estimated length of from 1,500 to 2,000 ft with a depth of about 40 ft, assuming a full depth bar rack. This would be the largest angled bar rack structure ever constructed; the largest constructed to date in the Northeast is the 108-ft-long, 36-ft-deep Hudson Falls Project bar rack. Constructing a free-standing structure that large in the river may require shutting down the project and coffer-damming the intake area, resulting in a major loss of generation in the Northeast for the duration of the construction period, which could be up to a year. Operating such a structure, with 1-in. spaced racks, would also require a major O&M effort, because of the debris loading (and head losses) that would occur, and the potential frazil ice problems and river ice loads during the winter months. Because of the high velocities and high debris loads in the upper Niagara River, angled bar racks would not be feasible at the Niagara River intakes.

- *Trashrack overlays:* Trashrack overlays would not be feasible because the river intakes do not have trashracks.

Copyright © 2005 New York Power Authority

- *Louvers:* Full-depth or even partial-depth louvers would have most of the same feasibility problems as described for the angled bar racks, although there really is no place in the river to design a louver structure, since there is no canal or forebay with controlled hydraulic conditions.

- *Barrier net:* A barrier net would not be feasible in the river because of high velocities and debris loading. The reported average velocity in the river of 2.3 fps is several times the maximum velocity of 0.5 fps often cited as the limit for operation of a barrier net.

- *Behavioral barriers:* As described for the LPGP and RMNPP, electrical fields and air curtains would not likely be feasible at the river intakes, but strobe lights and sound generators could be considered. The same advantages and disadvantages for these devices, as discussed for LPGP and RMNPP, would also apply at the river intakes (see Table 6.2.2-1). Another potential disadvantage of trying to deploy these devices at the river intakes, however, is that they would have to be deployed on the face of the intake structures (there are no gate slots that could be used to deploy these devices on gate frames). The velocity at the river intake portals is also higher than at the other stations (estimated to be up to 12 fps), and that would have to be considered in any application of strobe lights or sound generators. However, as described for the other stations, although it may be technically feasible to deploy these devices at RMNPP, there is little evidence that these devices will effectively work with the resident warmwater/coolwater fish community of the Niagara River.

6.2.3 Summary of Options for Fish Protection at the Niagara Project

As described in the previous sections, most of the commonly used fish protection measures would not be feasible to implement at the Niagara River intakes, the LPGP, and the RMNPP, because of the scale and unique design of the project facilities, and the warmwater/coolwater fish community of the Niagara River. The only measures judged to be potentially feasible for installation would be the behavioral devices of strobe lights and sound generators. However, although these devices have shown

Copyright © 2005 New York Power Authority

some promise in effectively diverting some anadromous species (particularly clupeids) away from intakes, they are still considered somewhat experimental or untested for most warmwater/coolwater species. Additionally, lights and sound technologies have not been used at intakes with velocities as high as those at the NPP intakes in the upper Niagara River and the LPGP and RMNPP intakes. Therefore, the potential success of these measures with these species cannot be assured.

Copyright © 2005 New York Power Authority

TABLE 6.2.1-1

APPLICABILITY OF FISH BARRIERS AT THE LEWISTON PUMP GENERATING PLANT

Technology	Description of Installation	Factors Affecting Performance	Potential Advantages	Potential Disadvantages
Narrow-spaced trashrack	Install in intake gate slots, and raise and lower for pumping and generating	- Velocities - Debris loads	- Relatively simple screening concept without major civil construction - May operate with two-way flows (pump/generating)	- Potential for fish impingement mortality - Affected by high debris loads (common in river) - Would require additional equipment to raise/lower the full set of trashracks
Eicher screen	Install in penstocks, with fish bypasses to return fish to reservoir	- Velocities - Debris loads	- May operate with two-way flows (pump/generating) - Effective with anadromous species, some potential with resident species	- Would require major civil construction - Velocities at LPGP intakes are too high - Would be non-standard application (two-way flows) - Potential turbulence/head losses in penstocks - Affected by high debris loads (common in river) - Not proven for resident fish
Barrier net	Deploy on reservoir side of LPGP; about 3,000 ft long, 40 ft deep	- Velocities greater than 0.5 fps preclude its use - Debris loads - Wind, wave action	- "Low-technology" - Effective with many species at other sites	- Would require mechanism to raise/lower net for two-way flow operation - Would be one of the largest barrier net applications - Affected by high debris loads (common in river and reservoir), wind/wave action - Potential icing, only usable in open-water months
Strobe lights/sound generators	Deploy on face of intake portals, or on intake frame in gatewell slot	- Species composition - Water clarity and ambient light (for strobe lights) - Velocity?	- Relatively easy to deploy with minimal effects on project operation - Minimally affected by high debris loads	- Effectiveness with resident fishes not known - Potential effects of the high velocities at the LPGP intakes is not known

Copyright © 2005 New York Power Authority

TABLE 6.2.1-1 (CONT.)

APPLICABILITY OF FISH BARRIERS AT THE LEWISTON PUMP GENERATING PLANT

Technology	Description of Installation	Factors Affecting Performance	Potential Advantages	Potential Disadvantages
Air bubble curtain	Deploy diffuser pipes on reservoir bottom upstream of intakes; potential length of up to 1,500 ft	- Species composition	Relatively easy to deploy with minimal effects on project operation	Shown to be ineffective for a range of species at steam electric stations

Copyright © 2005 New York Power Authority

TABLE 6.2.1-2

APPLICABILITY OF FISH BARRIERS AND A FISH BYPASS AT THE ROBERT MOSES NIAGARA POWER PLANT

Technology[1]	Description of Installation	Factors Affecting Performance	Potential Advantages	Potential Disadvantages
Strobe lights/sound generators	Deploy on face of intake portals, or on intake frame in gatewell slot	- Species composition - Water clarity and ambient light (for strobe lights) - Velocity? - Presence of partial or full trashracks	- Relatively easy to deploy with minimal effects on project operation - Minimally affected by high debris loads	- Effectiveness with resident fishes not known - Potential effects of the high velocities at the RMNPP intakes is not known
Fish bypass	A 260-sq. ft. opening[2] on the shoreline end of the station, leading to an 8-12-ft. diameter pipe that traverses to the tailrace or lower river. Pipe would require a submergence below forebay level of 15-25 ft., and would be 700-2,100 ft. long depending on desired exit velocity and location of plunge pool	- Species composition and distribution in forebay - Ability of fish to locate bypass entrance, with competing powerhouse flows - 17-ft. forebay water level fluctuation - Entrance hydraulics	- Gravity flow bypass not requiring pumping or high-tech equipment - Once fish enter bypass pipe, high velocity in pipe will ensure bypass to lower river	- Probable low bypass efficiency due to competing powerhouse flows - Design head would result in high impact velocities and possible fish mortality at discharge - Additional mortality could result if plunge pool depth in lower river is insufficient - Would require major civil construction and possible impact on power generation and highway passage at the powerhouse

Notes:

[1] Low-velocity screens, high-velocity screens, angled bar racks, trashrack overlays, louvers, barrier nets, and some behavioral barriers (electrical fields and air bubble curtains) were judged to be infeasible at the RMNPP.

[2] This assumes a bypass flow of 1,000 cfs (per Clay 1995). If U.S. Fish and Wildlife Service criteria were strictly adhered to (5% of powerhouse flow), a bypass flow of 5,100 cfs would be required, but this would require a structure that may not be feasible at the RMNPP.

