Memo to Public Files

To: Public Files
From: Kenneth Hogan
Date: June 20, 2014
Dockets: P-1892- 027, P-1855-046, P-1904-074
Project: Wilder, Bellows Falls, and Vernon Hydroelectric Projects

Subject: Submittal of Supporting Documentation

Electric Power Research Institute. 2014. Request for Proposal, Assessment of Technologies to Study Downstream Migrating American Eel Approach and Behavior at Iroquois Dam, the Beauharnois Power Canal and the Beauharnois Generating Station.

REQUEST FOR PROPOSAL

ASSESSMENT OF TECHNOLOGIES TO STUDY DOWNSTREAM MIGRATING AMERICAN EEL APPROACH AND BEHAVIOR AT IROQUOIS DAM, THE BEAUHARNOIS POWER CANAL AND THE BEAUHARNOIS GENERATING STATION

INVITATION AND INSTRUCTIONS TO BIDDERS

INVITATION

On behalf of the Eel Passage Research Center, the Electric Power Research Institute (EPRI) invites your firm to submit a proposal responsive to the requirements set forth below and in the enclosed documents. These instructions establish a single format which must be followed by all Bidders to provide the reviewers with the basis for a uniform and impartial evaluation of each bid. Bidders are encouraged to read these instructions carefully and thoroughly review all of the information provided. Failure to comply with any of these instructions may jeopardize consideration of your proposal for contract award. Do not hesitate to submit questions or ask for clarification on technical or commercial topics. EPRI's desire is to receive proposals that are based on a sound and thorough understanding of the objectives of this work and the terms and conditions that will govern contracting.

REQUEST FOR PROPOSAL CONTENTS

The following documents collectively constitute EPRI's Request for Proposal (RFP).

- Invitation and Instructions to Bidders (this document)
- Scope of Services (i.e., technical work scope)
- List of RFP Recipients (Appendix A)
- Example of EPRI Sourcing Agreement (Appendix B) to be completed by EPRI upon award of Contract
- EPRI Standard Terms and Conditions (Attachment A to Appendix B)
- Example Statement of Work (Attachment B to Appendix B) to be filled out by the Consultant upon Contract award
- EPRI Form 112 (provided electronically as Excel spreadsheet)
- *Review of Technologies for Guiding, Capturing, Holding, Transporting and Monitoring Outmigrating Eels* prepared by Versar, Inc for New York Power Authority, July 2009 (Appendix C)
- Engineering drawings of Iroquois Dam (Appendix D). Bidders should note the confidentiality of this information as indicated in Appendix D.

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INSTRUCTIONS TO BIDDERS

- Proposals must be received by e-mail (Paul Jacobson of EPRI (pjacobson@epri.com) no later than **4:00 p.m. (EST, Eastern Standard Time) on Wednesday, March 26, 2014**. No late proposals will be accepted.
- Bidders must provide acknowledgement of receipt of this RFP package by **4:00 p.m. (EST) on Monday, February 24, 2014.**
- Bidders must also provide notification of their intent to submit a proposal by **4:00 p.m. (EST) on Friday, March 7, 2014.** Such notifications shall be sent via email to Paul Jacobson.
- Attendance at a pre-bid teleconference scheduled at **10:00 a.m. (EST) on Wednesday, March 12, 2014** is strongly encouraged, but not mandatory. Dial-in information will be provided by EPRI to those Bidders who provided a notification of intent to submit a proposal as instructed above.
- All inquiries and technical questions regarding this RFP shall be submitted via e-mail to Paul Jacobson no later than **4:00 p.m. (EST) on Friday, March 14, 2014.** Accordingly, questions and answers (if any) will be provided to all recipients of the RFP that have provided notification of the intent to submit a proposal.
- EPRI reserves the right to revise or amend any portion(s) of the RFP prior to the date set for receipt of bids. Such revisions, if any, shall be announced by addendum to this RFP to all bidders that have provided notification of their intent to submit a proposal. Additional instructions for providing acknowledgement of receipt of any addenda will be forthcoming with addenda issuance.
- Bidders must understand all regulations for conducting business in Canada and United States and proposing firms must have all necessary registrations and certifications to conduct business in any country where work is proposed to occur. Costs associated with registrations and certification to conduct business in any country where work is proposed is at the sole expense of the Consultant.
- Personnel must be able to travel and do business in both Canada and United States by no later than Wednesday, April 9, 2014. Costs associated with registrations (e.g., work Visas) and travel documents (e.g., passports) are at the sole expense of the Consultant.
- Bidders are responsible for reviewing EPRI's standard terms and conditions. Any proposed exceptions must be clearly stated and explained in the proposal submission. Willingness to accept EPRI contract terms and conditions will be a consideration in the selection of the contractor.
- Issuance of this RFP does not commit EPRI to award a contract and EPRI will not pay costs incurred in the preparation and/or submission of a proposal.
- Contract award, if any, is anticipated for April 9, 2014 and will be offered to that responsive and responsible bidder whose bid, conforming to all instructions, is most advantageous to EPRI.

- Proposed labor rates, direct expenses, and rental rates will be firm through February 28, 2015.
- Bidders are encouraged to develop teaming relationships with other firms in order to establish a team that has the expertise to investigate each portion (near-field and far-field) of the Scope of Services. In this case, one of the firms must act as the Prime Consultant, handling administrative tasks and coordinating technical investigations as well as providing any technical expertise they might have. Appendix A is the distribution list that received the Request for Proposal. Bidders are also permitted to propose firms not included in Appendix A and to distribute the Request for Proposal to other firms or entities that might have an interest in participation. Bidders should note that EPRI/EPRC may elect to conduct only a portion of the work or to assemble a team of firms to conduct a modified Scope of Work, and in that case, EPRI would coordinate consultants and activities.
- Bidders should be aware that all information, data, findings, conclusions, engineering designs, specifications, calculations, and reports arising from all aspects of this study will be the property of EPRI and the EPRC. Distribution, reuse, and dissemination of information of any kind for whatever reason will be at the sole discretion of EPRI and EPRC. Please see EPRI Terms and Conditions in Appendix B for a clear definition of intellectual property, ownership, license grants, restrictions, and title for all information and work products arising from this project.
- EPRI WILL NOT TREAT CONFIDENTIALLY MARKED INFORMATION AS CONFIDENTIAL. YOU AGREE TO THIS CONDITION BY SUBMITTING A PROPOSAL.
- The following evaluation criteria will be used by EPRI in evaluating proposals submitted in response to this RFP. Bidders should not minimize the importance of an adequate response in any area, as all of the criteria listed will be considered in determining EPRI's selections.

Evaluation Criteria	Weighting (%)
Technical Proposal	50%
Price	25%
Business Capabilities	25%

PROPOSAL REQUIREMENTS

- Bidders must submit proposals in English and include their technical work scopes based on the Scope of Services. Alternate technical approaches are encouraged.
- Technical works scopes are limited to 60 pages, exclusive of personnel resumes, pricing forms, business capabilities, and any illustrations or conceptual design drawings.
- Font must be no smaller than Times New Roman size 11.

- Bidders must submit business capabilities for the Prime Consultant and all teaming partners or subcontractors, including a brief history of the firm, the firm's technical capabilities, and experience profiles for projects similar to the Scope of Services.
- Bidders must submit an organizational structure that clearly details project responsibilities, reporting protocols, and lines of communication among the Bidder's employees and all teaming partners.
- Bidders must submit resumes of all technical staff that will work on the project. Resumes must state how long an individual has been with the firm, what office location the individual reports to, and where that individual resides. Professional resumes must not exceed 3 pages per individual.
- Bidders must submit a detailed cost break down of all labor, expenses, equipment purchase and rental, and other costs anticipated to complete their proposed Scope of Services. Costs should be presented by major tasks and subtask detailing both man-hours and expenses. Work will be conducted on a Time and Materials Cost Not-To-Exceed basis. In addition to a detailed cost breakdown, bidders must fill in EPRI Form 112 (provided electronically as Excel spreadsheet) and submit the signed form with their proposal.

ELECTRIC POWER RESEARCH INSTITUTE

SCOPE OF SERVICES

INTRODUCTION

Downstream passage of eels at hydroelectric projects is a concern in several regions of the world, including the Atlantic coasts of North America, Europe, Scandinavia, and the British Isles; as well as Australia, New Zealand, New Guinea, and Asia. The concern is perhaps greatest for the closely related species of the North Atlantic, the American eel and the European eel. The European Union and Norway have listed the European eel as critically endangered, and the American eel faces possible listing under the U.S. Endangered Species Act and the Canadian Species at Risk Act. The Committee on the Status of Endangered Wildlife in Canada recommended listing the American eel as a species of "special concern" in 2006 and as a "threatened" species in 2012. The Province of Ontario has listed the species as "endangered". The owners of hydropower projects distributed throughout the portions of North America, Europe, Scandinavia, and the British Isles that drain to the Atlantic Ocean face mandates to reduce anthropogenic mortality and provide safe downstream passage for eels.

While providing upstream passage for juvenile eels at hydroelectric projects is relatively straightforward and effective, ensuring safe downstream passage of adults at hydroelectric projects has proven to be problematic. This is particularly true at larger facilities with deep and wide intake structures. The behavior of eels during downstream migration poses challenges for protecting them from passing through turbines and guiding them to alternative passage routes. Currently, no effective method exists to pass eels safely around large, operating hydroelectric facilities. Measures mandated at some smaller facilities are problematic for plant operators due to the protracted, episodic nature of outmigration and the lack of effective protection and passage technologies. As regulators and fisheries managers effectively press for upstream eel passage, they expect that downstream passage measures will be implemented in the future, when eels passed upstream have matured and migrate downstream to the sea.

The collaboratively funded Eel Passage Research Center (EPRC) was formed to research methods for providing economical, biologically and operationally effective downstream passage for migrating eels at large and medium-sized hydroelectric facilities. Current funders of the EPRC are hydroelectric generators in Canada and the United States concerned with mitigating turbine passage mortality at their facilities and the Fish Enhancement, Mitigation and Research Fund which is administered by the U.S. Fish and Wildlife Service. Regulatory and resource management agencies consult with the EPRC. The Electric Power Research Institute (EPRI) coordinates and manages the activities of the EPRC. The EPRC began in 2013, and the focal point for research and development is the St. Lawrence River, above Montreal. The EPRC's current objective is to build upon previous research conducted on the St. Lawrence River to develop means to guide and collect eels for transport below hydroelectric facilities in order to reduce turbine passage mortality. This Scope of Services (SOS) is one of the first steps in an EPRC multi-year approach aimed at meeting that objective.

PROJECT SETTING

The St. Lawrence River (River) is an international waterway located in northern New York State and southeastern Canada. The river originates from Lake Ontario and flows approximately 1,400 kilometers (km) to the Gulf of St. Lawrence. It is the principal outlet for the waters of the Great Lakes and drains an area approximately 1.6 million square kilometers, representing 25% of the world's fresh water. The Boundary Waters Treaty of 1909 between the United States and Canada established the International Joint Commission (IJC) with jurisdiction over boundary waters between the two nations, including portions of the St. Lawrence River where it constitutes boundary waters. The two hydroelectric developments on the St. Lawrence River, the International St. Lawrence Power Project and the Beauharnois Generating Station, each have been the subject of research on turbine passage mortality among downstream migrating American eels. Brief descriptions of the facilities follow.

In 1952, the governments of the United States and Canada submitted applications to the IJC for the development of hydroelectric power in the International Rapids section of the St. Lawrence River, extending from approximately Ogdensburg, NY, to Cornwall, Ontario. The IJC issued an Order of Approval for construction of the hydroelectric project in October 1952. The International St. Lawrence Power Project consists of three major water control structures and numerous dikes. The major structures are the Iroquois Dam, Long Sault Dam, and the Moses-Saunders Power Dam. Operating in concert with and under regulation of the International St Lawrence River Board of Control (RBC; a committee of the IJC), the structures are used to control water levels in Lake Ontario and the upper St. Lawrence River for the purpose of commercial navigation, hydroelectric power production, and protection of riparian interests from Lake Ontario to Montreal.

Moving in a downstream direction, Iroquois Dam is the first structure on the River and is located approximately 120 km from Lake Ontario between Iroquois, Ontario, and Waddington, NY. The dam is approximately 600 m long and has no hydroelectric generating capability. Iroquois Dam's principal functions are to control water levels in Lake St. Lawrence, the downstream impoundment created by Long Sault Dam and the Moses-Saunders Power Dam, and to assist in ice formation on the River. Iroquois Dam consists of 32 sluiceways that are each 15.2 m wide with an average water depth of 13.1 m. Each sluiceway has a vertical lift gate that is typically maintained in the raised position. When water levels must be controlled, the gates are lowered to restrict flow. The average discharge of the River at Iroquois Dam in summer and early fall is 7,388 m^3/s, resulting in an average water velocity through each gate of approximately 1.2 m/s.

Long Sault Dam is located in the Town of Massena, NY, 39 km downstream of Iroquois Dam and 5.3 km upstream of the Moses-Saunders Power Dam. The principal functions of Long Sault Dam are to impound Lake St. Lawrence and to provide spill capability into the South Channel (one of the original River channels prior to impoundment of Lake St. Lawrence) during periods of high river flow. Spill from Long Sault Dam is an infrequent occurrence because river flows rarely exceeds the powerhouse capacity of Moses-Saunders Power Dam.

The Moses-Saunders Power Dam (Power Dam) consists of two hydroelectric generating stations forming one continuous structure that spans the international portion of the St. Lawrence River between Cornwall, Ontario, and Massena, NY. Each side of the Power Dam consists of 16 propeller or Kaplan turbines (32 total), each with an installed generating capacity of approximately 57 MW at a flow of 275 m^3/s and normal head of 25.3 m. Total installed capacity of the Power Dam is about 1,824 MW. The New York side of the Power Dam is called the Robert Moses Power Dam (RMPD) and is owned and operated by the New York Power Authority (NYPA). The Ontario side of the Power Dam is called the Robert H. Saunders Generating Station (RSGS) and is owned and operated by Ontario Power Generation (OPG). The operation of the Power Dam is controlled by a regulation plan implemented by the IJC and overseen by U.S. and Canadian regulation representatives who report to the RBC. The RBC regulates flows daily and weekly.

Beauharnois Generating Station (Station), owned and operated by Hydro-Québec (HQ), is located 85 km downstream of the Power Dam and 40 km southwest (upstream) of Montreal. The Station is entirely in Canadian waters in the Province of Quebec. It is one of the world's largest hydroelectric facilities, consisting of three hydroelectric generating stations forming one continuous structure that spans the Beauharnois Power Canal. It contains 36 generating units with an installed capacity of 1,658 MW. The Station has 26 Francis and 10 propeller type turbines and is located at the end of the Beauharnois Power Canal, a 25-km-long, 1-km-wide, man-made canal leading from Lake St. Francis to the Station. Maximum discharge of the Station is 8,200 m^3/s. The average flow during the eel migration season in the Canal represents from 85% to 90% of the total natural flow of the St. Lawrence River at this location. The Station is operated essentially as a run-of-river facility.

PREVIOUS RESEARCH

From 1997 through 2002 NYPA studied downstream migrating American eels in the St. Lawrence River as part of its Federal Energy Regulatory Commission (FERC) relicensing process for the RMPD. The objectives of the iterative studies were to determine the effect of turbine passage on downstream migrating eels, characterize the behavior of downstream migrating eels in the vicinity of the Power Dam, and investigate technologies that could guide outmigrating eels to locations where they can be collected and transported around the Power Dam. The following results of those studies represent pertinent background information for this Scope of Services:

- All American eels in the Lake Ontario/upper St. Lawrence River system that migrated up the River as juveniles are female, and in the "silver" downstream migrating life phase average approximately 950 mm total length.
- Turbine passage survival of adult outmigrants was approximately 75% at RMPD.
- The outmigration season occurs from June until the end of October, and outmigration generally peaks over a broad period from mid-July until mid-September. The trend in abundance shows a substantial decline in the number of eels leaving Lake Ontario and the upper St. Lawrence River.
- Maturing outmigrants (silver or silvering eels) in Lake St. Lawrence were captured only by collection techniques that sampled offshore and in the water column, such as mid-

water trawling and stow netting. Sampling methods such as hoop nets or electrofishing collected only non-mature yellow eels.

- High conductivity and significant depth in Lake St. Lawrence precluded the use of radiotelemetry techniques for studying the behavior of outmigrating eels.
- High background noise near the Power Dam precluded the use of standard hydrosonic telemetry equipment; specialized hydrosonic equipment operating at 200 kHz was developed to study outmigration behavior.
- Surgically implanting a tag in the body cavity was determined to be the best tagging technique; however, handling and tagging of mature outmigrants affected normal outmigration behavior. More than 50% of test specimens did not migrate within 30 days of tag implantation.
- Seventy-five percent of downstream migratory behavior occurred at night.
- All migrants exhibited “submarining” behavior, moving up and down in the water column as they migrated.
- Migrating eels exhibit no apparent preference for either shoreline or the middle of the river and no apparent spatial pattern when approaching the Power Dam (i.e. passage through the dam was uniformly distributed across the intake area).
- Migrating eels were able to explore the intake area without being entrained but did so relatively quickly; 92% spent 21 minutes or less exploring the intake area before passing through a turbine.
- Physical barriers and guidance devices were considered impractical at the Power Dam due to the large size of the intake area (1 km across and up to 37 m deep) and the uniform spatial distribution of outmigrants.
- Of the three water control structures associated with the International St. Lawrence Power Project, Iroquois Dam seems to provide the best opportunity to collect outmigrating eels due to its configuration, relatively shallow depth, and relatively narrow width.
- A large-scale, proof-of-concept study showed that 77.6% of eels migrating at night were guided or diverted away from an underwater light field installed on an 80-m-long research platform anchored mid-channel just upstream of Iroquois Dam. The light field was created with 84, 1000-watt underwater lights that created a “wall of light” 90 m long and 52 m wide from surface to bottom.

HQ has also conducted extensive research relevant to understanding eel behavior and has characterized debris load in the Beauharnois Power Canal. The following results of those studies also represent pertinent background information for this Scope of Services:

- In 1994, survival of downstream migrating eels passing through the Francis-type turbines was determined as 84.2% while 76.1% of eels passing through the propeller turbines survived, resulting in a total station mortality estimate of 18% for Beauharnois.

- Debris loading in the Beauharnois Power Canal peaked in August during the 1996 debris study; debris abundance was greatest on river right of the canal. Most of the debris (80%) was concentrated in the upper 1.5 m of the water column; about 60% of debris was in the upper 1.5 m of water column on the left side of canal. Aquatic vegetation (*Myriophyllum sp*., or milfoil, and *Ceratophyllum sp.*, or coontail) dominated the debris load. Debris was sampled using vertical strings of three to five drift nets; each conical net consisted of a metallic ring 32-cm in diameter with 1.5-cm bar mesh and a 0.7-m^2 opening. The strings of drift nets were deployed from bridge pilings, and soak time varied from 15 minutes to 18 hours depending on loading.
- Monitoring of tagged outmigrating eels released during the summer of 2000 upstream of the RMPD revealed that the average travel time to reach the Beauharnois Dam was about 8.2 days. Most tagged eels were detected approaching the dam at night (between 2300 and 0200 hrs). The average depth of detections was 8.5 m, and vertical movements in the water column were 10.5 m on average.
- In 2004, performance of a laser light (40 watts, 532 nm) for guiding eels at the Les Cèdres Station (located in the natural river channel of the St. Lawrence adjacent to the Beauharnois Power Canal) showed little promise because light transmitted only a short distance in the water column, most likely due to the amount of suspended particulate matter in the canal.
- During an investigation of light avoidance in 2004, researchers documented partial avoidance (33.3%) of light brighter than 100 lux using two incandescent lights (12,000 watts each) suspended 1 m above the water surface at an angle of 32 degrees.
- A preliminary study in 2011-2012 using infrasound to influence the behavior of outmigrating eels proved unsuccessful. During two trials, infrasound units were suspended in the water column and operated at 12, 12.5 and 16 Hz for designated on/off intervals. Eel behavior was monitored with DIDSON. No avoidance behavior was detected at any distance from the units.
- A 2012-2013 preliminary acoustic telemetry study of the migration pattern of silver eels in the Beauharnois Power Canal revealed that most moved rapidly straight down the canal (mean 15 hrs transit time). Maximum travel speed was estimated to be 1.3 m/s (minimum was 0.8 m/s). Most detection occurred in early August. Spatial patterns suggested that eels follow higher velocity flows. Most migration occurred at night, and a portion of downstream migrants may use the shipping canal (Beauharnois Lock) to bypass the hydro station; further study is needed to confirm these results.

The results of NYPA's and HQ's studies were used to aid in the development of NYPA's settlement for relicensing the St. Lawrence-FDR Power Project. The FERC also utilized these results in their Environmental Impact Statement for this license issuance. As part of the settlement agreement, NYPA established a Fish Enhancement, Mitigation, and Research Fund to be administered by the U.S. Fish and Wildlife Service (USFWS) to benefit fisheries resources in the Lake Ontario/St. Lawrence River Basin and to continue research on the American eel. A Fisheries Advisory Committee (FAC) acts as advisor to USFWS. In 2006, the FAC identified six key topics for investigation relating to the downstream migration of American eel. Each of the topics focuses on a particular guidance system, technology, or set of methods that could be used to pass outmigrating American eels around large hydroelectric generating stations or to study their behavior:

- the use of physical barriers to guide outmigrating eels and the feasibility of using them at Iroquois Dam;
- the use of attractants or repellents (e.g., chemicals, electrical fields, electromagnetic fields, directed flows) to guide outmigrating eels and the feasibility of using them at Iroquois Dam;
- the use of infrasound to guide outmigrating eels and the feasibility of using it at Iroquois Dam;
- the use of light to guide outmigrating eels and the feasibility of using it at Iroquois Dam;
- techniques for collecting, holding, and transporting outmigrating eels, with particular emphasis on feasibility of use in the area of Iroquois Dam; and
- the potential effects of telemetry on the migration behavior of eels and the feasibility of using telemetry or other monitoring technologies in the vicinity of Iroquois Dam to determine the effectiveness of various guidance or concentration devices.

On behalf of the FAC, NYPA issued a Request for Proposals to conduct a comprehensive, world-wide search for literature and information to gather and collate the most recent research and data pertaining to the six identified topics and to present the information in the form of a "white paper." Versar Inc. conducted the research and delivered the final white paper entitled, *Review of Technologies for Guiding, Capturing, Holding, Transporting, and Monitoring Outmigrating Eels* in July 2009 (Appendix C). This report is provided to prospective bidders as essential background information for this SOS. Bidders are encouraged to review this document to gain an understanding and appreciation for the extent of scientific information the EPRC has considered in developing its program and this SOS. Additional references listed below provide information from researchers that have previously investigated the use of three-dimensional telemetry and hydroacoustics to track and discern American eels.

Brown, L.S., A. Haro and T. Castro-Santos. 2003. Three-dimensional movements and behaviors of silver-phase migrant American eels at a small hydroelectric facility. Abstract of presentation delivered at the International Eel Symposium, 11 August 2003, Quebec, Canada.

Brown, L.S. 2005. Downstream passage behavior of silver phase American eels at a small hydroelectric facility. MS. University of Massachusetts Amherst.

Brown, L.S., A. Haro and T. Castro-Santos. 2007. Three-dimensional movement of silver-phase American eels (*Anguilla rostrata*) in the forebay of a small hydroelectric facility. *In:* Proceedings of the 2003 International Eel Symposium, American Fisheries Society Symposium Publication, Bethesda, Maryland. J. M. Casselman and D. K. Cairns, eds.

Haro, A., D. Degan, J. Horne, B. Kulik, and J. Boubee. 1999. An Investigation of the Feasibility of Employing Hydroacoustic Monitoring as a Means of Detecting the Presence and Movement of Large, Adult Eels (Genus Anguilla). Internal Report No. 99-01. Conte Anadromous Fish Research Center. Turner's Falls, MA.

Haro, A., T. Castro-Santos, L. McLaughlin, and K. Whalen. 2002. Simulation of Migration and Passage of American Eels at Riverine Barriers. American Fisheries Society. Bethesda, MD.

STUDY APPROACH

The EPRC is concerned with reducing turbine mortality among outmigrating adult eels at the Moses-Saunders Power Dam and Beauharnois Generating Station as well as conducting research that can generally advance overall knowledge concerning the behavior of downstream migrating eels. Based on previous studies of outmigrating eels on the St. Lawrence and the findings of Versar (2009), members of the EPRC have identified trap-and-transport as a preferred alternative, such that outmigrating eels would be directed to a collection point at (or above) Iroquois Dam, transported downstream and released back into the St. Lawrence below Beauharnois Generating Station. A similar program should be developed at the Beauharnois Generating Station to accommodate safe passage of the eels that do not migrate upstream past the Power Dam or those downstream migrants that escape collection at Iroquois Dam. Future studies by the EPRC will be directed toward evaluating eel behavior in response to various cues (e.g., electricity, electro-magnetic fields, velocity gradients, sound and vibration, or others not yet identified) intended to guide eels toward a collection location. It is anticipated that preliminary studies will be conducted *in situ* on a small scale or in a laboratory setting to identify potential effectiveness and determine if further study in the St. Lawrence River is warranted. If feasible and effective, guidance technologies could be deployed on a larger scale to guide eels to collection locations at Iroquois Dam or in the Beauharnois Power Canal.

The purpose of this study is to determine if existing technologies are capable of documenting relative abundance and distribution of outmigrating eels as well as the behavior of eels during outmigration. Behaviors of interest include, but are not limited to, diurnal variation of downstream movement, favored locations in River channel or the water column during migration, vertical and/or horizontal movements, reaction to physical structures such as a nose pier or water control gate, and whether eels outmigrate in groups or aggregates. In the future, if larger scale guidance devices are feasible, these technologies would be used to help determine where behavioral guidance devices should be located to target outmigrating eels and to document the behavior of outmigrating eels when they encounter the guidance device at Iroquois and Beauharnois Dams. Based on existing information, the EPRC believes that various forms of hydroacoustic technology (or multiple technologies deployed simultaneously), such as multiple beam sonar and sound-imaging sonar, currently provide the most promise to accomplish the objectives of this study, but EPRC is open to any and all technologies that show promise.

TECHNICAL WORK SCOPE

Note to Bidders: This Scope of Service was developed by the technical committee of the EPRC based on our understanding of the existing information and the technical expertise of the committee. The committee recognizes that there may be more than one approach to meeting the technical objectives of the project and Bidders are encouraged to provide alternate proposals on any component of this Scope of Services where they believe their approach would be better suited to accomplishing study objectives.

There are two study areas of interest for this project. One location is Iroquois Dam while the other location is the Beauharnois Power Canal and Generating Station. This project is intended to be a pilot study, deploying sonar technologies on a small scale to meet study objectives first in a relatively small sampling area at Iroquois Dam. If proven feasible at that location, the equipment will be moved to at least two more locations at Iroquois Dam to prove applicability at those locations as well. Collectively, results from this sequential testing approach will provide the necessary data to determine overall applicability of a technology at any location along Iroquois Dam and the information required to design a larger scale sampling system for potential future use.

While specific field testing will occur at Iroquois Dam, there is equal interest in ensuring that the system tested will also function in the Beauharnois Power Canal and at the Generating Station. Therefore, the development and testing of any system at Iroquois Dam must also consider how that system could be deployed in the Beauharnois Power Canal and at the Generating Station. The EPRC realizes that such a system would likely need to be adapted to specific conditions of the Power Canal and the Generating Station (e.g., different equipment mounting designs, more or fewer system components, etc.) but the intent is to develop a system that can be used equally well in all locations.

As a secondary objective to proving these technologies at Iroquois Dam and ensuring the feasibility of use in the Beauharnois Power Canal and at the Beauharnois Generating Station, the EPRC is also interested in determining if the data collected during testing can provide preliminary information on the relative abundance, distribution, and migratory behavior of outmigrating eels at the Dam.

TASK 1 – SYSTEM DESIGN

The successful Consultant's deliverable for Task 1will be a detailed design for a system (preferably non-invasive) to determine outmigrating eel relative abundance and distribution far-field as eels approach the Dam and the behavior of eels in the near-field of the Dam as eels pass through the gates. Detailed designs must include descriptions of the equipment that will be used, engineering designs for deployment structures that will mount on the Dam, and electrical and housing requirements to run and house equipment. *Bidders should note that engineering designs (including engineering drawings) for all devices or structures that will be attached to the Dam at any location both above and below the waterline will need to be reviewed and approved by OPG and NYPA before installation can proceed. Bidders should also note that any devices or structures mounted to the Dam cannot interfere with normal operations of the Dam.*

Bidders are required to submit in their proposal a conceptual design that will form the basis of the detailed design should their firm be awarded the project. Detailed design and deployment plans are not required for the proposal submittal but Bidders must provide sufficient conceptual design, configuration, and deployment information (including conceptual drawings or illustrations of the proposed system) for EPRI/EPRC to complete a thorough evaluation of their proposal.

The Dam is approximately 0.6 km long and consists of 32 gate structures (see Project Setting discussion, Appendix D for design information, and Versar 2009 for plan and elevation view photographs). The entire flow of the River passes through Iroquois Dam at this location except for a relatively small volume required to operate the adjoining Iroquois Lock. If a gate is in the open (raised) position at the Dam, recreational boat traffic is permitted to pass through the gate.

The sampling area for the system to be tested should be approximately 35 m wide (i.e. two gate structures wide) by 100 m long (i.e. 100 m upstream from the face of the Dam) and 13 m deep (average depth at the Dam). For purposes of this SOS, the far-field zone will be from 15 m upstream of the Dam to 100 m upstream of the Dam. The near-field zone will be from the Dam face to 15 m upstream. Desired resolution for target positioning within the far-field zone should be 2- 4 m in the horizontal direction (X, Y) and less than or equal to 1 m in the vertical direction (Z) and desired resolution for target positioning in the near-field should be less than 1 m in the horizontal direction (X, Y) and less than or equal to 0.5 m in the vertical direction (Z). **Bidders are encouraged to propose different sample areas and target positioning resolution with the understating that the EPRC would like to maximize the area that can be ensonified and collect the highest resolution data possible with minimal deployment of equipment.** Conceptual design information provided in the proposal should include but not be limited to:

- specific type of technologies that will be used including a full description of the system(s) capabilities;
- proportion of total study area that can be "covered" with the system (i.e. what proportion of the 35 m wide x 100 m long x 13 m deep area will be covered);
- anchoring and attachment devices/requirements for equipment;
- electricity and hardwiring requirements;
- on-site computers, data storage, and communications equipment (including any proposed equipment for remote communication); and
- housing requirements for on-site equipment.

TASK 2 – DEVELOPMENT OF AN EQUIPMENT DEPLOYMENT AND STUDY PLAN

The successful Consultant will develop an equipment deployment plan and a detailed study plan for review prior to field activities beginning. The equipment deployment plan will be required for installation of equipment on the Dam and will be reviewed and approved by OPG and NYPA. The study plan will define sampling activities and will be reviewed and approved by the

EPRC. For the deployment plan, Bidders should include in their proposal the logistics they will consider and how they would approach installation of the equipment at the Dam. Bidders are encouraged to submit examples of similar plans they have developed or describe specific circumstances where they have conducted similar work. For the detailed study plan, Bidders should include in their proposal approaches/methods they will use to groundtruth and/or verify accuracy of data and validity of target identification, sampling schemes and schedules (see Task 3 for timing of field operations) necessary to prove the technology at three locations at the Dam, data reduction and analysis methods, how they will determine, with certainty, if the technology can be reliably scaled up to a larger deployment, and how they will analyze the data to determine if any preliminary patterns on downstream eel migration are evident.

TASK 3 – FIELD OPERATIONS

Note to Bidders: Iroquois Dam is a working water control structure with mechanical and electrical hazards on deck. In addition, current velocity in the vicinity of the Dam and through the gate structures can approach 2.0-2.5 m/s under some conditions, creating significant boating hazards and difficulties in deployment of equipment above and below the waterline. ***Safety is of the utmost importance to EPRC, OPG, and NYPA.*** *The Consultant will be required to develop a safety plan for work on the Dam and for work from a boat (if required). The plan will be reviewed by OPG and NYPA and must be strictly adhered to at all times. Safety violations could result in the Consultant's employees being restricted from access to the site and repeated violations could result in termination of all site work.*

Bidders must describe in their proposal how they will execute the study plan developed in Task 2 in a cost effective and efficient manner. Proposals must clearly detail the specific responsibilities for each member of the field crew and their capabilities and experience in conducting their assigned tasks. The majority of testing must be conducted between mid-July and mid-September, which coincides with the peak of outmigration activity in this portion of the River. Installation, groundtruthing or target verification, and demobilization activities can occur outside this time window but proving the feasibility of the technology to monitor outmigrating eels must occur at this time. Bidders should note that preliminary information on migration of eels in this portion of the River collected during NYPA's light study indicates that eels appear to migrate alone or at least not in close proximity to one another when multiple eels are migrating at the same time. This, coupled with decreasing abundance of outmigrants and a large study area, may make target acquisition a challenge.

TASK 4 – PROJECT COORDINATION AND UPDATES

SUBTASK 4.1 - KICKOFF MEETING

The Consultant's Project Manager and key team members of the Consultant's Team will be required to attend a one-day kickoff meeting to discuss the study scope, schedule, communication protocols, and overall general approach. The meeting is expected to occur in April 2014 and could be held in northern New York (Massena) or southern Canada (a likely location would be Cornwall, Ontario). A site visit to the Dam is expected to occur during the kickoff meeting.

SUBTASK 4.2 – PROJECT UPDATES

Throughout this study, the Consultant will be required to participate in periodic progress updates. The updates will be in the form of a short written report and a teleconference (video conference or web meetings could be used as well). Updates will occur weekly during field operations, biweekly during planning phases, and monthly during other portions of the study. Updates will consist of reviewing study activities and data collected since the preceding update, planning upcoming study tasks, and resolving difficulties encountered during the study. The written report must be submitted one day prior to the teleconference and will be used to guide discussion. Teleconferences are expected to be 1 hour long, and Bidders should anticipate a total of 12 progress reports and conferences during the course of the project.

TASK 5 – PRESENTATION OF FINDINGS

The Consultant must provide the EPRC with preliminary findings and conclusions of the research within 40 calendar days of the end of field operations. The Consultant will present the findings and conclusions to the EPRC at a meeting in northern New York (Massena) or eastern Ontario (a likely location is Cornwall, Ontario) in December 2014 (tentatively December 9 or 10). Bidders should anticipate the preparation of a detailed presentation for the meeting including the results of field testing, data analyses, videos, pictures, and other media to convey study results and activities. Bidders should also anticipate that significant portions of the presentation and the effort required to develop the presentation can be used in development of the Comprehensive Report (Task 6).

TASK 6 – REPORTING

The Consultant must provide a comprehensive report that summarizes and synthesizes all important and relevant findings of the study and describes and illustrates the experimental set-up and testing protocols for the project.

The comprehensive report shall be delivered in four phases: an annotated outline, a Draft Report, a Preliminary Final Report, and a Final Report. The annotated outline must detail the contents of each major section and subsection of the report. The EPRC will review the outline and provide comments and direction for changes of organization and potential analysis approaches. The Draft Report must be as close to Final Report quality as possible, including all tables, figures, maps, or other graphics. EPRI will review the Draft Report and provide edits and comments. The Consultant will incorporate the edits and comments as appropriate and provide a Preliminary Final Report for review by partners of the EPRC. The Consultant will incorporate the edits and comments as appropriate and provide the Final Report to EPRI for distribution at its discretion.

The EPRI anticipates developing a SharePoint (or similar) type website where the Consultant can submit electronic copies of all reports, data, illustrations, and video and photographic documentation. All versions of the report will be submitted in the form of electronic media in accordance with the EPRI format required at the time of the report preparation. The current format is available at: http://contractor.epri.com. All electronic files must be checked for viruses and must be accompanied by a hard-copy printout to be used by EPRI for verification purposes only. Failure to comply with report preparation requirements will be corrected by the Consultant at its sole expense. If engineering drawings (PE stamped as well as non-stamped) are required for facility structure or facility component design and fabrication, the Consultant will be required to submit one, full-size hardcopy of any design drawings, redline mark-up drawings, and As-Built drawings as well as electronic versions in pdf and dwg format.

Note to Bidders: Bidder should be aware that all information, data, findings, conclusions, engineering designs, specifications, calculations, and reports arising from all aspects of this study will be the property of EPRI and EPRC. Distribution, reuse, and dissemination of information of any kind for whatever reason will be at the sole discretion of EPRI and EPRC. Please see EPRI Terms and Conditions in Appendix B for a clear definition of intellectual property, ownership, license grants, restrictions, and title for all information and work products arising from this project.

TASK 7 – DATA MANAGEMENT AND QUALITY ASSURANCE/QUALITY CONTROL

Accurate collection of data, transcription of raw data into electronic format, management and maintenance of data files, security, and safety of data files, and documentation of study activities will be essential to ensure study quality, repeatability, and potential scalability for future use in larger applications. Bidders' proposals must describe in detail how field and laboratory data will be recorded, what methods that will be used to ensure greater than 98% transcription accuracy of raw data, how data files will be named and organized, and how data (including electronic files, video, still picture documentation, and field notes) will be protected from loss (misplaced, theft, fire, flood, or other risks). In addition, Bidders must describe a quality assurance/quality control program that ensures the highest quality data possible. The program must include steps (including verification and documentation of training) for assuring that all members of field or laboratory crews are qualified to perform assigned duties and are performing their duties according to standard procedures.

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SCHEDULE

It is the intent of EPRC to complete the majority of this work by the end of 2014. Information from this study will play an important role in planning and decision making for activities in 2015 and beyond. Bidders can propose an alternate schedule but justification for the changes, including an explanation of how the alternate schedule will be of significant benefit to EPRC's overall program objectives must be provided by the Bidder.

MILESTONE	COMPLETION DATE
Pre-bid Teleconference	March 12, 2014
Inquiries/Technical Questions Due	March 14, 2014
Proposal Due Date	March 26, 2014
Contract Award	April 9, 2014
Kick-off Meeting	April 2014
Annotated Outline	September 5, 2014
Complete Field Operations	October 3, 2014
Draft Report	November 15, 2015
Presentation of Preliminary Findings at Meeting	December 9 or 10, 2014
Preliminary Final Report	January 23, 2015
Final Report	February 20, 2015

COST

Bidders must submit a detailed cost break down of all labor, expenses, equipment purchase and rental, and other costs anticipated to complete their proposed Scope of Services. Costs should be presented by major tasks and subtask detailing both person-hours and expenses. Work will be conducted on a Time and Materials Cost Not-To-Exceed basis. Additional explanation for submittal of costs is provided in the Instruction to Bidders as part of the RFP package.

CORRESPONDENCE

During the course of this work, all correspondence and questions regarding work schedules, project updates, communications concerning delays or problems in conducting the scope, reports, etc. should be addressed to EPRI's Project Manager listed below. Delivery of reports as detailed in this RFP should be addressed only to EPRI's Project Manager.

Dr. Paul Jacobson
Project Manager
Electric Power Research Institute
14820 View Way Court
Glenelg, MD 21737
(410) 489-3675
pjacobson@epri.com

APPENDIX A

RFP DISTRIBUTION LIST

RFP Distribution List

Company	Contact	E-mail
AECOM	Valérie Tremblay	valerie.tremblay@aecom.com
Aquacoustics	Don Degan	djdegan@aquacoustics.com
ASI Group	Carmen Sferrazza	carmen@asi-group.com
Biosonics, Inc.	James Dawson	jdawson@biosonicsinc.com
Blue Leaf Environmental	Mark Timko	mtimko@blueleafenviro.com
Environnement Illimité, Inc.	Marc Gendron	marc.gendron@envill.com
Golder Associates	Kevin Trimble	Kevin_Trimble@golder.com
Hatch	Trion Clarke	tclarke@hatch.ca
Hydroacoustic Technology, Inc. (HTI)	Patrick Nealson	pnealson@htisonar.com
Kongsberg Underwater Technology, Inc.	Jeff Condiotty	jeff.condiotty@kongsberg.com
Lotek Wireless, Inc.	Donna Kehoe	dkehoe@lotek.com
Milieu, Inc.	Denis Desrochers	denis.desrochers@milieuinc.com
Milne Technologies	Scott W. Milne	info@milnetechnologies.ca
Normandeau Associates, Inc.	Timothy Brush	tbrush@normandeau.com
Normandeau Associates, Inc.	Maryalice Fischer	mfischer@normandeau.com
Pacific Northwest National Laboratory (PNNL)	Kenneth D. Ham, Ph.D.	kenneth.ham@pnnl.gov
ProFish Technology SA	Damien Sonny, Ph.D.	D.Sonny@profish-technology.be
SENES Consultants Limited	Paul Patrick, Ph.D.	ppatrick@senes.ca
St. Lawrence River Institute of Environmental Sciences	Matt Windle	mwindle@riverinstitute.ca
Turnpenny Horsfield Associates Ltd	Andy Turnpenny, Ph.D.	andy.turnpenny@thaaquatic.com
U.S. Fish and Wildlife Service (USFWS)	Kurt Steinke	kurt_steinke@fws.gov
Versar	H. Ward Slacum, Jr.	wslacum@versar.com
Versar, Inc.	Mark Southerland	msoutherland@versar.com
W.F. Baird & Associates Coastal Engineers, LTD	Derek C. Williamson, P.E.	dwilliamson@baird.com
WSP Group (Genivar)	Ann Rocchi	Ann.Rocchi@genivar.com
WSP Group (Genivar)	Jean Therrien	jean.therrien@genivar.com

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APPENDIX B

EXAMPLE EPRI SOURCING AGREEMENT

- **EPRI STANDARD TERMS AND CONDITIONS (ATTACHMENT A)**
- **EXAMPLE STATEMENT OF WORK (ATTACHMENT B)**

ELECTRIC POWER RESEARCH INSTITUTE, INC.