Copyright © 2005 New York Power Authority

TABLE 6.2.2-1

APPLICABILITY OF FISH BARRIERS AT THE NIAGARA RIVER INTAKES

Technology[1]	Description of Installation	Factors Affecting Performance	Potential Advantages	Potential Disadvantages
Strobe lights/sound generators	Deploy on face of river intake portals[2]	- Species composition - Water clarity and ambient light (for strobe lights) - Velocity?	- May be operated with minimal effects on project operation - Minimally affected by high debris loads	- Effectiveness with resident fishes not known - Potential effects of the high velocities (12 fps) at the river intakes is not known - Some interruption of project operations may occur during installation

Notes:

[1] Low-velocity screens, high-velocity screens, angled bar racks, trashrack overlays, louvers, barrier nets, and some behavioral barriers (electrical fields and air bubble curtains) were judged to be infeasible at the Niagara River Intakes.
[2] There are no gate slots that could be used to install these devices on the river intakes.

Copyright © 2005 New York Power Authority

7.0 LEWISTON RESERVOIR

7.1 Description

The Lewiston Reservoir, which stores water used by the LPGP, has a useable storage capacity 69,500 acre-ft and a gross storage capacity of 74,250 acre-ft. The normal operating elevation ranges from El. 620 ft to El. 658 ft. At maximum elevation, the water in the reservoir is about 42 ft deep and covers an area of about 1,900 acres. The average water depth at maximum drawdown is just over 3 ft. The surface area of the reservoir at various water level elevations is provided below (Kleinschmidt Associates 2002).

Elevation (ft)	Surface Area (acres)
620	1,239.0
625	1,681.1
630	1,804.6
635	1,857.0
640	1,867.9
645	1,876.9
650	1,885.3
655	1,892.5
658	1,896.5

The reservoir maintains a relatively large surface area above El. 630 ft but shrinks in size substantially between El. 630 and El. 620 ft.

Reservoir operation is such that the water level is highest on Monday mornings and lowest Friday afternoons. The facility is operated in generation mode Monday through Friday with partial refilling during the night and complete refilling on the weekends.

The reservoir bottom is relatively flat with a slight grade downward from east to west (Kleinschmidt Associates 2002). The bottom is relatively featureless, and flow toward the plant is

Copyright © 2005 New York Power Authority

generally unencumbered. At two locations along the dike (northeast and south sides), troughs near the base of the rip-rap retain isolated pockets of water during drawdown and fish are sometimes stranded in these troughs. Fish may also become stranded in relatively flat sections of the bottom.

The Lewiston Reservoir dike is rock-filled with an impervious core, approximately 6.5 miles long. The dike is 55 ft high and 260 ft wide at its foundation and 41 ft wide at its crest. The west ends of the dike rest on bedrock while the east end of the dike is constructed on natural soil over bedrock.

7.2 Fisheries

During angler surveys conducted during 1982-1983, most anglers at the Lewiston Reservoir targeted yellow perch and smallmouth bass, with rock bass and freshwater drum also included in the catch (NYPA 1984).

Stantec (2005) reports that more recently, anglers have indicated that yellow perch is the primary target species (up to 100 anglers/day) and that most angling effort is directed to the period shortly after ice-out. Angling for northern pike is also common in the spring.

7.3 Fish Stranding

As noted in Section 7.1, some fish (i.e., minnows and round gobies) are stranded in narrow troughs along the rip-rap dike when the water level in the reservoir is drawn down late in the week. Some small fish (unknown species) were observed in the trough on the northeast side of the reservoir during our site visit on September 5, 2003. Any fish not being stranded would still run the risk of being entrained through the pump turbines during generation and ultimately through the turbines of the RMNPP.

Copyright © 2005 New York Power Authority

To a certain extent, the Lewiston Reservoir acts like a "put and take" fishery as the fish community is supplemented by the pumping of water from the forebay into the reservoir every night and on weekends while spawning and recruitment is likely negligible.

7.4 Habitat Alteration

7.4.1 Potential Opportunities

There are two options for habitat alteration that are either directed at eliminating fish stranding during drawdown or at increasing fish stocks in the reservoir. The first option would involve removal or filling in of flow impediments along the dike in the northeastern and south sides of the reservoir by filling in the troughs.

The second alternative would involve creation of refugia in the reservoir to increase the retention time of fish in the reservoir by reducing the risk of entrainment through the pump turbines during generation cycles. Two options to accomplish this would be construction of submerged dikes that would retain water in relatively large pools during drawdown periods or excavation of one or more retention pond(s), in the dewatered area of the reservoir, where fish can remain during drawdown. The main drawback of the former option is the loss of live storage for generation (approximately 50 acre-ft for a 20 ft high berm), while the excavation of retention ponds or construction of a berm would result in the short-term disruption of normal generation schedules during construction. Retention ponds or a berm would likely retain benthic fish species, such as brown bullhead and round goby, rather than the more desirable game species such as yellow perch and smallmouth bass. Use of mercury vapor light to attract fish to the retention areas could be used but have proved ineffective for sport species (see Section 6.1.2.1).

Other types of habitat structures, such as artificial reefs or fish attraction devices (FAD's) may attract sport fish and non-sport fish and retain them in the reservoir. Although, FAD's have mostly been used in marine environments there is reason to believe they would be effective in Lewiston Reservoir. For example, Prince and Maughan (1979) found that artificial tire reefs placed in Smith Mountain Lake, Virginia concentrated sport fish; including smallmouth bass, largemouth bass, and bluegill, and non-sport

Copyright © 2005 New York Power Authority

fish; including gizzard shad. These alternatives have not been fully investigated in this study and further study is needed to assess their potential effectiveness, engineering feasibility, and operational impacts.

7.4.2 Potential Impediments

The main obstructions that are stranding fish in the reservoir appear to be small piles of rocks that were installed at the toe of the dike for embankment stability purposes when slides and slippage occurred during the original construction. To remove the obstructions, the least cost option would be to level out the piles to eliminate the pools in which fish are sometimes stranded. However, this option is not feasible from an engineering standpoint, as it would affect the stability of the embankment.

In addition to options identified by the stakeholders we looked at an option to create retention ponds. This option would require more work, due to the amount of material that would have to be moved. To create a 1.0 acre pond, 4.0 ft deep would require the excavation and spreading of 174,000 cu ft of soft clay material. To use earth-moving equipment, this work would have to be done in the dry, so the work would have to be scheduled during low water level periods on Thursdays and Fridays or a dredge could be used to perform the work. Additionally, the substrate of the reservoir is too soft to use bulldozers, and bulldozers and other heavy equipment would not be able to traverse the rip-rap. The work would have to be done using a long reach excavator or dredge, which would access the material to be removed from either the top of the dike or from a floating barge. Costs, scheduling, engineering, and environmental factors should be evaluated if this option is pursued as part of any habitat improvement project in the future.

Copyright © 2005 New York Power Authority

8.0 POTENTIAL BENEFITS OF ENTRAINMENT

As discussed in earlier sections of this report, fish entrained into the NPP intakes in the upper Niagara River may be pumped into the Lewiston Reservoir where they may remain or return to the forebay through the pump turbines of the LPGP during electric generation. Fish may also pass through the turbines at the RMNPP either directly following or after an unknown residence time in the Lewiston Reservoir. Some fish, particularly small fish, likely survive passage through the turbines at RMNPP and LPGP. The alternative for many fish (particularly small or poor swimming fish) that are along the eastern shore of GIP, and avoid entrainment at the NPP intakes, is likely passage over the American Falls. It is very unlikely that significant numbers of fish survive the passage over the American Falls.

Fish that are entrained by the intakes or pass over the falls are lost to their upper Niagara River stocks, regardless of the extent of survival of fish taking either route. Some of the fish that are entrained become part of an urban/semi-urban fishery in the Lewiston Reservoir. In addition, the lower Niagara River is a major stopover location for northern gulls and other waterfowl in the fall and winter. Many of these gulls feed on dead or disoriented fish that have passed through the turbines of RMNPP and on fish that have passed over the Horseshoe or American Falls. More than 10 species of gulls can be identified in the area on any given fall or winter day and the area has become an important destination for bird watchers from Ontario and New York State as well as other parts of Canada and the United States. The RMNPP tailrace provides a much more convenient bird watching opportunity than the base of the falls in the winter.

The tailrace of RMNPP and the lower Niagara River supports an intensive sport fishery. Fish passage through RMNPP likely enhances this fishery by providing forage, whether the passed fish are alive, dead, or disoriented, for fish in the tailrace area. NYPA provides a fishing pier in the tailrace area.

Notwithstanding the loss of fish from the upper river stocks, the positive effects of entrainment have been the creation of a fishery in the Lewiston Reservoir, the creation of an important bird watching

Copyright © 2005 New York Power Authority

site and the source of forage to fish and birds in the area near the tailrace. Many of the small fish that provide these benefits might have been otherwise killed passing over the American Falls.

In light of the perceived benefits of entrainment at NPP, one has to consider the value of fish protection devices at the intakes on the Niagara River or at LPGP. Since it has been assumed that many weak-swimming and small fish that avoid entrainment at the NPP intakes may pass over the American Falls and have little chance of survival, fish protection at the intakes would likely only benefit mature strong-swimming fish that are capable of moving upstream in the GIP. Similarly, application of fish protection technologies at LPGP would limit the pumping of fish into the Lewiston Reservoir with a consequent negative effect on that urban/suburban fishery. Consequently, application of fish protection devices at NPP should be considered with caution as the potential benefits may not exceed the potential impacts on current resource uses.

Copyright © 2005 New York Power Authority

9.0 CONCLUSIONS

Fish habitat in the immediate area of the NPP intakes and in the GIP, in general, is not likely to attract and retain most species of fish due to relatively high currents (generally 2+ fps), relative depth (generally >6 ft and >20 ft near the intakes) and general lack of vertical structure. In addition, the shorelines near the intakes are highly altered, consisting primarily of riprap and sheet piling. Although the habitat near the intakes is not attractive, fish do come in contact with the intakes due to active and passive movements. Fish may come in contact with the intakes during movements upstream and downstream within the river, during foraging and, for those fish that are incapable of maintaining position in the relatively strong currents, as drift in the river flow. Many of the fish that are on the east side of the GIP, particularly those that do not have the swimming ability to move substantially upstream in the ambient currents, may become entrained or pass over the American Falls.

Fish that are entrained in the NPP intakes pass into the forebay of RMNPP where they may be entrained into the Lewiston Reservoir (at night and on the weekends when LPGP is operating in pumping mode) or be entrained through the turbines of RMNPP. Fish survival through the turbines at RMNPP could not be estimated but is likely higher for small fish than for larger fish based on studies at other locations. The survival of fish passing over the American Falls is considered to be near 0% because of the boulder field at the base of the falls and absence of a plunge pool.

Fish that pass through the turbines at RMNPP (whether alive, stunned, or dead) provide a source of forage to fish and birds in the tailrace area and thus contribute to a significant fishery and water bird viewing opportunities in the tailrace of RMNPP.

Fish that are entrained into the Lewiston Reservoir become part of an important urban/suburban fishery. Fish are pumped into the reservoir at night and on the weekends and may be entrained through the turbines during the day Monday through Friday. Habitat in the reservoir is mostly open water and vertical structure is limited primarily to the rip-rap lined dike. We investigated the potential of improving habitat characteristics or otherwise retaining more fish within the reservoir. Although there are

Copyright © 2005 New York Power Authority

opportunities to potentially increase the retention time of fish within the reservoir and to increase the size of the fish community, these opportunities have to be evaluated in light of cost, scheduling, engineering, and environmental factors if they are to be considered for a future habitat improvement project.

The biological effectiveness and engineering feasibility of constructing intake protection devices was investigated, and none would be both biologically effective and feasible to construct at NPP. In addition, many of the small, poor swimming fish that would be excluded from the intakes in the upper Niagara River if a fish protection device were constructed would be killed passing over Niagara Falls.

Copyright © 2005 New York Power Authority

REFERENCES

Amaral, S. 2003. The Use of Angled Bar Racks and Louvers for Guiding Fish at FERC-licensed Projects. Presented at FERC Fish Passage Workshop, Alden Research Laboratory, Inc., Holden, MA.

American Society of Civil Engineers. 1995. Guidelines for Design of Intakes for Hydroelectric Plants. New York: Committee on Hydropower Intakes.

Becker, J.M., Abernethy, C.S., and D.D. Dauble. 2003. Identifying the effects on fish of changes in water pressure during turbine passage. Hydro Review .

Bell, M.C. 1991. Fisheries Handbook of Engineering Requirements and Biological Criteria. Fish Passage Development and Evaluation Program, U.S. Army Corps of Engineers, Portland, Oregon.

Bell, M.C., and A.C. DeLacey. 1972. A Compendium on the Survival of Fish Passing through Spillways and Conduits. Fisheries Engineering Research Program, U.S. Army Corps of Engineers, Portland, Oregon.

Cada, G.F. 2001. The development of advanced hydroelectric turbines to improve fish passage survival. Fisheries 26(9):14-23.

Cada, G.F., and M.J. Sale. 1993. Status of fish passage facilities at nonfederal hydropower projects. Fisheries 18(7):4-12.

Carlson, D. 2001. List of Fishes of the Niagara River in New York State. Annual Report to Lake Ontario Committee of Great Lakes Fisheries Commission. New York State Department of Environmental Conservation.

Copyright © 2005 New York Power Authority

Clay, C.H. 1995. Design of Fishways and Other Fish Facilities, Second Edition. Lewis Publishers.

Collins, N.H., and C.P. Ruggles. 1982. Fish Mortality in Francis Turbines. Research Report prep. by Montreal Engineering for the Canadian Electrical Association.

Ecological Analysts, Inc. 1984. Lewiston Reservoir Aquatic Ecology and Water Quality Studies, November 1982 to August 1983, prep. for American Bechtel.

Eicher, G.J., Bell, M.C., Campbell, C.J., Craven, R.E., and M.A. Wert. 1987. Turbine-related Fish Mortality: Review and Evaluation of Studies. Final Report prep. for the Electric Power Research Institute, Research Project 2694-4.

Electric Power Research Institute. 1992. Fish Entrainment and Turbine Mortality: Review and Guidelines, EPRI TR-101231. Prep. by Stone and Webster Environmental Services.