EXAMPLE - SOURCING AGREEMENT

<%Agreement.VendorName%>

<%Agreement.ID%>

"«TITLE»"

This SOURCING AGREEMENT (including this document, the EPRI Terms and Conditions (Attachment A), and all other referenced attachments, the “Agreement”) is entered into on the Effective Date by and between EPRI and the contractor identified below (“Contractor”):

1. PARTIES:

Electric Power Research Institute, Inc. (“EPRI”)
3420 Hillview Avenue
P.O. Box 10412
Palo Alto, California 94303

<%Agreement.VendorName%>
<%Vendor.OrderAddr1%>
<%Vendor.OrderCity%> <%Vendor.OrderState%>
<%Vendor.OrderZipCode%>

2. STATEMENT OF WORK

The Statement of Work is included in this Agreement as Attachment B incorporated into and made an integral part of this Agreement.

3. PERIOD OF PERFORMANCE
The Period of Performance will begin on «POPSTART», or the last date of execution, whichever is later (“Effective Date”), and will end on «POPEND».

4. COST TYPE: This Agreement is <<Cost Reimbursable (“CR”)>> <<Time and Materials (“T&M”)>> <<Fixed Price (“FP”)>>.

5. FUNDING

5.1 Contractor will be paid on a cost reimbursement basis. The Contract Cost Limitation (“CCL”) is $«CCL» and consists of the estimated costs and fee as shown in the attached Form 112 (Attachment C).

5.1 Contractor will be paid on a time and material basis. The Contract Cost Limitation (“CCL”) is $«CCL» and consists of the estimated costs as provided in the attached Form 112 (Attachment C). Labor rates are fixed for the duration of the Agreement and are applicable to Contractor employees only.

5.1 Contractor will be paid on a fixed price basis. The fixed price is «CCL» and milestone payments will be made in accordance with the following Milestone Schedule.

ELECTRIC POWER RESEARCH INSTITUTE

Milestones Schedule:		
Milestone Description	**Due Date**	**Milestone Payment**

5.2 COMMITTED FUNDS LIMITATION

EPRI has committed $«curyearcmt» for the Work in calendar year <<year>>. This is the total amount Contractor is authorized to expend in that year until notified of additional commitments. Unless otherwise notified by EPRI, the Contractor may carry forward any unexpended Committed Funds into succeeding years. Additionally, unless otherwise notified by EPRI, effective January 1 of each succeeding calendar year during the Period of Performance, EPRI hereby commits the following amounts:

Year	Committed Funds
	$«curyearcmt2»

EPRI anticipates that it will commit funds for succeeding calendar years during the Period of Performance in the following amounts and will notify the Contractor of such commitments.

Year	Anticipated Funds
	$

5.3 INVOICING AND PAYMENT.

All invoices will reference the Agreement number <%Agreement.ID%> and will be either electronically transmitted to EPRIinvoices@epri.com or mailed to EPRI at the following address by the 15th of each month:

Electric Power Research Institute, Inc.
Attn: Accounts Payable
3420 Hillview Avenue
Palo Alto, CA 94303-1338

Do not submit to multiple locations to ensure timely processing of the invoice.

5.4 CONTRACTOR COST PERFORMANCE REPORT ("CCPR")

5.4.1 The Contractor Cost Performance Report ("CCPR") will be used by EPRI to measure Contractor's financial performance under this Agreement. The CCPR is to be completed in accordance with the requirements set forth in the enclosed CCPR form.

5.4.2 The CCPR will be submitted within fifteen (15) days from receipt of the Executed Agreement or Letter Agreement. The "Initial Forecast" will cover the period of performance of the Agreement.

5.4.3 A CCPR is required when the CONTRACTOR Cost Limitation equals or exceeds $75,000 and a period of performance that continues for six months or longer. Thereafter it will be required for the duration of the Agreement. Additionally, a CCPR is required if specified as a deliverable in the "Delivery Schedule" section of the Agreement.

5.4.4 FAILURE TO COMPLY with the reporting requirements within 60 days will result in the delayed processing of Contractor invoices.

5.4.5 Contractor **SHALL EMAIL** the CCPR to EPRI at CCPR@epri.com **AND** to the EPRI Project Manager. Questions regarding the CCPR requirements should be directed to the CCPR desk, (650) 855-2016.

6 DELIVERABLES AND DELIVERY SCHEDULE

All Deliverables will be sent to the EPRI Project Manager unless noted otherwise below:

TECHNICAL REPORT SUMMARY

Technical Status Reports	By the 15th of the following month
Interim Reports	
Draft Final Report *****	Sixty (60) days prior to expiration of the Agreement.
Final Report *****	Upon the completion or termination of the Work.

***Copy of transmittal letter (or e-mail) will be sent separately to the Contract Negotiator.**

FINANCIAL REPORTS

CONTRACTOR Cost Performance Report (Not applicable at this time)	Initial forecast 15 days after contract thereafter by the 15th of each month.
Indirect Rate Report	To EPRI Corporate Audit Manager no later than 120 days following CONTRACTOR's fiscal year in which the rates are claimed.

7. TECHNICAL REPORTS

EPRI interim and final reports prepared by the Contractor under this Agreement will be submitted to EPRI in the form of electronic media in accordance with the EPRI format required at the time of the report preparation. The current format is available at: http://contractor.epri.com or contact the Project Manager. The electronic files will be virus checked and must be accompanied by a hard copy printout to be used by EPRI for verification purposes only. Failure to comply with report preparation requirements will be corrected by Contractor at its sole expense.

8. SOFTWARE DELIVERABLES AND QUALITY STANDARDS (**OPTIONAL – AS REQUIRED)** Computer software is a deliverable under this Agreement. The Software Quality Requirements applicable to this Statement of Work are set forth in “EPRI SOFTWARE DEVELOPMENT GUIDELINES” located at: http://mydocs.epri.com/docs/SDRWeb/processguide/index.html and in Attachment C and are hereby made a part of this Agreement. Questions should be directed to the EPRI Software Quality staff at phone: (650) 855-7931. The EPRI Software Quality Manager will approve selection of all Contractor software subcontractors prior to beginning software development. The EPRI Software Development Guidelines will flow down to these subcontractors.

9. EPRI PROJECT MANAGER

The EPRI Project Manager is «pmgr» and may be reached at «PMGRPHONE».

10. CONTRACTOR KEY PERSONNEL

«KEYPERSON» is the Key Person for the work performed under this Agreement.

11. NOTICES:
All notices or communications required or permitted under this Agreement will be in writing and personally delivered or sent by registered or certified mail or by facsimile transmission to the address of each party as set forth below, or to such other address as either party may substitute by written notice to the other in the manner expressly provided for herein.

Electric Power Research Institute, Inc.
PO Box 10412, Palo Alto, CA 94303-0813
3420 Hillview Avenue, Palo Alto, CA 94303
Phone/Fax: <%CurrentUser.Phone%>

<%Agreement.VendorName%>
<%Vendor.OrderAddr1%>
<%Vendor.OrderCity%>
<%Vendor.OrderState%>
<%Vendor.OrderZipCode%>
Phone/Fax No.: ______________________

12. FINAL RELEASE
Upon completion of the Work and EPRI's acceptance of the final deliverables or termination of this Agreement, the Contractor will provide a mutually acceptable release to EPRI of all contract claims and obligations except for the provisions of the Sourcing Terms and Conditions: Article 5 (License Grant, Restrictions, and Title), Article 7 (Confidentiality), Article 8 (Representations and Warranties), Article 10 (Indemnification), Article 12 (Dispute Resolution) and Article 13 (Miscellaneous).

13. EXECUTION

This Agreement represents the entire agreement between the parties and supersedes all prior and contemporaneous agreements and understandings (oral and written) with respect to the matters covered by this Agreement. Neither party has entered into this Agreement based on representations other than those contained in this Agreement. This Agreement may be amended only by a written agreement signed by all parties. This Agreement may be executed in counter-parts. Each party represents and warrants that the person signing this Agreement on such party's behalf has been duly authorized and empowered to enter into this Agreement.

IN WITNESS WHEREOF, the parties hereto have caused this Agreement to be executed by their duly authorized representatives:

<%Agreement.VendorName%> **ELECTRIC POWER RESEARCH INSTITUTE, INC.**

By:	**By:**
Print Name:	**Print Name:**
Title:	**Title:**
Date:	**Date:**

ATTACHMENT A
SOURCING TERMS AND CONDITIONS

ARTICLE 1 – Definitions

1.1 "Background Intellectual Property" means a Party's Intellectual Property (including inventions, original works of authorship or trade secrets) existing prior to the commencement of any Work under this Agreement or a Party's Intellectual Property existing during performance of the Work under this Agreement, but owned or developed separate from the Work under this Agreement and without the use of the other Party's Intellectual Property.

1.2 "Change Notice" means a unilateral written notice issued by EPRI to change a term in the Agreement or directing the Contractor to take an action not required by the Agreement.

1.3 "Confidential Information" means any information which is confidential in nature and which does not include information that: (i) is or becomes generally available to the public through no act or omission of the receiving party; (ii) was in the receiving party's lawful possession prior to the disclosure as evidenced by written records and had not be been obtained, directly or indirectly, from the disclosing party; (iii) is lawfully disclosed to the receiving party by a third party without restriction on disclosure; or (iv) is independently developed by the receiving party without access or reference to the disclosing parties information as evidenced in written records, or (v) is disclosed by operation of law.

1.4 "Contract Cost Limitation" means the maximum amount that EPRI will be obligated to pay Contractor for the performance of the Work.

1.5 "Deliverables" means the version of Research Results and/or EPRI Materials to be delivered under this Agreement or any amendment thereto.

1.6 "Derivative Works" means any form into which Research Results may be recast, transformed or adapted including the modification, revision, condensation, translation, abridgment and/or expansion of EPRI Materials.

1.7 "EPRI Materials" means, without limitation, all data, documents, machine readable software ("Object Code"), human readable software ("Source Code") (collectively, "Software") owned by EPRI as of the effective date of this Agreement and/or any amendment thereto.

1.8 "Foreground Intellectual Property" means a Party's Intellectual Property developed in the performance of any Work under this Agreement.

1.9 "Intellectual Property" means a Party's patent, copyright, trademark, trade secret or other rights.

1.10 "Permitted Subcontractors" means Contractor's subcontractors, consultants and other EPRI authorized third parties who, in connection with the Work, have executed a non-disclosure agreement with Contractor, which includes requirements for Contractor to protect EPRI Materials and Research Results at a level no less protective than required by this Agreement. Non-disclosure agreement(s) will be made available within thirty (30) days of EPRI's written request.

1.11 "Research Results" means all tangible and intangible results developed, conceived, procured and/or first reduced to practice by Contractor in the course of performing the Work including, without limitation, any real, personal and/or intellectual property rights, Derivative Works, Deliverables, or inventions, discoveries, Software, books, records, reports, notes, computations, analysis, photographs, or samples.

1.12 "Third Party Intellectual Property" means intellectual property owned by a person or entity other than EPRI or the Contractor.

1.13 "Work" means all research, development, and other services required to be performed by Contractor with the Attachment B SOW under this Agreement.

ARTICLE 2 - Fees and Payment

2.1 Fees. Subject to the terms of this Agreement, EPRI will pay Contractor the amounts described in this Agreement. Any fee rates described herein will be fixed for the duration of the Agreement.

2.2 Limitations. EPRI will not be obligated to pay Contractor in excess of the Contract Cost Limitation under any circumstances. Contractor will notify EPRI in writing at any time Contractor has reason to believe its costs will exceed the Contract Cost Limitation.

2.3 Cost Reimbursable. If, and only if, the cost type of this Agreement is designated as Cost Reimbursable, this Article 2.3 will apply.

(a) EPRI will not be obligated to pay Contractor (1) in excess of the Contract Cost Limitation under any circumstances, and/or (2) in excess of the annual Committed Funds Limitation for any calendar year. Payment will be made for costs properly incurred per the following EPRI policy entitled, "Cost Reimbursement Contracts: Allowable and Unallowable Costs", located at www.epri.com. If Contractor does not submit its proposed final indirect rates to EPRI's Audit Department at IndirectRates@epri.com within one hundred and twenty (120) days after the expiration of Contractor's fiscal year, the lower of provisional indirect rates used for billing or actual indirect rates will be considered Contractor's maximum billing rates for reimbursement purposes of indirect cost.

(b) If the Contract Cost Limitation is more than $50,000, Contractor will notify EPRI in writing whenever it has reason to believe that the costs it expects to incur in the sixty (60) days, when added to costs previously incurred, will exceed seventy-five (75) percent of the Contract Cost Limitation. If Contractor is unable to complete the work for the Contract Cost Limitation, EPRI and Contractor may agree to (i) an increase in the Contract Cost Limitation; (ii) a de-scope of the remaining Work; or (iii) termination of the Agreement pursuant to Subarticle 11.2.

(c) Contractor will invoice EPRI on a monthly basis by the 15th day of each succeeding month. The invoice will indicate Contractor cost sharing (if any). Each invoice will show the period of time covered by the invoice, cumulative expenditures through the current billing period, expenditures for the specific billing period and an itemized statement of direct and indirect costs in at least the same level of detail as set forth in the Form 112 attached hereto as Attachment C.. Contractor's final invoice will be submitted no later than one (1) year after written acceptance of the final Deliverable by EPRI or termination of the Work. After this date, EPRI will be under no further obligation to make payments to Contractor.

2.4 Time and Materials. If, and only if, the cost type of this Agreement is designated as T&M, this Article 2.4 will apply.

(a) The rates specified in the Funding Section are inclusive of all labor charges, indirect costs, and fees and are fixed for the duration of the Agreement. Allowable direct costs will be billed as actual, unburdened costs.

(b) Contractor will provide written documentation of all direct labor hours and costs upon EPRI's request. Contractor will maintain documentation of all costs and will provide written documentation supporting of all Contractor costs upon EPRI's request.

(c) Contractor will invoice EPRI on a monthly basis by the 15th day of each succeeding month. Invoice will indicate Contractor cost sharing (if any) and provide a detailed statement of labor hours incurred along with any EPRI authorized direct charge(s). Contractor's final invoice will be submitted no later than ninety (90) days after written acceptance of the final Deliverable by EPRI or termination of the Work. After this date, EPRI will be under no further obligation to make payments to Contractor.

(d) If the Contract Cost Limitation is more than $50,000, Contractor will notify EPRI in writing whenever it has reason to believe that the costs it expects to incur in the sixty (60) days, when added to costs previously incurred, will exceed seventy-five (75) percent of the Contract Cost Limitation. If Contractor is unable to complete the work for the Contract Cost Limitation, EPRI and Contractor may agree to (i) an increase in the Contract Cost Limitation; (ii) a de-scope of the remaining Work; or (iii) termination of the Agreement pursuant to Subarticle 11.2.

2.5 Fixed Price. If, and only if, this Agreement is designated as Fixed Price, this Article 2.5 will apply.

(a) Contractor will invoice EPRI upon successful completion and approval by EPRI of the milestones.

(b) EPRI will not have the right to audit Contractor under this Article 2 unless otherwise noted herein.

2.6 Travel. EPRI will reimburse Contractor for all reasonable travel and living expenses incurred by Contractor in performing Work pursuant to this Agreement, provided Contractor proposes and receives prior written consent from EPRI prior to incurring such expenses. Personal car expenses will be reimbursed at the then-current IRS rate per mile. Airfare will be reimbursed up to coach fare basis only. Copies of all travel tickets and related travel expenses are required for reimbursement of travel costs.

2.7 Audit. EPRI may audit Contractor records specifically related to this Agreement no more than once a year, and the latter of once within the third year following final payment or third year after the period of performance end date under this Agreement, at EPRI's expense, and with fifteen (15) days prior written notice. In the event the audit reveals paid unallowable costs, non-reimbursable costs or other overages, EPRI will notify Contractor in writing of such amount(s) and Contractor will within thirty (30) days refund said amount(s) to EPRI. If no refund has been received after thirty (30) days has expired, EPRI may withhold or offset other payables to Contractor under this Agreement or any other Agreement or future Agreement for the amount(s) due, if such amount(s) exceed five percent (5%) of the amount(s) paid by EPRI during the relevant period and Contractor will reimburse EPRI for its costs related to the audit.

2.8 Reports. Contractor will from time to time (as specified in this Agreement or the SOW, or if not so specified, at least monthly) during the term of this Agreement or any extension thereof keep EPRI advised as to Contractor or Contractor's employee's progress in performing the Work hereunder and that Contractor will, as requested by EPRI, prepare written reports with respect thereto, including but not limited to administrative/financial reports as may be set forth in the SOW or required by the EPRI Contact Person.

ARTICLE 3 - Contractor Duties

3.1 General. Contractor will perform the Work on the terms set forth under this Agreement.

3.2 Report Income. Contractor will report as income all compensation received by Contractor pursuant to this Agreement and will pay all self-employment and other applicable taxes thereon in a timely manner. If requested by EPRI, Contractor will provide copies of tax statements.

3.3 Standard of Care. Contractor and Contractor's Employees agree to perform Work with a standard of care, skill and diligence normally provided by a professional person in the performance of services of the type rendered hereunder.

3.4 Safety. Contractor, Contractor's Employees and other individuals working under the direction of the Contractor agree to perform Work in a safe, workmanlike manner and in compliance with all customary safety practices and in accordance with all State, Federal and local laws, ordinances and regulations. If the Work is done on a third party site, Contractor will be responsible for signing and complying with Site Access Agreements with that third party, if any.

3.5 Subcontract and Consultant Flow-Down Requirements. Contractor will ensure that it has a written agreement with each of its subcontractors involved in performing the Work. Except as otherwise authorized in writing by EPRI, the Contractor will assure that the provisions in this Agreement are inserted in all agreements Contractor has with each of its subcontractors involved in performing the Work so that the provisions are applicable to each subcontractor and its employees.

3.6 Additional Duties. Contractor will: (i) promptly notify the EPRI Project Manager ("PM") in writing of any technical, financial, or legal issue which may affect the Work adversely; (ii) promptly notify EPRI Contract Negotiator in writing of any contractual issues, schedule delays or potential or actual legal claims; (iii) assist EPRI, at EPRI's expense, to perfect EPRI's rights in EPRI Materials and/or Research Results; (iv) refer all media inquiries regarding this Agreement to the EPRI PM; (v) utilize the Discovery Disclosure Form located at www.epri.com to provide prompt written notice to EPRI Legal regarding any invention or discovery made, conceived, or first reduced to practice by Contractor or Permitted Subcontractors; (vi) ensure that qualified women, minorities and disabled veteran business enterprises have maximum practicable opportunities for any resulting subcontract or purchasing awards; and (vii) in the event Contractor observes or is asked to do something which the Contractor considers as unethical or illegal, Contractor is required to notify EPRI via its Corporate Responsibility HOTLINE at (800) 826-6762 or any successor number that EPRI provides to Contractor in writing.

ARTICLE 4 - Contractor Changes

4.1 Changes. EPRI may, at its sole discretion, modify, stop, and/or cancel the Work under this Agreement and/or reassign its personnel through the issuance of a Change Notice to the Contractor. As appropriate, EPRI will equitably adjust the Contract Cost Limitation. Contractor will have thirty (30) days from receipt of the Change Notice to submit a written request for adjustment. Contractor will notify EPRI of any circumstance(s) which it becomes aware of that would require the issuance of a Change Notice. Contractor will be required to continue to perform the Work unless EPRI has issued a stop work or termination notice.

ARTICLE 5 - License Grant, Restrictions, and Title

5.1 Contractor License. EPRI grants Contractor a limited, revocable, royalty-free, nonexclusive, nontransferable license to reproduce and use the EPRI Materials specifically identified in the Attachment B, SOW, or any amendment to this Agreement, only in the performance of Work under this Agreement and not for the benefit of any third party. Release of EPRI Materials to Contractor is subject to Export Control review and clearance by EPRI. Contractor will have no right to distribute, sublicense, sell, lease, rent, or otherwise commercialize EPRI Materials or EPRI Intellectual Property Rights. Within thirty (30) days of the date of termination or the natural expiration of this Agreement, Contractor agrees to return all copies of the EPRI Materials to EPRI and/or erase all electronic copies from Contractor computers, servers, or hand-held devices. If Contractor erases or destroys the EPRI Materials, Contractor will certify the destruction in writing by a duly authorized representative of Contractor.

5.2 Contractor License Restrictions. Notwithstanding the License granted in Subarticle 5.1, Contractor will not, without EPRI's prior written consent or as otherwise expressly permitted by this Agreement, directly or indirectly:

(a) include any Third Party Intellectual Property within the Research Results or Deliverables without first granting to or obtaining for EPRI a nonexclusive, royalty-free, paid-up, irrevocable, perpetual, world-wide unrestricted license, with the right to grant sublicenses to exercise all rights in, all and any such Third Party Intellectual Property;

(b) disclose to or permit the use of EPRI Materials, EPRI Intellectual Property or Research Results by any third party;

(c) claim any interest in, or take any actions inconsistent with EPRI's interests in EPRI Materials, EPRI's Intellectual Property or the Research Results;

(d) prepare or have prepared Derivative Works;

(e) reverse engineer or use any other method to obtain the Source Code version of any EPRI Materials or EPRI's Intellectual Property rights;

(f) install or use any Source Code which may be provided hereunder on any computer system other that as expressly permitted in the Agreement;

(g) use any EPRI Materials to create materials the same as or substantially similar to EPRI Materials;

(h) remove, alter or otherwise obscure any EPRI proprietary rights notices from EPRI Materials, EPRI's Intellectual Property, or Research Results.

5.3 Title. Except for rights expressly granted in this Article, EPRI will retain all right, title and interest in the Research Results, EPRI Materials and EPRI Intellectual Property, and Contractor waives any and all interest or ownership right(s) therein. Further, EPRI reserves all rights and remedies under copyright, trademark, patent, service mark, trade secret, unfair competition and other applicable laws.

(a) EPRI will own, and Contractor hereby assigns, transfers and conveys to EPRI in perpetuity all right, title , and interest in and to Foreground Intellectual Proeprty and Research Results, and all intellectual property rights with respect thereto.

(b) Assistance. Contractor agrees to execute such documents, render such assistance, and take such other action as EPRI may request, at EPRI's expense, to apply for, register, perfect, confirm, enforce and protect EPRI's rights in the Technology.

(c) Copyright Notices. Contractor agrees that EPRI may apply copyright notices to all copyrightable items of Foreground Intellectual Property and Research Results, indicating EPRI's ownership of the copyrights in the item, using the following form:

> © Copyright 20_ Electric Power Research Institute, Inc., All Rights Reserved". The year in the notice will be the first year of publication or, if unpublished, the year in which the item was completed.

(d) Notice of Inventions and Discoveries. Whenever any invention or discovery is made, conceived or first reduced to practice by Contractor or Contractor's Employees or subcontractors (if any) in the performance of this Agreement, Contractor will promptly furnish EPRI with complete information thereon in a format acceptable to EPRI including, without limitation, a written description thereof giving the date of invention and names of the inventors and others involved in its development.

(e) Agreements with Employees. Except as otherwise authorized in writing by EPRI, Contractor will obtain written agreements with Contractor's Employees (if any) as necessary to effectuate the purposes of this Agreement.

(f) No Claim. Contractor agrees that it will not assert or establish or assist any third party with respect to any claim for intellectual property rights inconsistent with those granted to EPRI herein.

(g) Contractor's Rights. Except as expressly authorized in writing by EPRI, Contractor will have no rights to use, sell, distribute, publish, reproduce, modify, create derivative works of, make, or have made the Foreground Intellectual Property or Research Results.

5.4 EPRI License. Contractor grants to EPRI (or its designees) a nonexclusive, perpetual, royalty-free, worldwide, unrestricted, sublicensable, irrevocable license to exercise all rights in any and all Contractor Background Intellectual Property included in the Research Results or that are necessary for the exercise of any rights in the Research Results.

5.5 Computer Programs. Contractor agrees that any computer programs and related software delivered to EPRI under this Agreement will be checked by Contractor to determine if it is free of viruses that are detectable using accepted industry practice at the time of delivery to EPRI. In addition, any such software delivered to other organizations, including but not limited to other EPRI contractors and electric utility companies, will also be checked by Contractor to determine if it is free of such viruses. Contractor will label all software and other electronic media with the date and method used to check for virus contamination and prior to delivery to EPRI or other organizations promptly replace any such software found to contain virus contamination as of that time with the software free of known viruses.

ARTICLE 6 - Property

6.1 Property. No equipment will be purchased with EPRI funds, nor will any improvement, modification or construction of real or personal property be made with EPRI funds unless such purchase or expenditure has been previously and specifically approved in writing by EPRI. Except in unusual circumstances, authorization for such purchases will not be granted. However, any equipment that is purchased pursuant to this Article will be used only for the performance of the Work.

6.2 Title and Insurance. Title to all property (including rights in intangible property such as software), which is purchased with EPRI funds during the performance of this Agreement, will vest at the time of acquisition in EPRI, and Contractor hereby assigns and agrees to assign such property and all related warranties to EPRI. Contractor will identify, maintain and dispose of EPRI property as instructed by EPRI. Contractor is liable for and will exercise due care of the EPRI property while in Contractor's possession, including carrying proper insurance for the property where necessary.

6.3 Identification. The Contractor will keep a list of all property that has a unit cost of $1,000 or more, or a lower amount if specifically requested by EPRI, for delivery to EPRI within 60 days upon completion of the Work or upon termination of this Agreement.

ARTICLE 7 - Confidentiality

7.1 Confidential Information. The parties agree that all EPRI Materials, Research Results, and EPRI Intellectual Property comprise Confidential Information. All information considered Confidential Information by Contractor must, prior to disclosure, (i) be labeled as "Confidential" or otherwise clearly identified as confidential, or (ii) if disclosed orally, be identified as confidential at the time of disclosure, and be reduced to writing, marked as "Confidential" and delivered to EPRI within twenty (20) days of such disclosure.

7.2 Protection of Confidential Information. The parties agree to protect each other's Confidential Information (including EPRI Materials) in perpetual confidence at a level no less protective than accorded their own Confidential Information. Disclosure of Confidential Information by Contractor will be strictly limited to Contractor's employees, Permitted Subcontractors, and governmental agencies for regulatory compliance purposes, on a need-to-know basis only, and subject to the execution of a non-disclosure agreement citing industry-wide accepted standards for the protection of Confidential Information. Upon EPRI's request, a copy of this non-disclosure agreement will be promptly provided by Contractor. Either party may disclose Confidential Information of the other party to the extent required by law.

7.3 Protection of Third Party Confidential Information. Contractor agrees to hold Confidential Information of a third party disclosed by EPRI in accordance with the requirements of Subarticle 7.2 above. Notwithstanding the foregoing, Contractor may only disclose such third party Confidential Information to only its employees on a need-to-know basis and subject to terms of confidentiality, which protect the third party Confidential Information equally as protective as this Agreement. Any disclosures by Contractor to persons other than Contractor's employees will only be permitted with EPRI's prior written consent.

ARTICLE 8 - Representations and Warranties

8.1 EPRI Warranty. EPRI represents and warrants that it has the right and power to enter into this Agreement.

8.2 Contractor Warranty. Contractor represents and warrants it can fulfill its obligations under the Agreement, has the right and power to enter into the terms of this Agreement and the authority to grant the license cited in Subarticle 5.4 without breaching any agreements which Contractor is bound, or infringing on any Third Party Intellectual Property rights. Further, Contractor warrants that EPRI's or its sublicensees' use or distribution of the Research Results and the Work will not infringe on any Third Party Intellectual Property Rights. Contractor warrants that it will comply with present and future applicable federal and state labor and employment laws, including, but not limited to health, safety and environmental laws, regulations and orders. Nothing in this warranty will be construed to limit any rights or remedies otherwise available to EPRI.

8.3 DISCLAIMER OF WARRANTIES. WITHOUT LIMITING THE FOREGOING, CONTRACTOR ACCEPTS THE EPRI MATERIALS "AS IS". EPRI DISCLAIMS ALL WARRANTIES AND REPRESENTATIONS, WHETHER STATUTORY OR IMPLIED, OF NONINFRINGEMENT, TITLE, QUIET ENJOYMENT, ACCURACY, MERCHANTABILITY, FREEDOM FROM MALWARE, OR FITNESS FOR ANY PURPOSE.

ARTICLE 9 – Limitation of Liability

9.1 LIMITATION OF LIABILITY. EPRI'S LIABILITY TO CONTRACTOR OR ANY THIRD PARTY FOR A CLAIM OF ANY KIND ARISING UNDER OR RELATED TO THIS AGREEMENT, ANY EPRI MATERIALS, RESEARCH RESULTS, OR WORK, WHETHER FOR BREACH OF CONTRACT OR WARRANTY, STRICT LIABILITY, NEGLIGENCE, INFRINGEMENT OR OTHERWISE, WILL NOT EXCEED THE AGGREGATE VALUE OF THE AMOUNTS UNDER THIS AGREEMENT. IN NO EVENT WILL EPRI, ANY SUBSIDIARY, SUPPLIER, OR SUBCONTRACTOR, OF EPRI BE LIABLE FOR AN INDIRECT, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES (INCLUDING WITHOUT LIMITATION, LOST REVENUES OR PROFITS, LOST DATA, WORKSTOPPAGE, COMPUTER FAILURE, OR MALFUNCTION) EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. NO ACTION, REGARDLESS OF FORM, ARISING OUT OF THIS AGREEMENT MAY BE BROUGHT BY CONTRACTOR MORE THAN ONE YEAR AFTER THE EVENTS WHICH GIVE RISE TO THE CAUSE

OF ACTION OCCURRED. IN NO CASE WILL ANY FUNDER OF EPRI OR ANY PERSON OR ENTITY ACTING ON BEHALF OF THE SAME WILL BE LIABLE TO CONTRACTOR.

ARTICLE 10 - Indemnification

10.1 Indemnification. Contractor will indemnify, defend and hold EPRI, EPRI funders, and sublicensees of the Research Results (collectively, "Indemnified Party") harmless from and against any and all claims, losses, costs, liabilities and expenses (including reasonable attorneys' fees), arising out of (a) any intellectual property infringement of any Research Results, and (b) Contractor's, or Permitted Subcontractor's, performance under this Agreement provided that: (i) the Indemnified Party gives written notice of any claim to Contractor; (ii) at Contractor's expense, the Indemnified Party provides assistance which Contractor may reasonably request for the defense of the claim; and (iii) Contractor has the right to control the defense or settlement of the claim, provided, however, that the Indemnified Party will have the right to participate in, but not control, any litigation for which indemnification is sought with counsel of its own choosing and at its own expense. If an injunction or order issues restricting the use or distribution of any Research Results, or if EPRI determines that any Research Results may become the subject of a third party intellectual property rights infringement claim, Contractor will, at its option and expense, (i) procure the right to continue using, reproducing, and distributing the Research Results, as applicable; or (ii) replace or modify the Research Results so that they become non-infringing, provided such modification or replacement does not materially alter or affect the use or operation of the Research Results. Without limiting EPRI's remedies, EPRI will be entitled to withhold and off-set payments to Contractor from this or any other Agreement with Contractor to cover potential damages, liabilities, costs, and expenses until such matter is finally resolved.

ARTICLE 11 - Termination

11.1 Termination for Cause. EPRI may, with written notice, terminate this Agreement or any part hereof, as follows: (i) immediately in the event of a breach by Contractor of Article 5 (License Grant, Restrictions, and Title) or Article 7 (Confidentiality); or (ii) immediately upon Contractor's attempt to assign this Agreement without EPRI's prior written approval; or (iii) upon Contractor's failure to cure a breach of this Agreement within thirty (30) days of written notification by EPRI that Contractor is in breach of the Agreement. The Termination for Cause is effective immediately upon receipt of the EPRI notice. Contractor will take all steps necessary to mitigate damages upon receipt of a notice of termination.

11.2 Termination for Convenience. EPRI may terminate this Agreement or any part hereof upon thirty (30) days written notice of termination for any reason or for no reason. As of the effective date of the termination, Contractor will return all EPRI Materials and deliver all Research Results including any works-in-progress within thirty (30) days of receipt of the termination notice. EPRI will reimburse Contractor for all verified allowable costs and EPRI approved non-cancelable commitments incurred prior to the date of receipt by the Contractor of the notice of termination as well as reasonable closeout costs, if any. Total payments to Contractor will not exceed the amount of the Contract Cost Limitation and Contractor will not be entitled to lost profits or consequential damages. Contractor will continue its performance of all non-terminated Work under this Agreement.

11.3 Effects of Termination. In the event this Agreement is terminated for cause pursuant to Subarticle 11.1 or for convenience pursuant to Subarticle 11.2 above, the License granted to Contractor will immediately terminate and Contractor will cease use of EPRI Materials, and within thirty (30) days of termination, Contractor will return all EPRI Materials including any reproductions, uninstall or otherwise permanently delete all EPRI Materials from Contractor's, its subsidiaries and affiliates or Permitted Subcontractor's computer systems, and provide EPRI with a written certification of such action signed by a duly authorized representative of Contractor. Contractor will have no right to receive any goodwill compensation relating to this Agreement, EPRI Materials, any other monies from EPRI, or ownership or any other right to EPRI Materials.

11.4 Survival. The provisions of Article 5 (License Grant, Restrictions, and Title) other than licenses to Contractor, Article 7 (Confidentiality), Article 8 (Representations and Warranties), Article 10 (Indemnification), Article 12 (Dispute Resolution) and Article 13 (Miscellaneous), and Subarticle 2.7 (Audit) will survive the termination of this Agreement.

ARTICLE 12 - Dispute Resolution

12.1 Arbitration. Any dispute, claim or controversy arising out of or relating to this Agreement or the breach, termination, enforcement, interpretation or validity thereof, including the determination of the scope or applicability of this agreement to arbitrate, will be determined by final and binding arbitration in Santa Clara County, U.S.A., before one arbitrator. The arbitration will be administered by JAMS pursuant to its Comprehensive Arbitration Rules and Procedures (or if the Contractor is located in a non-U.S. territory, the International Chamber of Commerce in accordance with its Rules of Arbitration). Proceedings will be conducted in English. Judgment on the award may be entered in any court having jurisdiction. The award will be payable in U.S. Dollars through a bank in the United States. This subarticlewill not preclude parties from seeking provisional remedies in aid of arbitration from a court of appropriate jurisdiction. Unless otherwise directed in writing by EPRI, Contractor will continue its performance under this Agreement. EPRI reserves all rights (including all legal and equitable remedies) not expressly granted to the Contractor.

12.2 Expenses. Each party will bear its own expense (including attorneys' fees) incurred in any dispute resolution or court proceeding, or settlement activities unless otherwise agreed by the parties or ordered in the Arbitration award.

ARTICLE 13 - Miscellaneous

13.1 Governing Law. This Agreement will be governed by and construed in accordance with the laws of the State of California, without giving effect to any principles that provide for the application of the law of another jurisdiction.

13.2 Export and Anti-corruption Laws. The parties will comply with all applicable export, anti-corruption and U.S. anti-boycott laws and regulations. The parties agree that access to Research Results and EPRI Materials licensed to Contractor in Subarticle 5.1 ("Licensed Products") is granted with the specific understanding and requirement that responsibility for ensuring compliance with all applicable U.S. and foreign export laws and regulations are being undertaken by the parties. This responsibility includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S resident is permitted access under applicable U.S. and foreign export laws and regulations. Both parties further understand and acknowledge their obligations to make a prompt report to each other and appropriate authorities regarding any access to or use of Research Results and Licensed Products hereunder that maybe in violation of applicable U.S. and foreign export laws and regulations. In addition, Contractor hereby warrants and agrees that no Licensed products, technical data, or other information or assistance furnished by EPRI pursuant to this Agreement, or any product or revision thereof, will be re-exported or otherwise used by Contractor or its authorized transferees outside of Contractor's principal domiciliary country. These obligations will survive any satisfaction, expiration, termination, or discharge of this Agreement or any other obligations.

13.3 Assignment. Contractor may not assign this Agreement, in whole or in part, whether by contract or operation of law, without EPRI's prior written consent, which will not be unreasonably withheld, and any purported attempt to do so will be considered as null and void. EPRI agrees Contractor may subcontract Work to a Permitted Subcontractor, provided, any subcontracting arrangement will not relieve Contractor of any of its duties or obligations. The terms of this Agreement will bind and inure to the benefit of permitted assigns.

13.4 Waiver. No failure or successive failures on the part of either party, its successors, or assigns, to enforce any covenant or agreement, and no waiver or successive waivers on its or their part of any condition of this Agreement or amendment will operate as a discharge of such covenant, agreement, or condition, or render the same invalid, or impair the right of either party, its successors and assigns, to enforce the same in the event of any subsequent breach or breaches by the other party, its successors, or assigns.

13.5 Severability. If any provision of this Agreement or any amendment is held to be invalid or unenforceable, the remaining provisions of this Agreement or amendment(s) will remain in full force.

13.6 Independent Contractor. Both parties will perform their obligations hereunder as independent contractors and will be solely responsible for their own financial obligations. This Agreement is not intended to and will not make Contractor an agent or employee of EPRI and Contractor hereby acknowledges and agrees that it is not an agent or employee of EPRI. Nothing contained in this Agreement will be construed to imply a joint venture, partnership or principal and agent relationship between the parties and neither party will have any right, power, or authority to create any obligation, express or implied, on behalf of the other in connection with the performance of this Agreement. Contractor agrees to furnish (or reimburse EPRI for) all tools and materials necessary to accomplish the Work, and will incur all expenses associated with performance, except as expressly provided in this Agreement. Contractor acknowledges that neither Contractor nor Contractor's employees or agents will be eligible for any EPRI employee benefits.

13.7 Commercial Items. Each EPRI Material is a "commercial item," as that term is defined at 48 C.F.R. 2.101. To the extent that any EPRI Material includes software or its related documentation, such software and related documentation constitute "commercial computer software" and "commercial computer software documentation," as such terms are used in 48 C.F.R. 12.212, and are provided to be used by or for the U.S. Government only as commercial end items. Any technical data provided with such EPRI Material is commercial technical data as defined in 48 C.F.R. 12.211. Consistent with 48 C.F.R. 12.211 through 12.212, 48 C.F.R. 227.7202-1 through 227.7202-4, and 48 C.F.R. 252.227-7015, all U.S. Government customers acquire the EPRI Material with only those rights set forth in this Agreement.

13.8 Force Majeure. Any delay in the performance of any duties or obligations of either party will not be considered a breach of this Agreement, if such delay is caused by a national labor dispute, shortage of material supply, fire, earthquake, flood, acts of terrorism or any other event beyond the control of such party, provided that such party uses reasonable efforts, under the circumstances, to notify the other party of the circumstances causing the delay and to resume performance as soon as possible.

13.9 Insurance. Contractor will maintain, and ensure all subcontractors maintain, insurance issued by insurers acceptable to EPRI of at least $2,000,000 per occurrence commercial general liability insurance including contractual liability insurance, $1,000,000 per accident automobile liability insurance, statutory levels of worker's compensation insurance, $1,000,000 per accident employer's liability insurance during performance of this Work, unless provided otherwise in the Agreement and any additional insurance necessary to protect itself and EPRI from all potential losses that may arise. If the commercial general liability insurance contains a general aggregate limit, the policy will be endorsed to state that the general aggregate limit will apply separately to this Agreement. Each such policy will, (i) name EPRI, its directors, officers and employees as additional insureds, (ii) provide for severability of interests, (iii) waive subrogation in favor of EPRI, its directors, officers, employees and agents, and (iv) require at least thirty (30) days written notice to EPRI prior to any material change or cancellation. Contractor will provide EPRI with evidence of compliance with all insurance requirements within ten (10) days of the Effective Date of this Agreement.

13.10 Endorsements. Contractor acknowledges that EPRI neither endorses products or services, nor allows the data or other results of the Work to be used as an endorsement. Therefore, Contractor agrees that it will not, whether explicitly or through implication, use EPRI's name, logo, trademarks, the name, title, or statements of EPRI employees, this Agreement, or the results of the Work for advertising or other promotional purposes, raising of capital, recommending investments, or in any way that states or implies endorsement by EPRI. Any exceptions to this subarticle will require the advanced written approval by EPRI's executive in charge of corporate communications, which may be withheld at EPRI's sole discretion.