Electric Power Research Institute. 1997. Turbine Entrainment and Survival Database - Field Tests, EPRI TR-108630. Prep. by Alden Research Laboratory, Inc.

Electric Power Research Institute. 1986. Assessment of Downstream Migrant Fish Protection Technologies for Hydroelectric Application. EPRI AP-4711, Project 2694-1. Prep. by Stone & Webster Engineering Corporation, Boston, MA.

Environnement Illimité, Inc. 2001. The Lewiston Reservoir Fish Survey Report for the Year 2000, prep. for the New York Power Authority.

Federal Energy Regulatory Commission. 1995. Preliminary Assessment of Fish Entrainment at Hydropower Projects – A Report on Studies and Protective Measures. Office of Hydropower Licensing, Washington, DC. Paper No. DPR-10.

Copyright © 2005 New York Power Authority

Franke, G.F., Webb, D.R., Fisher, R.K., Mathur, D., Hopping, P.N., March, P.A., Headrick, M.R., Laczo, I.T., Ventikos, Y., and F. Sotiropoulios. 1997. Development of Environmentally Advanced Hydropower Turbine System Concepts, Report No.: 2677-0141. Prepared for USDOE (Idaho) by Voith Hydro Inc.

Goodyear, C.D., T.A. Edsall, D.M.O. Dempsey, G.D. Moss, and P.E. Polanski. 1982. Atlas of the Spawning and Nursery Areas of Great Lakes Fishes. In: Volume X: Niagara River. Biological Services Program, U.S. Fish and Wildlife Service and U.S. Army Corps of Engineers, FWS/OBS-82/52.

Greeley, J. R. 1929. Fishes of the Erie-Niagara System. Biological Survey of the Erie-Niagara System. Albany, NY: State of New York Conservation Department.

Guida, E., G. Hunter, and F. Skinner. 2003. A Safe, Low Maintenance and Cost Effective Acoustic Solution for Fish Control at Water Intake Facilities. Presented at Waterpower XIII, Buffalo, NY, July 29-31, 2003. BAE Systems – Ocean Systems, Braintree, MA.

Guilfoos, E,R., Williams, R.W., Rourke, T.E., Latvaitis, P.B., Gulvas, J.A., and R.H. Reider. 1995. Six Years of Monitoring the Effectiveness of a Barrier Net at the Ludington Pumped Storage Plant on Lake Michigan. Paper presented at Waterpower ’95. pp. 1966-74.

Kleinschmidt Associates. 2002. Summary Report for the Fish Survey Conducted in the Upper and Lower Niagara River during the Year 2001.

Larinier, M., and J. Dartiguelongue. 1989. La circulation des poissons migrateurs: Le transit a travers les turbines des installations hydroelectriques. Bull. Peche Pisci. pp. 312-13.

Marmulla, G. 2001. Dams, Fish and Fisheries: Opportunities, Challenges and Conflict Resolution. FAO Fisheries Technical Paper No. 419. FAO, Rome.

Copyright © 2005 New York Power Authority

Nestler, J.M., Dennerline, D., Weiland, M., Weeks, G., and D. Degan. 1999b. Richard B. Russell Phase III Completion Report: Impacts of Four-Unit Pumpback Operation. Army Engineer Waterways Experiment Station, Vicksburg MS. Abstract available online at www.stormingmedia.us/cgi-bin/79/7929/A792953-198-2t.php .

Nestler, J.M., Sykes, J.A., and W.G. Lynch. 1999a. Pumped storage and the fishery: insights from Richard B. Russell Dam. Hydro Review (July)18-26.

New York Power Authority. 1998. Hydropower and Ice on the Upper Niagara River: Studies of Measures to Mitigate the Impacts of Ice on Power Generation and Shoreline Property. Niagara Falls, New York: NYPA.

New York Power Authority. 1984. Application for Amendment of License, FERC Project No. 2216, vol. II, Exhibit E.

Niagara Mohawk Power Corporation. 1977. Intake Screen Fish Impingement Report for C.R. Huntley Power Station for the Period June 1974 – July 1975. Prep. by Sartor Associates, Syracuse, New York.

Normandeau Associates Inc. 2002b. Cowlitz River Project: 2002 Turbine Survival Study. Prep. for Tacoma Power. (Cited in Tacoma Power, 2000).

Normandeau Associates Inc. 2002a. Tapoco Hydroelectric Project FERC No. 2169 Fish and Aquatics Study: Fish Entrainment Assessment (Draft). Prepared for APGI, Tapoco Division.

Odeh, M. 1999. A Summary of Environmentally Friendly Turbine Design Concepts. Prep. for the United States Department of Energy, Idaho Operations Office, Advanced Hydropower Turbine System Program.

Copyright © 2005 New York Power Authority

Odeh, M., and C. Orvis. 1998. Downstream Fish Passage Design Considerations and Development at Hydroelectric Projects in the Northeast USA. In: Proceedings of the Symposium on Fish Migration and Fish Bypass Channels, University of Agricultural Sciences, Vienna, September 24-27, 1996. pp. 267-80.

Odeh, M. 1988. A Computer Expert System for the Analysis and Design of Cavitating Control Valves. Ph.D. dissertation, Utah State University, Logan, UT.

Pope, G. undated. Niagara River Hydroelectric Development – Fish Entrainment Issue. Unpublished notes prepared for the Ontario Ministry of Natural Resources, Ontario Power Generation.

Popper, A.N., and T.J. Carlson. 1998. Application of sound and other stimuli to control fish behavior. Trans. Amer. Fish. Soc. 127:673-707.

Prince, E.D., and O.E. Maughan. 1979. Attraction of Fish to Tire Reefs at Smith Mountain Lake, Virginia. American Fisheries Society, North Central Region. Spec. Pub. 6. Ross, Q. E., D. J. Dunning, J. K. Menezes, M. J. Kenna, and G. W. Tiller. 1996. Reducing impingement of alewives with high-frequency sound at a power plant intake on Lake Ontario. N. Am. J. Fish. Mgt. 16:548-59.

Ross, Q. E., D. J. Dunning, R. Thorne, J. K. Menezes, G. W. Tiller, and J. K. Watson. 1993. Response of alewives to high-frequency sound at a power plant intake on Lake Ontario. N. Am. J. Fish. Mgt. 13:291-303.

Sartor Associates. 1977. Intake Screen Fish Impingement Report for C.R. Huntley Power Station for the Period June 1974 - July 1975, prep. for Niagara Mohawk Power Corporation.

Scott, W.B., and E.J. Crossman. 1979. Freshwater Fishes of Canada. Ottawa: The Bryant Press Limited.

Copyright © 2005 New York Power Authority

Stantec Consulting Services, Inc. 2005. A Recreational Fishing Survey of Lewiston Reservoir in 2002. Prep. for the New York Power Authority.

Tacoma Power. 2000. Cowlitz River Project.
http://www.newwww.ci.tacoma.wa.us/power/parks/cowlitz, updated May 1, 2002.

Therrien, J., and G. Bourgeois. 2000. Fish Passage at Small Hydro Sites. Prep. for CANMET Energy Technology Centre by Genivar Consulting Group, Inc.

Tullis, J.P. 1989. Hydraulics of Pipelines: Pumps, Valves, Cavitation, Transients. New York: John Wiley and Sons.