13.11 Order of Precedence. In the event of a conflict between or among the terms of the Agreement documents, the order of precedence will be: the Sourcing Agreement, the Sourcing Terms and Conditions, any SOW, and then any other attachments to the Agreement in the order presented. If there are multiple Agreement amendments, the most recent amendment will have the highest precedence and the oldest amendment will have the lowest precedence.

13.12 Publicity. Contractor may not issue any publicity releases (including news releases and advertising) relating to this Agreement and the Work performed hereunder without the prior written approval of EPRI's executive in charge of corporate communications. Any inquiry the Contractor receives from news media concerning this Agreement will also be referred to the EPRI's executive in charge of corporate communications for coordination prior to response. Any technical paper, article, publication, or announcement of advances generated in connection with Work performed under this Agreement, during the Term or thereafter, will give credit to EPRI. Nothing contained in this subarticle will be deemed to grant Contractor any license with respect to the results of the Work.

13.13 Additional Obligations. Contractor will maintain complete and accurate information related to the location of project records associated with this Agreement, to include, but not be limited to, EPRI Materials, Research Results, or any other real, personal, and intellectual property, and will allow EPRI, with fifteen (15) days notice, to do a physical audit of the project records. Contractor will retain Research Results for three years after final payment is received. Contractor will not, without the prior written permission of EPRI, subcontract out any of the Work or substitute or substantially change the participation of any key personnel identified in this Agreement. Contractor will not perform Work on a third party's site without first obtaining from the third party a written waiver and release of claims for direct, indirect, special and/or consequential damages in favor of EPRI.

13.14 Additional Provisions. Provided that this Agreement is not entered into with a Contractor outside of the United States, the following additional provisions apply. Contractor will comply with the following Federal Government provisions (Appendix A to 2 CFR Part 215 – Contract Provisions which are incorporated herein by reference as though set forth in full text to this Agreement: (i) E.O. 11246 - Equal Employment Opportunity; as amended by E.O. 11375 – Amending Executive Order 11246 Relating to Equal Employment Opportunity, and as supplemented by regulations 41 CFR, part 60, "Office of Federal Contract Compliance Programs, Equal Employment Opportunity, Dept of Labor; (ii) Copeland "Anti-Kickback" Act (18 U.S.C. 874 and 40 U.S.C.276c) as supplemented by Dept of Labor regulations (29 CFR part 3) (applicable to construction and repair contracts in excess of $2500); (iii) Davis-Bacon Act, as amended (40 U.S.C. 176a to a-7) as supplemented by Dept of Labor regulations (29 CFR part 5) (applicable to construction contracts in excess of $2000); (iv) Contract Work Hours and Safety Standards Act (40) U.S.C. 327-333 as supplemented by Dept of Labor regulations (29 CFR part 5) (applicable to construction contracts in excess of $2000 and in excess of $2500 for other contracts involving mechanics or laborers; (v) Rights to Inventions Made under a Contract or Agreement (37 CFR part 401 "Rights to Inventions Made by Nonprofit Organizations and Small Business Firms Under Government Grants, Contracts, and Cooperative Agreements" and any implementing regulations issued by the awarding agency; (vi) Clean Air Act (42 U.S.C. 7401 et seq.) and the Federal Water Pollution Control Act as amended (33 U.S.C. 1251 et seq.) (applicable to contracts $100,000 or more); (vii) Byrd Anti-Lobbying Amendment (31 U.S.C. 1352) (applicable to contracts $100,000 or more; and (viii) Debarment and Suspension E.O.s 12549 and 12689. If this Agreement exceeds the Federal small purchase threshold, Contractor will be required to certify regarding its exclusion status and that none of its principal employees are on GSA's List of Parties Excluded from Federal Procurement or Non-procurement Programs. Further, Contractor will be required to furnish a certificate, if none is on file, in compliance with the Byrd Anti-Lobbying Amendment if or when this Agreement reaches $100,000 or more. Re-certification is required on an annual basis.

ELECTRIC POWER RESEARCH INSTITUTE

ATTACHMENT B

STATEMENT OF WORK

(Contractor's proposals will form basis for Statement of Work - Bidders not required to fill out at this time)

ELECTRIC POWER RESEARCH INSTITUTE, INC.

SOURCING AGREEMENT

<%Agreement.VendorName%>

<%Agreement.ID%>

"«TITLE»"

1. Introduction & Background

2. Objectives

3. Scope of Work/Task Descriptions

4. Deliverables

5. Schedule

Task Description	**Completion Date**

6. EPRI Material / Other Documents:

ATTACHMENT C – FORM 112

(Excel file provided electronically with RFP package)

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

APPENDIX C

Review of Technologies for Guiding, Capturing, Holding, Transporting, and Monitoring Outmigrating Eels (Versar, 2009)

REVIEW OF TECHNOLOGIES FOR GUIDING, CAPTURING, HOLDING, TRANSPORTING, AND MONITORING OUTMIGRATING EELS

Prepared for:

New York Power Authority
123 Main Street
White Plains, NY 10601

Prepared by:

Versar, Inc.
9200 Rumsey Road
Columbia, MD 21045

July 2009

Review of Technologies for Guiding, Capturing, Holding, Transporting, and Monitoring Outmigrating Eels

Prepared for:

New York Power Authority
123 Main Street
White Plains, NY 10601

Prepared by:

Versar, Inc.
9200 Rumsey Road
Columbia, MD 21045

July 2009

FOREWORD

Versar, Inc., assembled a Project Team that included both in-house staff and outside experts to address the various questions and issues related to downstream passage of American eels (*Anguilla rostrata*) in the vicinity of the New York Power Authority's (NYPA) St. Lawrence-FDR Power Project. Individual members of the Project Team wrote or co-wrote particular sections of the technical report; the authors of Sections 3 through 9 are identified beneath the headings of those sections. All members of the team worked collaboratively to identify and acquire information and reviewed drafts of each section. Many members of the team participated in conference calls and electronic mail exchanges that proved to be of great value in interpreting and synthesizing the extensive and diverse information acquired for this report. Dr. Kevin McGrath (NYPA) and Mr. Scott Ault (Kleinschmidt Associates) interacted extensively with the Project Team and provided invaluable details and information.

Versar's Project Manager was Dr. William Richkus. Contributing members of Versar's staff included Ms Beth Franks, Dr. Lisa Methratta, Mr. Ward Slacum, Mr. William Burton, and Ms Jodi Dew. Contributing outside experts and their particular areas of contribution included

- Mr. Greg Allen, Alden, Inc. (engineering)
- Ms Ruth Balkin, Balkin Information Services (library services)
- Mr. Jacques Boubée, National Institute of Water and Atmospheric Research, New Zealand (all technical areas)
- Mr. Maarten C.M. Bruijs, KEMA Nederland BV, The Netherlands (all technical areas)
- Dr. Charles Coutant, Oak Ridge National Laboratory, U.S. Department of Energy (retired) (induced flows and all technical areas)
- Mr. Brian Eltz, Connecticut Department of Environmental Protection, Inland Fisheries Division (telemetry, capture/hold/transport)
- Dr. Alex Haro, United States Geological Survey, S.O. Conte Anadromous Fish Research Laboratory (all technical areas)
- Mr. Peter Johnson and Mr. Carl Schilt, LGL Limited (telemetry, capture/hold/transport)
- Dr. Paul Patrick, SENES Consultants Limited (hybrid technologies, all technical areas)
- Dr. Arthur Popper, Environmental BioAcoustics LLC, and University of Maryland (sound)
- Dr. Weiming Li, Michigan State University (attractants/repellents)

EXECUTIVE SUMMARY

This report summarizes the results of a review and synthesis of literature, research, and information on technologies and methods for guiding, capturing, holding, transporting, and monitoring downstream migrating eels. The objective of this effort is to assess the potential applicability of the various technologies for use in developing a trap-and-transport program for outmigrating eels at Iroquois Dam on the St. Lawrence River. Five technologies of potential value for guiding outmigrating eels to a collection location were evaluated: physical barriers, attractants and repellents,[1] infrasound, light, and combined or "hybrid" technologies. A wide range of methods for capturing, holding, and transporting migratory fish were reviewed for their potential applicability for use with eels at Iroquois Dam, including methods used in commercial eel fisheries, trap-and-transport programs for other species of fish (e.g., salmon smolts), and several European programs that target outmigrating eels. Various technologies for monitoring the movements of eels were reviewed to determine their applicability and value for use in studies that would be necessary to design and test a prototype trap-and-transport program at Iroquois Dam as well as to assess the performance of an installed system.

Guidance Technologies

Physical Barriers

- Eels respond to physical barriers differently than most other species of fish; instead of avoiding barriers, eels generally make physical contact with them and often attempt to pass through them. Eels tend to be impinged on barriers when flow velocity is greater than 1 m/s, such as at Iroquois Dam.
- The literature provided no examples of attempts to use physical barriers to direct the movements of outmigrating eels in a system as large as the St. Lawrence River. Most applications were at intakes of steam electric-generating facilities or relatively small hydroelectric facilities.
- Based on the very limited findings of some studies of diversion efficiency with potential relevance to Iroquois Dam, the effectiveness of a 1,000-m-long barrier placed at a 30º angle to the current would be low as a result of its great length combined with eels' tendency to bump into barriers and attempt to pass through them rather than to be guided by them.
- A physical barrier across the width and depth of the river would be subject to extensive debris loading, particularly with submerged aquatic vegetation, which would reduce its effectiveness and require extensive maintenance.

[1] Light and infrasound are two specific kinds of stimuli to which eels have been shown to respond; therefore, they were designated for review individually. The category "attractants and repellants" was established to encompass a variety of other kinds of stimuli, such as chemical or electromagnetic cues, that might be effective for influencing the behavior of outmigrating eels.

- Conceptual estimates of the cost to construct and operate a 1,000-m physical barrier situated at a 30^{o} angle to current are $155 million and $3.2 million (± 50%) annually, respectively (2007 U.S. dollars).

Attractants and Repellents

- Little is known about the effectiveness of stimuli other than light and sound that could serve as attractants or repellents for use in concentrating fish in general, and virtually no information specific to eels is available. Extensive basic research would be required to identify and evaluate appropriate attractants or repellents for outmigrating eels.
- Laboratory studies have shown that eels are able to detect small concentrations of particular chemicals and respond to them behaviorally during certain life stages. Chemical attractants would be very difficult to deploy effectively to control the movement of outmigrating eels in a large river because the chemical would be dispersed downstream, in the direction of travel of the outmigrating eels.
- Eels have been shown to detect electromagnetic fields and respond to them behaviorally during some life stages, but little is known other than the observations of simple responses. Extensive basic research would be required to determine how to project an electromagnetic field, measure field intensity throughout the water column, and predict the potential adverse effect of the field on non-target species.
- Anecdotal information suggests that outmigrating eels aggregate naturally, sometimes forming an "eel ball," immediately before or during migration. No information is available about an underlying physiological mechanism that would explain this phenomenon (e.g., pheromones or other behavioral processes). Researchers were uncertain about how this behavior could be developed into an effective means of concentrating outmigrating eels.
- Methods are being developed for using induced currents or flows (i.e., local currents created artificially) to guide movements of migratory fishes other than eels (e.g., juvenile salmonids), but no information is available about the potential effectiveness of those methods for use with eels or on a large expanse of river, such as at Iroquois Dam. Basic studies with eels would be needed before testing such methods at Iroquois Dam.
- The costs to deploy any of these attractant or repellant technologies at Iroquois Dam could not be estimated because available information was insufficient to develop conceptual designs for potential applications.

Infrasound

- The literature offered little information about the potential for using infrasound to control eel movement, except for one study on a small river in Europe. The findings of that study suggest that increasing the scale of infrasound technology for application in a very large area such as the St. Lawrence River at Iroquois Dam would be difficult.

- Technology for using infrasound to guide eels is in very early stages of development. A considerable amount of basic research would be required to evaluate its feasibility for affecting the behavior of eels in the St. Lawrence River. If the results of basic research were promising, considerable further effort would be required to design and build a robust system suitable for testing at Iroquois Dam.
- Eels might have to be exposed to a "sound field" for a considerable time in order to elicit a response. Prolonged exposure could cause eels to become habituated to the sound and eventually to move through the sound field rather than to avoid it. No data about the habituation of any fishes to infrasound were available.
- Using infrasound in the St. Lawrence River could be very costly because the field of effect seems to be limited to within two to three meters of a source. A large physical infrastructure might be required to support sufficient sound-generating equipment to apply the technology effectively across the length of Iroquois Dam
- The potential effectiveness of infrasound for guiding eels in the St. Lawrence River is highly uncertain because data in the literature are equivocal, and the logistical feasibility of using the technology in a large river seems questionable.
- The effect of infrasound on non-target species is unknown, but such effects would have to be understood to avoid harming other, non-target species.
- Although information about the cost of infrasound emitting devices is available, information about the potential effectiveness and range of the emitters and about how eels would respond to sound fields in a large river is insufficient to develop a reasonable conceptual design for, and estimate the cost of, an infrasound-based diversion system for use at Iroquois Dam.

Light

- The avoidance of light by eels in darkness is well documented at many sites, but some reports indicate that light has had little or no effect on eels' behavior in other locations and under different circumstances.
- Information about the wavelength(s) and intensity of light required to elicit a response is limited.
- Using light to guide outmigrating eels at Iroquois Dam would require a large infrastructure that would be difficult to construct and maintain.
- Studies of the effects of light on other species in the St. Lawrence River would be required before planning to use light to guide outmigrating eels at Iroquois Dam in order to avoid causing unintended adverse effects on other species.
- Outmigrating eels at Iroquois Dam could be exposed to a light array for up to 9 minutes, based on documented rates of downstream movement in the St. Lawrence River. Exposure of that duration prompts concern about the possibility of habituation to light and, thus, decreasing effectiveness of a light-based guidance system; however, no eel-specific data about habituation to light are available.

- A telemetry study in the St. Lawrence River demonstrated that 25% of outmigrating eels move downstream during the day, when lights are unlikely to be effective because the contrast between artificial light and normal daylight would be insufficient for eels to notice the light array.
- A simple conceptual model based on data from a study of the response of eels to a light barrier near Iroquois Dam and known patterns of movement of eels in the area estimated that a large array of lights deployed across the river at Iroquois Dam might yield diversion efficiencies ranging from 13% (accounting for some habituation) to 58.5% (assuming no habituation).
- Conceptual estimates of the cost to construct and operate a light barrier at Iroquois Dam (30^o angle to current), are $132 million and $5.6 million (± 50%) annually, respectively (2007 U.S. dollars).

Combinations of Technologies

- Fish can respond to more than one stimulus simultaneously (e.g., light, sound, flow), which suggests the possibility of combining technologies for influencing their behavior.
- The potential benefit of combining two technologies in the same location is that, operating simultaneously and each generating a different stimulus, they could improve overall guidance efficiency under a wide range of environmental conditions.
- Installing two technologies on the same barrier/support structure could be cost-effective.
- Total costs are likely to be greater than a marginal increase in guidance efficiency would warrant.

Collection, Holding, and Transportation Technologies

- Many of the methods for capturing, holding, and transporting eels reported in the literature were applied in small rivers and streams and have little applicability for use in a large system like the St. Lawrence River at Iroquois Dam.
- Several techniques were identified that could be feasible for use if scaled to the substantially larger size that would be required at Iroquois Dam.
- Large facilities on rivers in Oregon and Washington concentrate and collect large numbers of salmon smolts effectively. These facilities typically collect fish from the upper portion of the water column, where most migrating salmon spend a significant amount of time. A telemetry study conducted on the St. Lawrence River showed that outmigrating eels use the entire water column, surface to bottom; consequently, any collection device to be used at Iroquois Dam may have to sample the entire water column. No techniques or equipment have been developed that can do that in a system as large as the St. Lawrence River.
- An inclined-screen trap seems to offer the best potential for collecting outmigrating eels at one or more gates at Iroquois Dam. The need to process large volumes of water and the potential for substantial loading with debris could be problematic.

- Few data are available about the direct effects of handling and transportation on the maturation and migratory motivation of eels; therefore, researchers could not determine the likelihood or extent of effects. Some recent data regarding capture of tagged eels in commercial fisheries in Quebec suggests that large eels that had been subjected to handling and transportation resumed migration with eels that were not subject to such stresses; nevertheless, handling and transportation should be minimized as a precaution.

- Conceptual estimates of the cost to construct and operate a modular, inclined-screen trap at Iroquois Dam are $12.6 million and $220,000 (± 50%) annually, respectively (2007 U.S. dollars). Operating costs do not include the cost of transportation, which would vary depending on such factors as a transport plan, the rate of capture, etc.

Monitoring Technologies

- Radio telemetry has a limited range on the St. Lawrence River because of the high conductivity of the water and, thus, would not be an effective method for a large-scale study.
- An acoustic telemetry study could be conducted using smaller transmitters than those used in previous studies. This technology could provide the resolution and detail about the behavior and movement patterns of eels that would be needed to evaluate the effectiveness of a concentration/guidance structure and the collection device.
- Some concerns remain about the effect of tagging and handling on the behavior of eels, regardless of the size of the tag. Any evaluation based solely on tagged fish will be subject to questions regarding the potential bias created by handling and tagging the subjects.
- Multi-beam imaging sonar (DIDSON) and active hydroacoustic monitoring (ADCP) systems could supplement information gathered with telemetry; however, those tools individually cannot provide the information required to evaluate the effectiveness of a trap-and-transport facility because their sample volumes are limited compared with the scale of the St. Lawrence River. Those technologies could be used near the entrances to traps and collection facilities to elucidate fine-scale behavior patterns. DIDSON sampling could be coupled with ADCP to assess eels' swimming behavior relative to flow fields near the entrances to collectors. Information gleaned from such a study could be used to optimize operating conditions at a collection facility. DIDSON and hydroacoustic monitoring would sample eels without tagging them, and comparing those data with acoustic telemetry data for tagged eels might provide the behavioral information necessary to answer some questions about the effects of handling and tagging.
- Collecting test specimens for a telemetry study in the St. Lawrence River proved to be difficult and costly; furthermore, the number of outmigrating eels is decreasing, which compounds the problem of collecting an adequate number of specimens. No more practical techniques for collecting eels are available other than those already being used in the area (i.e., trawling and stownetting).

- Researchers noted that collecting fish from downstream locations for use in studies in the vicinity of Iroquois Dam might not be ideal because the behavior of eels that have nearly completed the freshwater phase of their downstream migration may differ from that of eels that are in the process of that migration. In addition, fish collected at significant distances downstream would be subject to substantial stress due to handling and transportation prior to being used in a study. Eels collected upstream of the dam are preferred. Fish collected from downstream locations might be acceptable if the transport distance is short and handling is minimized.

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1.0 INTRODUCTION

The American eel (*Anguilla rostrata*) is a catadromous species that spawns in the Sargasso Sea in the center of the Atlantic Ocean but grows to sexual maturity in freshwaters from Greenland to South America. Eels historically were abundant in the St. Lawrence River and estuary, tributaries of those systems, and Lake Ontario. The abundance of eels in the upper St. Lawrence River and Lake Ontario has declined significantly in recent decades. This decline is consistent with general declines in populations of the American eel in North America and the European eel (*Anguilla anguilla*) in Europe (Haro et al. 2002; Wirth and Bernatchez 2003). Eels from the upper St. Lawrence River and Lake Ontario (USLRLO) stock that migrate downstream to the ocean when they are sexually mature are all large females, and some stakeholders contend that they contribute substantially to the total fecundity of the continent-wide eel population (e.g., Casselman 2003). These downstream migrants must pass two large hydroelectric projects during their outmigration: Moses-Saunders Power Dam in Massena, New York, and Beauharnois Generating Station, just upstream of Montreal, Quebec. Virtually all eels passing these dams travel through generating turbines, which results in some mortality.

The New York Power Authority (NYPA), owner and operator of the St. Lawrence-FDR Power Project (FDR Project), is seeking to identify feasible means of moving outmigrating eels past the FDR Project without going through turbines so as to prevent or reduce turbine-related mortality. To contribute to an evaluation of strategies for providing passage around the hydro-electric facilities, Versar was awarded a contract to review and synthesize the literature on technologies that may be useful for guiding the movements of outmigrating eels, for capturing, holding and transporting eels, and for monitoring and tracking the behavior of eels. This report synthesizes the relevant literature pertaining to each of those topics and provides comments regarding the applicability of technologies and methods at Iroquois Dam, the site NYPA indentified as a possible location for a trap-and-transport program for outmigrating eels.

1.1 PROJECT SETTING

The St. Lawrence River is an international waterway located in northern New York State and southeastern Canada. The river originates from Lake Ontario at Cape Vincent, New York, and flows approximately 1,400 kilometers (km) to the Gulf of St. Lawrence; it is the principal outlet for the waters of the Great Lakes. The area of the drainage basin is approximately 480,000 km^2.

Iroquois Dam is part of the International St. Lawrence Power Project. Located approximately 120 km downstream of Lake Ontario and 45 km upstream of Moses-Saunders Power Dam, Iroquois Dam spans the St. Lawrence River from Iroquois, Ontario, to Waddington, New York (Figure 1-1). The dam is approximately 600 m long and has no hydropower generating capability. It is used to control water levels in the impoundment upstream of Moses-Saunders Power Dam and contributes to controlling ice that might affect operation of the downstream power dam. The structural characteristics and surrounding environment of the dam are important for evaluating potential technologies that might be deployed there. The dam consists of

32 sluiceways, each of which is approximately 15.2 m wide and has an average water depth of 13.1 m. Thirty-one of the sluiceways are located within United States waters. Each sluiceway has a gate that can be raised or lowered as necessary. The gates typically are maintained in the raised position, which allows water to pass freely underneath (Figure 1-2). Several of the western-most gates generally are raised to a higher level to allow the passage of recreational boat traffic. When water levels must be controlled, the gates are lowered into the water column to restrict flow. The average annual flow at Iroquois Dam is approximately 7,070 m^3/s. The average flow during the period of downstream migration of eels (between June and October) is somewhat greater at 7,388 m^3/s. Based on average flows during the migration period, water depth, and the size of the sluiceways, average water velocity at the dam during migration is approximately 1.2 m/s.

Figure 1-1. Aerial photograph of Iroquois Dam showing the border between the United States and Canada. River flow is to the north (photo courtesy of NYPA).

Figure 1-2. View of Iroquois Dam from downstream along the United States' shoreline showing raised water-control gates. Flow is toward the observer (photo courtesy of NYPA).

The 1-km-long Moses-Saunders Power Dam (MSPD) spans the international portion of the St. Lawrence River 45 km downstream of Iroquois Dam, between Massena, New York, and Cornwall, Ontario (Figure 1-3). The half of MSPD located in Canada is called Robert H. Saunders Generating Station (RSGS) and is owned and operated by Ontario Power Generation (OPG). The half of MSPD located in the United States is called Robert Moses Power Dam (RMPD) and is owned and operated by NYPA. RMPD is one component of NYPA'S FDR Project, which includes associated dikes and other structures and is licensed by the Federal Energy Regulatory Commission (FERC). RSGS and RMPD each house 16, fixed-blade propeller turbines, each with an installed generation capacity of 57 MW at a flow of 275 m^3/s; total installed capacity of MSPD is 1,824 MW. The head (vertical drop) at MSPD is approximately 25 m. Impounded waters upstream of MSPD are known as Lake St. Lawrence. The lake extends 60 km upstream to above Iroquois Dam. As noted earlier, most eels migrating downstream past Iroquois Dam will pass through Lake St. Lawrence and through the power generating turbines at MSPD.

Figure 1-3. Map of the St. Lawrence River and Lake Ontario showing the locations of major dams. (Figure provided courtesy of NYPA.)

Beauharnois Generating Station is the second power project on the St. Lawrence River that outmigrating eels must pass. It is located about 85 km downstream of MSPD, 40 km southwest of Montréal (Figure 1-3). It is one of the world's largest hydroelectric facilities and is entirely in Canadian waters. The dam is approximately 900 m long and has 36 generating units with a total installed capacity of 1,658 MW.

1.2 INITIATION OF THE TECHNOLOGY REVIEW PROJECT

FERC issued a new, 50-year license for the FDR Project to NYPA on October 23, 2003. As part of the settlement agreements associated with obtaining the new license, NYPA established a Fish Enhancement, Mitigation, and Research Fund. The fund is administered by the U.S. Fish and Wildlife Service (FWS) to benefit fisheries resources in the Lake Ontario/St. Lawrence River Basin and to continue research on the American eel and other species that may be affected by the FDR Project. A Fisheries Advisory Committee (FAC)[2] acts as technical

[2] Stakeholders with the opportunity to be represented on the FAC include FWS, U.S. Bureau of Indian Affairs, U.S. Geological Survey, New York State Department of Environmental Conservation, Ontario Ministry of Natural Resources, Power Authority of the State of New York, St. Regis Mohawk Tribe, St. Lawrence Aquarium and Ecological Center, St. Lawrence County Environmental Management Council, and New York Rivers United.

advisor to FWS. A subcommittee of the FAC, the Eel Study Group (ESG),[3] is charged with advising the FAC about studies needed to determine how to pass outmigrating American eels safely around the hydroelectric projects on the St. Lawrence River.

The FAC/ESG identified five key topics for investigation relating to the downstream migration of American eels. Each of the topics focuses on a particular guidance system, technology, or set of methods that could be used to pass outmigrating American eels around the FDR Project or to study their behavior. During the course of investigations, an additional technology was specified for evaluation: physical barriers. The six topics evaluated in this report are

- the use of physical barriers to guide outmigrating eels and the feasibility of using them at Iroquois Dam;
- the use of attractants or repellents[4] (e.g., chemicals, electrical fields, electromagnetic fields, directed flows) to guide outmigrating eels and the feasibility of using them at Iroquois Dam;
- the use of infrasound to guide outmigrating eels and the feasibility of using it at Iroquois Dam;
- the use of light to guide outmigrating eels and the feasibility of using it at Iroquois Dam;
- techniques for collecting, holding, and transporting outmigrating eels, with particular emphasis on feasibility of use in the area of Iroquois Dam; and
- the potential effects of telemetry on the migration behavior of eels and the feasibility of using telemetry or other monitoring technologies in the vicinity of Iroquois Dam to determine the effectiveness of various guidance or concentration devices.

On behalf of NYPA, Kleinschmidt Associates (Kleinschmidt) issued five Requests for Proposals (RFPs) to develop individual “white papers” on each of the five original topics. In each of those RFPs, Kleinschmidt indicated that alternative approaches for addressing the topics would be acceptable. Versar submitted proposals in response to each of the RFPs as well as an alternative proposal recommending that NYPA select Versar as a single contractor for all five topics to improve cost efficiency and eliminate redundancy in literature searches and information acquisition.

Versar assembled a Project Team that included national and international experts for all of the topics defined by the ESG to prepare this consolidated report. Synthesizing all of the available, relevant information allowed for a comprehensive integration of detailed technical knowledge of the biology and behavior of the American eel across all of the six topics listed

[3] Members of the ESG include Power Authority of the State of New York, New York State Department of Environmental Conservation, FWS, and Ontario Ministry of Natural Resources.

[4] Light and infrasound are two specific kinds of stimuli to which eels have been shown to respond; therefore, they were designated for review individually. The category “attractants and repellants” was established to encompass a variety of other kinds of stimuli that might be effective for influencing the behavior of outmigrating eels.

above. This synthesis emphasizes the applicability of each of the technologies at Iroquois Dam and identifies research needs for furthering the potential applicability of the various technologies. Each of the component white papers was prepared by an individual member or subgroup of the Project Team, as indicated in the individual sections. All members of the Project Team reviewed each white paper.

1.3 PRIOR, RELEVANT EEL STUDIES FUNDED BY NYPA

NYPA contributed a substantial body of knowledge relevant to the six topics obtained through studies it funded during the process of relicensing the FDR Project. An overview of those studies provides a context for interpreting this report. All of the studies are described in greater detail in later sections of this report. FERC and NYPA considered a wide variety of environmental issues during licensing proceedings and in studies conducted before the license was issued. A Cooperative Consultation Process Team (CCP Team) including representatives of NYPA and other interested parties (e.g., resource agencies, local and regional governments, non-government organizations, members of the general public) was formed as part of a cooperative approach to the process of relicensing. The CCP Team identified issues and determined appropriate study objectives, information needs, and levels of analysis. Issues were delegated to specific committees charged with defining the scopes of recommended studies. Ecological issues were addressed by the Ecological Subcommittee (ESC). The ESC designated a subgroup, the Eel Working Group (EWG), to address potential consequences for eels as a result of concerns about the status of the USLRLO stock. The EWG was the predecessor of the FAC's current ESG.

The EWG, which included representatives of NYPA and NYPA's consultants, defined the kinds of studies needed to address the eel issues and the scope of work for each study. Studies of outmigrating eels were conducted throughout the general FDR Project area from upstream of Iroquois Dam to downstream of RMPD. These began with a pilot study in 1998 that investigated (1) methods for collecting eels to be used in studies, and (2) the efficacy of telemetry for monitoring the movements of eels (i.e., methods of attaching telemetry tags to eels and methods of differentiating between sexually mature eels that would be expected to migrate downstream and immature eels that would not be expected to migrate).

Studies continued in 1999 and had five objectives:

- determine the most efficient collection gear and techniques among four candidates: electro-fishing, hoop netting, eel potting, and trawling;
- describe the spatial and temporal distributions of collected eels;
- describe specific morphological parameters of collected eels as a function of collection technique, capture location site, and season;
- further develop and refine techniques to differentiate between immature and maturing eels; and

- determine if hydrosonic biotelemetry equipment exists or could be developed that would permit successful monitoring of the movement patterns of outmigrating eels in the immediate vicinity of Robert Moses Power Dam.

Telemetry studies conducted in 2000 had two major objectives:

- tag 200 outmigrating eels with depth-sensitive hydrosonic transmitters, and
- monitor movements of tagged eels as they approached the FDR Project.

Studies conducted in 2001 included

- sampling specific habitats in Lake St. Lawrence in the vicinity of the FDR Project for downstream migrants using three kinds of gear: hoop nets, electrofishing, and stow-nets;
- evaluating injuries caused by each kind of gear;
- comparing the relative efficiency of the three kinds of gear for capturing outmigrating eels;
- comparing the results of that survey with results of previous gear studies;
- evaluating each gear's potential to collect the number of mature eels required for a large-scale telemetry study;
- continuing telemetry studies of the migratory behavior of eels upstream of the FDR Project; and
- refining receivers and transmitters to allow for fine-scale positioning of eels when they reach the forebay of the FDR Project.

Studies at the FDR Project showed that eels approaching the project are widely dispersed, both vertically and laterally (Section 9.2.2.1), suggesting that diverting and capturing outmigrating eels there would be extremely difficult. The focus of subsequent studies, therefore, shifted to a location in the St. Lawrence River that might be more suitable for diverting and capturing outmigrating eels, Iroquois Dam. In 2002, NYPA conducted a detailed, proof-of-concept study of light avoidance a short distance upstream of Iroquois Dam to determine if outmigrating eels avoid artificial light. In that same year, NYPA continued to develop telemetry technologies specifically for use at Iroquois Dam, including testing a tag that included a behavioral switch that would prolong the life of tag batteries, determining transmitter range in the area of the dam, developing and testing a time-synchronization system for the global positioning system (GPS) to enable precise positioning of a signal, and developing and testing the accuracy of a new positioning algorithm for establishing tag position. The 2002 studies were the last conducted during the pre-license study period. NYPA provided data and reports from all of these studies to Versar's Project Team at the initiation of the technology review project.

2.0 PROCEDURES FOR IDENTIFYING AND OBTAINING RELEVANT LITERATURE AND INFORMATION

A comprehensive search for literature and information was conducted for each of the topics addressed in this report. The two basic objectives of this review of literature were to

1) search the available literature and synthesize information concerning the six topics related to guiding, collecting, holding, and transporting outmigrating eels, in particular identifying any work conducted since 2001, and

2) determine the relevance and applicability of that information for use in guiding outmigrating eels to a potential collection location at Iroquois Dam on the St. Lawrence River, New York.

Most of the useful information about some topics could be found in published literature and through direct contacts with scientific researchers. For other topics, a major portion, if not most, of the information relevant to eels was unpublished and had to be obtained through discussions with researchers, fishers, and seafood dealers. The literature and information search and review began with a comprehensive review of work conducted by NYPA at Iroquois Dam and a review by the Electric Power Research Institute (EPRI) entitled *Review and Documentation of Research and Technologies on Passage and Protection of Downstream Migrating Catadromous Eels at Hydroelectric Facilities* (EPRI 2001a). EPRI authorized the use of its earlier review as a foundation for adding the findings of more recent studies to compile this review.[5]

A bibliographic database containing literature and other documents relevant to each of the subtopics was compiled. The database was developed from keyword searches of the ISI Web of Science® electronic database, agency documents posted on the World Wide Web, theses and dissertations from universities, and literature of which the authors were aware based on their professional experience and contacts with other researchers. The electronic search on Web of Science was conducted for all years available (1900-present) using the genus *Anguilla* and the following keywords:

- Light
- Infrasound
- Barrier (screens, bar racks, louvers)
- Telemetry
- Transport, Capture, Catch, Hold
- Attractant and Repellent (endocrine, neurobiology, olfaction, alarm pheromones)
- Magnetic

Results were screened for relevancy, and any references judged to be unrelated were excluded from the database. Searches for theses and dissertations related to the keywords were conducted at multiple universities including University of Connecticut, University of Maine,

[5] Approved by Dr. Douglas Dixon, EPRI, via electronic mail dated April 16, 2008.

University of Rhode Island, University of Massachusetts, and Virginia Polytechnic Institute and State University. All the references in EPRI's report (2001a) were incorporated into the database, as well as the list of references that NYPA provided to Versar. Balkin Information Services, a New York certified, women-owned library subcontractor, assisted Versar to identify and obtain copies of 77 additional relevant publications, some of which were not readily available through standard bibliographic search systems. Sources that Balkin used to identify and acquire the publications included professional associations; authors; Blackwell Synergy, a document delivery company located in Washington, D.C.; National Marine Biological Library; Oxford University Press; other publishers; Sage Online; Science Direct; SpringerLink; and Wiley Interscience.

The bibliographic database was compiled using Reference Manager bibliography-management software (version 11.01; Thompson ISI ResearchSoft 2005). The bibliography can be searched by title, author, journal, date, and keywords. Abstracts were included in the bibliography when accessible to aid in keyword searches. The database file is attached to this report as a compact disk and may be obtained directly from Versar. Table 2-1 is a summary of the citations included in the electronic bibliography by topic area.

Table 2-1. Summary of citations included in the Reference Manager electronic bibliography (CD attached).

Subject	Number of References
Cited in the Attractant/Repellent Section	206
Cited in the Infrasound Section	63
Cited in the Physical Barriers Section	13
Cited in the Light Section	41
Cited in the Capture/Hold/Transport Section	123
Cited in the Telemetry Section	120
Total references in bibliography	2327

The search for published information was accompanied by extensive networking with eel researchers, eel managers, eel fishers and wholesalers, seafood dealers, and vendors of monitoring technology in North America, Europe, and New Zealand. The list of individuals solicited for information on various elements of the project is presented in Appendix A. A survey entitled "Initial Request for Information on Eels" was sent to known eel researchers and professionals via electronic mail. The list of contacts was established from the extensive network of eel researchers known to members of the Project Team and from lists of attendees at research meetings that focused on eels. The survey requested each individual to identify which of the six topics related to eels in which they had relevant experience. Response to the survey was limited, but the results were used to identify professionals in each topic area from whom to request further information. For the topics of telemetry and other behavioral monitoring technologies, a questionnaire was sent via electronic mail to researchers identified as having had experience with eels and relevant technologies. The questionnaire requested each researcher to identify any direct experience with studies of eels that used telemetry or other behavioral sampling technologies. Researchers that responded with relevant experience were requested to send pertinent reports or publications related to their research and to identify colleagues who might be able to provide additional relevant information. Follow-up inquiries to fill in information gaps were made by electronic mail or phone. All known vendors of fisheries telemetry technologies were surveyed by electronic mail and telephone to obtain information about the capabilities of their equipment to determine if it would be useful for tracking eels at Iroquois Dam. Section 9 identifies the contacted vendors. In an effort to acquire specific information regarding the effects of handling silver eels, a separate questionnaire was sent via electronic mail to researchers known to have experience with collecting and handling eels to be used in telemetry studies. That questionnaire requested researchers to identify how eels were captured and transported, how long they were held before being released, and if handling resulted in any noticeable effects.

3.0 PHYSICAL BARRIERS FOR GUIDING DOWNSTREAM MIGRATION OF SILVER EELS

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Physical barriers of numerous kinds (e.g., screens, bar racks, louvers) have been used for many decades to prevent fish from moving either passively or actively into water intake structures ranging from irrigation canals, to power plant cooling water intakes, to turbines at hydroelectric facilities. Their potential for preventing outmigrating silver eels from entering water intakes and for diverting the eels' path of movement was reviewed comprehensively in a report published by the Electric Power Research Institute (EPRI) entitled *Review and Documentation of Research and Technologies on Passage and Protection of Downstream Migrating Catadromous Eels at Hydroelectric Facilities* (EPRI 2001a). The findings of that review were as follows (EPRI 2001a, p. 4-14):

> *The behavior of migrating silver eels when they encounter physical barriers, such as bar racks, is unlike that of any other fish for which such diversion structures have been successfully employed. Silver eels show no visual response to physical barriers, and thus cannot be visually guided by them. Response to the barrier is triggered by physical contact with the structure. Maintaining velocity at the face of the structure < 1.0 m/s is necessary to avoid eel impingement. Eels attempt to pass through structures, which, at high velocities can result in injury (e.g., broken vertebrae, loss of caudal fin). At non-impingement velocities, contact with a structure results in rapid movement upstream (the "Startle" response) rather than a search across the face of the barrier for an outlet. However, once acclimated to the barrier, eels often tend to remain in physical contact with it, despite having the ability to move away from or through it. High diversion percentages in some flume studies may be a result of test configurations (e.g., surface to bottom bypass entrances) unlikely to be feasible in the field. No successful field diversion has been documented to date. Existing literature suggests that physical barriers have potential for use, but most likely in smaller river systems and at smaller projects, where construction of barriers across the entire water column might be feasible.*

Large portions of the text of EPRI's (2001a) report concerning studies of physical barriers and their effectiveness for eels are reiterated in this section with some expansion to include additional relevant details of that work. As described in Section 2 of this report, a search of the literature was conducted to identify any additional studies of the effectiveness of physical barriers for guiding migrating eels published or conducted since 2001. As part of that search, the network of eel researchers identified in conducting this project was queried for any knowledge of additional studies. Appendix A lists all of the eel researchers contacted during this project and identifies the various technologies and areas of information for which they provided input.

Researchers who had published papers on physical guidance of eels were contacted to identify any other researchers who may be studying the topic. Determinations of the relevance and applicability of new information were based substantially on the conclusions of a working paper entitled *Preliminary Technical and Economic Feasibility of Deploying a Trap and Transport System for American Eel at Iroquois Dam* (Kleinschmidt 2006). Versar's engineering consultant for this project, Alden, conducted an independent review of the information presented by Kleinschmidt (2006) before it was incorporated into this report.

3.1 REVIEW OF PHYSICAL BARRIERS AS EVALUATED BY EPRI

The difficulty of developing structural barriers to guide the movements of outmigrating eels arises from the fact that eels behave very differently than other species for which diversion structures have been employed successfully. Eels appear to bump into structures and, in many cases, to attempt to force their way through them. Berg (1995; as cited in Thon 1999) found that eels up to 70 cm long could pass through bars spaced 25 mm apart, and eels of 55 cm to 60 cm could pass through 20-mm spaces. Schultze (1989; see translation in Appendix B of EPRI 2001a) described the history of a hydroelectric project in Germany, where loss of eels that passed through the turbines prompted installation of a rack with bars spaced 20 mm apart. The velocity of the current at the rack ranged from 0.8 m/s to 1.3 m/s, and the mortality of migrating eels was large. The eels suffered skin damage, multiple spine fractures, and broken tails, most likely as a result of trying to pass through the bars tail first or inadvertently having their tails entrained between the bars by the flow. Schultze reported that eels could not maintain their positions during flume studies at water velocities of 1 m/s, which would explain the observed impingement. He also concluded that through-rack velocities of less than 0.5 m/s were necessary to avoid impingement, particularly at the lower water temperatures prevalent during migration. Similarly, outmigrating silver stages of New Zealand's *Anguilla* species, which are much larger than American or European eels, are trapped and killed on the penstock screens at large hydroelectric projects (Mitchell and Chisnall 1992).

Adam and Schwevers (1997) completed detailed observations of the responses of silver eels to angled racks of vertical bars and flow velocity in an experimental channel (30 m long, 2 m wide, and 1.2 m deep). That report does not indicate whether the diversion studies were done in the dark or with light, which could influence eels' behavior. The researchers investigated eels' responses to various configurations of angled racks:

- a rack of vertical bars spaced 20 mm apart, angled at 90º and 15º to the direction of flow;
- a bar screen with 20-mm spacing placed at an angle of 25º against the bottom and angled at 90º to the direction of flow; and
- louvered panels with 100-mm spacing set at an angle of 15º to the direction of flow.