Turnpenny, A.W.H. 1998. Mechanisms of Fish Damage in Low-head Turbines: An Experimental Appraisal. In: Fish Migration and Fish Bypasses, Fishing News Books, Blackwell Scientific Publications, Oxford. pp. 300-314.

TVGA Engineering, Surveying, P.C., and C&C Technologies, Inc. 2002. Hydrographic Survey of Lewiston Reservoirand Forebay.

U.S. Army Corps of Engineers. 1995. Proceedings: 1995 Turbine Passage Survival Workshop. Portland District, Portland, OR.

URS Corporation, Gomez and Sullivan Engineers, P.C., and E/PRO Environmental & Engineering Consulting, LLC. 2005b. Niagara River Water Level and Flow Fluctuation Study, prep. for the New York Power Authority.

URS Corporation, Gomez and Sullivan Engineers, PC, and E/PRO Engineering & Environmental Consulting, LLC. 2005a. Aquatic and Terrestrial Habitat in the Niagara River and Lewiston Reservoir, prep. for the New York Power Authority.

Copyright © 2005 New York Power Authority

Warner, J. 2003. Successes and Disappointments in Fish Passage at FERC Projects in New England. Presented at FERC Fish Passage Workshop, Alden Research Laboratory, Inc., Holden, MA.

Winchell, F., S. Amaral, and D. Dixon. 2000. Hydroelectric Turbine Entrainment and Survival Database: An Alternative to Field Studies. Paper presented at Hydrovision 2000.

Copyright © 2005 New York Power Authority

APPENDIX A

Copyright © 2005 New York Power Authority

APPENDIX A – REVIEW OF FISH MORTALITY DUE TO TURBINE PASSAGE

The review strives to compare the relevant physical characteristics of the turbines under study with the turbines at the two NPP facilities (i.e., RMNPP and LPGP) in order to determine the direct applicability of data collected at these other sites. An assessment of the quality of the data collected and its applicability to the NPP sites is also provided.

EPRI Turbine Entrainment and Survival Database (1997)

In the EPRI *Turbine Entrainment and Survival Database* (EPRI 1997), the results of turbine survival studies from 41 hydroelectric facilities in the United States, encompassing a total of 51 individual turbines, were summarized. The objective of the study was to produce a comprehensive database of completed turbine survival studies that could be used to evaluate the amount and quality of existing information when trying to determine survival estimates at other facilities.

Included in the database are the results of studies that utilized paired releases of experimental (i.e., subject to passage through the turbine) and control (i.e., usually released in tailrace or draft tube discharge) fish in order to estimate immediate and delayed turbine passage survival. The studies included in the database used either full-flow tailrace netting or balloon tag retrieval procedures to recapture experimental and control fish downstream from the turbine. No studies using naturally entrained fish were reported in the database because they generally lacked sufficient detail with respect to species and size groups, generally due to the small sample sizes under study.

The results of the database analysis are turbine survival estimates calculated using the relative recovery method based on either the number of experimental and control fish recaptured or the number of experimental and control fish released. The final turbine survival estimate is calculated by dividing the proportional survival rate of the experimental fish with the proportional survival rate of the control fish. The validity of these methods is subject to a number of assumptions. If survival estimates are based on the number of fish recovered, then the probability of recapturing live and dead fish within both the experimental and control groups is assumed to be equal. If survival estimates are based on number of fish

Copyright © 2005 New York Power Authority

released, it is assumed that the probability of recapturing both experimental and control fish is equal. However, the database points out that "these assumptions may not hold true for some of the data that is included in the database" (EPRI 1997). The data were carefully reviewed with this caveat in mind when discerning the validity of the database for comparison with the NPP.

Of the 52 turbine studies summarized in this compilation, 20 involved Francis (vertical) turbines, the same type used in RMNPP and LPGP. One study involved a Francis (vertical, double runner), and nine studies focused on Francis (horizontal) and horizontal variants (i.e., double, quad, triple and twin runners). Other turbine types studied included Kaplan variations (15 studies) and fixed propeller (2 studies), as well as single studies of bulb (S-Type), mixed flow, and tube (S-Type) turbines. The applicability of data from turbines other than Francis (vertical) type (i.e., the type of turbine used at the NPP) is very limited due to substantial differences in physical characteristics and their associated impacts on fish passage survival. As fish mortality and physical characteristics vary substantially among different types of turbines, only data from studies involving Francis (vertical) turbines has been summarized in the following discussion.

The relevant site characteristics of the hydroelectric plants and specific turbines included in the EPRI document are summarized in Table A-1. The characteristics of RMNPP and LPGP turbines are included for comparison. A total of 20 studies on fish passage through Francis (vertical) turbines, at 18 different hydroelectric facilities, were summarized by EPRI. Sites with similar characteristics to the RMNPP turbines are highlighted in yellow, while characteristics similar to the LPGP turbines are highlighted in blue.

The rated head of the projects in the database ranged from 13 to 258 ft. Several studies were in the general range of the LPGP's rated head of 75 ft (62 to 100 ft considered comparable), although only one study (258 ft) came close to RMNPP's rated head of 300 ft. Rated horsepower was only identified in 7 of the studies. The highest rated amount was 20,000 hp, close to LPGP's 28,000 hp, but significantly

Copyright © 2005 New York Power Authority

TABLE A-1

SUMMARY OF HYDROELECTRIC FACILITIES AND FRANCIS (VERTICAL) TURBINE CHARACTERISTICS TURBINE SURVIVAL DATABASE

Site Name	Rated Head (ft)	Rated Power (hp)	Rated Power (MW)	Rated Flow (cfs)	Speed (rpm)	Runner Diameter (in)	Runner Velocity (ft/s)	No. Runner Blades	No. Wicket Gates	No. Stay Vanes
Alcoa	43		4	1,600	90	100	39.3	16	18	
Bond Falls	210	9,300	6	450	300					
Caldron Falls	80		3.2	650	226	72	71.0			
Colton	258	15,080	11.2	450	360	59	92.6	19	2.8	
E.J. West	63	17,150	12.8	2,450	112.5	131	64.1	15	28	19
Hardy	100		10	1,500	163.6	84	59.8	16		
Hoist	142	2,400	1.8		360					
Holtwood	62	20,000	14.9		94.7			16		
Minetto	17.3		1.6	1,500	72	139	43.6	16	28	
Peshtigo	13		0.36	460	100	80	35.0			
Potato Rapids	17		0.44	440	135	80	47.0			
Potato Rapids	17		0.5	500	123	84	45.0			
Prickett	54		1.1	326	257	53	59.9			
Rogers	39.2		1.7	727	150	60	39.3	15		
Sandstone Rapids	42		1.9	650	150	87	57.0			
Schaghticoke	153	6,300	4.7	410	300	51	66.1	17	28	8
Stevens Creek	28		2.35	1,000	75	135	44.2	14	20	
Vernon	34		2.5	1,280	133.3	62	36.3	14	16	
Vernon	34		4.2	1,834	74	156	50.3	15	20	
White Rapids	29	4,385	3.27	1,540	100	134	58.4	14	20	
Average	72	10,659	4	987	169	92	53	16	20	14
Maximum	258	20,000	14.9	2,450	360	156	92.63	19	28	19
Minimum	13	2,400	0.36	326	72	50.5	35	14	2.8	8
RMNPP	**300**	**273,000**	**200**	**8,850**	**120**					
LPGP	**75**	**28,000**	**27.5**	**3,450**	**112.5**					

Source: EPRI 1997. Yellow shading represents characteristics similar RMNPP; blue shading represents characteristics similar LPGP.

Copyright © 2005 New York Power Authority

lower than RMNPP's 273,000 hp. The rated power (MW) of the turbines in the database ranged from 0.36 MW to 14.9 MW, significantly lower than RMNPP (200 MW, following completion of upgrades) and LPGP (27.5 MW). Rated flows ranged from 326 to 2,450 cfs, although flow was not reported for two of the studied turbines. These flows are considerably lower than both RMNPP (8,850 cfs) and LPGP (3,400 cfs). Rated speed ranged from 72 to 360 RPM, with four studies approaching or slightly greater than RMNPP's speed of 120 RPM (112.5 to 135 RPM) and three studies equaling or slightly lower than LPGP's speed of 112.5 RPM (100 to 112.5 RPM).

The majority of the physical characteristics of the turbines presented in the EPRI database are considerably smaller in magnitude than those of the RMNPP. One study (Colton hydroelectric facility) approached the rated head of RMNPP, but the rated flow at this site (450) was significantly lower than RMNPP's. Several of the studies were similar to RMNPP in terms of the speed of the turbines, but the other characteristics of these sites did not approach the scale of RMNPP. This lack of similar physical characteristics substantially limits the applicability of data from the EPRI database in its direct use for predicting survival of fish traveling through the RMNPP turbines.

The physical characteristics of one site's turbines (E.J. West hydroelectric facility) were similar to those of LPGP. Although at a slightly lower head and rated flow, the speed of the turbines was the same. Several individual characteristics from some of the other sites were similar to those of LPGP (e.g., rated head, rated horsepower, rated flow and speed), although other characteristics of the turbines were significantly different, thereby limiting the direct applicability of the data.

For each of the studies, the EPRI survival database reports the water temperature, the season of study, species used, the range of species sizes under study (and sometimes the average size), the number of experimental and control fish released and recovered and the number alive immediately, after 24 hours and after 48 hours. Immediate, 24-hour and 48-hour survival were calculated using both the number released and number recovered method for experimental fish, while control survival is calculated using only the number recovered method.

Copyright © 2005 New York Power Authority

Winchell et al. (2000) summarized the information contained within the Turbine Survival Database. Fish survival rates for four size classes of fish from all Francis turbines are presented in Table A-2. Results shown include minimum, maximum and mean values for immediate and 48-hour survival. Data from studies with control mortality >10% were excluded from analysis. It should be noted that the direct application of this data to the NPP are limited due to the fact that data from all types of Francis turbines (e.g., horizontal and vertical) have been included in the presented survival estimates. However, Winchell et al. (2000) have identified some general trends with respect to fish passage survival including:

- fish size, turbine type, turbine rotational speed and turbine size resulted in the clearest survival trends;
- species of fish did not result in any obvious differences in survival probabilities;
- survival rates for Francis turbines were more variable than those observed for other turbine types (e.g., Kaplan, fixed propeller);
- survival was typically higher for smaller fish, generally those less than 8 in.;
- lower rotational speeds (i.e., those less than 250 rpm) typically resulted in decreased mortality;
- results are quite variable between turbines, with some Francis types showing high rates of survival for all sizes of fish; and
- 48-hour survival was approximately 3-4% lower than immediate survival for all sizes of fish (when immediate survival was relatively high).

The results generally seem to indicate that fish size is more important than species with respect to survival probability and that higher survival could generally be attributed to slower turbine rotational speeds and smaller size classes of fish.

For the purposes of the NPP turbine survival estimate, the list of potential studies in the survival database with direct relevance to the NPP has been pared down based on the comparability of several key

Copyright © 2005 New York Power Authority

TABLE A-2
FISH PASSAGE SURVIVAL ESTIMATES THROUGH FRANCIS TURBINES

Hydraulic Capacity	Fish Size (in)	No Turbines(2)	Average Immediate Survival(1)			Hydraulic Capacity (cfs)	No Turbines(2)	Average 48 hr Survival(1)		
			Min.	Max.	Mean			Min.	Max.	Mean
40-1,600	<3.9	13	85.9%	100.3%	93.9%	440-1,600	11	80.9%	101.1%	90.4%
370-1,600	3.9-7.8	19	74.8%	100.0%	91.6%	370-2,450	17	73.7%	101.8%	87.8%
370-2,450	7.8-11.8	18	59.0%	100.0%	86.9%	440-2,450	15	47.4%	96.4%	80.4%
440-1,600	11.8+	14	36.1%	100.0%	73.2%	440-1,600	13	33.8%	94.1%	66.8%

Source: Winchell et al. 2000

(1) "Average of all control-adjusted estimates provided in EPRI (1997) including all species and test conditions but excluding tests with less than 90% survival of control groups." Instances where survival exceeds 100% indicates higher mortality among control fish than experimental fish.

(2) "Number of turbines for which survival estimates are available."

Copyright © 2005 New York Power Authority

turbine physical characteristics. As indicated by Winchell et al. (2000) turbine speed (rpm) seems to be one of the more important turbine characteristics in terms of fish survival. EPRI (1997) also found that the mortality associated with a fish colliding with turbine components is minimal in Francis turbines with runner peripheral velocities of 40 fps or lower. Higher tip speeds may result in a greater number of strikes and speeds lower than 20 fps may eliminate strike mortality.

Five studies in the database (i.e., E.J. West, Peshtigo, Potato Rapids (2 turbines), Vernon and White Rapids) have comparable turbine speeds to those found in the RMNPP (120 rpm) and LPGP (112.5 rpm). Speeds in these six studies range from 100 rpm to 135 rpm. The results of survival studies from these five turbines are presented in Table A-3. It should be noted that in most cases, other physical characteristics of the selected turbines do not approach the magnitude of those found in the NPP, with the exception of the E.J. West facility, which is quite similar in scope to the LPGP. Results were excluded where control mortality exceeded 10% (for immediate and/or 48-hour). This resulted in the exclusion of one additional facility (White Rapids), which has a similar rpm speed to NPP, but control mortalities for all studies conducted at the facility were greater than the selected range of acceptability. In addition, single sampling events involving a wide range of fish sizes (i.e., greater than approximately 50-75 mm) were not reported due to the necessity to separate size related impacts. Fish species have been grouped based on family characteristics including centrarchids/percids (sunfish/perch), cyprinids (minnows), salmonids (salmon and trout) and catostomids (suckers and redhorse). Where several individual studies were conducted on similar species and a similar size range (e.g., in two different seasons), survival estimates were averaged. Only survival estimates based on the results of the number of experimental and control fish recovered have been presented. Generally for the turbines with similar speeds to that of RMNPP had experimental turbine survival rates ranging from 36% to 100%, depending on fish size.