Eels moving downstream bumped headfirst into the bar racks angled at 90º and 15º. At velocities less than 50 cm/s, eels were able to swim away from the racks and, thus, avoided entrainment; at velocities greater than 50 cm/s, eels typically became impinged on the bars. After initially being impinged, they were observed physically forcing themselves through the bars, if possible. At velocities of 1 m/s or more, all eels were impinged on the racks or screens. Eels encountering the shallow-angled (25º) bar screen were observed following the screen up to the water surface; however, they failed to move through the 15-cm gap between the end of the screen and the water surface and, as in other tests, attempted to force themselves through the bars. The louvered panels were totally ineffective; eels moved through them with no hesitation. Eels moving downstream often collided with the racks and exhibited no lateral searching behavior in front of angled racks before physically touching the structures throughout the tests. Schultze (1989) reported the same behavior. This suggests that establishing the correct placement of diversionary devices (e.g., angled bar racks) and egress points (e.g., bypass facilities) would be difficult.

Adam and Schwevers (1997) also suggested that the positive guidance observed with the 25º angled screen (a screen extending from bottom toward the surface across the entire width of a water body at an angle of 25º to the horizontal) could be used in combination with a collection device at the surface to bypass eels downstream. The observations of impingement and flow velocity clearly indicated that maintaining approach velocities of less than 50 cm/s for angled screens is necessary to minimize impingement. Further testing is required to define the relationship between impingement, eel size and swimming behavior, and flow velocity more completely.

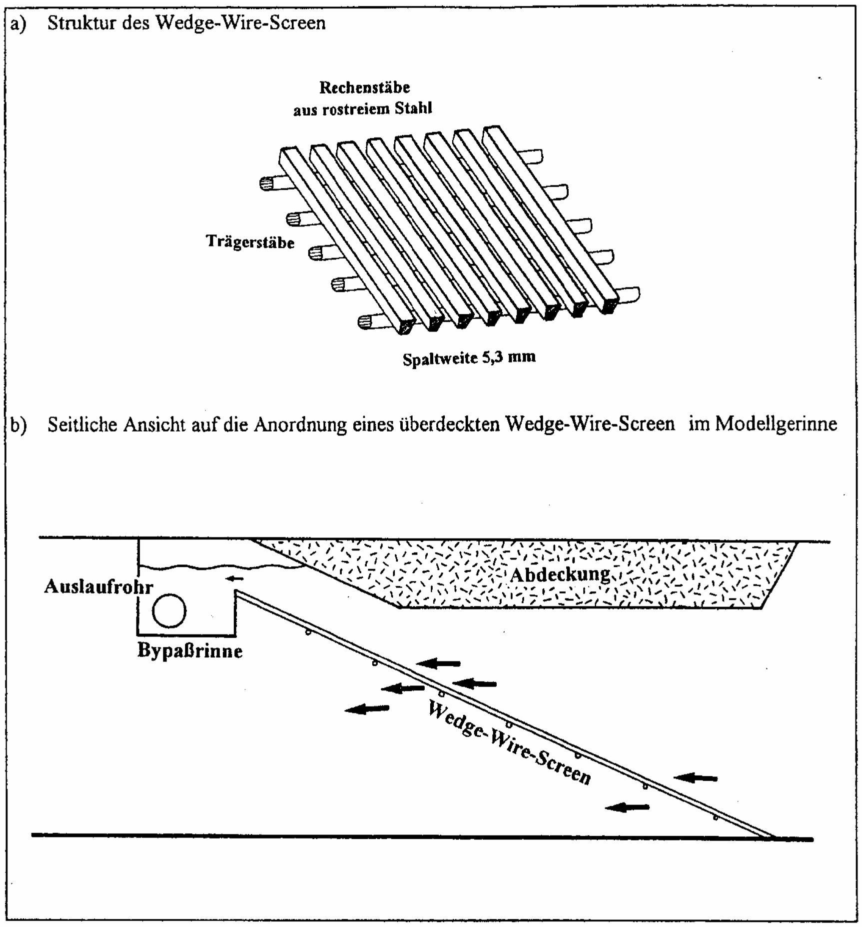
EPRI (2001b) presented the results of two years of study of the effectiveness of angled bar racks and louvers for diverting silver American eels. The work was conducted in the dark in a 24.4-m long flume that was 1.7 m wide and 2.1 m deep. Bar-slat spacing of 25 mm and 50 mm were tested; louvers were spaced 50 mm apart. Approach velocities at the structures were 0.3, 0.6, and 0.9 m/s for bar racks, and 0.3, 0.6, and 0.75 m/s for louvers. Guidance efficiency was greater than 54% for all tests with bar racks and for tests at 0.6 m/s with louvers. Guidance efficiency with the 50-mm bar rack declined from a high of 72.7% at 0.3 m/s to a low of 54.5% at 0.9 m/s. Efficiency also increased markedly with the structures at a 15º angle to flow, exceeding 90% at velocities of 0.3 m/s and 0.6 m/s with bar racks. For the 15º angled structures, however, a solid bottom overlay was attached to the lower 30 cm of both the bar racks and the louvers to improve the guidance of bottom-oriented species, including eels. Those studies suggested no difference in guidance efficiency between the bar rack and the louver arrays and that the 15º structures were much more effective than those with a 45º angle. EPRI (2001b) concluded that bar racks and louver arrays angled at 15º appeared to have potential to provide relatively high rates of diversion; however, they cautioned that their experimental facility employed a full-depth bypass and relatively short lengths of bar racks and louvers, which is unlike structures that might be installed at actual hydroelectric facilities. EPRI (2001b) further concluded that field tests are required to assess the diversion potential of these devices for eels more accurately. Adam and Schwevers (1997) also tested the response of eels to louvered panels. In their flume, eels repeatedly swam through louvers spaced at 100-mm placed at a 15º angle to the flow. This is very different than the diversion efficiency documented by EPRI (2001b) for studies with louvers spaced 50 mm apart and placed at an angle of 15º. An additional difference in observations is that silver eels used in EPRI's (2001b) tests appeared not to be impinged on bar racks at any of the velocities used in the experiments, but that they chose to remain physically in contact with the racks, despite having the ability to swim away from or pass through the barrier.

Adam and Schwevers (1997) also investigated the use of wedge-wire screens (5.3 mm bar spacing) for diverting eels. They reported that the eels' response was related to velocity. Eels exhibited a "startle" response when flow velocity was slower than 0.7 m/s, but no eels were impinged on the screens even at velocities faster than 1.0 m/s, and they showed no impingement damage. Schultze (1989) concluded that some variation of wedge-wire screens was the kind of diversion structure most likely to be effective at a German project. He found that although eels showed the "startle" response when they first encountered the screen, they were not impinged on the smooth surface at velocities that exceeded their swimming ability (> 0.7 m/s) but, instead, were pushed up the angled screen into a bypass structure placed perpendicularly to the flow, and did not suffer any injury. He proposed installing a wedge-wire screen at an angle of 40º to the horizontal plane (Figure 3-1).

Therrien and Verreault (1998) presented preliminary results of studies of a fine-grid (1-cm mesh size) inclined screen at a single-turbine hydroelectric facility on the Rimouski River, a small tributary of the St. Lawrence River with a mean annual flow of 30.8 m^3/s. The installation included an air-jet device for cleaning the screen. Some installation problems were encountered, including clogging of the screen with leaves, which the authors believed allowed eels to pass the screen. They reported that 61 eels were diverted into the bypass and suggested that their system could be 100% effective if properly installed.

A study conducted by Barnes-Williams for Stillwater Hydro Partners at the Stillwater Project (FERC No. 4684) on the Hudson River, New York, suggested that angled racks with bars spaced 2.54 cm apart may have been effective at guiding eels to a surface bypass; however, some limitations in the sampling design resulted in uncertainty about the guidance efficiency (F. Winchell, Alden, e-mail to Doug Dixon, June 7, 2001).

At the Lakeport Project (FERC No. 6440) at Lake Winnipesaukee in New Hampshire, a 12.5-m plastic rack with 0.95-cm bars spaced 2.11 cm apart was installed at a vertical angle to the flow with 5.2 m of exposure to the water. This system apparently was successful at diverting eels to a bypass. No report on this project could be obtained to provide more detail about the structure and its rate of success (Alex Hoar, FWS, e-mail to author, July 12, 2001).



a) Structure of the wedge-wire screen: (1) rack bars of stainless steel (triangular or trapezoidal); (2) carrier bars (round); (3) interstitial width 5.3 mm (i.e., between triangular stainless steel bars).

b) Side view of the arrangement of a covered wedge-wire screen in the model channel; Auslaufrohr=discharge pipe, BypaBrinne=Bypass gutter, Abdeckung=cover.

Figure 3-1. Structure of a wedge-wire screen and its arrangement in the model channel (Source: Adam and Schwevers 1997)

3.2 REVIEW OF STUDIES OF PHYSICAL BARRIERS SINCE 2001

A search for information and literature on physical barriers to guide outmigration of silver eels found very few studies conducted since EPRI's review (2001a).

3.2.1 Perforated Screen at the American Tissue Project

Beginning in 2004, Ridgewood Power has voluntarily installed a perforated screen over trash racks (Figure 3-2) at the American Tissue Project (FERC 2809) on the Coboseeco River in Maine every fall. An adjacent deep gate is opened at night while the screen is in place. The effectiveness of this system has not been studied formally, but spot inspections of the tailrace area during annual fall migrations have revealed no dead eels, suggesting that this approach has been successful in diverting outmigrating eels away from the turbine (G. Whipplehauser, Maine DMR, pers. comm., April 5, 2008).

3.2.2 French Trash Rack Studies

A draft report (EPRI, in press) presents results of two studies of the effectiveness of trash racks for diverting migrating European eels at a hydroelectric project in France. Researchers used telemetric techniques to evaluate the efficiency of trash racks with two different bypass systems. The work was conducted at the Baigts-de-Bearn hydroelectric dam (hereafter Baigts Dam) on the Gave de Pau River in southwest France. One system was a trash rack and surface bypass constructed specifically to aid the downstream migration of salmonid smolts (Figure 3-3). The second system was a setup for salmon smolts adapted with a surface-to-bottom bypass to assist migrating eels (Figure 3-4). Flows in the Gave de Pau River averaged 77 m^3/s from 1980 to 2000. Baigts Dam is 57 m long and has two sluice gates (595 m^3/s capacity) and a flushing gate (298 m^3/s capacity). A trash rack (40 m long and 5 m high) with bars spaced 30 mm apart protects the forebay. The top edge of the trash rack is submerged 2 m during normal operating conditions and has a solid concrete wall above it. The surface bypass is fed with an average flow of 2.2 m^3/s. Fish move through the bypass and along a 45-m long open channel before being released downstream. This system yielded 45% passage efficiency for salmon smolts (Chanseau et al. 2002). When this passage was combined with passage from spills through the flushing gate, smolt passage efficiency was 92%.

The study also investigated the passage efficiency of this system for outmigrating eels. Studies were conducted for 84 consecutive days between October 2004 and January 2005. Eels purchased from fishermen were implanted with a radio tag (48-49 MHz) and a Passive Integrated Transponder (PIT) tag. In addition to monitoring the movements of fish, temperature, conductivity, and turbidity in the river; water level in the forebay and diurnal brightness were measured continuously to evaluate their effect on passage success. River flow during the experiment was less than the average between 1980 and 2000, measuring 45 m^3/s, 51 m^3/s, and 67 m^3/s during November, December, and January, respectively. Turbine flow ranged from 11 m^3/s to 79 m^3/s. Sluice-gate spill was due primarily to permanent leaks, except during three floods, when spill briefly increased to 50 m^3/s, 170 m^3/s, and 250 m^3/s. The horizontal component of velocity at the trash rack was directed downstream and ranged between 12 and 40 cm/s depending on turbine-flow conditions. The vertical velocity component at the trash rack was directed downward at a rate ranging from 1 to 5 cm/s, again depending on the operating conditions of the turbines.

Figure 3-2. Perforated screens are laid over trash racks on the American Tissue Project on the Coboseeco River, Maine, to divert eels to a deep by-pass (photo courtesy of A. Haro, USGS).

Figure 3-3. Trash rack and surface bypass on the Baigts-de-Bearn hydroelectric dam on the Gave de Pau River, France (Source: EPRI, in press).

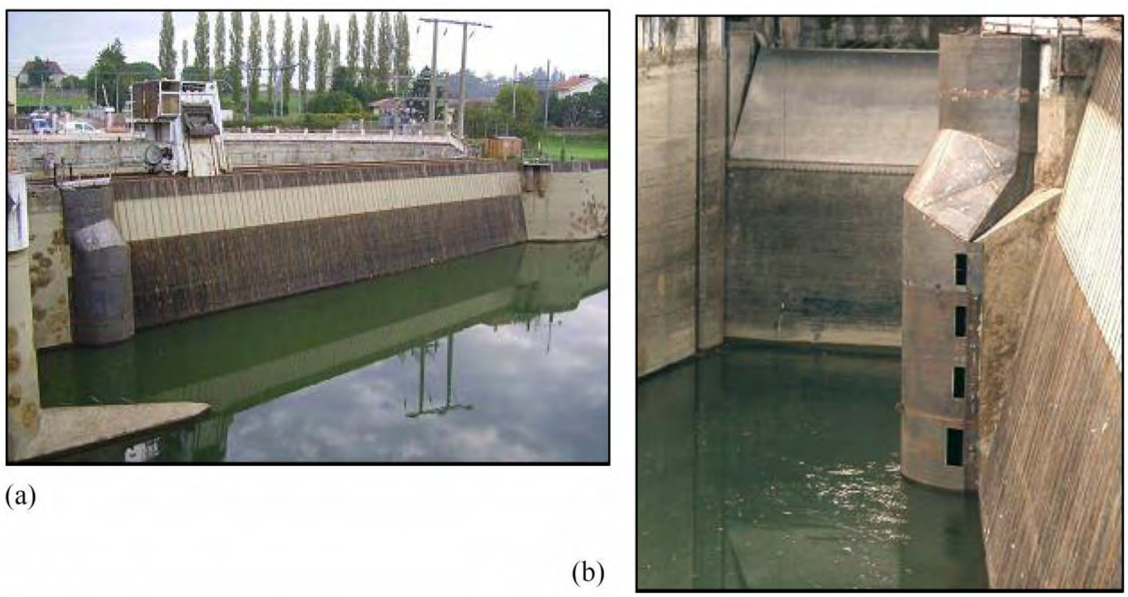


Figure 3-4. Surface-to-bottom bypass modification in 2005; (a) front view, (b) lateral bypass entrance gaps along the trash rack on Baigts Dam, France (Source: EPRI, in press)

A total of 40 eels were released during 12 events from a site 1.5 miles upstream of the dam. Eighty percent of the eels passed the project within 5 days, and 90% had passed after 10 days. For all eels combined, 80% of distance was traveled at night (5 p.m. to 9 a.m.). About 57.5% of eels migrated during peak flows, and distance traveled increased as flow increased (Figure 3-5), which was also when turbidity was greatest. During the 2004/2005 study, 60% of the tagged eels that reached the project passed through the bars of the trash rack and subsequently through the turbines (Table 3-1; Figure 3-6). Spill condition had a significant effect on passage path, and most passages (70%) occurred when there was no spill (Table 3-1). River flow did not appear to affect passage path except that passage via the fish ladder occurred during low river flow, generally after those eels had made long excursions within the reservoir. The ratio of bypass flow to turbine flow had no detectable influence on passage path.

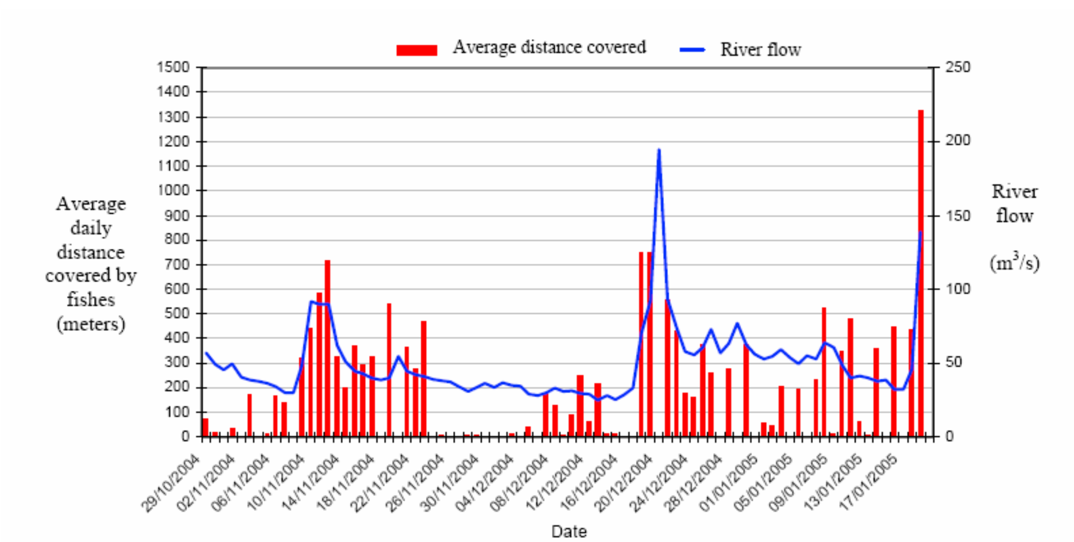


Figure 3-5. Relationship between distances covered by eels and river flow over time at Baigts Dam, France (Source: EPRI, in press)

Table 3-1. Summary of 2004/2005 passage paths of eels at Baigts Dam, France (Source: EPRI, in press)

	Fish passage paths – number of individuals and percentages					
Spill condition	**Turbine**	**Bypass**	**Sluice-gate**	**Upper spill-valve**	**Old fish ladder**	**Total**
Spill = 0	18 (64.3%)	5 (17.9%)	2 (7%)	0 (0%)	3 (10.7%)	28 (70 %)
Spill > 0	6 (50%)	2 (16.7%)	3 (25%)	1 (8.3%)	0 (0%)	12 (30 %)
Total	**24 (60%)**	**7 (17.5%)**	**5 (12,5%)**	**1 (2.5%)**	**3 (7.5%)**	**40 (100%)**

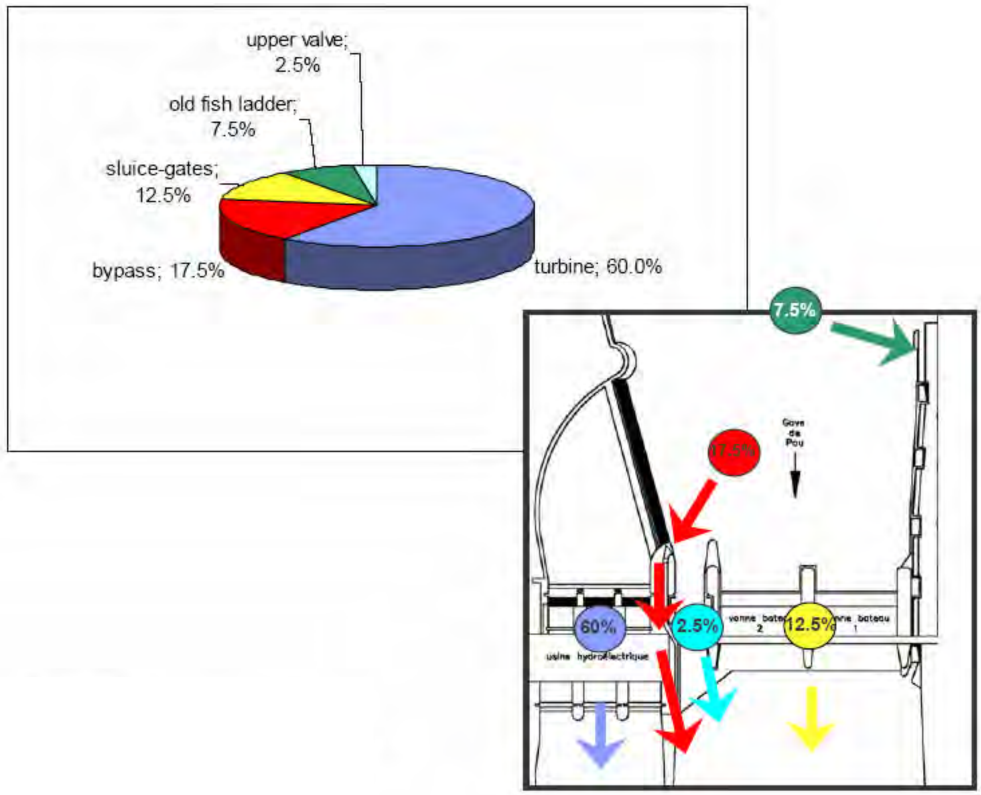


Figure 3-6. Distribution of eels' paths of passage at Baigts Dam, France, during the 2004/2005 study (Source: EPRI, in press)

The efficiency of the surface bypass was approximately 20%. The trash rack had, on average, low diversion efficiency; 60% of eels passed through the trash racks and subsequently through turbines (Table 3-1). The low efficiency could have been influenced by the location of the surface bypass, which was positioned appropriately for passing salmon smolts, but not for eels. Passage through the trash rack was significantly linked to the duration of excursions prior to reaching it. Trash rack passage increased with increasing flow velocity (Figure 3-7) and with increasing turbidity (Figure 3-8), but turbidity was correlated primarily with river flow. Eel size appeared to influence the mode of downstream passage. Eels with heads smaller than 25 mm in diameter (i.e., small eels) bypassed the turbines with 11% efficiency, whereas efficiency was 31% for larger eels (head diameter > 25 mm). Passage of eels through the trash rack occurred mainly near the bypass entrance. Mortality of 7 of the 10 dead eels found downstream of Baigts Dam was attributed to turbine strikes.

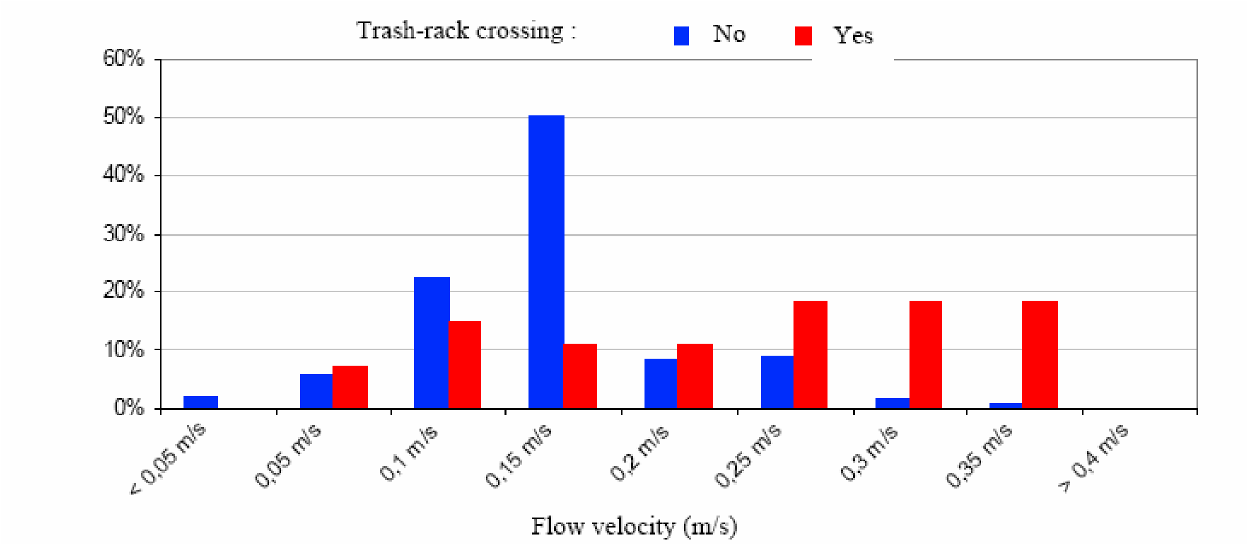


Figure 3-7. Percentage of eels that passed through (red) or did not pass through (blue) the trash rack, as a function of average flow velocity at Baigts Dam, France (Source: EPRI, in press)

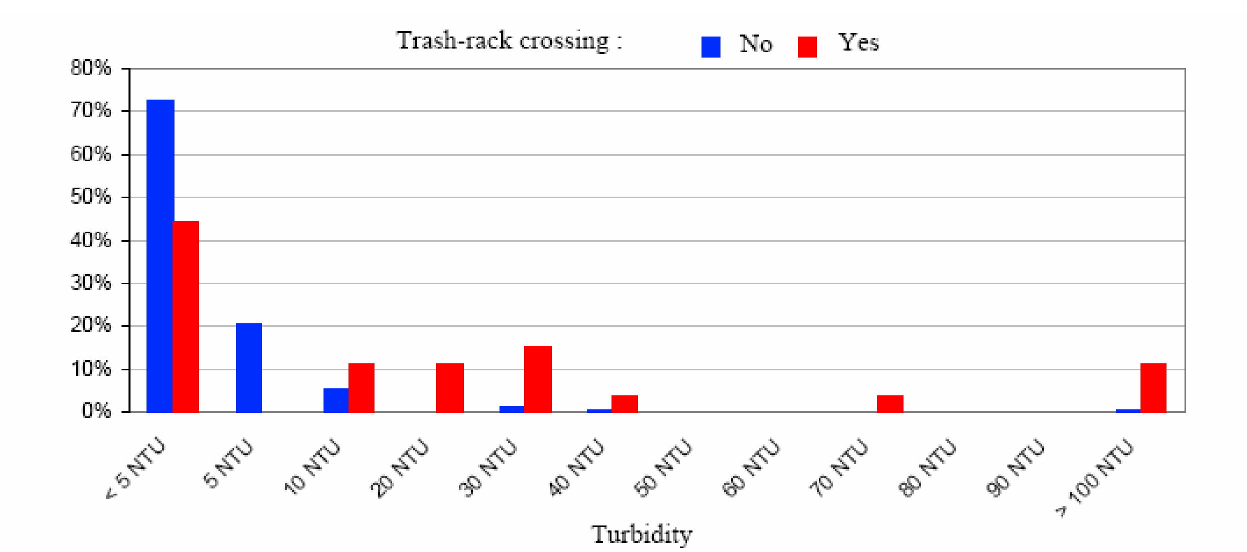


Figure 3-8. Percentage of eels that passed through (red) and did not pass through (blue) the trash rack as a function of turbidity at Baigts Dam, France (Source: EPRI, in press)

The second study, which was conducted between October 2005 and March 2006, evaluated a modified, non-surface bypass. The bypass consisted of a half-cylindrical structure installed vertically in front of the existing bypass but emptying into it. The structure extended to a depth of 7 m, and entrances consisted of lateral openings facing the trash racks (Figure 3-4). Presumably, the intent was for eels moving along the face of the trash rack to enter the structure through the lateral openings and then move up and through the existing bypass. Thirty-nine eels purchased from a commercial dealer were tagged and released on November 10. The radio-tracking and PIT-tag detection systems were similar to those used in the first experiment, except that an additional tracking and detection system was deployed 4.83 km upstream of the dam. River flow ranged between 33 m^3/s and 600 m^3/s. Turbine flow ranged between 0 m^3/s and 84 m^3/s. Spill varied between 3.4 m^3/s and 600 m^3/s. Spill flow exceeded turbine flow only during periods corresponding to peak river flow (5% of the time).

As found during the first study, the distance traveled by all tagged eels was strongly related to water flow. Tagged eels traveled a combined total of 473 km, 62% (292 km) of which occurred during 10 days of high flow. Most movement (77%) occurred at night. The turbines were the dominant point of passage. Nearly 54% percent of the 39 tagged eels passed through the turbines, 36% through the sluice gates, 8% through the upper spill valve of the flushing gate, and only 2.6% through the experimental bypass (Figure 3-9; Table 3-2). About 38.5% of passages occurred when there was no spill, compared to 70% in the first experiment. The condition of the sluice gates influenced the passage point. When the gates were closed, 85% of eels passed through the turbines and 15% through the sluice gates and spill valve; when they were open, 63% of passages occurred through the sluice gates and 4% through the bypass. The efficiency of the sluice gates as a point of passage was greater when the ratio of spill flow to turbine flow was larger. This result is consistent with findings of other bypass studies (Section 3.1).

Table 3-2. Comparison of 2004/2005 and 2005/2006 eel-passage paths at Baigts Dam, France (Source: EPRI, in press).

Path	2005	2006
Turbines	24 (60%)	21 (53.8%)
Bypass	7 (17.5%)	1 (2.6%)
Upper spill-valve	1 (2.5%)	3 (7.7%)
Old fish pass	3 (7.5%)	--
Sluice gates	5 (12.5%)	14 (35.9%)

Eels spent only a small amount of time near the trash rack (~ 60% of eels spent < 30 seconds) and then either passed through it or were repelled. As in the first experiment, eels spent long periods of time exploring larger areas near the trash rack. As before, the trash rack had a low repelling efficiency (25%), but passage was only weakly related to the duration of previous excursions. In general, high water flow and high turbidity led to a high rate of passage through the trash rack. Head size was also an important factor. Most eels (81%) with heads smaller than 30 mm in diameter passed through the trash rack, whereas only 57% of those with heads larger than 30 mm passed through the trash rack (Figure 3-10). The passage of eels whose heads were larger than the space between the bars suggests that factors other than bar spacing, such as flow velocity or ability of eels to contort their bodies, can influence the ability to pass such structures. Four of the 21 eels that passed through the turbines (19%) died.

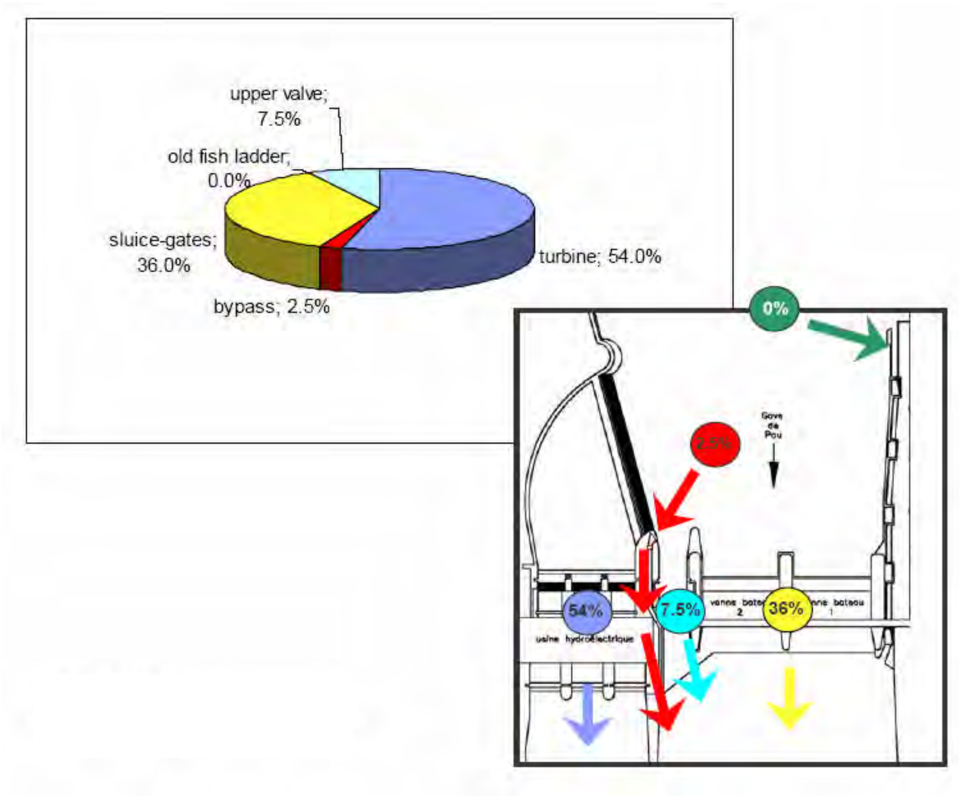


Figure 3-9. Distribution of eels' paths of passage at Baigts Dam, France, during the 2005/2006 study (Source: EPRI, in press)

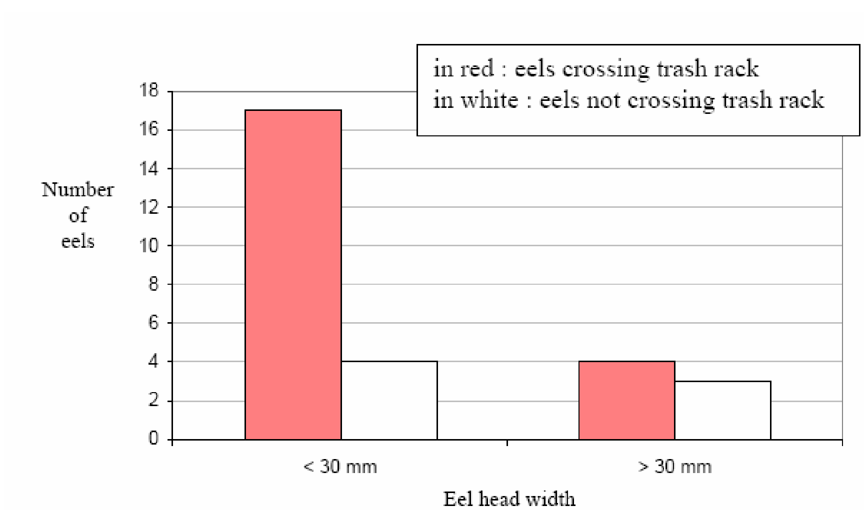


Figure 3-10. Trash rack crossing as a function of head width at Baigts Dam, France (Source: EPRI, in press)

The second study also monitored the activity of eels kept in captivity. The activity of captive eels was strongly correlated with environmental variables and similar to that of radio-tracked eels in terms of the distance traveled. Activity increased with river flow and turbidity and decreased with conductivity. The activity of eels in captivity appeared to be a useful indicator of activity in the river; however, the degree of correlation was determined to be insufficient to provide reliable information for enabling dam operators to facilitate eel passage by shutting down the project.

An additional element of the second study involved tracking 25 tagged eels released upstream of the Castetarbe project, 3 miles upstream of Baigts Dam. The bars on the trash rack at that project were spaced 25 mm apart. Forty-eight percent of released eels passed through the spillway, 20% through the turbines, 20% through the surface bypass, fewer than 10% through the fish passage, and fewer than 5% through the trash-rack cleaner. The relatively greater passage through surface bypasses and the fish passage compared to bypass percentages at Baigts Dam suggests that smaller bar spacing may have been a contributing factor.

3.2.3 Field Study of an Angled Louvre Array with Bypass

EPRI (2007) sponsored a study to evaluate the movement patterns of American eels encountering a full-depth louver array located in the power canal on the Connecticut River in Holyoke, Massachusetts. The array, located on the first level of the three-level canal system, was 6.1 m tall and extended 134 m diagonally across the canal at an angle of 15º, ending at the entry to the bypass pipe (Figure 3-11). Louver slats on the array were spaced 50 mm apart. The array was installed in 1992 to divert surface-migrating fish in the first-level canal into a bypass conduit and back into the Connecticut River below the dam. In 2002, the louver was extended to full depth to improve downstream guidance of shortnose sturgeon (*Acipensar brevirostrum*).

Eels for the experiment were collected from the downstream fish sampler at the end of the first-level canal bypass pipe. The fish sampler consisted of an inclined wedge-wire screen that directed fish to a sampling table (Figure 3-12). These eels had already passed through the bypass system, which created potential for bias in the study results. The study focused on the movement patterns of eels, not the effectiveness of a bypass device, per se. All eels used in the experiment were thought to be mature silver eels that had dark dorsal and white ventral coloration, broad pectoral fins, and large eyes. The experiment was conducted on the first level of the canal, where water depth ranged from 5.5 to 7.0 m

A pulse-coded, radiotelemetry tag (150 MHz) was implanted in each purchased eel. Two data-logging stations for underwater antennas, three data-logging stations for aerial antennas, and radio receiver systems were installed in an array throughout the study area to monitor movement. The louver structure was a barrier to underwater signals and prevented reception of radio-transmissions from the downstream side of the louvers. Later in the study, 27 eels were marked with only a floy tag as a control to determine how surgical procedures may have influenced movement patterns. Eels were held for 30 to 36 hours after tagging and then released during 3 flow regimes: 28.3 m^3/s (a total of 13 radio-tagged eels released in two 2 events),

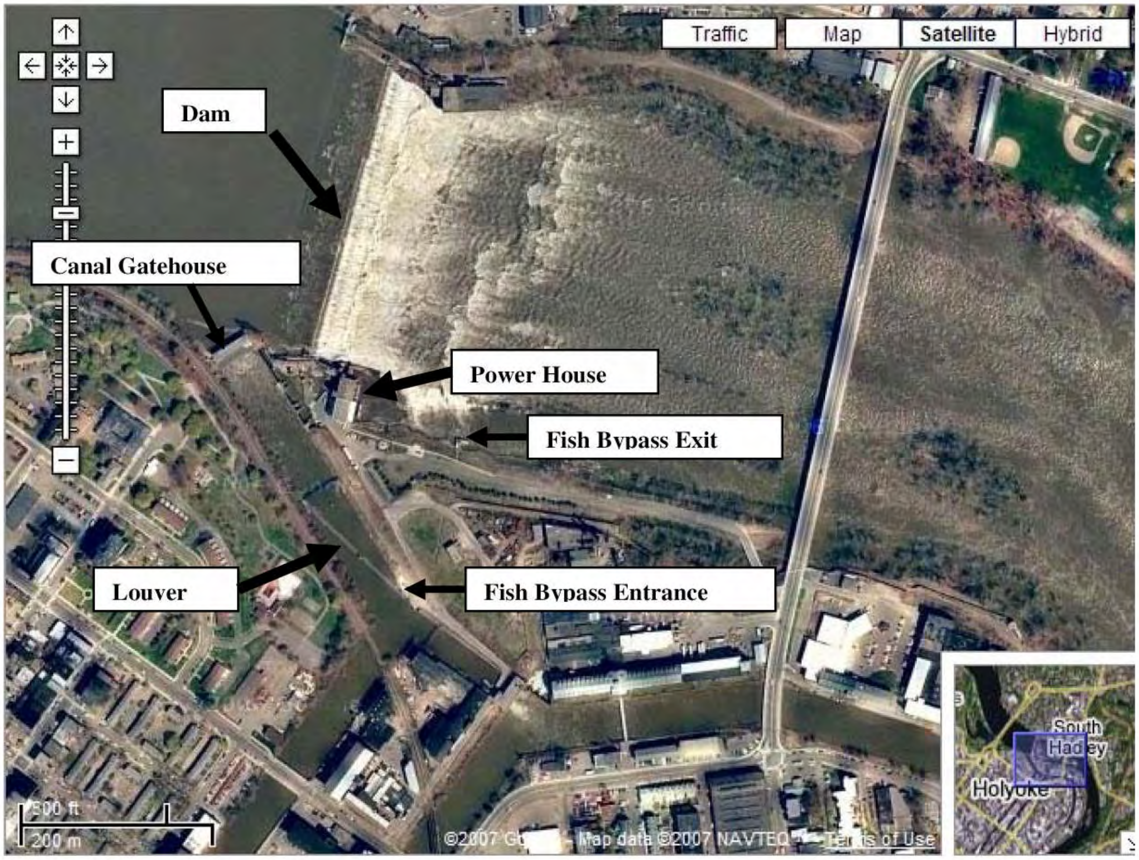


Figure 3-11. Aerial view of the Holyoke Project facilities including canal and louver array (Source: EPRI 2007)

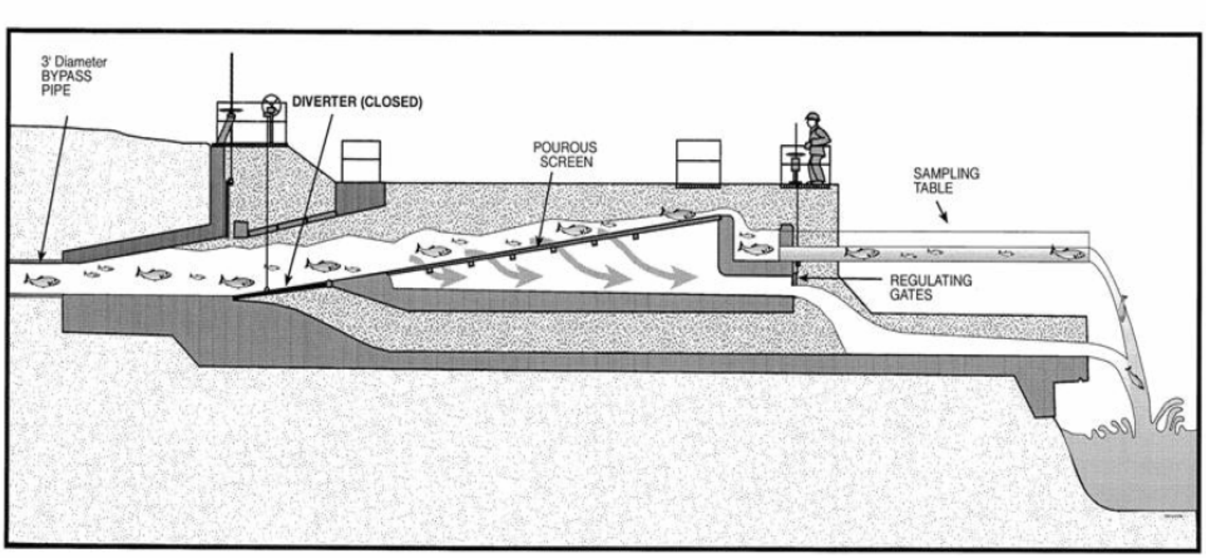


Figure 3-12. Diagram of the Holyoke downstream fish sampler while in sampling mode. The diverter gate is closed, which allows an inclined wedge-wire screen to separate fish and debris from the water column and divert them to a sampling table (Source: EPRI 2007).