EPRI Fish Entrainment and Turbine Mortality Review (1992)

EPRI (1992) summarizes the results of 33 studies that examined fish passage survival at turbines located throughout the United States, as well as one from Nova Scotia, Canada. The summary focused on data from species other than salmonids, which, at the time, had been extensively studied. EPRI indicated

Copyright © 2005 New York Power Authority

TABLE A-3

SURVIVAL ESTIMATES FROM FRANCIS TURBINES WITH ROTATIONAL SPEEDS SIMILAR TO NPP

Species Group	Size Range (in.)	Survival Estimate[1]	
		Immediate	48-hour
E.J. West			
Centrarchids	>9.8	0.870	0.720
Salmonids	>9.8	0.932	0.932
Peshtigo			
Centrarchids (3)	2.0-3.9	1.001	1.006
Centrarchids (3)	3.9-5.9	0.992	0.988
Centrarchids (2)	5.9-7.8	1.000	0.988
Cyprinids/Catostomids (2)	2.0-3.9	1.004	1.019
Cyprinids/Catostomids (2)	3.9-5.9	0.939	0.907
Cyprinids/Catostomids (1)	5.9-7.8	0.940	0.851
Cyprinids/Catostomids (3)	7.8-9.8	0.963	0.956
Cyprinids/Catostomids (3)	9.8-12.8	0.841	0.861
Cyprinids/Catostomids (2)	>12.8	0.757	0.757
Potato Rapids (Unit 1)			
Cyprinids/Catostomids (1)	2.0-3.9	0.860	0.859
Cyprinids/Catostomids (1)	3.9-5.9	0.676	0.640
Cyprinids/Catostomids (1)	5.9-7.8	0.553	0.538
Cyprinids/Catostomids (2)	7.8-9.8	0.590	0.579
Cyprinids/Catostomids (1)	9.8-12.8	0.521	0.536
Cyprinids/Catostomids (2)	>12.8	0.361	0.338
Centrarchids (2)	3.9-5.9	0.860	0.845
Potato Rapids (Unit 2)			
Centrarchids (2)	2.0-3.9	0.965	0.923
Centrarchids (3)	3.9-5.9	0.945	0.865
Centrarchids (1)	5.9-7.8	0.983	0.914
Cyprinids/Catostomids (2)	2.0-3.9	0.958	0.802
Cyprinids/Catostomids (1)	5.9-7.8	0.778	0.747
Cyprinids/Catostomids (1)	9.8-1.8	0.627	0.474
Cyprinids/Catostomids (2)	>12/8	0.628	0.530
Vernon			
Salmonids	4.3-8.4	0.947	0.943

Source: EPRI 1997

[1] Survival estimates exceeding 1.000 indicates that control mortality exceeded treatment mortality.

Copyright © 2005 New York Power Authority

that the information review did not seem to be sufficient to determine predictive correlations between turbine types and fish size classes, although several general trends were evident.

Passage survival through Francis turbines is highly variable and generally results in a higher mortality rate than that observed for Kaplan turbines. The overall estimated mortality for Francis turbines was 20%, compared to 12% for Kaplan turbines. Eicher et al. (1987) indicated that this trend may be due to the fact that Francis turbines are more often located in areas with high head and a higher runner elevation in comparison to the tailwater elevation. In a survey of previous mortality studies, Eicher et al. (1987) demonstrated that both head and peripheral runner velocity correlated positively with fish passage mortality. Other trends identified include:

- Smaller fish tend to suffer lower mortality than larger fish. Larger fish generally had greater incidence of observable turbine injury.
- Maximum survival tends to be when units are operating at peak efficiency.
- Naturally entrained fish appeared to exhibit lower mortality rates compared to artificially introduced fish.
- Mortality outside peak operating range appears to be related to cavitation or sub-atmospheric pressure.
- Operation at low gate settings may result in increased mortality due to narrow clearance between wicket gates.
- Size of clearance between turbine parts may be particularly important for passage of larger fish at higher runner speeds.

As reported in EPRI (1992), Collins and Ruggles (1982) estimated that juvenile salmonid mortality would be in the range of 10% at most Francis turbines operated at peak efficiency, although mortality could rise to over 50% at turbines with smaller clearances, particularly small turbines with high head.

Copyright © 2005 New York Power Authority

Several of the studies documented in EPRI (1992) were also included in the discussion of EPRI's Turbine Survival Database (EPRI 1997) and have therefore not been further discussed here. Three of the other studies covered in EPRI (1992) come from Francis (vertical) turbines with similar rpm characteristics to the turbines of the NPP. These studies include Centralia on the Wisconsin River, Escanaba on the Escanaba River in Michigan and French Landing on the Huron River in Michigan.

Turbine mortality studies conducted at Centralia Hydroelectric Project used three size classes (<2.8 in., 2.8-3.9 in., >3.9 in.) of fish species including golden shiner, fathead minnow and white sucker. High net injury (71.3% for fish <2.8 in.) observed during the catch efficiency tests, resulted in a decrease in the reliability of the data. The study concluded that experimental test results (i.e., mortality) were generally lower than or equal to net mortality. Approximately 59% of all naturally entrained fish collected in the tailrace were alive prior to netting.

Turbine mortality studies of naturally entrained fish at Escanaba Hydro Dam #1 found that 5.1% of all entrained fish were injured and turbine mortality was estimated to be 10.4%. Species used in the study were primarily sunfish (82.5%), including black crappie, rock bass, bluegill and pumpkinseed. No size ranges of fish used in the study were provided. Overall mortality was influenced by one sampling event that resulted in a 65% mortality rate for approximately 600 juvenile black crappie. Excluding this significant mortality event, overall mortality decreases to 6.4%.

Turbine mortality studies at Escanaba Hydro Dam #2 found that 4.9% of all entrained fish were injured and overall turbine mortality was estimated to be 6.1%, slightly lower than the observed mortality at the higher speed Escanaba Hydro Dam #1. A total of 58.2% of the naturally entrained species were sunfish, although no size ranges were presented.

Turbine mortality studies conducted at French Landing dam and Hydroelectric generating station involved a controlled, paired release program, using predominantly black crappie (76%) and bluegill (18%), as well as lower numbers of walleye, white bass, channel catfish, bullhead, and white sucker. No size ranges were presented in the summary (EPRI 1992). The overall study was plagued by high 72-hour control mortality (approximately 32%), which substantially reduces the reliability of the data. Control

Copyright © 2005 New York Power Authority

adjusted overall mortality was 16% for all fish. Black crappie exhibited 50% control mortality and 50% test mortality, although none of the turbine passed crappies that died exhibited any signs of external injury.

The average mortality rates for several migratory species traveling through Francis turbines included in the review are presented in Table A-4. However, as this data includes all facilities covered in the review, there is limited applicability to NPP, due to differences in the physical characteristics of the facilities.

Overall the data from studies documented in EPRI (1992) are fairly limited in its applicability for comparison with NPP. While several of the test facilities were similar in terms of turbine rotational speed (deemed an important determinant of turbine passage mortality), other key parameters (i.e., average head, rated flow) were significantly lower than those of NPP. In addition, high control mortalities were observed for several of the studies, resulting in potentially compromised, and therefore unreliable, mortality data.

Tapoco Hydroelectric Project

The Tapoco Hydroelectric Project, consisting of four individual developments owned and operated by Alcoa Power Generating Inc., is located on the Little Tennessee and Cheoah Rivers in the States of North Carolina and Tennessee. Normandeau Associates (2002a) conducted a fish entrainment study as part of the facilities' FERC relicensing project. Normandeau identified a number of factors that influence fish survival during turbine passage. These included:

- Turbine type – The space between turbine components is a key consideration when determining turbine passage survival potential and Francis runners have more closely spaced componentry compared to similar sized Kaplan runners. This negatively influences survival of fish, particularly larger size classes.