70.8 m^3/s (20 radio-tagged eels), and 79.3 m^3/s (27 radio-tagged eels and 27 floy-tagged eels). Flow rates were maintained in the canal for at least three days following release. Data for 12 eels from each group were selected randomly for behavioral comparison. Some eels passed through the louver array, and some through the bypass, but the numbers moving via those two routes were not reported (i.e., passage efficiency was not reported).

The surgical implantation procedure appeared to affect initial downstream movement. At a flow velocity of 79.3 m^3/s, 40% of radio-tagged eels were detected within 3 hours, whereas 70% of floy-tagged eels were detected within that time, suggesting that the surgical procedure delayed migration. Eighty percent of the radio-tagged eels exhibited significant migration delay. Radio-tagged eels spent most time on the bottom, upstream of the louver array near the release location and the louver approach zone, where they appeared to be resting to recover from surgery. Fish that passed through the louver and the bypass were distributed equally with distance upstream from the louver. Eels released during the 28.3 m^3/s flow regime had the greatest residence time, typically exiting only after the 70.8 m^3/s regime commenced. Eels released during the 70.8 m^3/s and 79.3 m^3/s flow regimes exited during the regimes in which they were released.

In general, eels exhibited exploratory swimming patterns upon encountering the louver. Eels swam close to the louver and occasionally came into contact with it, resulting in a variety of behaviors including scattering, continued movement without response, becoming stationary near the bottom, or quickly passing through the louver or to the bypass. Such behaviors are similar to those reported in several laboratory studies summarized in Section 3.1. The behavior of eels that went through the bypass was not markedly different than the behavior of those that passed through the louvers. In general, eels' behavioral patterns consisted of long delays in movement followed by brief bursts of highly energetic swimming behavior. The telemetry paths of several of the tracked eels demonstrated that they could and would move downstream of the louvers, then return to the upstream side. Eels did not appear to become impinged along the louver structure at the tested flow rates. Eels were able to move upstream, downstream, and throughout the water column in front of the array at all velocities. This behavior is consistent with behavior described in the summary of findings of previous studies presented in Section 3.1, illustrating that physical structures do not guide eel movements consistently.

3.2.4 Flume Study of a Bar Rack and Bypass System

With funding provided by EPRI, Alden carried out a study of silver eels to compare the effects of implanted radio tags and external floy tags and to compare the behavior of tagged eels during initial exposure to a bar rack/bypass system with their behavior during a subsequent exposure (EPRI 2001b). A secondary objective was to quantify the efficiency of the bar rack/ bypass system. This study was a follow-up to the louver study described in Section 3.2.3. The experiment was carried out in a flume measuring 24.4 m long, 6.1 m wide, and 3.1 m deep, with test flow velocities to 14.2 m^3/s. A 3.1-m steel bar rack with 5.1-cm clear spacing was mounted in the center of the flume. Guidance walls extending upstream from both sides of the bar rack caused water velocity to increase toward the bar rack. The bypass entrance was situated toward the bottom middle of the bar racks.

Eels for the experiment were purchased from a commercial supplier and, thus, had been subjected to handling and holding. For each trial, 10 eels were surgically implanted with dummy radio tags. The dimensions of the dummy tags were similar to those of the real radiotelemetry tags used in the louver study described in Section 3.2.3. Another 10 eels were tagged externally using floy tags with PIT tags affixed at the posterior ends for monitoring. A 24-hour, post-tagging recovery period preceded each test run. The group of 20 tagged eels was released into the bottom of the flume in lighting conditions that mimicked dusk. Six groups of 20 were tested in all. Each trial lasted 3 hours to parallel the amount of time that floy-tagged eels were studied per trial in the field louver study. After the initial trials, each group of fish was retested to study the effect of prior exposure to the bar rack on behavior.

Responses of internally and externally tagged eels did not differ. A large percentage (33% to 62%) of the test eels did not move downstream, which raised doubts about the representativeness of the test results. Observed diversion percentages, therefore, were not considered to be representative of natural behavior. Lack of movement could have been a function of the stress of handling and holding or of conditions in the flume but could not be explained conclusively. Behavior was noticeably different between initial and secondary exposures to the bar rack/bypass system. More eels remained upstream of the bar rack during their second exposure, again suggesting a possible handling effect. The methods used in this study did not enable researchers to evaluate the effects on behavior of recovery time following surgical implantation of tags.

3.2.5 Trash Rack with Surface-sluice and Bottom-sluice Bypasses

Gosset et al (2005) evaluated the effectiveness of two kinds of bypasses for redirecting outmigrating silver eels at the Électricité de France hydroelectric plant at Halsou on the Nive River in southwestern France (Figure 3-13). Flow ranged between 6 m^3/s and 300 m^3/s (during rain storms). At the Halsou plant, a 172-m-long by 2.5-m-tall gravity dam diverts water into a headrace (925 m long by 3 m deep by 11 m wide). The dam bypass has bottom baffles. Three turbines generate a flow of 30 m^3/s over a 4.25-m vertical drop. A 20-m-long by 3-m-tall trash rack equipped with an automated system for removing debris is angled at 25º from the vertical plane in front of the intakes. Bars on the rack are 8 mm thick and spaced 3 cm apart. The trash rack is angled at 15º in relation to the axis of the headrace. Maximum water velocity in the headrace is 1.6 m/s and about 0.5 m/s in front of the trash rack. Floodlights normally illuminate the forebay area at night but were turned off during the study period.

The surface bypass is located on the right bank of the forebay at the end of the trash rack. It is equipped with a flap gate that is 1.38 m long and 0.90 m wide. As a result of variations in water level caused by freshets and suspension of turbine operation, opening the surface bypass caused variable flow patterns (0.4 m^3/s-1.0 m^3/s). Opening the surface bypass also caused surface velocity parallel to the trash rack, which was especially high above the turbine closest to the bypass.

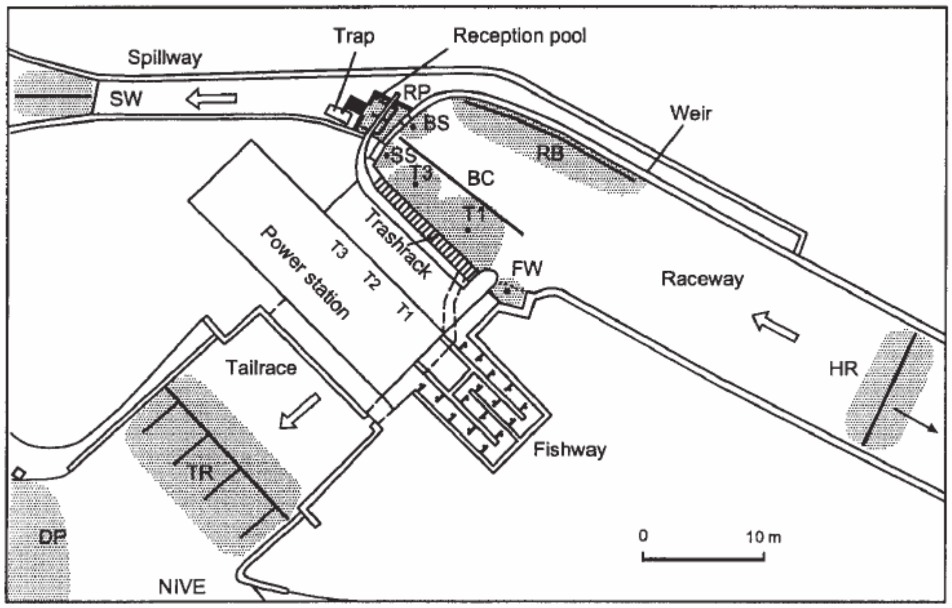


Figure 3-13. General view of the Halsou hydroelectric power plant and radiotelemetry surveillance zones (see text for explanations), on the Nive River, France; shaded areas are areas of tag detection from antennae indicated by two-letter/number designations (Source: Gosset et al. 2005)

The motorized bottom gate also is located on the right bank of the forebay, 5 m from the end of the trash rack. A discharge tower equipped with a vertical flap gate was built at the outlet of the bottom sluice to enable flow through the bottom gate to be similar to flow through the surface bypass (0.6 m^3/s). Fish that pass through the bottom gate fall into a collecting pool connected to the discharge canal. From there, fish are swept by the current onto a screen and caught in a trap from which they were recovered by nets. Surface and bottom bypasses were opened on alternate days for three years. The trap was sampled twice a day for the first two years (8:30 am and 6:00 p.m.) and at least once per day in the third year (8:30 a.m.). Morphological characteristics of captured fish were recorded.

Eels to be used in the study either were trapped at the power station or caught via electrofishing upstream of the dam. A group of eels was surgically implanted with radio-tags. The trailing antenna transmitters were uncoded ATS model 10/28 (frequency 48-49 MHz, length 45 mm, diameter 11 mm, weight 8g). The ratio of transmitter weight to eel weight was less than or equal to 2% in nearly all cases. Manual and automated radiotracking devices were deployed throughout the study site. Eels were released within hours of being tagged. Three groups were released: 15 from October 20 to November 22, 1999, average weight 850g; 30 from October 10 to November 26, 2000, average weight 608g, and 25 from November 9 to January 23, 2002, average weight 623g. Environmental parameters and flow characteristics also were monitored regularly.

The trap captured a combined total of 637 silver eels from both bypasses over three years (66 in 1999, 75 in 2000, and 496 in 2001). Most captures occurred at night (6:00 p.m. to 8:30 a.m.) and were associated with higher flow (Figure 3-14). In 2001, 436 eels were caught during a single night when flow during a freshet more than doubled to 25 m^3/s. More eels were caught through the bottom bypass (95% in 1999, 72% in 2000, and 63% in 2001), except during the one night of exceptional capture in 2001. Radiotagged fish displayed similar passage patterns in all three years (Table 3-3); 8% to14% passed through the surface bypass, whereas 42% to 53% passed through the bottom bypass. Efficiencies could not be compared directly because fishing effort was not constant over the two sampling periods. The entrance to the trap became clogged when the surface bypass was open during higher flows. This is likely to have resulted in an underestimation of passages through the surface bypass because pulses of downstream migration generally occurred during such flows. The authors concluded, nonetheless, that eels preferred to use the bottom bypass because the rate of passage through the bottom bypass was consistently about 3 to 4 times greater than the rate of passage through the surface bypass (Figure 3-15). The surface and bottom bypasses combined were 56% to 64% efficient for diverting eels. A significant drawback of the bottom bypass is that it required constructing a tower to regulate discharge and reduce flow at its entrance. Reduced flows (~ 0.3 m/s) were required to prevent eels from becoming impinged on the trash rack and subsequently dying. Implementing such a system at a hydroelectric project on a deep river system would be complicated and costly.

Table 3-3. Distribution of radio-tagged eels at Halsou on the Nive River, France (Source: Gosset et al. 2005)

		1999	2000	2001	Total
Released		15	25	34	74
Passed at the station*		5 (33%)	11 (44%)	20 (59%)	36 (49%)
Swam through the power station, directly or after a stay in the raceway†	Bottom sluice	4	5 to 9	6	15 to 19 (42 to 53%)
	Surface sluice	0	1 to 3	2	3 to 5 (8 to 14%)
	Turbines	1	1 to 3	8 to 9	10 to 13 (28 to 36%)
	Station weir	0	0 to 1	3	3 to 4 (8 to 11%)
	Fishway	0	0	0 to 1	0 to 1 (0 to 3%)
Total efficiency of the 2 sluices†		80%	72 to 80%	40%	56 to 64%
Swam upstream of the raceway and come back into the Nive*	Dam	10 (66%)	13 (52%)	5 (15%)	28 (38%)
	Abandoned or lost	0	1 (4%)	8 (40%)	9 (12%)
	Dead	0	0	1	1 (1,4%)

*Percentage calculated according to the number of tagged fish.
†Percentage calculated according to the number of fish that passed through the power plant.

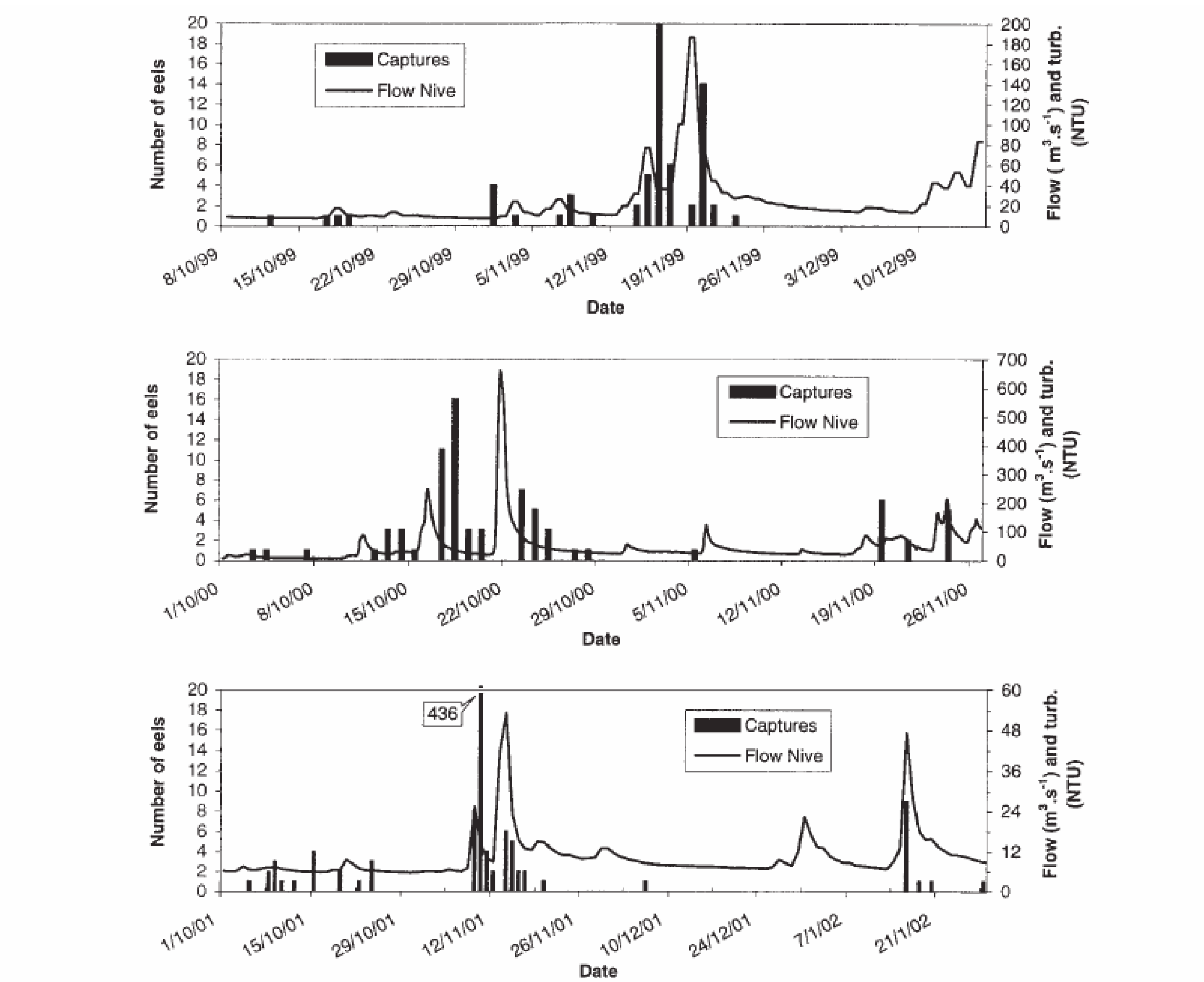


Figure 3-14. Daily captures of outmigrating eels during the 1999, 2000, and 2001 studies in relation to flow and turbidity of the Nive River, France (Source: Gosset et al. 2005)

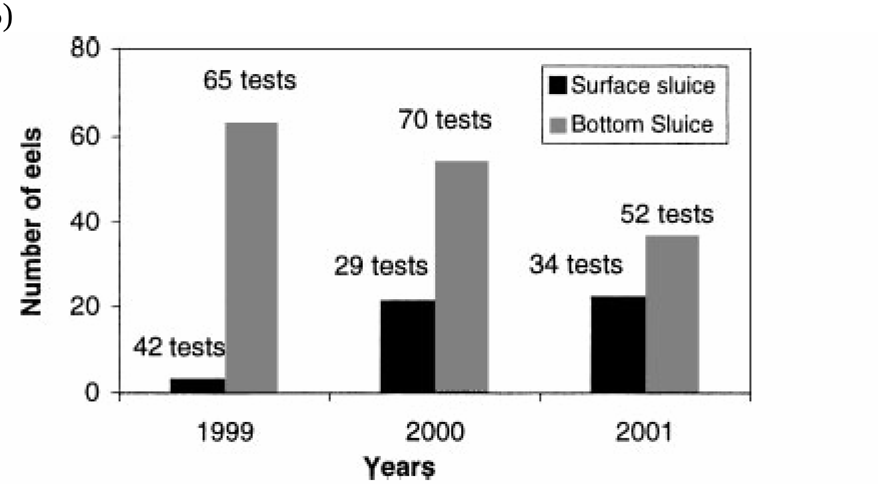


Figure 3-15. Number of unmarked eels caught in the trap according to the bypass in use at Halsou on the Nive River, France (Source: Gosset et al. 2005)

Radiotracked eels exhibited behavior that could be interpreted as either foraging or exploration in the forebay, spending from 30 seconds to 14.25 days in that area. Eels often remained still, in place, near the spillway in the absence of significant current, generally around mounds of sand/mud created by counter-currents. Most movement occurred near the bottom. Eels often passed in front of the trash rack several times without penetrating the bars, suggesting that the trash rack had a repelling effect that appeared to increase with flow. The bars were spaced 3 cm apart, and 80% of the tracked eels' heads were larger then 3 cm in diameter. The efficiency of both bypasses was lower (40%), and the number of passages through the trash rack was greater (40% to 45%) in the year when turbine flow was lowest. The authors suggested that 2-cm bar spacing would prevent entrainment of almost all silver eels. (90% of eels in the Nive River have heads > 2cm wide)

3.3 SYNTHESIS AND RELEVANCE TO IROQUOIS DAM

The results of the relatively few studies of physical barriers conducted since 2001 are consistent with the findings of all the studies reviewed by EPRI (2001a). The effectiveness of physical barriers for redirecting the path of movement of outmigrating eels appears to be limited and highly variable. The greatest success appears to be in small systems where all outmigration routes except for bypass openings can be blocked, and where eels are physically unable to pass through the barrier (e.g., bar spacing < head diameter). Diversion percentages varied widely and appeared to be affected by a number of factors, including river flow rate, turbidity, localized flow in the vicinity of the physical barrier, by-pass flow as a percentage of total and turbine flow, and the orientation of the physical barrier relative to the direction of flow. For systems employing trash racks, the bar width in relation to head width was important; however, as shown at Baigts Dam, eels with heads wider than the width of the bars were still able to pass through the trash rack. This finding suggests that torque caused by local hydrodynamics may force fish through the barrier. Damage of eels attempting to pass through barriers also was reported. The presence of an angled louver did not appear to be effective in redirecting eels or significantly altering their behavior.

All of the studies identified dealt with relatively small rivers or streams or small flumes. In contrast, the St. Lawrence River at Iroquois Dam is a much larger system. The river is 600 m wide at the dam, with water flow of 7,070 m^3/s to 7,388 m^3/s during June through October, when silver eels are migrating through that area. Based on the dimensions of the 32 sluiceways at Iroquois Dam (15.2 m wide and water depth of 13.1 m), velocities through the dam range from 1.1 m/s to 1.2 m/s. These are much higher flows and velocities than those in any of the studies reviewed. Although the diversion percentages estimated in the studies reviewed are not particularly relevant to the situation at Iroquois Dam, information about how eels respond to a barrier, and how velocity in the immediate vicinity of the barrier may affect eels' response to it would be relevant for Iroquois Dam.

3.4 CONCEPTUAL DESIGN OF A PHYSICAL BARRIER FOR EELS AT IROQUOIS DAM

In a working paper, Kleinschmidt (2006) presented a conceptual design for a physical barrier to guide eels in the St. Lawrence River in the vicinity of Iroquois Dam. The device described in that working paper consisted of an angled bar rack intended to divert eels moving downstream into a collection facility installed in the dam itself. Kleinschmidt (2006) described the structure as follows:

> *The angled bar rack would cover the entire water column and consist of vertically oriented steel bars with 35 mm (3.8 cm) clear spacing which would physically exclude most eels based on an average head width > 40 mm for the large eels that migrate out of the St. Lawrence River. The structure would be angled to the direction of the river flow. While in theory as the angle to the flow decreases, guidance effectiveness would be expected to increase, the most effective orientation for guiding American eel is not known (note that studies reviewed did not include as a variable the angle of the barrier relative to current direction).*

Kleinschmidt's evaluation of the conceptual design considered deploying the angled bar rack at 15º, 30º, and 45º to the direction of flow, either in a straight-line or a V-shaped configuration. Conceptually, a straight-line configuration would be oriented such that the upstream end of the array would meet either shoreline and the downstream end would terminate at a sluiceway on either end of the dam, which would be the location for the collection device. This configuration would be intended to form a barrier to direct all eels passing downstream to the collection device. The shoreline in the vicinity of Iroquois Dam is shaped in such a way that an extremely long structure would be required to reach from either shore to either end of the dam; therefore, Kleinschmidt (2006) evaluated the V-shaped configuration with the vertex pointing upstream of the dam and the arms terminating at collection facilities on each side of the dam (i.e., at gates 1 and 32). Figure 3-16 shows water control gates at Iroquois Dam in their raised position; collection facilities would be installed in the openings below the gates.

The V-shaped configuration would minimize the length of the structure for each of the three orientations evaluated. A V-shaped configuration pointing downstream of the dam also is possible and would require only one collection facility; however, that configuration would require other in-river infrastructure, with accompanying additional costs, and Kleinschmidt did not evaluate it. As depicted in Figure 3-17, the orientation of the guidance structure would substantially affect its size. A structure placed at 15º to the flow would have a total length of 2,120 m, whereas a structure placed at 45º to the flow would have a total length of 776 m. As a result, costs also would vary substantially. Several gates may have to be kept unobstructed to allow for recreational boat traffic, which would affect the lengths of structures discussed here to a small degree. Also, the structure would have to be constructed and positioned so as to avoid interfering with operation of the dam.

Additional specifications and assumptions considered in the conceptual design of the angled-bar guidance system included: assuming an average water depth of 14 m; installing piers spaced at 18-m intervals to support the structure; and, installing an 8-m wide deck spanning the piers to support personnel and provide access to equipment access and trash rakes. The original cost estimates in Kleinschmidt (2006) were calculated in U.S. dollars (2006) and converted to Canadian dollars. For consistency of comparison among the different technologies evaluated in this report, Kleinschmidt's (2006) estimates of cost in 2005 Canadian dollars were converted back to U.S. dollars using an exchange rate of 1.23 (Canadian/US) and adjusted to 2007 dollars using a multiplier of 1.06.

Figure 3-16. Photograph of Iroquois Dam with water control gates in their raised position; collection facilities would be constructed within the sluiceways beneath the gates (Source: Kleinschmidt 2006)

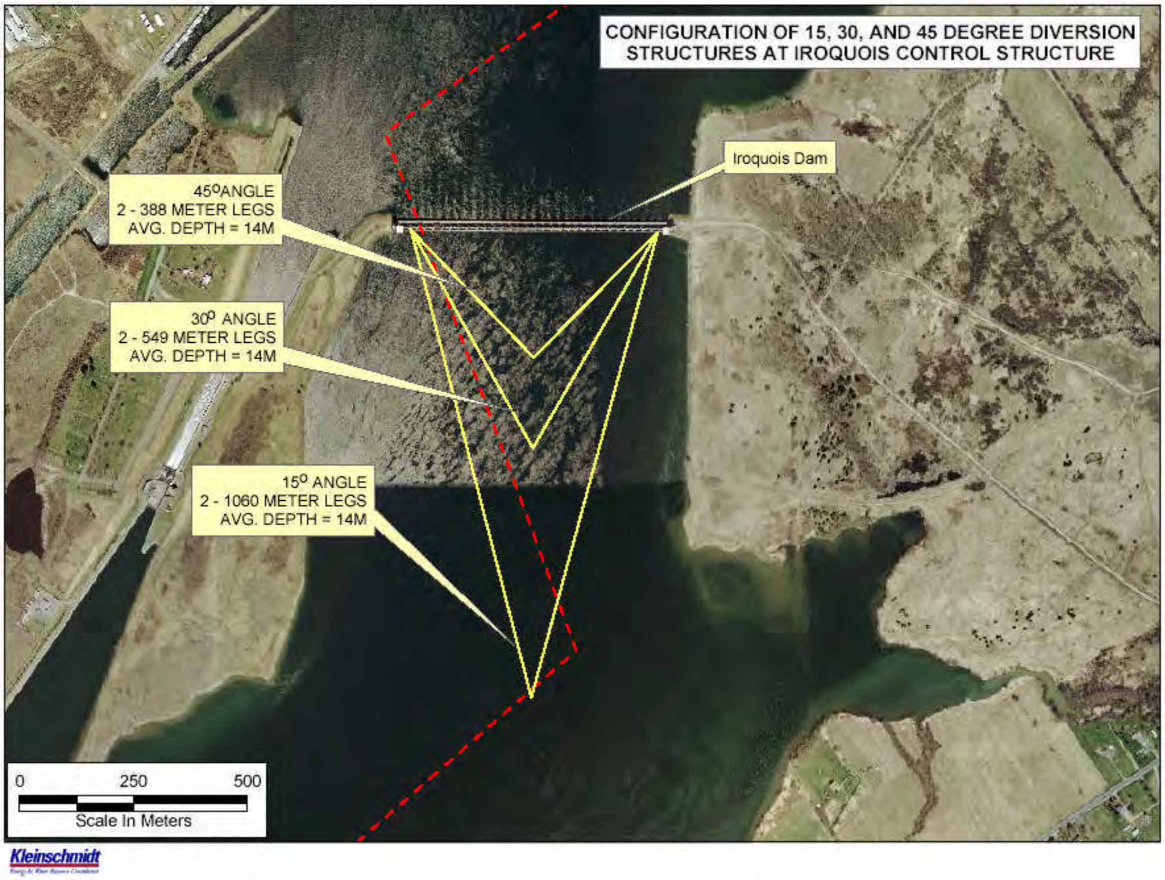


Figure 3-17. Illustration of guidance structure options at Iroquois Dam; dashed red line indicates the boundary between Canada (left) and the United States (right) (Source: Kleinschmidt 2006).

Kleinschmidt (2006) identified some advantages of this conceptual structure: it would span the entire river (except for sluiceways left open for boat traffic), and it would be effective both at night and during the day (in contrast to a light barrier that would be effective only at night). Several disadvantages also were identified:

- The diversion efficiency of physical barriers on the scale considered here is unknown for eels.
- High flow velocities (> 1 m/sec) have been shown to cause eels to be impinged on physical barriers.
- Heavy loading of debris due to the presence of submerged aquatic vegetation is likely to create operational problems.
- The potential for fouling by zebra mussels is significant.
- Logistical support for construction does not currently exist (e.g., facilities for construction workers).

- The structure could adversely affect species other than eels that are diverted, captured, handled, and released.
- Eels from Lake St. Lawrence and Lake St. Francis downstream of the structure would still be subject to turbine passage at the Moses-Saunders or Beauharnois projects.

Construction of the proposed structure is feasible but would be very complex. The massive size of the structure, water depth, and water velocity would require the use of specialized construction techniques that cannot be identified fully within the scope of this evaluation. A project of this magnitude would require skills available only from some of the world's largest design and construction firms, and innovative construction techniques, equipment, or both probably would have to be developed specifically to install this structure. Acknowledging such uncertainties about construction, the following assumptions were made in order to estimate the time required to build the proposed structure. In general, construction would be separated into two phases. Phase 1 would include bidding, engineering, and permitting, and Phase 2 would be installation. Kleinschmidt (2006) estimated that Phase 1 would take at least 2 years.

In addition to the complexity of designing the structure itself, obtaining regulatory approval could be a long process. Regulatory agencies from which approval of the design and placement of the structure would be required include the International Joint Commission (IJC) as well as provincial and state governmental agencies in Canada and the United States. The process of applying for and obtaining review and approval of the various designs and permits ultimately would determine the time required to complete the process. NYPA discussed potential regulatory requirements applicable to an eel diversion structure at Iroquois Dam with Mr. Mark Colosimo (IJC, U.S. Section Engineering Advisor) in May 2007. Based on a brief description of the conceptual design, Mr. Colosimo indicated that the IJC would have an interest or concerns only if any modifications of Iroquois Dam associated with any passage facilities would affect water levels or cause flooding. He indicated that if such a project were to proceed to the design stage, NYPA would have to work through the St. Lawrence River Board of Control to advise the IJC of plans and request review and opinion. Installing a structure along the St. Lawrence River at Iroquois Dam to direct or capture migrating eels would require a permit from the U.S. Army Corps of Engineers (USACE). According to USACE-Buffalo District's Regulatory Division, no Nationwide Permit is applicable to structures of the kind considered here. As a result, any structures to be installed probably would require an Individual Permit Authorization because Iroquois Dam is located in a Section 10 waterway. An Environmental Assessment (EA) would be required (J. Krawczyk, USACE Buffalo District, pers. comm.).

Construction time would vary based on the final design of the structure but Kleinschmidt (2006) estimated that installation would take 3 to 5 years. Several key assumptions formed the basis for that estimate: winter ice conditions would limit the construction season to 8 months per year; installation of support piers for the longest system would require three crews working over a period of five years; construction of various structure elements would be concurrent; and additional time (5 to 10 years) might be needed to construct and test a prototype system before deploying the full-scale system.

Capital costs were calculated as cost per linear meter and extrapolated based on the length of the structure. Appendix A of Kleinschmidt's (2006) report presents more details about the estimated costs of the proposed physical barrier at Iroquois Dam. Table 3-4 summarizes the total estimated cost for installation and the annual cost of operation and maintenance of angled bar racks and two traps at Iroquois Dam based on installation at angles of 15º, 30º, and 45º to the direction of flow.

Table 3-4. Estimated costs of installing, and operating and maintaining a V-shaped physical barrier to guide eels at Iroquois Dam for three possible angles of installation in relation to river flow (Source: Kleinschmidt 2006); costs have been adjusted to 2007 U.S. dollars

Angle (length in meters)	**Cost of Installation**	**Annual Cost of Operation & Maintenance**
15º (2,120)	$284,200,650 ± 50%	$4,688,130 ± 50%
30º (1,098)	$155,320,162 ± 50%	$3,180,000 ± 50%
45º (776)	$114,186,992 ± 50%	$2,749,106 ± 50%

As part of the current project, Alden (2007) reviewed the data presented by Kleinschmidt (2006) and completed an independent cost analysis. Alden concluded that the clear spacing of 3.8 cm between the bars of the proposed rack would provide a physical barrier to adult eels; however, an angled bar rack or louver array with larger slat spacing (up to 30.5 cm) might effectively exclude eels due to behavioral avoidance of turbulent flows at the face of the array, particularly given the relatively high approach velocities that occur at Iroquois Dam (i.e., > 1 m/s). Studies have demonstrated that louvers with wide slat spacing (up to 30.5 cm) can effectively guide juvenile salmonids at high approach velocities (> 1 m/s); however, the behavior of silver eels in response to physical barriers appears to be quite variable and substantially different than that of other species of fish. Eels' apparent avoidance of the light platform used in NYPA's light-diversion study when lights were not turned on (Section 6) suggests the possibility of structure avoidance, but the stimuli that induced the avoidance response could not be determined. Wider spacing between bars, if effective for silver eels, would result in less restriction of flow through the structure, decreased debris loading, and reduced installation and maintenance costs. Developing optimum design criteria for a guidance facility at Iroquois Dam would require pilot-scale field studies to explore various design parameters associated with the ability of angled bar racks and louvers to effectively guide silver eels. Such parameters include bar and louver spacing, approach angle, and velocity. Studies of this kind might also be useful for identifying the stimuli created by the light platform that caused eels to redirect their movement.

The scale of the proposed bar rack is large, and the structures required to support the racks and withstand the forces from the river would be similar in size to the dam itself. The system would require a bottom sill to provide a seal and support the bar rack panels, and the main structural components should be made of concrete to limit corrosion. The spacing of the support piers should be large enough to pass ice floes to limit the potential for ice jams. A detailed hydraulic study would be required to address this issue. As stated in Kleinschmidt (2006), the bar racks would have to be removed in the winter to limit ice damage.

Alden reviewed Kleinschmidt's estimates of costs and generally agreed with the overall magnitude of the estimated cost of the bar rack barriers. Alden has estimated costs for numerous large hydropower plants and cooling water intake structures. The cost of bar rack structures reported by Kleinschmidt (2006) averaged about $650 per square foot (converted to 2007 U.S. dollars) compared to the $800 per square foot that Alden estimated for a similar large project. The differences in costs probably are due to greater water depth (100 ft) and construction techniques used in Alden's estimate for the other site. Construction of the proposed structure at Iroquois Dam would require divers, barge-mounted cranes, barges, tugs, and shore-based cranes. Alternative and creative construction techniques could reduce the installation cost and schedule; however, the potential savings are difficult to quantify on a project of this scale. Additionally, an evaluation of a project in its conceptual phase cannot address uncertainties in the design, construction, and costs that cannot be predetermined (e.g., labor difficulties, weather, delivery delays, etc.); therefore, the contingency of 40% used in Kleinschmidt's (2006) cost estimates is appropriate.

Significant effort would be required to maintain the proposed racks in clean condition, as identified in Kleinschmidt's report. The labor and operation costs presented in that report are reasonable; however, the estimated operation and maintenance cost did not include the cost of replacing components. Those costs would include periodic repair or replacement of major components such as bar racks, trash rakes, cranes, transport vehicles, etc. The bar rack would be made of steel or Hydrothane and would deteriorate over time. Other equipment would require periodic maintenance or replacement. Alden recommended including costs to replace major components every 10 years in estimates of operation and maintenance costs, which would significantly increase those estimates.

3.5 FEASIBILITY OF USING A PHYSICAL BARRIER TO COLLECT OUTMIGRATING EELS AT IROQUOIS DAM

NYPA's request for proposals posed questions regarding each of the technologies and required responses to be drawn from review findings. The following questions were developed regarding physical barriers.

- **Are there regulatory, engineering, or environmental encumbrances that would preclude deployment of a physical barrier at Iroquois Dam?**

The engineering requirements to construct a physical barrier at Iroquois Dam appear to be very challenging but could be met, albeit at considerable cost. Maintenance costs for a structure such as the one conceived by Kleinschmidt (2006) would be substantial, as indicated in Section 3.4, and might not be determined fully until a structure is in place. The regulatory requirements (i.e., those of IJC and USACE) would not preclude a barrier but would require extensive work to complete a NEPA assessment and an extended permitting period. Some of the concerns, such as the effects on species of fish other than eels or on recreational boating, could be significant and might require extensive study. Overall, no obstacles would completely negate the possibility of installing a physical barrier, but substantial requirements could involve considerable expense and time.

- **What configuration (angled to the flow or perpendicular) of a barrier would be most appropriate based on the information collected?**

None of the studies of physical barriers reviewed for this report investigated the relative effectiveness of barriers deployed at different angles in relation to the direction of flow. Barriers placed perpendicular to flow, such as trash racks immediately in front of turbine intakes, in some cases were associated with impingement or damage of eels as they tried to pass through the barrier when velocities were high. Eels do not appear to respond to barriers by moving back and forth parallel to them in search of an unobstructed path as other fish do (e.g., alosines or salmonids). The variety of behaviors that eels exhibited upon encountering barriers in most studies was relatively consistent: a "startle" response resulting in rapid upstream movement away from the barrier after contact; remaining in physical contact with the barrier for extended periods (e.g., "resting" on it); or vigorous attempts to pass through the barrier. Those behaviors appeared to be independent of the angle of the barrier to flow direction.

- **What guidance efficiency would be expected and under what conditions?**

The inconsistent findings of studies of physical barriers for guiding eels provide no substantial basis for estimating the potential efficiency of such a barrier at Iroquois Dam. High efficiency would be likely using a barrier with small bar spacing, but would be subject to greater debris loading and stress from river flow. In addition, eels appear to be impinged on impenetrable barriers at flow velocities greater than 1 m/s, which are typical at the dam. The discussion of the potential guidance efficiency of a conceptual light barrier presented in Section 6.3 notes that a light barrier would be effective only at night, when approximately 75% of eels in NYPA's telemetry studies moved downstream. A mechanical barrier would be effective both during the day and at night and, thus, could influence the movements of 33% more of the outmigrating eels than a light barrier. If a structure installed at an angle of 30º relative to the direction of flow is assumed to be the most cost-effective strategy, the total length of the barrier would be more than 1,000 m. That is at least an order of magnitude greater than the lengths of physical barriers described in the reviewed studies. No data from those studies indicate diversion percentages for a physical barrier of that length. EPRI (2001b) reported diversion efficiencies as high as 90% in flume studies with a barrier angled at 15º under some circumstances; the width of the flume, however, was less than 2 meters. If 10% of outmigrating eels pass through every two meters of a barrier, even at that small angle to the direction of flow, the overall efficiency of a of 1,000-m barrier would be near zero.

- **In a general sense, what are the prospects that a physical barrier can be used to guide eels to a collection facility on the St. Lawrence River in the vicinity of Iroquois Dam?**

The major successes with physical barriers for guiding eels have been in small river systems. The installation of a barrier that would completely block downstream movement of eels (e.g., bar spacing smaller than the diameter of eels' heads) could result in injuring eels that attempt to pass through the barrier and probably also would be infeasible because of debris loading and cost. Barriers intended to divert eels as a result of a behavioral response rather than physical blocking (e.g., wide-spaced louvers) are not be likely to be successful, given the results of the reviewed studies; eels do not appear to respond visually to physical barriers and try to pass through barriers at high flows such as those in the vicinity of Iroquois Dam. The only finding that suggests the possibility that eels might exhibit a behavioral response to some characteristic of a physical structure is the apparent eel avoidance of the NYPA light study platform when lights were not turned on. Those results are discussed in detail in Section 6.3. As explained there, however, the observed behavior could be unrelated to the presence of the platform and there is no information on what, if any, stimuli eels may have been responding to that would contribute to designing a potentially effective physical guidance structure.

4.0 ATTRACTANTS AND REPELLENTS

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Attractants and repellents are stimuli that outmigrating eels might be able to detect and to which they might exhibit behavioral responses. Stimuli that elicit behavioral responses are candidates for use in guiding and collecting eels. Eels could detect these stimuli through one or more senses, and the stimuli might either attract or repel eels in ways that could be exploited to guide their movements. The capabilities of light and sound for guiding the movement of outmigrating eels are evaluated in detail in Sections 5.0 and 6.0. A substantial body of research has investigated the use of light and sound to guide the movements of fish; consequently, the range of literature available for evaluating those candidate guidance systems is relatively wide. The potential attractants and repellents reviewed in this section (i.e., electromagnetic fields, electrical fields, induced flows, and chemicals) have been subjected to little or no study of their efficacy for affecting the movements of eels or other fish; therefore, information about their efficacy for manipulating the behavior of other life forms is reviewed to provide a context for considering how such technologies might be used to guide outmigrating eels.

The use of chemical or physical attractants and repellents to manage pests or invasive species is common across a wide variety of taxa. Insects in particular have been the target of olfactory cues used as mechanisms of biological control (Lanier 1990). Examples exist for the spruce bark beetle (*Ips typgraphus* L.), fruit flies (*Tephritidae spp.*), the cotton boll weevil (*Anthonomus grandis*), ambrosia beetles (*Gnathotrichus sulcatus, G. retusus*, and *Trypodendron lineatum*), the European elm bark beetle (*Scolytus multistriatus*), and lepidopteran species among others (Lanier 1990). Technologies based on olfaction are being developed to control the population of sea lamprey (*Petromyzon marinus*) in the Great Lakes (Li et al. 2007). A variety of repellent technologies have been proposed as means to steer bats and migrating birds away from wind turbines (e.g., Nicholls and Racey 2007). The mechanistic understanding obtained from this applied research to develop methods for reducing or eradicating pest populations could be relevant in developing systems for directing migrating fish around man-made structures.

4.1 INFORMATION SEARCH

The attractants and repellents addressed in this section have never been used to guide eels; therefore, the network of eel researchers described in Section 2.0 did not provide a sufficient source of information for evaluating the techniques considered here. A large amount of information exists about stimuli to which fish, in general, and *Anguilla* species, specifically, respond; however, that information does not address the potential applicability of the stimuli for use as attractants or repellents to manage the movement of outmigrating eels. Bibliographic searches conducted as described in Section 2.0 were a major source of the information summarized here. In addition to primary research articles, multiple books, reports, conference proceedings, and white papers have been published on these topics. Conversations with experts working in attractant and repellent research were just as valuable as the written resources. We also were fortunate to have access to the insight of commercial and recreational fishers, whose knowledge of the waters they work is extensive. Although this section focuses on the *Anguilla* species (American eel, *Anguilla rostrata*; European eel, *A. anguilla*; Japanese eel, *A. japonica*; New Zealand eels, *A. australis* and *A. dieffenbachia*), it draws on additional information for a variety of other animal taxa.

4.2 EELS' SENSORY SYSTEMS

Fish are able to detect and respond to a suite of chemical and physical stimuli through a unique set of physiological mechanisms. These sensory systems play critical roles during sexual and ontogenetic development, migration, mate attraction, and predator avoidance. Highly specialized sense organs detect attractant and repellent stimuli and communicate with the brain through specific neural pathways (Leonard and Summers 1976; Diebel et al 2000; Laberge and Hara 2001). The olfactory sensory epithelium within the nares has millions of specialized receptor neurons capable of sensing dissolved chemicals at extremely weak concentrations, as well as small changes at such low levels (Nishi et al. 2004; Li et al. 2007). Single-domain magnetic crystals within the olfactory epithelia of some fish species are believed to function in magnosensory perception (Diebel et al 2000; Lohmann and Johnsen 2000). The lateral line system, a complex of tubules with sensory cells beneath the skin, detects changes in the motion of water across the body from which eels can identify water currents and turbulence (Popper and Platt 1993). All of these complex sensory mechanisms act in concert to relay information about the surrounding environment to the brain. The fish can then display behavioral responses based upon multiple sensory inputs.

At the cellular level, the general organization and principles of eels' sensory systems resemble those in other species of teleost fish (Wootton 1999). The molecular and gross morphological patterns of eels' sensory systems, however, are unique and may afford distinct abilities to sense particular cues. A uniquely adaptive ability to sense specific environmental signals may have evolved in association with the complex life history of eels. The life cycle of the American eel begins in the center of the Atlantic Ocean, the Sargasso Sea, when the eel larva, called the leptocephalus, hatches from the egg. The leptocephalus, carried northward in the Gulf Stream, transforms into a glass eel (a more elongated, unpigmented eel-like shape) near the coast and migrates inland into estuaries, streams, rivers, and lakes to grow and transform further into the elver (a small pigmented version of the adult eel). In fresh water, the elver grows into the larger yellow eel and finally, after a period of 8 to 30 years, into the sexually mature silver eel. The silver eel then migrates back to the Sargasso Sea to spawn. The physical and physiological transformations that occur at different stages of the eel's life cycle provide the opportunity, and probably the necessity, for modification of sensory capabilities; therefore, adaptive sensory systems are likely to have evolved for individual life stages (Tomoda and Uematsu 1996). Dramatic endocrine changes accompany the elaborate transformations (Heyland et al. 2004). It would seem likely that such changes and the need for a capability to migrate successfully over long distances require some sensory abilities not present in species that do not migrate or experience such major transformations (Barbin 1998; Wiltschko and Wiltschko 1990).

This section addresses a range of stimuli to which eels might respond and, therefore, that could provide means of altering the movement patterns of outmigrating eels. In addition, the phenomenon of "eel balls" is addressed. This tendency of outmigrating eels to aggregate naturally in some circumstances has been noted by a number of observers. If the cues that prompt the formation of eel balls could be identified (i.e., the attractants), they could contribute to the development of a means of efficiently concentrating outmigrating eels to facilitate capturing them.

4.3 ELECTROMAGNETIC FIELDS

Earth has a natural magnetic field with field lines beginning at the South Pole and extending to the North Pole following the curvature of the planet (Figure 4-1). Earth's magnetic field could inform two kinds of sensory capabilities (Lohmann and Johnsen 2000). The first is magnetic compass sense, which refers to an animal's ability to orient its movements with respect to the geomagnetic field. An animal also must have a second sensory capability known as map sense to migrate successfully. Map sense is an animal's ability to know where it is with respect to its destination so that it can determine the appropriate course. Earth's magnetic field varies over the surface of the planet in terms of factors such as field intensity and field-line inclination (Figures 4-1 and 4-2), which makes the natural magnetic field a potential tool for position-finding. Some animals use electromagnetic cues to discern local environmental variation. The parameters of Earth's magnetic field that would be associated with magnetic compass sense and map sense differ; consequently, migratory animals could possess two different sensory mechanisms, each of which detects a separate component of the magnetic field and has unique physiological processes. The ability to use electromagnetic cues has been demonstrated across multiple animal taxa including insects, mollusks, crustaceans, and all five classes of vertebrates including fish (Wiltschko and Wiltschko 1990). Recent studies of birds and teleost fish have provided information about the mechanisms of magnosensory perception in vertebrate taxa (McCleave and Kleckner 1982; Lohmann and Johnsen 2000).

Orientation in the water column and behaviors such as homing seem to be associated with the presence of magnetic material found in many marine fish species, including yellowfin tuna (*Thunnus albacares*), albacore tuna (*T. alalunga*), bigeye tuna (*T. obesus*), bonito (*Sarda sarda*), Atlantic herring (*Clupea harengus*), and Atlantic mackerel (*Scomber scombrus*) (Walker 1984; Walker et al. 1984; Hanson and Westerberg 1987). Similar associations have been reported for diadromous chinook salmon (*Oncorhynchus tschawytscha*), sockeye salmon (*O. nerka*), chum salmon (*O. keta*), and European eel (Kirschvink et al. 1985; Mann et al. 1988; Walker et al. 1988; Sakaki et al. 1990; Ogura et al. 1992; Hanson and Westerberg 1986, 1987). Some freshwater fish, including European carp (*Cyprinus carpio*) and European perch (*Perca fluviatilis*), also possess magnetic material (Hanson and Walker 1987; Hanson and Westerberg 1987).

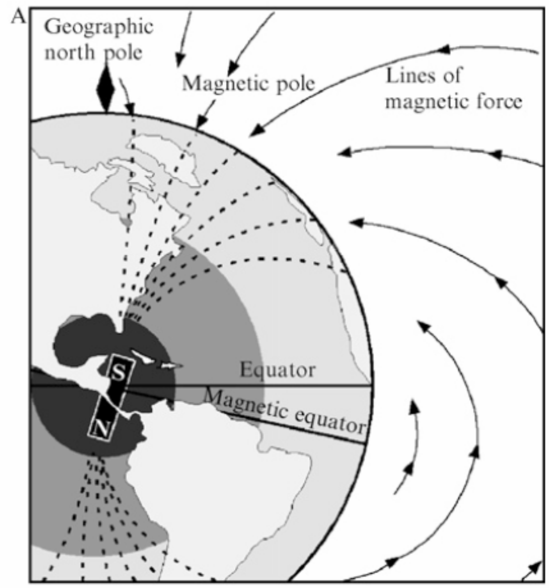

Figure 4-1. Magnetic field of Earth. Earth's primary magnetic field is produced in the core and contains both dipole and non-dipole components. The dipole component is represented by the bar magnet in Earth's core and is much greater than the non-dipole component (not shown). The field due to the magnetic dipole is represented by field lines. Field-line intensity (increasing with increasing proximity of field lines) and inclination (increasing with increasing angles of intersection of field lines with the surface) both increase systematically between the magnetic equator and the magnetic poles. (Source: Walker et al. 2006).

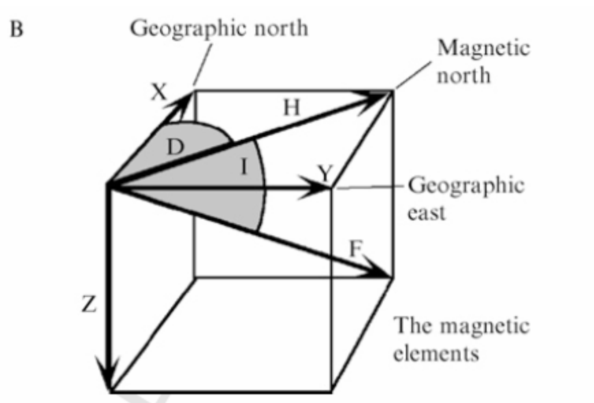

Figure 4-2. The elements of the total magnetic field vector (F) at the surface of Earth. The total field vector is composed of elements (arrows) in the north (X), east (Y), and vertical (Z) axes. The vector element in the horizontal plane (H) points in the direction of a handheld compass needle. Declination (D) is the angle between the H and X elements. Inclination is the angle between the H and F elements. (Source: Walker et al. 2006).

Natural and artificially generated magnetic fields can elicit behaviors in both adult fish and those in early life stages. Trout (*Salmo trutta*) larvae and fry have been shown to swim toward an artificially induced, constant magnetic field and into small traps (Formicki et al. 2000, 2001, 2002). Trout embryos and larvae also exhibit an increase in heart rate, whereas newly hatched larvae show an increase in the rate of pectoral fin movement in the presence of an artificially generated, constant magnetic field (Winnicki and Formicki 1990; Formicki and Winnicki 1996, 1998). Trout embryos change their body axis alignment to orient their axis of symmetry along magnetic field lines. Behavioral studies suggest that some species of fish can detect and respond to changes in the intensity of a magnetic field. In laboratory studies, animals appear to be most able to discriminate anomalies in the magnetic field when the conditioned response requires movement and when the fields are spatially distinctive (Walker et al. 1997). This has been demonstrated for rainbow trout (*O. mykiss*), yellowfin tuna (*T. albacares*), and honeybees (Walker 1984; Walker and Bitterman 1985).

Several laboratory studies have examined the behavioral responses of various species and life-stages of eels to an induced electromagnetic field. In general, an individual eel is placed in a container, a magnetic field of known intensity is induced parallel to the fish's body, and a response variable (e.g., change in heart rate or change in orientation) is measured (Figure 4-3). Responsiveness to induced electromagnetic fields has been demonstrated in American eel elvers (McCleave and Power 1978), European silver eels (Karlsson 1985), and Japanese eels in the glass, yellow, and silver eel stages (Nishi et al. 2004; Nishi and Kawamura 2005; Nishi et al. 2005).

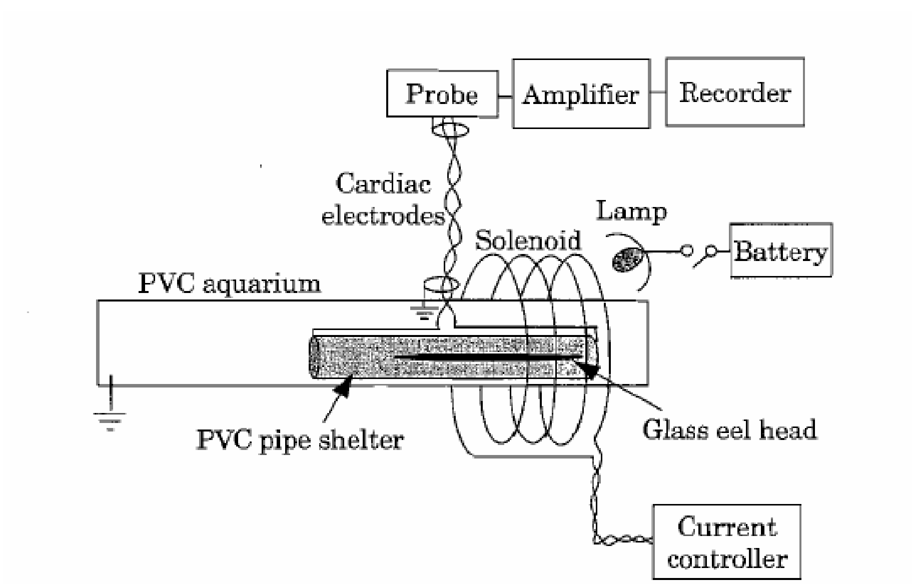

Figure 4-3. Generalized experimental apparatus used for conditioning eels to artificial magnetic fields (Source: Nishi et al. 2005)

Japanese eels exhibit a conditioned response to induced magnetic fields in the glass, yellow, and silver stages (Nishi et al. 2004; Nishi and Kawamura 2005; Nishi et al. 2005). Some reports have suggested that a magnosensory memory imprinted in the glass stage may be retained into adulthood, when the information may aid in the reverse migration back to oceanic spawning habitats (Nishi and Kawamura 2005). Similar studies have shown that European eels exposed to magnetic fields changed their preferred body orientation (Karlsson 1985). Current research with European eels is seeking to determine if eels have a magnetic map sense that aids in navigation (C. Durif, pers. comm.). Using telemetric tracking, Tesch (1974) showed that yellow-phase European eels from the German North Sea swam along a north-south axis (toward the Elbe Estuary), whereas silver eels swam in a north-westerly direction (toward the North Sea). In tank studies, altered magnetic field direction was associated with altered orientation in European eels (Tesch and Lelek 1973a, b; Tesch 1974). A later laboratory experiment found that yellow and silver eels both preferred to orient in either the northwest or southeast direction (Tesch et al. 1992). Van Ginneken et al. (2005) used a microelectronic system in a pond in the Netherlands to monitor subjects' preference for PVC tubes oriented either south-southwest (toward the Sargasso Sea) or west-northwest (perpendicular to the Sargasso Sea). They found that European eels in the yellow phase exhibited a preference for a south-southwest orientation, toward the Sargasso Sea (van Ginneken et al. 2005). In studies conducted in a circular tank, American silver eels oriented southward, toward the Sargasso Sea (Miles 1968).

While magnetic perception has been suggested as a factor in successful migration of tagged European eels through deep water (Tesch 1978), very few field studies have been conducted to investigate the role of magnosensory perception in migratory behavior. Westerberg and colleagues examined how a high-voltage, direct-current cable influenced the movement patterns of migrating European silver eels in the Baltic Sea. Silver eels tended to change their direction when passing over the cable, but the disturbance to the geomagnetic field caused by the cable did not deter migration (Westerberg and Begout-Anras 1999; Westerberg 2000). Formicki et al. (2004) examined how the presence of magnets influenced catch totals and species composition using fyke nets in a lake in Poland during the months of May through June. In that study, cylindrical magnets (11.6 mm diameter X 4.6 mm height) each generated a 0.1-mT (1.0 X 10^{-4} T) magnetic field perpendicular to the magnet and 10 cm away from it. The fyke nets were 80 cm tall with 6-m wings. Three sets of three fyke nets were set up around the lake. One net in each set had 12 magnets with their S poles directed into the fyke net; the second ring had 8 magnets with their N poles directed into the trap. The second fyke net in the set had the same number and arrangement of magnets except that the direction of the poles was reversed. The third fyke net in each set was rigged with dummy magnets that did not produce an electromagnetic field. The total catch was greater in both fyke nets that had magnets (1677 and 1771 fish, respectively) compared to the control (1169 fish), a statistically significant difference. The magnets also affected the species composition of the catch. The nets with magnets caught significantly more Cyprinids (1223 and 1167 v. 677 fish) and percids (452 and 410 v. 375 fish), which generally are considered to be nonmigrating species. There was no significant difference in the number of European eels caught in fyke nets with magnets (90 and 89 v. 112 fish). The captured eels were primarily 0.2- to 0.3-kg, yellow eels that were feeding intensively and did not resemble eels prepared to migrate. The authors suggested that the eels did not respond because they were not in a migrating phase of their life history. Alternatively, they suggested that the field strength used, which was greater than the natural field, may have been too high to elicit a response from eels.

The range of sensitivity to magnetic fields has been examined for some species of eels. Induced test fields ranging in intensity from 12,663 to192,473 nT[6](1.27 X 10^{-5}T to 1.92 X 10^{-4} T) promoted the deceleration of heart rate for each life stage of Japanese eels (Nishi et al. 2004; Nishi and Kawamura 2005; Nishi et al. 2005). The field studies of Westerberg and colleagues showed that European silver eels modified their movements slightly in response to a cable producing a 5-µT (5 X 10^{-6}T) magnetic field (Westerberg and Begout-Anras 1999; Westerberg 2000). An increase in the intensity[7] of the electric current from 10^{-2} µA/cm^2 to 10^2 µA/cm^2 caused American eel elvers to change direction (McCleave and Power 1978). Studies evaluating the American eel's ability to sense electromagnetic stimuli have produced mixed results. American eel elvers changed their spatial orientation after an electric field was manipulated (McCleave and Power 1978; Souza et al. 1988). Other studies found no response to similar manipulations (McCleave et al. 1971; Rommel and McCleave 1973). Nishi et al. (2004) suggested that this discrepancy was due to differences in the methods used to measure response.

4.3.1 Mechanism of Detection

The mechanism of magnetoreception in animals has been difficult to pinpoint for several reasons (Lohmann and Johnsen 2000). Magnetoreceptors do not necessarily need to contact the external environment directly because magnetic fields can pass through tissue. The mechanism of detection, therefore, could be located virtually anywhere in the body or even dispersed throughout the body. For example, if the signal transduction process occurred through a series of chemical reactions in one or more locations within the body, then no obvious structure would be required. Most of what is known about magnetoreception in vertebrates and the underlying mechanisms of detection has been inferred from behavioral experiments, theoretical considerations, and a few electrophysiological and anatomical studies (Lohmann and Johnsen 2000).

Biogenic magnetite crystals (Fe_3O_4; approximately 50 nm in diameter) have been proposed as magnetoreceptors that could provide both compass sense and map sense in eels (Lohmann and Johnsen 2000). Magnetite crystals function as permanently magnetized bar magnets that are able to align themselves with Earth's magnetic field when allowed to rotate freely. An individual 50-nm crystal cannot interact strongly enough with the geomagnetic field to provide much information (Kirschvink and Walker 1985); however, if crystals are arranged in a chain—as they are in magnetotactic bacteria (Frankel and Blakemore 1980), chinook salmon (*O. tshawytscha*; Kirschvink et al. 1985), and rainbow trout (*O. mykiss*)—the individual magnetic moments of the crystals sum linearly (Diebel et al. 2000). Although the average orientation of a freely rotating chain will be aligned with the external magnetic field, the intensity of the field influences the variance in the chain's orientation. Once detected by

[6] nT is the abbreviation of nanotesla, the SI unit of measure for magnetic field strength.
[7] µA/cm^2 is the abbreviation of microampere per square centimeter, the SI unit of measure for magnetic field intensity.

magnetoreceptors, geomagnetic field data must be transduced to the nervous system. As they rotate to align with the geomagnetic field, crystals may exert pressure on some secondary receptors such as hair cells or mechanoreceptors (Lohmann and Johnsen 2000). Another proposed mode of transduction may be through the opening of ion channels directly, perhaps through cytoskeletal connections between the crystals and the channels. The location of magnetite crystals within the cells of rainbow trout hints at a mechanical connection by which movements of the crystals could change the membrane potential of the cell by opening mechanoreceptive transmembrane ion channels (Kirschvink and Gould 1981; Walker et al. 1997).

In eels, single-domain magnetic crystals occur within cells of the olfactory lamellae (Diebel et al. 2000). Magnetite particles also have been identified in bone material from the skull of silver European eels (Hanson et al. 1984a, b; Hanson and Westerberg 1986; Hanson and Walker 1987). Unidentified magnetic material also occurs in the vertebral column and the pectoral girdle (Hanson et al. 1984b). Plugging the nasal cavity of Japanese eels with petroleum jelly to render individuals anosmic (unable to smell) eliminated any behavioral response to induced magnetic fields compared to an unmanipulated control group (Nishi et al. 2005). This discovery provides some evidence that organs of magnosensory perception might occur in or around the olfactory lamellae of the nares. The region of the nares that might contain the magnetite-based sensory system is innervated by the superficial ophthalmic ramus of the fifth cranial nerve (rosV), also known as the sensory branch of the trigeminal nerve. This sensory complex has been proposed as a mechanism for collecting magnetic information and delivering it to the brain in chinook salmon (*Oncorhynchus tshawytscha*; Kirschvink et al. 1985), tuna (*Thunnus albacares*; Walker 1984), and rainbow trout (*Oncorhynchus mykiss*; Diebel et al. 2000) among others. No unequivocal evidence is available, however, to indicate that this is the mechanism of magnosensory perception in eels (Hanson et al. 1984a, b).

4.3.2 Strength of Evidence

The literature reviewed suggests that eels may possess magnetite crystals that could be involved in providing magnetic compass and map senses. These crystals are located in a region of the olfactory organ that is suitably innervated to deliver information to the brain. Studies of physiological and behavioral responses suggest that some species of fish can detect and interpret variations in the magnetic field; however, scientists have not determined definitively how chains of magnetite crystals interact with olfactory cells or the precise location of the afferent synaptic links between the rosV nerve and the magnetite.

Much of the research conducted on magnosensory perception in fish has been conducted under controlled laboratory conditions. In general, detection is measured as a change in heart rate, and elicited behaviors involve changes in body orientation. The responses observed in laboratory studies, however, may have been caused by the electrostatic shock created by inducing current rather than by the resulting change in the magnetic field itself (C. Durif, pers. comm.). To date, no studies have documented changes in behavior in response to magnosensory stimuli; consequently, less is known about how this stimulus would influence natural populations of fish, particularly migrating eels. Numerous studies of fish have demonstrated that behavioral responses to sensory stimuli documented in the laboratory cannot be replicated in natural, field environments. Some field evidence from the Baltic Sea, however, suggests that migrating European silver eels may change direction in response to very small disturbances of the geo-magnetic field (Westerberg and Begout-Anras 1999; Westerberg 2000). The authors of those studies cautioned that more research is required to obtain definitive answers because of the low spatial resolution and high levels of uncertainty in their findings. The few known field studies offer limited information about the applicability of manipulations of electromagnetic fields as a guidance system; consequently, the feasibility of using electromagnetic fields for guiding the movements of outmigrating eels in the field cannot be assessed at this time.

4.4 ELECTRICAL FIELDS

The repulsive effect of electrical fields on the swimming behavior of fish has been known at least since 1912, when Larsen was granted a patent for an electrical guiding system (Thon 1999). The induction of an electric field in water causes an approaching fish to swim toward the anode (the electrode through which positive electrical current flows). Strong electrical fields may cause paralysis or mortality. Given the potential for electrical fields to modify directional behavior in fish, an electrical barrier of the appropriate intensity, frequency, and duration could function as a guidance mechanism for eels.

4.4.1 Electrical Barriers used to Guide Eels at Hydroelectric Facilities

Gleeson (1997) investigated the utility of electricity to guide the movement of American eels. He found that a potential gradient (e.g., when the field is first charged or upon an initial rapid approach by the eel) elicited a quick avoidance response. At low electrical potentials (to a maximum of 3 to 6 volts), the directions of eels' movements were not affected. Voltages of 12 and above stunned eels, whereas no response was evident at or below 1.5 volts. Gleeson (1997) designed an electrical guidance technology that he deployed at a small, low-head dam. The guidance system consisted of a single, exposed training wire running parallel to and upstream from the dam crest that, when powered, was intended to divert eels into a net at one end of the dam. The effectiveness of this technology as a diversion mechanism in the field is not known because it was not tested rigorously. Generating an electrical potential sufficient to prevent eels from moving through an area without charging the field to a voltage that will stun the eels on approach is one challenge involved with applying electrical systems to deter and guide eels. In Gleeson's (1997) study, eels that approached the electric field too rapidly could be stunned, sink, and be moved downstream by the current so that they were not successfully diverted.

Mitchell and Boubée 1992 showed that the efficacy of electrical barriers for diverting downstream migrating *Anguilla* species in New Zealand may depend on the size of the eel; larger eels responded to a smaller voltage differential than smaller eels did in their study.

Hadderingh and Jansen (1990) tested the effectiveness of electric screens for diverting fish in the lab and in the field. In the field, the response of European eels to an electric screen was recorded at the intake of a pumping station. The screen was made up of several active electrodes (cathodes) strung across the intake channel and several inactive electrodes (anodes) placed downstream of the cathodes. The electric field was pulsed at a rate determined on the basis of information collected during laboratory trials. Water velocity ranged from 3 to 13 cm/s at 0.5 m in front of the screen. The eels taken in the study were juvenile yellow stage, between 10 and 20 cm long. Wave action and algal blooms influenced the effectiveness of the method. In general, the method was more effective for eels than for other species, but variability was significant; effectiveness ranged between -38%[8] and 75%. Hadderingh and Jansen (1990) concluded that the effectiveness of electric screens for diverting fish from water intakes was highly variable in algae-rich waters.

An electrical impulse tuner was installed 200 m in front of a cooling intake, at an angle of about 45º to intake flow, at a power plant in Sweden to deflect European eels into a side channel (Halsband 1989 as cited in Thon 1999). This method was very effective for diverting eels and reducing their impingement. Thon (1999) noted that diverting eels from cooling water intakes, where their primary direction of movement is downstream rather than into the plant, is likely to be easier than diverting them away from a hydroelectric facility intake, which is in the direct path of their migration. Another project carried out by Borchard and Bosse (1995 as cited in Thon 1999) at a power plant on the Sieg River (maximum water velocity 1.2 m/s) in Germany used a combination of electrical and physical barriers. Sixty-centimeter-tall, half-pipe bypass structures were installed on the bottom parallel to the bar rack and leading to a 30-cm bypass pipe, and the main electrode was mounted 40 cm above the pipe halves (Halsband and Halsband 1989 as cited in Thon 1999; Figure 4-4). The pipe halves were placed to guide silver eels away from the turbines. The impulse current was intended to prevent eels swimming in the pipe halves from escaping over the tops of the tubes. This structure did not effectively divert silver eels away from turbine passage. Even with the half-pipe structure in place, eels continued to swim into the turbines. Thon (1999) concluded that electric diversion and guidance systems rarely work properly for eels. The effectiveness of electric fields may be limited by water depth where the technology is deployed. The typical arrays produce a maximum uniform field that extends only about 5 m from the source, making these systems unsuitable for use in large bodies of deep water (P.W. Sheehan, Ontario Power Generation, email to D. Dixon, EPRI, May 11, 2001).

[8] Negative effectiveness means that more eels were taken when the electric screen was turned off than when it was on.

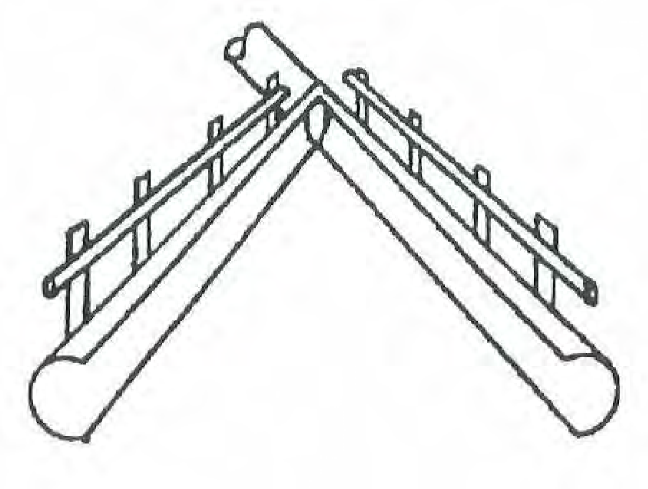

Figure 4-4. Half-pipe electrical barrier as described in Halsband 1989 (Source: Thon 1999)

4.4.2 Electrical Barriers used to Guide Eels at Pumping Stations and Water Intakes

Electrical barriers also have been used to prevent eels from passing through grills and pumps at water intakes of power plants and pumping stations. Thon (1999) reported on an electrical barrier at a cooling water intake on the Saale River in Halle, Germany. An alternating current transformer wired to the two grills of the intake appeared to prevent impingement of juvenile fishes (Hattop 1964 as cited in Thon 1999). A chain of electrodes used at a pumping station on the Eider Canal in Germany was tested by placing a tube of netting containing sample fishes (of which 15 were eels) in the field (Meyer-Waarden 1954 as cited in Thon 1999). All fish in the netting swam away from the electrodes; however, the authors suggested that low water flow and low pump suction may have contributed to the response to the electrical barrier. At a cooling canal for a BP petroleum refinery in Hamburg, Germany, electrical circuits were laid to act as barriers to fish and mitten crabs (Meyer-Waarden and Halsband 1975 as cited in Thon 1999). These barriers held back about 90% of aquatic animals and prevented clogging of the cooling water pipes. In contrast, similar electrical barriers implemented near cooling water intakes at power plants on the Maas and Amer rivers and at the Bergum power plant in Germany were ineffective (Hadderingh et al. 1983). Likewise, electrical guidance systems at the nuclear power plant in Brunsbüttel, Germany; a power plant on the Leine River in Germany; and at three power plants on the Rhine River also were inefficient for diverting fish (Möller et al. 1991 as cited in Thon 1999; Sprengel 1991 as cited in Thon 1999; Weibel 1991).

4.4.3 Electrical Barriers used to Prevent Entry of Asian Carp into the Great Lakes

An electrical barrier is currently in place to prevent northern expansion of the range of the invasive Asian carp (*Hypophthalmichthys molitrix*) into the Great Lakes ecosystem (EPA 2004). The barrier was constructed on the Chicago Sanitary and Ship Canal, which is the only hydraulic connection between the Great Lakes and the Mississippi River, where Asian carp occur in abundance (Figure 4-5).

Figure 4-5. The location of the Asian carp barrier on the Chicago Sanitary and Ship Canal. (Source: http://www.epa.gov/glnpo/invasive/asiancarp/).

A temporary version of the barrier was activated in April, 2002, at a cost of $2.2 million. Controlled experiments using fish raceways demonstrated that individual Asian carp turned around during 379 of 381 attempts to cross a simulated barrier based on the real one. One small fish was able to penetrate the barrier twice, and researchers suggested that smaller fish may be less susceptible to electric current (INHS 2008). The Illinois Natural History Survey evaluated the effectiveness of the temporary barrier by tracking the movements of 100 tagged common carp (*Cyprinus carpio*) near the canal (EPA 2008). Only one tagged individual breached the barrier. The turbulence caused by a passing barge is believed to have facilitated that breach. A permanent barrier was activated in 2005 at a cost of $9.1 million (Figure 4-6). The system consists of two rows of cable electrodes that span the canal. The cables extend from a control building on the side of the canal to the bottom of the canal via bore holes drilled into the bedrock. The cable electrodes are spaced 220 m apart and stretch across the bottom of the canal. On the opposite side of the canal, the cables return to another control house through more bore holes. Direct current (DC) pulsed through the electrodes elicits an avoidance response in fish, causing them to swim away from the barrier. The simultaneous operation of both sets of electrodes provides a consistent electric field that is expected to prevent fish from being swept through by ship turbulence. Simulations at a fish hatchery together with field telemetry have shown that the permanent barrier is very effective for preventing the passage of fish into Lake Michigan.

Figure 4-6. Schematic of the permanent barrier constructed on the Chicago Sanitary and Ship Canal to prevent range expansion of Asian carp (Source: http://listentoyourlakes .typepad.com/greatlakes/invasive_species /index.html)

4.4.4 Electrical Barriers used to Deter Migration of Sea Lamprey

An electric weir was installed on the Brule River in Wisconsin from 1960 to 1978 (Smith and Tibbes 1980) to prevent sea lamprey (*Petromyzon marinus*) from reaching upstream spawning sites. The device consisted of parallel electrode arrays stretched across the river and charged with 115 volts of alternating current (AC). The AC array stunned some fish as they swam upstream through it and killed some non-target species, including trout and salmon. To alleviate this unintended mortality, DC electrical fields were added downstream of the weir to divert fish into a mechanical trap. Sea lamprey caught in the mechanical traps were destroyed, and other captured fish were released upstream of the barrier. At one time, 55 electric weirs were operated throughout Wisconsin specifically to control the sea lamprey population. These weirs were unsuccessful for that purpose. Electric weirs are costly to operate and harm spawning trout. In 1977, 1,436 steelhead trout were caught in the Brule River weir, and 7.4% of those were killed. Electrical weirs eventually were phased out because of the problems associated with this diversion technique.

4.4.5 Electrical Barriers used to Repel Sharks from Recreational Swimming Areas

Electrical barriers have been used to prevent sharks from coming into proximity with recreational swimmers in South Africa. A prototype electrical barrier was used during the 2000 summer Olympics in Sydney, Australia, to safeguard triathletes as they traversed Sydney Harbor. Lemon sharks (*Negaprion brevirostris*) and tiger sharks (*Galecerdo cuvier*) in captivity are repelled by underwater electric current at distances up to 15 m from the source (Hicks 1963 as cited at http://www.elasmo-research.org/education/white_shark/deterrents.htm). These currents are too weak to be sensed by humans. Captive juvenile dusky sharks (*Carcharhinus obsurus*) were deterred by an AC current of 7 to 10 volts (Smith 1974). Electrification of an insulated underwater cable placed beneath the sand around a recreational bathing beach on the Natal coast of South Africa appeared to repel sharks from associated beach nets; when the cable was switched off, 89 sharks were caught in the nets. Electrical barriers alone have had mixed success along other beaches in South Africa without shark nets (Cliff and Dudley 1992).

4.4.6 Factors Affecting the Effectiveness of Electrical Fields for Guiding Outmigrating Eels

Silver eels are reported to react less strongly and more slowly to electrical fields than yellow eels (Meyer-Waarden et al. 1975 as cited in Thon 1999). Eels' response to electrical stimuli also appears to be influenced by water temperature. Reactions are slower and more sluggish below 9 °C because the eels' metabolic rate declines. This temperature has also been reported to be the temperature of maximum migration activity for silver eels (Thon 1999).[9] Flow velocity less than 0.3 m/s and the absence of turbulent flow around the electrodes also may be necessary for successful implementation of electrical barriers (Halsband 1989 as cited in Thon 1999). At greater water velocities (such as the > 1 m/s velocities at Iroquois Dam) downstream migrating eels may be physically forced to break through the electrical field.

Depending on the strength of the electrical field, eels can be immobilized, as during collection using electroshockers. Incapacitation of migrating eels could lead to stress, injury, and potentially death (e.g., via predation). Rauck (1980 as cited in Thon 1999) reported on an electrical fish guidance system installed near the intake at a nuclear power plant in Brunsbüttel, Germany. Within a few months, thousands of eels were impinged on the grill. Rauck suggested that was due to entrapment of eels between the grill and the electrical barrier. That is, even if impinged eels were able to swim back upstream against the 1.8 m/s current, they would have had to endure more electrical impulses than during downstream passage due to their slow rate of upstream movement through the electrical barrier. Similar patterns were reported at the Weser power plant in Germany, where eels were trapped on the downstream side of the electrical barrier (Berg 1995 as cited in Thon 1999).

The studies reviewed clearly indicate that eels respond to electrical fields. However, there appear to be significant challenges that would have to be overcome in creating electrical fields that are capable of guiding the movements of downstream migrating eels without incapacitating them. Electrical barriers that have proven effective for some species of fish, such as the Asian carp, prevent that species from moving upstream past the barrier. Most of the applications of electrical fields to deter or guide fish moving downstream were unsuccessful. The probability of electric fields being effective in guiding the movements of outmigrating eels in the St. Lawrence River and concurrently not significantly impacting non-target species is very low.

[9] Thon (1999) discussed silver eels that typically exhibit fall migrations in Europe; outmigrating eels in the St. Lawrence River pass Iroquois Dam during summer, when water temperatures may be substantially higher than 9 °C.

4.5 INDUCED FLOWS

Downstream migrating fish appear to seek river currents to assist their directional movement. Such behavior suggests the possibility of using induced currents as a means of artificial guidance. Selection of river currents has been demonstrated most extensively in salmonids (Coutant and Whitney 2000) but also has been indicated for eels (Jansen et al. 2007). This behavior makes sense from an evolutionary perspective because hitching a ride on river flows minimizes the need to expend energy to swim downstream. The downstream trajectory becomes the sum of the river's flow plus any orienting movements made by the fish. The conserved energy can then be used for swimming when flows diminish, growth (e.g., juvenile salmon), or reproduction (e.g., maturing eels).

Field telemetry studies have demonstrated the responses of fish to flows. When downstream-migrating salmon smolts encounter the less turbulent waters of reservoirs on the Columbia River, their unidirectional movement becomes progressively more random (e.g., Venditti et al. 2000). They move more laterally and upstream, and wandering is common in the calm forebays of dams (Coutant and Whitney 2000, 2006). Similar circling behavior has been observed among silver eels approaching hydroelectric dams in Germany (Behrmann-Godel and Eckmann 2003) and the Netherlands (Jansen et al. 2007). Jansen et al. (2007) evaluated the routes of outmigrating silver eels in the River Meuse and showed that eels took routes with the most river discharge. Telemetry of migrating eels has shown that they often exhibit an oscillatory vertical swimming pattern, suggesting that they continually search the water column for zones of faster downstream velocity (American eel: Haro et al. 2000; New Zealand long finned eel: Jellyman and Tsukamoto 2005; American eel: McGrath 2005; European eel: Westerberg et al. 2007; Figure 4-7). This behavior could be especially important for eels because they are inefficient swimmers (Boisclair and Tang 1993). A fair amount of observational and experimental evidence indicates that fish, in general, detect and respond to fine-scale hydraulic patterns characteristic of mildly turbulent flowing water (Bleckmann 1986; Popper and Platt 1993; Pavlov et al. 2000; Liao 2006, Liao et al. 2003). Experimental studies of the swimming mechanics and behavior of fish indicate that they use these hydraulic patterns to maintain position or enhance swimming efficiency (Liao 2007). Such responses suggest the possibility that manipulating hydraulic patterns could be a mechanism for altering movement patterns of fish in natural environments.

Several studies of the effectiveness of other factors for diverting silver eels noted their preference for travelling in water moving at the highest velocities. At the Killaloe eel weir on the River Shannon in Ireland, Nolan et al. (1986) found the largest number of migrating silver eels in the center of the river, where currents were strongest, suggesting a selection for high water velocities. Hadderingh and Smythe (1997) invoked the eels' known preference for water moving at higher velocities to explain why the repulsive effect of light was weaker in swiftly moving water. Hadderingh et al. (1999) found that 75% of silver eels in a laboratory flume preferred a swimming route with the highest velocity (25 cm/s), although avoidance of light preempted some of the attraction of swift currents.

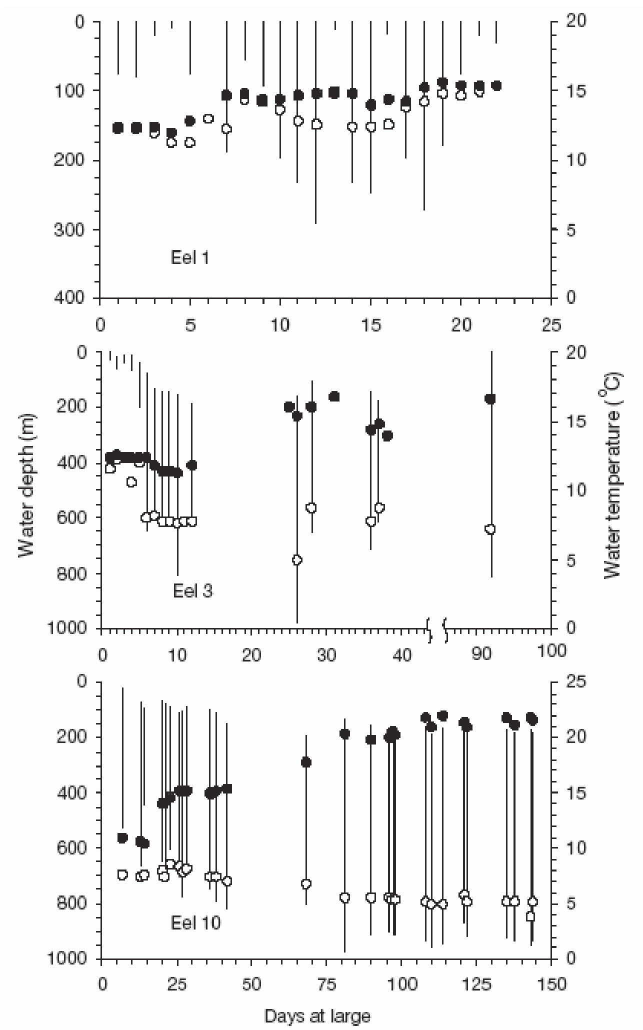

Figure 4-7. Minimum and maximum daily swimming depths (vertical lines) for 3 longfin New Zealand eels recorded using pop-up, archival transmitting tags. Eels were collected in Lake Ellesmere, South Island, New Zealand, and released to the open sea. Open circles indicate minimum water temperatures encountered; filled circles indicate maximum temperatures (Source: Jellyman and Tsukamoto 2005).