Copyright © 2005 New York Power Authority

TABLE A-4
SUMMARY OF AVERAGE MORTALITY RATES THROUGH FRANCIS TURBINES

Species / Group	Average Mortality Rate (%)
Salmonids (salmon, trout)	18.2
Clupeids (shad, alewife)	
- adult	16.0
- juveniles	28.6
Centrarchids (crappie, bass)	11.7
Percids (walleye, darter, perch)++	23.6
Esocids (northern pike)	22.3
Catostomids (suckers)	24.0
Cyprinids (shiner)	20.0

Source: EPRI 1992

Copyright © 2005 New York Power Authority

Turbine speed – Higher rpm's increase the probability of a fish striking the structural elements of the turbine.

- Small fish (<8 in) tend to comprise a high proportion of overall entrainment and generally have higher survival rates. This tends to reduce the overall impact of entrainment on fish populations.
- Pressurized intake tunnels may increase the risk of decompression trauma in fish as they move from a high hydrostatic pressure environment at the intake (deeper water) to a lower pressure environment in the tailrace.

Cowlitz River Project

Normandeau Associates (2002b) conducted a fish turbine passage survival study in March 2002 at the Mayfield Hydroelectric Facility owned by Tacoma Power, located on the Cowlitz River in the State of Washington (Tacoma Power 2000). The Mayfield facility consists of four Francis (vertical turbines), each with a rated power of 40.5 MW, for a total capacity of 162 MW. Average rated head at the facility is 182 ft. One of the units (Unit 41) in the powerhouse has 24 wicket gates, 16 buckets and a rated discharge of 3,290 cfs. The other three units (Units 42-44) have 20 wicket gates, 15 buckets and rated discharge capacities of 3,370 cfs. Steelhead and coho salmon smolts were used for balloon tag retrieval studies to estimate the survival through the turbines. Survival through Unit 41 was 82.6 % and 84.7% for steelhead and coho salmon respectively, while for Units 42-44, survival was 97.1% for both species. Higher survival rates for Units 42-44 may be due to fact that they have a fewer number of wicket gates and therefore fish have a lower probability of striking turbine components.

Fish Passage at Small Hydro Sites (Therrien and Bourgeois 2000)

Therrien and Bourgeois (2000) conducted a review of turbine mortality literature and identified several general trends associated with Francis turbines. These include:

- The runner entrance (wicket gates, blades, and the runner's peripheral speed) is the major area of the turbine associated with fish mortality.

Copyright © 2005 New York Power Authority

- Higher mortality associated with higher runner peripheral speed and greater wicket gate opening (possibly due to less clearance between end of wicket gate and runner).

Plant head is generally not correlated with mortality. Influence of head may be overstated due to the fact that mortality from Francis turbines, which are generally installed at higher head facilities, is greater than for Kaplan turbines. As reviewed in Therrien and Bourgeois (2000), Eicher et al. (1987) found that Francis turbines operating at 40 ft and 410 ft resulted in similar fish mortality.

Copyright © 2005 New York Power Authority

APPENDIX B – PHOTOS

Copyright © 2005 New York Power Authority

PHOTO 1

RAPIDS UPSTREAM OF AMERICAN FALLS

Copyright © 2005 New York Power Authority

PHOTO 2

CURRENTS TO APPROACH CHANNEL TO AMERICAN FALLS

Copyright © 2005 New York Power Authority

PHOTO 3

ENTRANCE TO AMERICAN FALLS APPROACH CHANNEL

Copyright © 2005 New York Power Authority

PHOTO 4

RAPIDS IN APPROACH CHANNEL OF HORSESHOE FALLS

Copyright © 2005 New York Power Authority

PHOTO 5

ROCK RUBBLE AT BASE OF AMERICAN FALLS

Copyright © 2005 New York Power Authority

PHOTO 6

ROCK RUBBLE AT BASE OF AMERICAN FALLS

Copyright © 2005 New York Power Authority

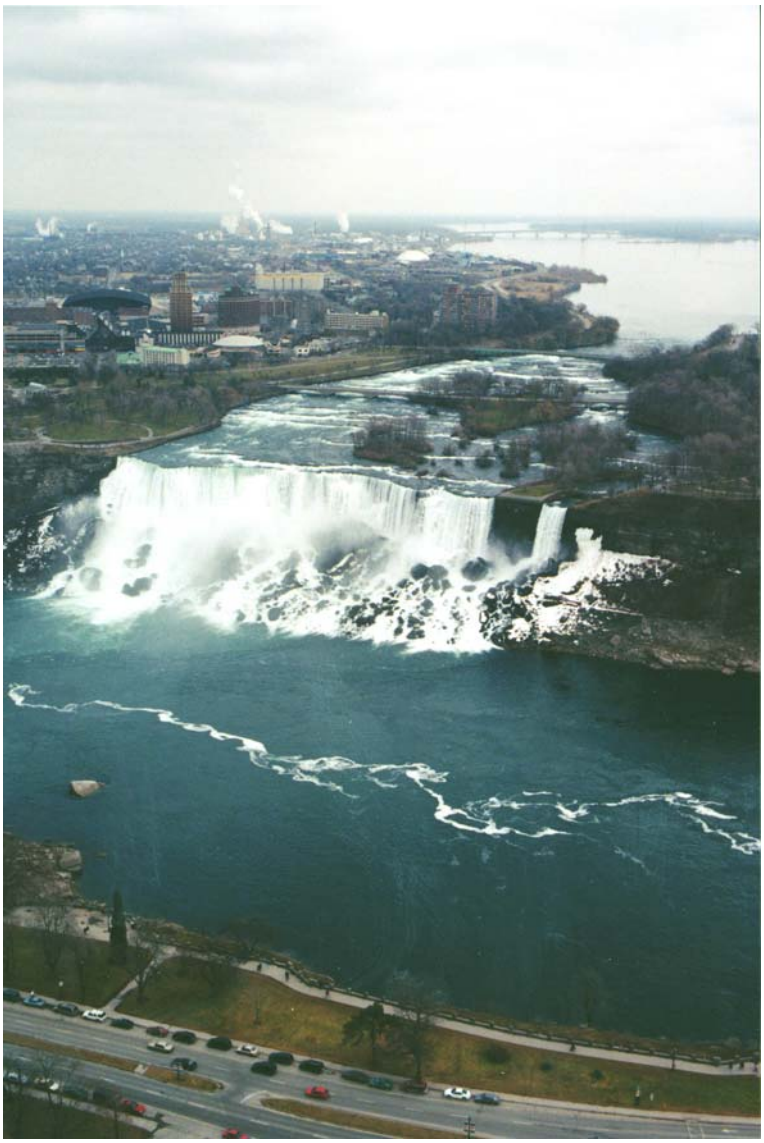
PHOTO 7

CANADIAN FALLS

Copyright © 2005 New York Power Authority

PHOTO 8

AMERICAN FALLS



Copyright © 2005 New York Power Authority

Critical Energy Infrastructure Information (CEII) has been removed from the following page(s).

This material is contained in:
Volume 3
Section: Fish Entrainment and Mortality Study

PHOTO 9

VIEW OF THE HARMONICA STRUCTURES OF THE NPP INTAKE DURING CONSTRUCTION

[CEII – Project Technical Details]

Copyright © 2005 New York Power Authority