Induced flows have been proposed as a way to guide juvenile salmonids in slack-water zones of reservoir forebays (Truebe and Truebe 1997, 1998; Coutant 1998, 2001b). The more river-like induced flows would be used to guide salmon smolts to dam bypasses or collection points. Testing of these concepts is in its infancy, and the benefits remain somewhat speculative. The results of studies using induced flows to direct Atlantic salmon smolts in New England were reasonably positive (Truebe and Truebe 1997, 1998). Field telemetry studies in the Cowlitz River, Washington, demonstrated that salmon smolts can be deflected by a plume of mildly turbulent water generated by a propeller system (Darland et al. 2001a, b) or venturi pump (Coutant et al. 2007) located on barges on narrow reservoirs. We know of no attempt to use induced flows to guide outmigrating eels.

4.5.1 Mechanism of Detection

Fish probably detect the mild turbulence of flowing water rather than bulk velocity. Natural rivers, even large ones, are turbulent. Roughness of the bottom and shoreline creates boils (turbulent bursts), rips (shear zones between differing velocities), and standing waves (wave-like surface features as water passes over rocks). For a general description of such features, see textbooks on river hydraulics such as Chaudhry (1993) or studies of stream turbulence such as Nikora and Smart (1997). Prominent anatomical features of fish such as the lateral line and inner ear systems can detect differential pressures and acceleration at velocity discontinuities in turbulent water (Popper and Platt 1993). Lateral line systems are water-filled canals in the skin or skull that are lined with sensory cells that detect water currents in the canals (Section 5.0). The fish respond to these hydraulic stimuli by positioning themselves in the turbulent water in a way that minimizes the expenditure of energy required to complete a function, such as maintaining position or swimming (Liao 2007). No detailed experiments have been conducted to determine the exact sensory perceptions and responses of outmigrating eels, but their ability to detect and use turbulent hydraulic features can be inferred from available literature. Detection of flow may be coupled with detection of odors to orient eels during migration in tidal estuaries or to move toward odor plumes dispersing from a chemical source, as is discussed further below.

4.5.2 Applications of Induced Flows

A "trail of turbulence" induced in a dam forebay has been proposed to enhance the opportunity for downstream migrating salmon to discover a fish bypass or collection facility (Truebe and Truebe 1997; Coutant 1998, 2001a, b). A path of currents with mildly turbulent features of riverine flow would be induced to attract and guide fish using their normal orientation mechanisms and hydraulic entrainment in the flow. As noted above, testing of these ideas is in its infancy. Evidence from existing facilities is being assembled, and new tests are being conducted.

Currents can be induced either passively or actively. Passive devices consist of physical features placed in the water that use the momentum of flowing water to create directed zones of turbulent flow. Active devices use propellers or pumps to generate flow where little exists.

Passive devices for inducing currents have a long history of use, primarily for managing sediment in rivers (Odgaard and Wang 1991a, b). They can include dikes, submerged berms, columns (like bridge pilings), and vanes. Vanes were installed in the Waikato River, New Zealand, to direct river flow such that it scours sediment from the intake basin of the Huntly Power Station. Circumstantial evidence (i.e., impingement of eels on intake screens) suggests that the vanes also guide outmigrating eels toward the intake (J. Boubée, pers. comm. 2007). Passive orientation of flows and salmon smolts toward a structural corner at the second powerhouse of Bonneville Dam (Columbia River, Washington) stimulated construction of a highly effective fish bypass at that location.

Active devices for inducing currents have a shorter history of use, and the technology is still developing. Truebe and Truebe (1997, 1998) experimented with using underwater propellers (modified commercial sewage mixers) to guide Atlantic salmon smolts in dam forebays in New England to bypasses. A similar propeller was tested for guiding juvenile Pacific salmon in the forebay of Cowlitz Falls Dam, Washington (Darland et al. 2001a, b). The experiments were generally successful in moving fish, largely by entrainment in bulk flow. An unnatural spiraling motion and high turbulence suggested that the propeller devices did not attract fish, but rather captured them through hydraulic entrainment. More recently, various sizes of hydraulic venturi pumps have been tested (Coutant et al. 2007). The venturi pump (designed by Mr. Gordon Burns) produces a discharge plume with currents more like the natural turbulence of rivers. Tests in the headwaters of Riffe Lake (Cowlitz River), Washington, indicated that chinook salmon (*O. tshawytscha*) smolts actively searched and entered the pump's discharge plume and then were guided along its trajectory.

In the absence of any studies of the responses of eels, particularly outmigrating and silver eels, to induced flows, the feasibility of employing this technology to guide the movements of outmigrating eels at Iroquois Dam cannot be evaluated at this time.

4.6 CHEMICAL ATTRACTANTS

4.6.1 Kinds of Compounds Detected by the Olfactory Organs of Fish

The olfactory systems of fish are known to detect a wide variety of water-soluble compounds. Among those, amino acids, bile acids, prostaglandins, and gonadal steroid hormones have been studied most intensively. The stimulatory effects of those four classes of compounds have been described for more than 30 species of fish (Hara 1994). The olfactory sensation of amino acids is believed to influence a wide spectrum of behaviors among fish, including reproduction, feeding, migration, recognition, and predator avoidance (Hara 1994). Olfaction of bile acids, although specifically tied to migratory and reproductive processes in sea lamprey (Li et al. 2002; Li and Sorensen 1997), is otherwise poorly understood. Prostaglandins are thought to influence reproductive processes through their role in the rupture of the follicle during egg development (Sorensen and Goetz 1993). Some species also may recognize some prostaglandins as reproductive pheromones (e.g., goldfish, *Carassius auratus*: Sorensen et al. 1998; loach, *Misgurnus anguillicaudautus*: Kitamura et al. 1994; Atlantic salmon, *Salmo salar*: Moore and Waring 1996; and Arctic char, *Salvelinus alpines*: Sveinsson and Hara 1995). Sensitivity to gonadal hormones (Andersen and Doving 1991) has been linked to reproductive behaviors in some species (e.g., goldfish, *C. auratus*: Dulka et al. 1987; catfish, *Clarias garipinus*; Resnick et al. 1989).

4.6.2 Mechanism of Detection

Distribution and Projection of Olfactory Receptor Neurons: Fish possess an acute olfactory sense enabled by a paired organ of olfaction occurring on the dorsal portion of the snout. The anterior and posterior nares of the olfactory chamber provide entry and exit openings for water flowing from the surrounding medium. Located within the olfactory chamber, the olfactory rosette is composed of a series of olfactory lamellae. Olfactory lamellae contain both sensory and nonsensory epithelia, but the olfactory receptor neurons (ORNs) occur only on the sensory epithelium (Figure 4-8). Three types of ORNs include microvillus, ciliated and crypt. Each fish has millions of ORNs whose axons ultimately converge to form the olfactory nerve (Yamamoto 1982). The olfactory nerve projects to the olfactory bulb, where the axons of the ORNs synapse with the dendrites of relay neurons called mitral cell neurons (Laberge and Hara 2001). Some evidence suggests that the olfactory bulb is functionally segregated, such that each kind of ORN confers the ability to sense particular chemical odorants in the environment (Thommesen 1982; Hansen et al. 2004). Compartmentalized structures called glomeruli occur at the interface between the ORNs and the mitral cell neurons; the glomeruli are believed to be where olfactory signals are integrated (Kosaka and Hama 1979).

Functional Variation in Olfactory Receptor Neurons: Evidence that the morphological differences between kinds of ORNs may produce variation in functional capability is mounting. For example, in trout and zebrafish, amino acids stimulate microvillus ORNs (Sato and Suzuki 2001; Lipschitz and Michel 2002), whereas pheromones stimulate ciliated ORNs (Sato and Suzuki 2001). No specific olfactory functions of crypt ORNs have been identified yet. Electron microscopy coupled with immunocytochemistry and in situ hybridization has further identified correlations between ORN morphology, odorant receptor type, and the spatial distribution of ORNs within the olfactory epithelium (Hansen et al. 2004). The distribution of kinds of ORNs within the olfactory bulb appears to be species specific. In goldfish, microvillus and crypt ORNs occur in high density dorsally and along the midline of the epithelium, whereas ciliated ORNs are distributed across the entire epithelium (Hansen et al. 2004, 2005). In catfish, the three kinds of ORNs are distributed heterogeneously (Hansen et al. 2005). Response to odorants varies regionally across the olfactory bulb depending on the species-specific distribution of the three kinds of ORNs. For example, the posterior part of the medial region of the olfactory bulb of the Crucian carp (*Carassius carassius*) is sensitive to skin extracts from conspecifics, whereas that region of the bulb does not respond to other stimulants (Hamdani and Doving 2003). Efforts have been made to understand variations in response across the olfactory bulb of the zebrafish by establishing the chemotopy of this sensory organ for particular odorant classes (Nikonov and Caprio 2001).

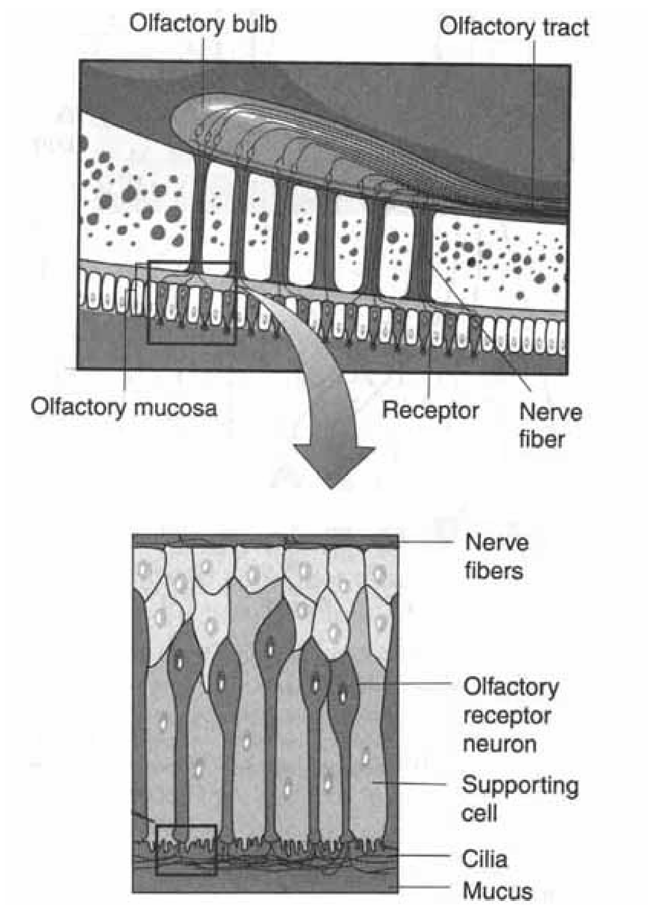

Figure 4-8. Olfactory organs of eels

4.6.3 Sensitivity and Specificity

Olfactory sensitivity to particular molecules is measured in the laboratory using an electro-olfactogram (EOG), in which an electrode is placed near the olfactory epithelium to detect the cumulative activity of receptors in response to specific odorants. In some instances an EOG is monitored simultaneously with an electroencephalogram (EEG) of the olfactory bulb (Hara and Zhang 1998). Simultaneous detection of physiological and behavioral responses to particular chemical concentrations in the olfactory bulb and epithelium confirms the mechanism of olfaction and demonstrates levels of sensitivity to specific cues. ORNs are present in eels as in other teleost fishes, and their functionality may change with ontogeny for some species (European eel: Chiba et al. 1999). Detailed knowledge of the upper and lower limits of detection and the spectrum of behaviors elicited across the range of detection would be required to develop a chemosensory guidance system for eels.

Odorants derived from conspecifics may play an important role in reproduction. European eels exhibit extreme sensitivity to conspecific bile; their detection threshold for conspecific bile is lower than a dilution of 1:10^7 (Huertas et al. 2007). Similar responses to conspecific skin mucus have been found at a detection threshold of 1:10^6 (Huertas et al. 2007). Qualitative differences in the chemical compounds of conspecific bile and skin mucus that vary with the sex and developmental stage of the donor (Huertas et al. 2007) may influence the response of the receiving organism (Figure 4-9). Close proximity to male European eels that had been injected with hormones to induce maturation stimulated gonad development in uninjected immature males (Huertas et al. 2006); however, the EOG response of immature males to candidate hormones produced by maturing males (testosterone, 11-ketotestosterone, 17β-estradiol, prostaglandin $F_{2\alpha}$) was insignificant. Water extracts conditioned with maturing males or females, however, elicited strong olfactory responses among immature males as detected through an EOG, which suggests the involvement of some other, unidentified chemical cue. Pankhurst and Lythgoe (1983) demonstrated that morphological changes that reduce olfactory sensitivity occur in the olfactory lamellae and mucous cells of European eels during maturation. The authors cautioned, however, that the changes may have been caused by artificial hormone treatments and recommended further study. Similar changes in morphology and sensitivity have been noticed in the sea lamprey (W. Li, pers. comm.), even though this species remains sensitive to particular odorants (e.g., sex pheromones). Further investigation is warranted to determine how olfactory abilities and the underlying mechanism of detection change with life stage among eels.

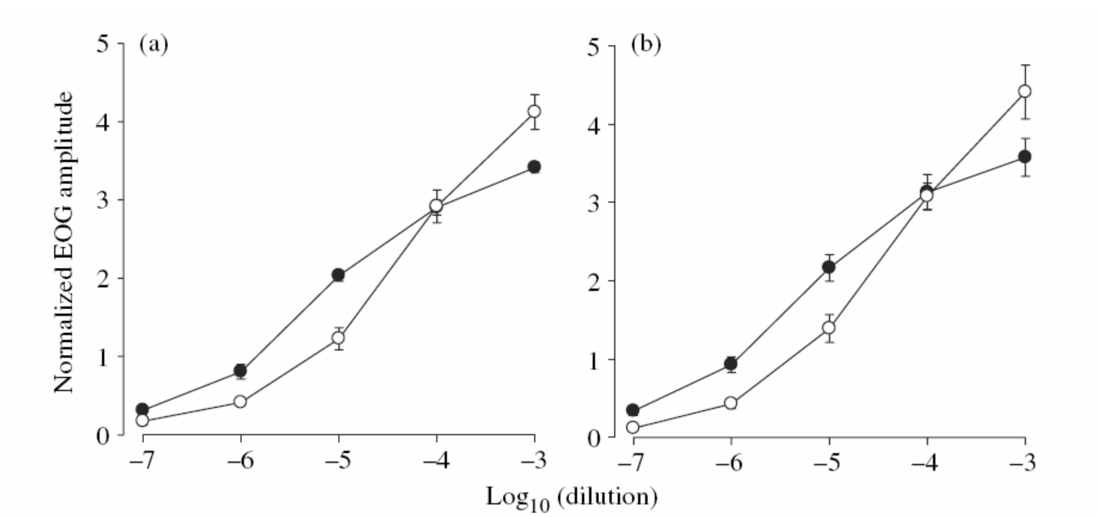

Figure 4-9. Plots of electro-olfactogram (EOG) amplitudes recorded in immature male European eels (n=6) in response to dilutions of bile from (a) immature and (b) mature conspecific males (solid circles) and females (open circles). Note the different shapes of the concentration-response curves in the two axes. (Source: Huertas et al. 2007).

4.6.4 Behavioral Responses

Behavioral responses are identified in the laboratory by exposing fish to potential attractants or repellents under controlled conditions and comparing behavior before and after exposure. The attractiveness of several naturally occurring chemical cues was explored in an experiment with American eel elvers. Odors from decaying leaves, the surfaces of aquatic plants, submerged stones, and migrating alewives were all highly attractive to elvers, whereas conspecific odors were only slightly attractive (Sorensen 1986). The observed reversal of eels' response (i.e., unattracted to attracted) to the odor of some leaves after they were cultured with stream water caused the researchers to hypothesize about the potential role of odorants generated by microorganisms (Sorensen 1986). Eight pure chemical compounds have been identified as attractants for European glass eels; eels displayed detection thresholds as low as 10^{-9} to 10^{-13} mg/l for these compounds (Sola 1995). European glass eels also display a positive chemotactic response to five non-protein amino acids (i.e., D-glutamine, D-asparagine, D-glutamic acid, D-alanine, and β-alanine) dissolved in either fresh or salt water; the thresholds of response are 10^{-9} M[10] for D- or β-alanine and 10^{-7} M for the other amino acids (Sola and Tongiorgi 1998). These five compounds have been proposed to function in foraging and conspecific recognition behaviors. Briand et al. (2002) reported a field study at a dam in France equipped with an eel ladder and a trap that directed water from a holding bin that had contained eels toward the fish passage. This treatment increased European eel catches 1.4 times, suggesting that waterborne cues from conspecifics can function as olfactory attractants for glass eels. Laboratory studies examining the influences of water odors on European glass eels simultaneously with the influences of salinity and temperature cues showed that although odors from natural surfaces seemed to attract eels, odorants generally only reinforced preferences determined by salinity and temperature (Tosi et al. 1990).

4.6.5 Olfaction in Migration and Homing

Research suggests that olfactory senses play a crucial role in the migration and homing behaviors of several species of fish. Field telemetry studies in which tagged individuals are tracked from a point of release have been used to investigate this phenomenon. Such studies have provided a variety of information about the direction, orientation, and vertical and horizontal migration patterns of the tagged individuals, which can then be related to environmental cues. Telemetric information, however, can be very difficult to relate directly to behaviors in the field. Another approach is laboratory experimentation in which the behavioral responses of fish in a tank are monitored. In both laboratory and field settings, the subjects' olfactory sense sometimes is intentionally disabled by filling the nares with petroleum jelly (Westin 1998; Barbin 1998; Barbin et al. 1998) or ablating the olfactory capsule (Hain 1975). Experimental removal of olfactory senses slows horizontal movements, increases residence time in estuarine habitats, and reduces or eliminates homing abilities in American eels in the yellow and silver stages (Barbin 1998; Barbin et al. 1998). Field studies showed that European eels in the silver stage from a stocking facility exhibited very different patterns of migration than eels from wild populations, possibly due to lack of the olfactory imprinting that is normally acquired during early life history (Westin 1990, 1998).

[10] M is an abbreviation for Molar or moles per liter, a common unit of measure for the concentration of a substance in solution. The molarity of a solution can be calculated by dividing the mass of the substance (g) by its molar mass (g/mole) and then dividing that quotient by the volume (l) of solution in which the substance is dissolved.

4.6.6 Olfaction and Flow

Several studies have indicated that olfaction may work in concert with sensitivity to changes in flow patterns (i.e., rheotaxis) that occur with tidal cycles (Hain 1975; Barbin 1998; Barbin et al. 1998). Sensitivity to flow could aid migration processes through a behavior called selective tidal-stream transport, which allows unidirectional migration despite tidal changes in the direction of flow (Creutzberg 1959; Barbin 1998). Fish that exhibit this behavior ascend into the water column when flow is directed in the migratory direction and then descend to and remain on the bottom when the flow reverses. This behavior, which would enable migrating fish to be carried with the favorable flow, could conserve 90% of the energy that would be required to swim the same distance (Weihs 1978). Removal of the olfactory senses either eliminated (American silver eels: Hain 1975; Barbin et al. 1998) or reduced (American yellow eels: Barbin 1998) selective tidal-stream transport behavior. These studies suggest that olfaction is tied to the detection of tidal variations in flow and may trigger the vertical migration response to such stimuli.

Flow can also influence the shape of odor plumes that influence swimming behaviors (Carton and Montgomery 2003; Figure 4-10). In unidirectional flow, odor plumes tend to take a conical shape, narrow at the source and widening with downstream distance from the source. Studies with emerald rockcod (*Trematomus bernacchii*) have demonstrated that fish tend to approach the source of an odor from locations downstream, where the plume is more dispersed (Montgomery et al. 1999). When presented with a plume of food odor in the laboratory, New Zealand eels exhibited differential behavior depending on distance from the source of the odor. Far from the source (> 40 cm), swimming velocity was greater, and odor-conditioned rheotaxis (i.e., a behavior in which odor detection results in upstream movement toward the source) was observed. This may be a fast and efficient means of arriving at an odor source. Close to the odor source (< 40 cm), individuals exhibited cross-stream casting behavior, presumably to pinpoint the source (Carton and Montgomery 2003).

In the presence of more complex flow patterns, a released chemical would be expected to disperse rapidly into eddies or filaments and to become distributed randomly in space. Upon detection of intermittent filaments of an odorant, fish may be able decide whether to follow a current or to increase their movement in a direction that deviates from the water current direction. Intermittent application of odorants resulting in dispersion of the odor through eddies, therefore, could significantly alter the path of movement of a downstream migrating fish.

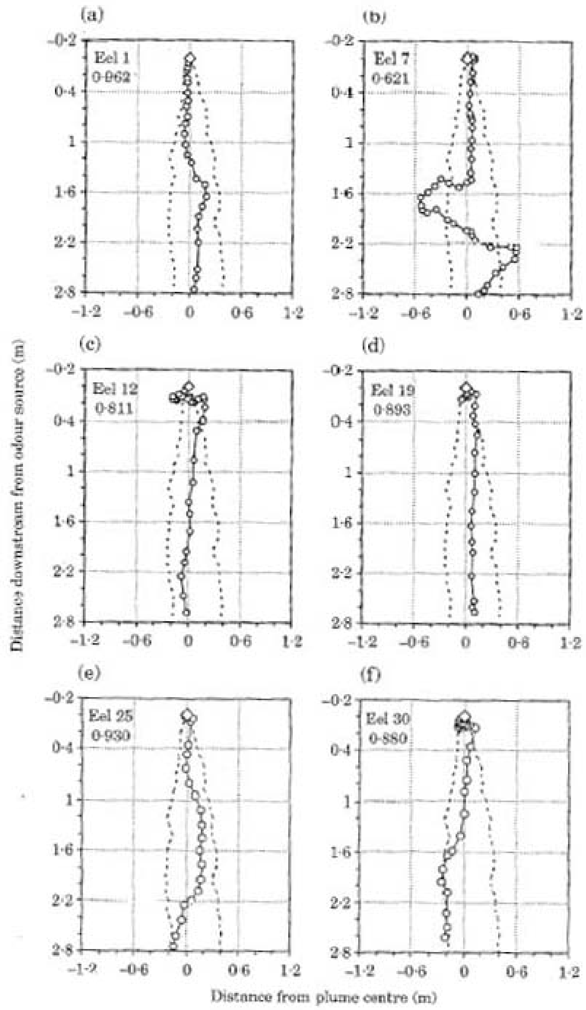

Figure 4-10. Six representative search paths (open circles) of eels localizing the source (open diamond) of an odor. The lateral margins of the mean-odor plume are represented by a dashed line. Stream flow is from top to bottom (Source: Carton and Montgomery 2003).

4.6.7 Definition of Pheromones and Homing Odorants

Pheromones are chemicals secreted to the surrounding medium, individually or in combination, that can elicit behavioral or physiological responses in a conspecific (for review, see Sorensen and Stacey 2004). In fish, these chemicals may function as antipredator and alarm cues, nonreproductive aggregants, and reproductive aggregants or stimulants (Sorensen and Stacey 2004 and references cited therein).

Homing odorants are chemicals that migrating species use to find home streams or natal spawning sites. Perhaps the best known examples of homing are from salmon species

(Salmonidae: Quinn 1993). During critical developmental stages, salmon form an olfactory memory of chemicals associated with natal habitats to which the population returns later in life. The chemicals may be secreted by conspecifics or by other organisms in the natal environment (e.g., Tosi and Sola 1993). Responses to homing odorants are learned (fish become imprinted), whereas responses to pheromones are innate.

Olfactory organs may become habituated when exposed to an odor for too long, at a very strong concentration, or both. Habituation may hinder a fish's ability to respond to pheromones or homing cues. In a natural habitat, a fish's olfactory organs are only intermittently exposed to odorant chemicals, which typically disperse into filaments or eddies. In chemical ecology, researchers often use the term "filament" to describe odorant packets in the odor plume propagating downwind or downstream (Farrell et al. 2002; Zimmer and Butman 2000).

4.6.8 Sea Lamprey Example

The sensitivity of the sea lamprey (*Petromyzon marinus*) to sex pheromones has been investigated in depth due to an interest in using chemicals as biological controls (Li et al. 2007). Sea lamprey is an invasive species that currently populates the Great Lakes, where it has negatively affected populations of lake trout and other species. First observed in Lake Ontario in the 1830s, sea lamprey spread to all the Great Lakes by the late 1940s. Although the sea lamprey is ecologically and phylogenetically different than eels, research efforts spurred by the growing interest in developing chemical methods for controlling sea lamprey populations may provide valuable insights about the potential to develop chemosensory guidance systems for eels. These studies initially employed a laboratory-choice design in which the amount of time ovulated females chose to spend in untreated water was compared to time spent in water containing the putative pheromone compounds (Li 1994; Siefkes et al. 2003; Sorensen et al. 2005). In some instances, those studies were combined with monitoring of the olfactory epithelium (Li et al. 2002; Sorensen et al. 2005).

Sex pheromones play a prominent role in the reproductive behavior of sea lampreys. Mature adult sea lampreys secrete a bile acid that triggers mate preference and mate searching behavior in ovulated females (Li et al. 2002; Siefkes et al. 2003; Siefkes et al. 2005). This hormone is secreted through the epithelia of the gill of spermiating males (Siefkes et al. 2003). Sufficient quantities are released in 4 hours to be detectible by females when diluted in 10^7 liters of water (Li 1994). This compound has been identified as 7α, 12α, 24-trihydroxy-5α-cholan-3-one 24-sulfate. The olfactory epithelium of the sea lamprey has been shown to be more sensitive to sulfated bile acids than to non-sulfated bile acids (Li et al. 2002), suggesting that different compounds may play different roles in the species' behavior.

In addition to being a direct reproductive chemical cue, pheromones may act as a cue for migration. Sulfated steroids (petromyzonol sulfate and allocholic acid) to which the sea lamprey epithelium is more sensitive are released by stream-dwelling larval sea lampreys and may thus provide a chemical guidepost for adults as they migrate to spawning streams (Polkinghorne et al. 2001; Sorensen et al. 2003; Sorensen et al. 2005). These chemicals are secreted in large amounts but have a low threshold of detection (picomolar), as would be expected of an effective chemical cue for migration. In an aquatic ecosystem, even a compound released in great quantities is tremendously diluted by the surrounding medium. The target receptor organisms, therefore, would need to be able to detect the compound at low concentrations (Polkinghorne et al. 2001; Sorensen et al. 2003). This is particularly relevant for sea lamprey, which tend to spawn in fast-moving water, which dilutes chemical compounds quickly.

Chemical attractants have been used successfully to trap ovulating female sea lampreys on the Ocqueoc River (mean depth=0.4m, mean discharge=1.6 m^3/s) in Michigan. Traps baited with spermiating males and placed in the natural flow path of the river had capture rates 70% greater than controls within 12 hours (Johnson N.S. et al. 2005). Traps baited continuously with washings from spermiating males had greater capture rates (52%) than those baited intermittently with pulses of washings (28%; Johnson N.S. et al. 2006). When their olfactory receptors were occluded, ovulating females were not attracted to washings from spermiating males in a laboratory-choice study and were unable to locate spermiating males in a spawning stream under natural conditions (Johnson N.S. et al. 2006). This suggests that the response of ovulating female sea lamprey to spermiating males is mediated by a pheromone signal released by the male and detected by the female olfactory system.

Siefkes et al. (2005) showed similar patterns of response among female lampreys exposed to water conditioned with extracts from spermiating males. Ovulating females placed in a two-choice maze both preferred and demonstrated search behaviors in response to this odorant, whereas males and pre-ovulating females did not. When released into a natural spawning stream, a synthetic form of this compound (10^{-12} M) and water conditioned with extract of spermiating male (2 X 10^{-12} M) both caused ovulating females to locate and swim toward the source of the odor.

These studies of lampreys illustrate that olfactory stimuli can be used to alter the behavior and contribute to the management of a species. The success with lampreys, however, is significantly associated with the fact that lampreys move upstream during their spawning migration. Using olfactory cues to manipulate the movement patterns of fish that migrate downstream, such as eels at Iroquois Dam, would be considerably more difficult (Section 4.8.5).

4.6.9 Compounds that Function as Pheromones for Fish

Several compounds have been suggested to have pheromonal properties for fish. These include tetrodotoxin, specific amino acids, purines, bile acids, gonadal steroids, and F-prostaglandins; however, release, olfactory sensing, and behavioral responses have been described only for gonadal steroids, prostaglandins, and bile acids (Sorensen and Stacey 2004 and references cited therein).

Specific pheromones and levels of sensitivity have been identified for some fish species. For example, in goldfish a steroid hormone (17,20-dihydroxy-4-pregnen-3-one) released by ovulating females induces increased milt production in males (Dulka et al. 1987). Mature female

Masu salmon (*Oncorhynchus masou*) release an amino acid that functions as a pheromone. Released in urine, this compound attracts males and advertises female readiness to mate (Yambe et al. 2006). Male Masu salmon respond to this chemical at concentrations as low as 10^{-14} M. Gonadotropin-releasing hormone (GnRH) also has been shown to have pheromonal properties in rainbow trout (*O. mykiss*); sensitivity of males and females to this compound was detected at 10^{-16} M using EOG (Anderson and Doving 1991). GnRH also functions in the release of pituitary gonadotropins, as a neurotransmitter, and in testicular development in the Japanese eel (Stell et al. 1984; Chiba et al. 1999). Four possible sex pheromones have been identified in Crucian carp. These compounds (i.e., 17,20β-dihydroxy-4-pregnen-3-one; 12,20β-dihydrxy-4-pregnen-3-one-20 sulfate; androstenedione; and prostaglandin F2α) have thresholds of detection at 10^{-9} M (Lastein et al. 2006).

4.6.10 Sensitivity of *Anguilla* Species to Putative Pheromones

Numerous studies demonstrate that *Anguilla* species are sensitive to compounds that function as pheromones in other fish. Several amino acids (glycine, L-alanine, L-valine, L-leucine, L-asparagine, L-glutamine and L-methionine) stimulate the olfactory mucosa in glass and elver stages of the European eel (Crnjar et al. 1992). Several D-isomers also attract European glass eels when dissolved in fresh water at 10^{-7} M (i.e., D-glutamine, D-asparagine, and D-glutamic acid and 10^{-9} M for D-alanine and β-alanine; Sola and Tongiorgi 1998). Eels detect the amino acids serine, histidine, cysteine, and betaine at thresholds between 10^{-8} and 10^{-7} M (determined via EOG; Eto and Shoji 2006). Aspartic acid induces a response at concentrations between 10^{-6} and 10^{-5} M, and methionine stimulates a significant response at concentrations between 10^{-5} and 10^{-4} M among Japanese eels (Eto and Shoji 2006). In a study of the response of European eels to several bile salts, all compounds tested (i.e., glycocholate, taurodeoxycholate, taurine, taurocholate, cholate, deoxycholate, glycochenodeoxycholate and taurochenodeoxycholate) were attractants at concentrations below 10^{-10} M; however, a subset of the compounds (i.e., taurocholate, cholate, deoxycholate, glycochenodeoxycholate and taurochenodeoxycholate) became repellents at higher concentrations (Sola and Tosi 1993). Geosmin, a naturally occurring compound produced by common freshwater actinomycetes (a type of bacteria), also acts as an attractant; European glass eels respond to concentrations as low as 10^{-13} M (Tosi and Sola 1993).

Eels respond to a variety of putative pheromone compounds in laboratory settings. European eels have demonstrated sensitivity to conspecific bile fluids (threshold < $1{:}10^{-7}$) and conspecfic mucus (threshold $1{:}10^{-6}$; Aroua et al. 2005). This sensitivity may vary with sex and life stage. For example, skin mucus from mature European eels elicited a higher level of activity than mucus from immature eels (Huertas et al. 2007).

These studies document that various life stages of several species of eels can detect putative pheromones at very low levels and exhibit behavioral responses to them; however, none of the studies address whether sexually mature American eels are attracted or repelled by specific compounds. Such specific information is a requirement if chemical compounds are to be considered for use in guiding or collecting migrating eels in the St. Lawrence River. Extensive research would be needed to collect such information.

4.6.11 Strength of Evidence

The feasibility of using chemical attractants, repellents, or both to alter the movements of eels has never been studied. As a result, the potential usefulness of chemical guidance techniques can only be inferred from general information about the responses of eels and other fish to various chemicals, and the validity of such inferences depends on the strength of the evidence that is available to support them. Odorants could be used to attract migrating or mature fish to a specified area. Several well designed and controlled laboratory experiments have shown definitive links between specific odorants and physiological and behavioral responses among fish. Many of these studies have been able to establish thresholds of detection for specific chemicals and for induced behavioral responses for specific species and life stages of fish. Research conducted with sea lamprey, goldfish, Crucian carp, and some *Anguilla* species provides good examples.

The loss of olfactory abilities appears to correlate with the loss of certain behaviors. Although filling the nares with petroleum jelly is a common method of inducing anosmia in fish, few studies have reported results for a handling-control group to determine how the treatment itself may have affected the behavior of fish. Such treatment could damage individuals in ways other than destroying olfactory sensation that would alter natural behaviors. One study in which anosmia was induced by ablating the olfactory capsule provided evidence that corroborates the results of studies that used petroleum jelly plugs to induce anosmia (Hain 1975). In general, small sample size and the potential adverse effects of study protocols make results inconclusive. As a result, these studies provide only weak supporting evidence for the hypothesis that olfactory cues are responsible for the reported behaviors.

4.6.12 Description and Relevance of “Eel Balls”

Eel balls have been described as aggregated spherical masses of mature fish that form either immediately preceding or during the fall migration (Medcof 1966, 1969). Eel balls may include from 15 to 2,000 fish (Medcof 1966; D. Witten, pers. comm.), and multiple balls measuring approximately 0.5 m in diameter may occur simultaneously within 25 m of each other (Medcof 1966). They may occur on the bottom, in the water column, or associated with a fishing gear in freshwater habitats (Medcof 1966, 1969). The stimuli that cause migrating eels to form eel balls are unknown; however, if such stimuli could be identified (e.g., some chemical attractant), they might be useful for stimulating the formation of eel balls or otherwise attracting or aggregating eels in a manner that would facilitate their capture.

Published Evidence and Anecdotal Accounts. Most of the evidence for the eel ball phenomenon is anecdotal, based on direct sightings or reported sightings by fisherman. Medcof (1966) reported observing eel balls in Lake Ainslie near its outflow into the Southwest Margaree

River in Nova Scotia during August 1935. Experienced fishermen in the same system have reported observing eel balls on the bottom and floating free offshore, near the water's surface (Medcof 1966). An eel fisherman reported conversations with previous generations of fishermen (bom 1892, 1912, 1915) about seeing eel balls during an unknown time of year in association with thunderstorms in the New York portion of the Delaware River, about 30 miles north of Port Jervis (F. Campfield, pers. comm.). It is not clear, however, whether these were silver or yellow eels (F. Campfield, pers. comm.) Eel balls were reported at the outlet of the Wesserunsett Lake (East Madison, Maine) during the fall at some point between 1995 and the present (D. Witten, pers. comm.). One large ball composed of 1,000 to 2,000 silver eels was observed in that lake during a period of low water. Another report noted the presence of an eel ball at the Southern end of Indian Pond (Saint Albans, Maine; D. Witten, pers. comm). This ball was composed of larger eels that were unable to move beyond the Indian Pond Dam due to low water. An eel ball composed of about 30 to 40 silver eels (the size of a bushel basket) was observed on the float of a carp net in the Upper St. Lawrence River during the fall (J. Cassellman, pers. comm.). Eel balls have been reported to occur in the mud of Prince Edward Bay at a depth of 0.6 m to 0.9 m during the winter (J. Cassellman pers. comm.). On one occasion, eels removed from a single hole in the mud filled a 180-kg to 200-kg barrel. European eels also are reported to migrate downstream in balls (Meek 1916).

The anecdotal reports described above might not refer to the same phenomenon. Reports varied in the kind of information offered, the size of the eel ball, the size of individuals involved, habitat, and other potentially related environmental conditions. Eel balls observed in different ecosystems by different fisherman consisted of as few as 15 to as many as 2,000 eels (D. Witten pers. comm.; Medcof 1966). The larger eel balls tended to be reported as single incidents (J. Cassellman, D. Witten pers. comm.). Some accounts suggested that environmental cues such as thunderstorms (F. Campfield, pers. comm.) or low water level (D. Witten, pers. comm.) may have been contributing factors. Man-made structures including dams (D. Witten, pers. comm.) and fixed fishing gear (J. Cassellman, pers. comm.) also have been reported to be associated with this phenomenon.

Potential Involvement of Chemical Cues in Eel Ball Formation. Contact pheromones, which are detected within very close proximity, are one potential mechanism by which eels may form and maintain eel balls during migration. Contact pheromones have been described for silverfish (*Lepisma saccharina* and *Ctenolepisma longicaudata*: Woodbury and Gries 2007), garter snake (*Thamnophis sirtalis parietalis*: LeMaster and Mason 2001; LeMaster et al. 2001), and putatively for roughskin newts (*Taricha granulose*: Thompson and Moore 2000, 2003). Although snakes, newts and eels are phylogenetically very different, similarities in body shape and morphological characteristics suggest the possibility that contact pheromones may be involved in eel balling (R. Mason, pers. comm. to W. Li). The possibility that chemical cues may play a major role in aggregating individual eels to certain locations for ball formation has not been investigated to date.

4.7 ALARM PHEROMONES AND OTHER CHEMICAL REPELLENTS

4.7.1 Alarm Signals and Responses

The ability to detect predators and respond to avoid them can reduce vulnerability to predation (Chivers and Smith 1998). Chemical “alarm” cues produced by conspecifics provide one mechanism for eliciting a predator-avoidance response (Brown and Smith 1997). Responses to antipredator alarm cues may include reducing foraging time, hiding, dashing, avoiding an area, or shoaling (i.e., forming aggregates of individuals moving in the same direction) (e.g., Lawrence and Smith 1989; Brown and Smith 1997, 1998). First identified in Cyprinid fish, alarm pheromones elicit predator-avoidance behavior in fathead minnows (*Pimephales promelas)* and Crucian carp exposed to pheromones produced by predators and conspecifics (Brown et al. 2001; Hamdani and Doving 2003). Laboratory experiments have demonstrated that fish can learn to associate danger with chemical cues from a predator (Brown and Smith 1997, 1998). When predator-naïve test subjects were exposed to extracts of damaged conspecifics and the odors of predators alone and in combination, only those exposed to treatments with conspecific cues exhibited alarm behavior. Subsequent (4 and 21 days later) exposure of the fish to the predator’s odor alone elicited behaviors initially observed only in response to conspecific cues (Figure 4-11; Brown and Smith 1997, 1998). Morphological responses to alarm pheromones also have been reported. For example, in response to conspecific skin extracts, body depth of Crucian carp increases, which is thought to aid in warding off predators (Stabell and Lwin 1997).

Recent evidence indicates that alarm pheromones are widespread among fish species. Laboratory studies have linked behaviors with these repellent cues. Naïve, hatchery-raised rainbow trout (*O. mykiss*) were conditioned to display predator-avoidance behaviors (e.g., decreased foraging, increased “freezing”) in response to secretions from damaged conspecifics and odor from northern pike (*Esox lucius*); subjects displayed the conditioned behaviors at both 4 and 21 days following conditioning (Brown and Smith 1998). Predator-avoidance behaviors in response to extracts from conspecifics or predators have been demonstrated in rainbow trout (*O. mykiss*: Brown and Smith 1997, 1998; Mirza and Chivers 2003), fathead minnows (*P. promelas*: Brown et al. 2001), Crucian carp (*C. carassius*: Hamdani and Doving 2003), finescale dace (*Chrosomus neogaeus*: Brown et al. 2000), green sunfish (*Lepomis cyanellus*: Brown and Brennan 2000), channel catfish (*Ictalurus punctatus*: Brown G.E. et al. 2003) and cichlids (*Cichlidae spp.*: Brown et al. 2004).

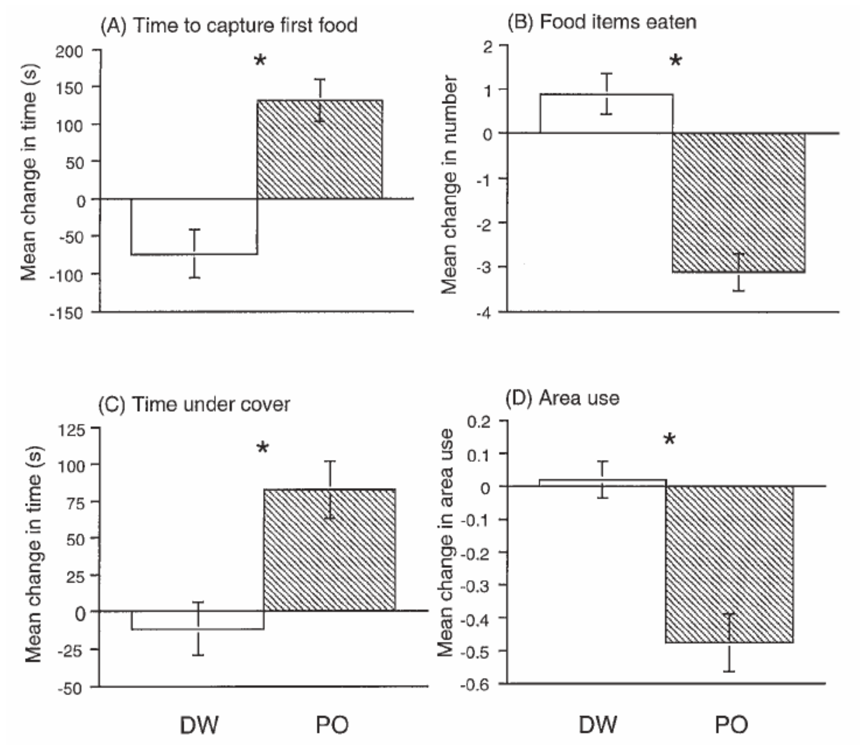

Figure 4-11. Change in response of rainbow trout to distilled water (DW, open bars) and pike (predator) odor (PO, solid bars) for each of four behavioral measures recorded 4 days after conditioning. Similar trends were observed 3 weeks after conditioning, although not all were significant. *Significant difference at $p < 0.05$ (Mann-Whitney U test) between DW control and PO experimental trials. Data are presented as mean ± standard error. Nonparametric statistics were used for the analysis. (Source: Brown and Smith 1998).

4.7.2 Examples of Other Chemical Repellents

Cross-reaction experiments with related species (e.g., two species in the family Gobidae, *A. semipunctatus* and *Brachygobins sabanus*; Smith et al. 1991) have shown that one species can react to alarm pheromones produced by another. In a laboratory study, fathead minnows (*P. promelas*) exposed to alarm cues produced by other species (i.e., heterospecifics) in the predator's diet in combination with those of conspecifics learned to recognize heterospecific alarm cues (Chivers et al. 2002). Pheromones derived from predators also act as repellents in other species. Using a two-choice tank design, Dittman and Quinn (1994) showed that precociously maturing male chinook salmon (*O. tshawytscha*) avoided water scented with a specific pheromone (17a,20b-dihydroxy-4-pregnen-3-one) produced by mature male salmon. A similar method was used to demonstrate that wild brook trout (*Salvelinus fontinalis*) avoid water scented with extracts of red fin pickerel (*Esox americanus*) and Atlantic salmon (*S. salar*; Keefe 1992). Such studies suggest the possibility that alarm cues produced by species other than eel may be able to evoke an avoidance behavior in eel; however, no research has investigated this possibility for *Anguilla* species.

4.7.3 Strength of Evidence

The fact that a chemical cue functions as an attractant or repellent in a laboratory setting does not necessarily mean that it would elicit similar responses under field conditions. For example, Magurran et al. (1996) demonstrated that an alarm substance called Schreckstoff caused hiding, darting, and freezing behavior in European minnows (*Phoxinus phoxinus*) under laboratory conditions but did not modify the behavior of wild minnows in the field. The researchers offered several potential explanations for this disparity between observations in the laboratory and in field studies. One is that the spatial context in which the cue is experienced may affect the fish's response to that cue. For example, the limited area of an enclosed aquarium is a much different spatial context than the natural environment, where habitats and escape routes are familiar. The authors likened this to the difference in a person's response to smelling smoke while outside compared to his or her response to the same smell detected inside a house, where confinement may increase the perceived danger. A chemical cue may be more effective when paired with a particular visual stimulus, such as the predator itself. In the absence of that visual stimulus, the subject may not display the expected response. Magurran et al. (1996) also discussed the possibility that dilution of pheromones caused by downstream river flow may have prevented the expected alarm response. Another researcher challenged these findings (Smith (1997), and other field studies have corroborated responses observed in the laboratory responses (e.g., Mathis and Smith 1992, 1993; Wisenden et al. 1994, 1995; Chivers et al. 1995). Wisenden et al. (2004) actually repeated Magurran et al.'s (1996) study under field conditions and found that the number of fish decreased in an area when chemical cues of a predator, the blacknose shiner (*Notropis heterolepis*), were released. Given that many publications have reported disparities between lab and field studies, significant field testing would be required to confirm responses that might be expected based on laboratory studies well before deploying any kind of chemical guidance method on a large scale.

No information is available concerning whether any chemical cues would repel eels at any life stage. Any consideration of using chemical repellants to guide the movements of outmigrating eels would first require laboratory research to establish that eels could detect and exhibit escape responses to specific chemicals. Positive laboratory findings would then have to be followed by extensive field studies to document similar responses under natural environmental conditions. A conceptual plan for using chemical compounds to alter movements of outmigrating eels would then have to be developed and tested. Clearly, little evidence suggests that chemical repellants would be useful in a trap-and-transport program at Iroquois Dam.

4.8 FEASIBILITY OF USING ATTRACTANTS AND REPELLENTS AT IROQUOIS DAM

4.8.1 Factors Affecting Feasibility

Adapting any of these potential mechanisms for using attractants or repellents to modify the behavior of outmigrating eels in natural systems for use at Iroquois Dam poses several challenges. The first is the large size and discharge rate of the river at the dam. The dam itself is 600 m long and spans the international portion of the St. Lawrence River (Kleinschmidt 2006). The dam consists of 32 sluiceways that are each 15.2 m wide and 13.1 m deep. The water around the dam ranges from 9 m to 12 m deep, and water velocity in the vicinity of the dam averages 1.2 m/s. A second issue is the potential to affect non-target species residing in the river. In addition to American eel, the St. Lawrence River is home to at least 85 other species of fish including smallmouth bass, walleye pike, northern pike, and yellow perch, each of which supports an important recreational or commercial fishery, or both. In addition, any of the guidance technologies could be subject to a variety of regulatory constraints, particularly regarding the release of chemical compounds into surface waters.

The fact that eels migrate downstream poses particular challenges for using any attractant or repellent. Telemetry studies near Moses-Saunders Power Dam indicate that downstream migrating eels actively moved at rates ranging from about 0.6 m/s to 0.8 m/s between Moses-Saunders Power Dam and Beauharnois Dam. This is substantially faster than the natural rate of water flow in this area, which was measured at between 0.2 m/s and 0.4 m/s. All eels also frequently moved up and down in the water column as they traveled downstream (EPRI 2001). This rate and diversity of movement means that any stimulus or cue deployed in the river would have to be detected over a wide portion of the river, over depth, width, and length, in order to reliably alter movement patterns of all eels moving past a given location.

4.8.2 Electrical Fields

Hadderingh and Jansen (1990) suggested that the effectiveness of electric screens was too variable for practical application in algae-rich waters; however, the presence of zebra mussels in the St. Lawrence River has resulted in extremely clear water with minimal algae, eliminating algae as a limiting factor for this technology. Hadderingh and Jansen (1990) also noted that constructing an electrical screen at a large power plant or hydroelectric intake probably would be too expensive and impractical. An inverted-V-shaped electric screen with arms at 30º to the direction of current at Iroquois Dam would need to be 1,000 m long (see Figure 3-17), which is larger than any system considered by Hadderingh and Jansen (1990). Several additional factors suggest that using an electrical barrier to guide outmigrating eels at Iroquois Dam would be impractical and infeasible. First, the magnitude of the voltage potential required to elicit avoidance behavior in eels could impair neuromuscular function, particularly in large eels, and might cause permanent physiological damage. Second, electrical stimuli probably would affect non-target species that are sensitive to the same range of voltage potentials. The physiological damage or mortality inflicted on other species could reduce the populations of those non-target species. Third, a system that requires wires strung across flowing water is susceptible to damage from debris being carried downstream. Fourth, the high water velocities at the dam (> 1 m/s) could prevent eels from avoiding the electrical field (i.e., the current might force eels into the field).

4.8.3 Electromagnetism

Electromagnetic sensitivity occurs in all five classes of vertebrates, and the role of electromagnetic fields in guiding migration has been described in detail for several species of migratory of fish (Quinn 1993). Electromagnetic sensitivity could function in sensing water flow and directionality, even in species that do not migrate over long distances. Much of the experimental work has been conducted in the laboratory using indirect indicators of response (e.g., heart rate). Less is known about directed behaviors, and little field validation exists for using this cue as a technology for directing the local movements of migratory fish. The amount of data on both laboratory and field responses of all life stages of eels to electromagnetic fields is very limited. Silver eels exhibited small directional changes in the few field studies known, but the strength of the magnetic field in these studies did not deter migration (Westerberg and Begout-Anras 1999; Westerberg 2000). We found no examples of the use of electromagnetic fields for the sole purpose of directing the movements of eels or any other fish species in a natural environment.

The logistics of generating electromagnetic fields of the strength and intensity that might elicit a response in eels (e.g., structural design, power requirements) are unknown, and the potential for affecting other species is great. Electromagnetic guidance technologies would not be species specific and could adversely affect other magnosensory or electroreceptive fishes in the St. Lawrence River, including pike and pickerel (*Esox spp.*), walleye (*Sander vitreus vitreus*), sturgeon (*Acipenser spp.*), sea lamprey (*Petromyzon marinus*), and alewife (*Alosa pseudoharengus*) (Scott and Crossman 1973; Chadwick and Claytor 1989; Le Pan et al. 2002). These non-target species may not occupy the same habitat on the same spatial and temporal scales as outmigrating American eels; therefore, further investigation would be required to identify the specific potentially affected, non-target species in the vicinity of Iroquois Dam. Existing evidence provides no clear picture of how eels at Iroquois Dam would respond to this technology if it were applied on a large scale in a natural habitat.

4.8.4 Induced Flows

Although using induced flows to guide outmigrating eels has a logical scientific foundation in the biology and behavior of fish in general and salmon smolts in particular, much more study and evaluation would be required to justify its use with eels in the field. Field studies with transmitter-equipped test fish using venturi pumps to generate turbulent plumes has emerged as the most appropriate method for demonstrating the effectiveness of induced flows for guiding salmon smolts. Similar experiments would be necessary to deterime if outmigrating eels respond to induced flows and to identify the characteristics of flows that could be used to alter their patterns of movement. If results of such studies demonstrated that induced flows could influence their movements, using induced flows to collect outmigrating eels at Iroquois Dam would be challenging because of the size of the dam. Existing hydraulics might be used to advantage, but too little is known about the hydraulics of the water upstream of Iroquois Dam to determine if existing currents tend to concentrate eels, such as natural currents concentrate salmon smolts at Bonneville Dam. The behavior of eels as they approach Iroquois Dam could be identified only through telemetry studies. Circumstantial evidence indicating that vanes installed to direct water flow (for sediment control) at Huntly Power Station in New Zealand also guide outmigrating eels toward the intake (i.e., impingment of eels on intake screens) suggests the possibility of installing vanes in the St. Lawrence River oriented toward a collection facility upstream of Iroquois Dam. This option would have the potential to be effective only if a location can be identified where eels are presently migrating in fairly high density. This caveat would be applicable to any active device for directing flow. Passive or active devices for directing flows might be used effectively in small areas to enhance the performance of physical guidance systems such as louver arrays or bar racks, as described in Section 3.0.

4.8.5 Attractant and Repellent Chemicals

Any chemical application would require careful consideration of detection and response thresholds, water volume, and flow patterns around the dam. Although eels' great sensitivity to putative pheromones at low concentrations could be advantageous, the effects of flow patterns on the rate and direction of dispersal of the chemical could present a challenge. A released chemical would disperse rapidly into eddies or filaments and become randomly distributed. Fish, however, may not have to detect an odorant continuously to be guided effectively. Upon detection of intermittent filaments of an odorant, fish may be able to decide whether to follow the direction of flow or to increase their movement in a direction that deviates from the direction of the current (Li, unpublished data). Intermittent application of odorants, therefore, could significantly bias the path of fish moving downstream. Odorants could be applied to induce a path that is biased toward a particular side or section of the river near the dam. Appropriate levels of odorants could be maintained on one side of the river to repel fish to the other side, whereas fish on the opposite side of the river would already be on the desired path. American eels use the entire water column and the entire width of the river during migration (McGrath 2005); therefore, a chemical attractant or repellent might have to be distributed broadly to increase the likelihood of reaching outmigrating eels.

Previous uses of chemical attractants in management programs (e.g., for sea lamprey) appear to have little relevance for outmigrating eels. In these applications, the target species detected low levels of a compound and initiated active search behavior to move upstream toward the source of the attractant. Telemetry studies of outmigrating eels in the St. Lawrence River indicate that the eels show unidirectional downstream movement at relatively rapid rates. Patterns of movement downstream in the direction in which a chemical attractant is also moving and dispersing would not contribute to concentrating the downstream migrants. Outmigrating eels, however, might respond to a chemical attractant released during the daytime, when they are not actively migrating or, perhaps, to one released in the early evening before active downstream movement begins[11]; this possibility has not been tested to date. If eels respond as hypothesized, attractants might serve as a means of concentrating eels to facilitate capturing them prior to or following active migration periods. When the eels are actively migrating downstream, releasing a compound that eels would avoid so as to divert them away from a major portion of the river cross-section might be of some value in altering the path of their downstream movements and concentrating them in a specific part of the river cross-section. No information is available about whether individual substances that eels detected in laboratory studies would be detectable in a natural setting when those substances are diluted and combined with all the other compounds present in the river water, and the likelihood that either of these guiding methods would be effective cannot be determined.

Released compounds could affect non-target species in unknown ways. Pheromone communication occurs between members of the same species, and their responses are innate. The chemicals that function as pheromones, however, are not necessarily species specific, and individual compounds may have pheromonal functions or other effects in more than one species. Some repellent pheromones isolated in one species are able to elicit alarm responses in other species (Smith et al. 1991; Chivers et al. 2002).

Regulatory constraints on releases of chemical compounds into surface waters would have to be considered; however, precedents indicate the feasibility of obtaining permits for some chemical attractants. EPA recently issued experimental user permits to the Great Lakes Fishery Commission for releasing synthesized sea lamprey pheromone into an experimental stream. EPA historically has issued numerous permits for application of insect pheromones.

The available evidence is insufficient to suggest that an olfactory cue deployed in the water column would be an effective guidance system for outmigrating eels. Much more study of specific compounds, concentrations of specific compounds, behavioral responses, and directed movements in the field is needed to develop a guidance system based on olfactory cues.

4.9 RESEARCH NEEDS

Research to further evaluate the potential for using attractants and repellents to collect outmigrating eels in the St. Lawrence River should focus on the most promising candidates for altering eels' movement patterns; however, no leading candidate attractant or repellent can be clearly identified based on the current scientific understanding of sensory cues reviewed in this section. Experimental evidence for all the sensory modalities and signals studied to date clearly indicates that eels are highly sensitive and responsive to their environments. A major gap in current knowledge is the lack of understanding of eels' exact behavioral responses to virtually every kind of sensory cue in natural habitats. A second gap in knowledge is that neither the exact nature nor the effective ranges of sensory stimuli has been identified for many sensory

[11] In telemetry studies conducted by NYPA, 75% of the movement of outmigrating eels occurred at night (Section 9).

systems. A third gap is that the hydraulic features (velocities, turbulence, directions of flow) of the river immediately upstream of Iroquois Dam have not been characterized. Background hydraulics must be known in order to apply any guidance technology effectively. A fourth gap is limited understanding of the exact movement patterns of eels as they approach Iroquois Dam. These gaps need to be filled in order to identify the behavioral guidance signals that are most likely be useful for achieving eel passage objectives. Follow-up studies should determine how any guidance signal can be effectively used in the St. Lawrence River.

4.9.1 Electromagnetism

When data for European, American, and Japanese eels are taken together, it seems evident that eels are capable of detecting electromagnetic fields throughout their lives. The main concern with these data is that most researchers look for conditioned changes in heart rate as the major indicator of detection. Although this approach is well established as a first step in demonstrating the function of a sense, it does not provide direct evidence of the behavioral relevancy of the sense. To determine if electromagnetic sensory perception could be useful as a guidance mechanism at Iroquois Dam, researchers need to determine if outmigrating eels respond consistently and predictably to electromagnetic fields in a quasi-natural environment. Do they orient or swim toward a particular direction in an electromagnetic field? Is this directionality modified by the strength or intensity of the field or by hydrodynamic conditions? Experiments to answer these questions will be difficult to design due to the large size of out-migrating eels and their natural swimming behavior (e.g., high speed, large vertical excursions). Additional research to identify the precise molecular, neural, and physiological basis of detection also would be valuable.

4.9.2 Induced Flows

A thorough understanding of the existing hydraulic patterns near and immediately upstream of Iroquois Dam is essential for assessing the potential for using manipulated flows to guide eels to collection points. This background information about hydraulic patterns will be essential for evaluating the utility of any candidate attractant or repellent. Eels may now be following specific hydraulic patterns that could be used to advantage for collecting them (e.g., the Bonneville Dam Corner Collector for salmon smolts). Field telemetry research at the Huntly Power Station in New Zealand, where vanes placed in the Waikato River to deflect sediment coincidentally appear to deflect eels, may be especially fruitful for determining the utility of passively altered flows for guiding American eels at Iroquois Dam; however, the species are different. A field study at a site on the St. Lawrence using passive vanes or active pumps and eels equipped with transmitters could test the ability of naturally migrating American eels in this system to detect and follow induced flows. Guidance tests in an experimental flume using a range of flow velocities, turbulence, and flow directions and video observation of American eels would be useful as an intermediate between laboratory and field testing.

4.9.3 Olfactory Detection of Attractant and Repellent Chemicals

Exploration of chemical attractants and repellents represents a fascinating direction for further research. Controlled experiments are needed to determine unequivocally if chemical extracts isolated from silver eels function as attractants or repellents. If definitive responses can be measured, then the tissue source(s) and routes of excretion of the chemicals involved should be identified. For some species, specific chemical attractants have been linked with specific behaviors, and the threshold concentrations of detection and response are well known for those species. Most literature suggests, however, that each species is likely to have a unique set of attractant pheromones and thresholds; consequently, more work on particular target species and life stages would be helpful. Well designed and controlled experiments with species such as sea lamprey, goldfish, Crucian carp, and some species of *Anguilla* are good models for similar studies of the American eel.

Similar research is needed concerning the alarm cues provided by pheromones. The most advanced research on this topic has identified extracts from conspecifics, heterospecifics, and predators that repel fish, but little is known about the chemical identity of those compounds. The chemical structure of specific repellents must be elucidated if they are to be used efficiently on a large spatial scale in a natural setting. The thresholds of detection and behavioral response for particular species and life stages to specific cues also require further study. If an alarm pheromone can repel outmigrating eels from half of a stream, then the probability that they would enter a passage could be increased dramatically. Initially, two questions need to be examined. First, do outmigrating eels respond to skin extracts of conspecifics? Second, do outmigrating eels respond to skin extracts of other fish species or to the compounds suspected to function as alarm cues in other fish species? If initial tests indicate that these chemicals repel eels, then more intensive effort should be focused on identifying the actual structures of the alarm substances.

Effective research on the utility of chemical attractants and repellents for guiding eels requires controlled experiments performed in a natural or semi-natural setting. Any candidate compounds would need to be tested under the hydrodynamic conditions present naturally at Iroquois Dam because flow rate, velocity, and characteristics of the candidate compound (e.g., molecular weight, density, viscosity, etc.) will affect the depth, width, and overall spatial distribution of filaments or eddies containing the compound. Such research would yield valuable information about whether an induced response to targeted cues is possible in the field.

4.9.4 Multiple-cue Recognition and Response

Most studies to date have examined neurological detection of or behavioral responses to individual cues. In their natural environments, however, fish sense a whole array of environmental cues simultaneously and integrate all of this information to make decisions. Once researchers have identified a leading attractant or repellent for guiding eels, further research to explore response to the leading candidate in the context of multiple environmental cues would provide a more biologically realistic set of conditions and allow researchers to investigate interactions between cues. Studies to explore multiple-cue recognition have the potential to result in a more effective, multi-cue guidance system.

4.10 OVERVIEW

NYPA's request for proposals posed a number of questions regarding each of the technologies and specified that responses should be drawn from the review of findings. The following questions were those posed for the attractants and repellants technology category.

- **Are there regulatory, engineering, or environmental encumbrances that would preclude deployment of attractants or repellents at Iroquois Dam?**

Regulations of organizations such as the IJC and the U.S. Army Corps of Engineers could preclude or require regulatory approval of placement of structures in the river that would be required to deploy any of the behavioral stimuli discussed (e.g., devices for inducing flows; wires, cables, or screens for an electrical field). Any such installations would pose engineering challenges due to the large scale of the river and the high water velocities. Any installed structure would be subject to fouling by floating debris, particularly submerged aquatic vegetation, which could interfere with the performance of the device. Approval from environmental agencies (e.g., USEPA) probably would be required to release chemicals; if chemical cues identified could be demonstrated to be highly specific and effective at small concentrations, such attributes would favor regulatory approval. However, the literature review identified few instances of chemical cues with such a narrow range of effects.

- **In a general sense, what are the prospects that attractants/repellents can be used to guide eels to a collection facility on the St. Lawrence River in the vicinity of Iroquois Dam?**

Given the hydraulic conditions and size of the St. Lawrence River at Iroquois Dam and the fact that outmigrating eels move rapidly past that location throughout the water column, the application of any of the attractant or repellant technologies would appear unlikely to be feasible. Extensive research, both laboratory and field, would be required before any of the technologies could even be further evaluated for their applicability.

- **For olfactory attractants/repellents, what chemicals and in what concentrations would be most appropriate based on current research?**

Insufficient information exists to answer this question for the purpose of guiding eels at Iroquois Dam. Further research using individuals from natural populations of outmigrating American eels in the silver phase would be required to identify particular compounds and concentrations that might be effective for guiding the movements of eels in the vicinity of Iroquois Dam. Most research on this topic has focused on European eels in the glass phase. Tables 4-1 and 4-2 summarize the compounds and concentrations that have been identified to be attractants or repellents for European glass eels.

Table 4-1. Potential chemical attractants

Concentration	Compound	Species/ Phase Tested	Study Type	Reference
10^{-9} to 10^{-13} mg/l*	2-methyl-3-methoxypyrazine; 2-isobutyl-3-methoxypyrazine; 4-methylthiazole; 4-isopropyl-7-methylcyclohexathiazole; 1,2,2,6-tetramethylcyclohexanol; 1-ethyl-2,2,6-trimethylcyclohexanol; (L) and (D) 2-methylfenchol.	European glass eel	Behavioral	Sola 1995
10^{-9} M or greater	D-alanine, and β-alanine	European glass eel	Behavioral	Sola and Tongiorgi 1998
10^{-7} M or greater	D-glutamine, D-asparagine, D-glutamic acid	European glass eel	Behavioral	Sola and Tongiorgi 1998
Below 10^{-10} M	glycocholate, taurodeoxycholate, taurine, taurocholate, cholate, deoxycholate, glycochenodeoxycholate and taurochenodeoxycholate	European glass eel	Behavioral	Sola and Tosi 1993
Further research needed to determine	Conspecific skin extracts, pheromones	Further research needed		

* A concentration measured in mg/l can be converted to M by dividing the number of milligrams per liter by the number of milligrams in 1 gram (i.e., by 1000) to determine the number of grams per liter and dividing that quotient by the molar mass (g/mole) of the substance to yield moles per liter or M. Sola (1995) did not report the molar mass of the subject compound.

Table 4-2. Potential chemical repellents.

Concentration	Compound	Species/Phase Tested	Type of Study	Reference
10^{-10} M or greater	taurocholate, cholate, deoxycholate, glycochenodeoxycholate and taurochenodeoxycholate	European glass eel	Behavioral	Sola and Tosi 1993
Further research needed to determine	Predator alarm chemicals	Further research needed to		

- **For electromagnetic attractants/repellents, what magnetic field strength and intensity would be most appropriate based on current research?**

Preliminary information suggests that altering the electromagnetic field or field intensity could repel eels; however, no information about the range of detection and response has been reported for American eels in the silver phase, and very little is known about physiological or behavioral responses of eels in general to this stimulus. The heart rates of Japanese eels slow in response to a magnetic field in the range of 12,663 to 192,473 n. American eel elvers can be compelled to change direction by changing the electric current density from 10^{-2} µA/cm^2 to 10^2 µA/cm^2. There are no studies in which electromagnetic fields have been manipulated to alter the behavior of eels in the field. Thus, the question posed cannot currently be answered, and whether this technology could be used to guide movements of outmigrating eels in any natural environment is not known.

- **For directed flows, what flow rate or range of flow rates would be most appropriate based on current research?**

There are no studies documenting the response of outmigrating eels to induced flow in any kind of river system; as a result, there is insufficient information available to answer this question. In theory, a path of currents with mildly turbulent features of riverine flow could be induced, either actively or passively, to attract and guide fish using their normal orientation mechanisms and hydraulic entrainment in the flow. Whether outmigrating eels would respond in this manner is unknown; however, circumstantial evidence (i.e., impingement of eels on intake screens) suggests that passive devices such as vanes can guide outmigrating eels toward an intake (J. Boubée, pers. comm. 2007).

- **Would habituation be a problem for electromagnetic, chemical or water flow cues? Can habituation be prevented or minimized and if so, how?**

Habituation refers to the reduced effectiveness of any attractant or repellent following a prolonged exposure to the stimulus. In theory, habituation may hinder a fish's ability to respond to an attractant or repellent. The sensory organs of fish often become habituated when continuously exposed to stimuli in laboratory conditions. In natural habitats, fish are not continuously exposed to odorant chemicals because they disperse into filaments or eddies. Field studies indicated that sea lamprey continue to respond to odorants applied in river for hours. Habituation of eels or any other fish species to electromagnetic fields has not been documented, and, thus, whether it would occur is not known. Habituation to induced flows is unlikely because the attractant (guidance) feature is a natural characteristic of the environment in which the fish lives and also complex in its physical characteristics.

- **How would natural flow conditions affect the efficacy of chemical cues applied to guide movements of a downstream migrating eel? How could these issues be resolved or minimized?**

Attempting to use a dissolved substance to elicit a response in outmigrating eels will pose a challenge mainly because the behavioral responses of downstream-migrating fish to odorants have been studied less than those of upstream-migrating fish. In theory, odorants could be equally effective in guiding the movement of fish, regardless of the direction of migration. Chemical cues are considered to be"directionless" and only to induce fish to react to a directional cue, such as water flow. As fish move downstream, the chemical cue is carried downstream and dispersed by natural patterns of flow; therefore, a downstream migrant would be likely to encounter the cue at some point. The question is whether that encounter would ellicit directed movement of the migrant. Eels use the entire water column during migration; consequently, the time during which the fish is exposed to the chemical and the concentration of the chemical to which the fish is exposed may be difficult to control. Time of exposure and concentration of the chemical will bear directly on the ability of the fish to detect and respond to the chemical; however, fish may not have to detect an odorant continuously to be guided. After its release into the water column, a chemical could be expected to disperse rapidly into eddies and filaments and to b distributed randomly. Upon detection of intermittent filaments of an odorant, fish may be able to decide whether to follow the direction of flow or to increase their movement in a direction that deviates from the direction of the water current. Intermittent application of odorants, therefore, could significantly bias the path of fish moving downstream. Odorants could be applied to guide eels into a path that is biased toward a particular side or section of the river near the dam. Appropriate levels of odorants could be maintained on one side of the river to repel fish to the other side, whereas fish on the opposite side of the river would already be on the desired path and would not need to be guided. American eels use the entire depth of the water column and the entire width of the river during migration (EPRI 2001). The distribution of a chemical, therefore, may have to be wide and deep enough to contact the target outmigrating eels.

- **What guidance efficiency would be expected for electromagnetic, chemical, and directed flows cues and under what conditions?**

The conclusion of this review is that deployment of any of the attractant or repellant technologies evaluated in this section is not feasible, and thus the potential guidance efficiency of their deployment cannot be assessed. Few laboratory studies have collected information that is directly relevant to NYPA's question, and the results of the few potentially relevant laboratory and field studies have not be tested through replication. Odorants and induced flow, however, seem to be the most promising of the guidance methods evaluated in this review based on the information available to date. Section 4.9 identifies research needs and priorities that would support an assessment of the feasibility and effectiveness of these methods.

5.0 RESPONSES OF EELS TO INFRASOUND

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5.1 BACKGROUND AND OVERVIEW OF AQUATIC BIOACOUSTICS

Fish, like other vertebrates, have a variety of different sensory systems that enable them to glean information about the world around them. In fishes, the "classic" senses of smell, taste, touch, sight, and hearing are accompanied by an ability to detect the hydrodynamic motions of water.[12] In addition, a number of fish species are able to detect electric fields, and there is evidence that some fishes also may be able to detect magnetic fields. Each sensory system provides information about certain types of signals, and all of this information is used to inform the animal about the environment around it.

Although each of the sensory systems may have some overlap in providing a fish with information about a particular stimulus (e.g., an animal might see and hear a predator), one or another sensory system may be most appropriate to serve an animal in a particular situation. Thus, vision is often most useful when a fish is close to the source of the signal, in daylight, and when the water is clear. However, vision does not work well at night, or in deep waters. Chemical signals can be highly specific (e.g., a particular pheromone used to indicate danger). However, chemical signals travel slowly in still water and diffusion depends on currents and so they are generally only effective over short distances. Acoustic signals in water travel very rapidly, travel great distances without substantially attenuating in open water, are highly directional, and thus provide the potential for two animals that are some distance apart to communicate quickly.

Because sound is potentially such a good source of information, fishes have evolved several mechanisms to detect acoustic signals, and many species use sound for communication (e.g., mating, territorial behavior). Indeed, fishes have two systems for detection of sound and hydrodynamic signals (water motion). The ear functions very much like that of other vertebrates. The lateral line, in contrast, is only found in fish and consists of a series of receptors along the body of the fish. Together, the ear and lateral line are known as the octavolateralis system.

5.1.1 Sound in Water

Before sound is discussed, it is important to define a few terms. Sound levels are always referenced relative to some arbitrary value. In water, this value is relative to 1 μPa

[12] This sense, which involves the lateral line, has been called "svenning" in honor of Professor Sven Dijkgraaf, one of the pioneers in the study of the lateral line (Dijkgraaf 1963) by Platt et al. (1989).

(microPascal).[13] Sound is also referred to using terms such as sonic signals, infrasound, and ultrasound. It should be noted that these terms are rather arbitrary in their definition. For the purposes of this report, the "sonic" range of hearing is defined as being from 50 to about 10,000 Hz (hertz = cycles/second), whereas ultrasound refers to signals above 10 kHz (kilohertz) and infrasound refers to signals below about 50 Hz. The hearing range of most fish species ranges from somewhat below 50 Hz[14] to about 1,000 Hz, whereas fish with specializations in the hearing pathway may hear from below 50 Hz to 3-7 kHz.

The basic principles of sound in water are the same as sound in air.[15] Any sound source produces both pressure waves and actual motion of the medium particles. However, whereas in air the actual particle motion attenuates very rapidly and is often inconsequential even a few centimeters from a sound source, particle motion propagates much further in water due to the much greater density of water than air. One therefore often sees reference to the "acoustic near field" and the "acoustic far field" in the literature on fish hearing, with the former referring to the particle motion component of the sound and the latter the pressure. Although there is often the misconception that the near-field component is only present near the source, this is not true. Indeed, all propagating sound in water has both pressure and particle motion components. Up to a distance from the source often defined as the point at a distance of wavelength of the sound divided by 2 pi ($\lambda/2\pi$), particle motion is considerable and decreases as the square or cube of the distance from the source, whereas pressure decreases by the distance (1/r). After this point, particle motion is generally relative small, and it decreases proportionally with pressure. For a 500-Hz signal, this point is about 0.5 m from the source.[16]

The issue with regard to near and far field is that fish are able to detect both pressure and particle motion, whereas terrestrial vertebrates generally only detect pressure. Fish directly detect particle motion with the inner ear, and they detect pressure with the swim bladder or other bubble of air, which then "reradiates" or resends the signal to the inner ear as near-field particle motion. Note, the ear can only detect particle motion directly and it needs the air bubble to produce particle motion from the pressure component of the signal.

If a fish is able to only detect particle motion, it is only sensitive to sounds when the source is nearby due to the substantial attenuation of the particle motion signal as it propagates away from the sound source. As the signal level gets lower (further from the source), the signal gets below the minimum level detectable by the ear (the threshold). Fish that detect both particle motion and pressure generally are able to detect lower intensity sounds than fish that only detect motion because the pressure component of the signal attenuates much less over distance than does the motion.

[13] In the older literature, the reference value is 1 microbar (μbar). To convert values from 1 μbar to 1 μPa, add 100 dB. Thus, a signal that has a level of -30 dB re 1 μbar in the older literature is +70 dB re 1 μPa in the more recent literature.
[14] See discussion related to Figure 5-1 for an explanation of this point.
[15] For discussions on underwater sound, see Rogers and Cox 1988; Kalmijn 1988, 1989.
[16] The wavelength of a sound in water is about 1,500 m/s (it varies depending on salinity, depth, and temperature). The wavelength is defined as 1,500/frequency, which means that for a 500-Hz signal, the wavelength is 3 m. For a 100-Hz signal, the wavelength is 15 m and the near-field transition point would be 15/6.28 = ~2.8 m.

5.1.2 Why Do Fish Hear?

Decades of research have shown that many fish species produce sound and use it for communication (e.g., Zelick et al. 1999 for a review of fish sounds and fish acoustic communication). However, it is likely that the majority of species does not make sounds or use sound for intraspecific communication (e.g., goldfish). Yet all species are likely to obtain a good deal of information about their environment from the overall acoustic milieu (e.g., Bregman 1990; Fay and Popper 2000) just as humans learn a good deal about a dark room from the sounds that it emits or from the sounds in the room itself. Similarly, it is likely that fishes (and all animals) obtain information about their environment from sounds that might include waves breaking on the shore, currents moving across the reef, or other diverse sources. Indeed, the importance of this ability is seen when one realizes that if fish had to depend on sight alone to learn what is going on in the world around them, they would have very limited information about potential predators and prey and of their "world," particularly at night or in murky waters. Again, using a human analogy, sound provides us with information from the whole world around us, including the space that is not within our visual field, and a similar use of sound is likely for fish.

Because fishes live in a naturally "noisy" environment (Myrberg 1980) and they have probably evolved to gain environmental information from this noise, anything that hampers the ability to detect biologically relevant signals will have a potentially deleterious effect on the survival of fish. A more comprehensive review of fish hearing is presented in Appendix A.

5.1.3 Hearing Range and Sensitivity

The lowest sounds a fish can hear at any frequency, often called the hearing threshold,[17] have been determined for perhaps 100 species of the more than 29,000 living fish species. Figure 5-1 shows hearing sensitivity of several species to illustrate the range and intensities of sound that different species can detect. By way of comparison, a young normal human can generally detect sounds from 20 Hz to almost 20,000 Hz, which means that humans have a much wider hearing range than most fishes.

The goldfish (*Carassius auratus*), one of the most sensitive of all fish species, can detect sounds from below 50 Hz to about 3,000 Hz (see Jacobs and Tavolga 1967; data in Fay 1988). In contrast, other species such as Atlantic cod (*Gadus morhua*) and salmonids (represented by *Salmo* in Figure 5-1) only hear to around 500-600 Hz and their sensitivity (lowest sound they can hear or threshold) is much poorer than that of the goldfish. Fish that hear particularly well, such as the goldfish, are called “hearing specialists” because they have special structures, described below, that enhance their hearing capabilities by allowing them to effectively detect the pressure

[17] Although the threshold is an important concept and it is used throughout the literature, it needs to be noted that a threshold is a statistical concept that is based on the lowest value of a signal that is detectable some percentage of the time. Very often, for fish, hearing thresholds are the lowest levels at which a fish will detect a sound 50% of the time. In other words, whereas a fish will detect a particular signal 50% of the time, it will not detect the same signal 50% of the time. Variation in threshold is well known for all animals and for all senses. It often reflects momentary changes in the detecting structure, in the motivation of the animal, and innumerable other factors.

component of the sound field. Other fishes, such as salmon, are often called "hearing generalists" because they have no special adaptation for hearing and primarily detect the particle motion component of the sound field. Although we have data for a small proportion of all of the extant fish species, it appears that most fish fall into the hearing generalist category, and this certainly includes most of the more common food fishes such as haddock, trout, and salmon as well as eels.[18]

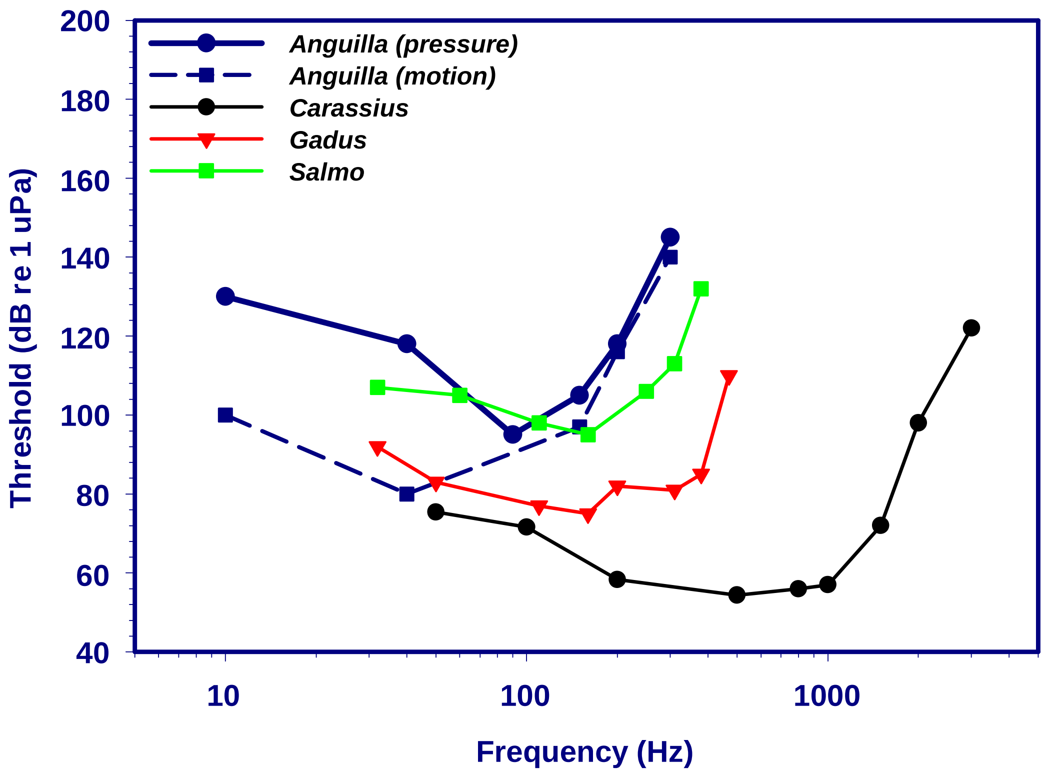

Figure 5-1. Hearing thresholds for select fish species. Note that the data for *Anguilla* represent thresholds in the pressure mode (solid line) and motion mode (dashed line).[19]

[18] Direct comparison of hearing data for different species is often problematic. Much of the data in the older literature (Fay 1988) were reported as pressure thresholds; however, we now know that many species, and particularly hearing generalists, are likely to primarily detect the particle motion component of a sound field. This means that data for such fish are likely incorrect because the investigators did not calibrate particle motion or necessarily present a substantial particle motion field. See a fuller discussion of this issue in Popper et al. 2003.

[19] Although it appears that *Anguilla* is the only genus to detect sounds below 30 Hz, some or all of the other species tested at 10 Hz probably would show broader hearing capabilities as well. Indeed, salmon (*Salmo*), Atlantic cod (Gadus), and several other species have been shown to detect sounds to below 1 Hz (Section 5.3.1). Goldfish (*Carassius*) are included in the graph to represent hearing range and lower thresholds (sensitivity) for hearing specialists versus the other species that are considered hearing generalists. Data for *Anguilla* are approximations of data from Jerko et al (1989) shown in Figure 5-5 (Section 5.4.1) because it was necessary to determine threshold values by extrapolation from Jerko's data.

Some fish are able to detect sounds well below the hearing range of humans (Section 5.3.1). Although only a few species have been studied (Popper et al. 2003), it appears that infrasound signals as low as 20 Hz are detected in taxonomically diverse species including eels, salmonids, and perch. It is not clear yet if infrasound detection is more broadly found among different fish species and/or whether such detection is widely found.

In addition to detecting sounds, the fish species studied to date, like humans, are able to discriminate between sounds, determine the position of a sound source around them (called sound source localization), and detect signals in the presence of other (background) sounds (Fay and Megela Simmons 1999; Popper et al. 2003). Most importantly, studies of the detection of signals in the presence of noise (such as might occur in the water near a dam) show that fish hearing is affected by the presence of background noise that is in the same general frequency band as the biologically relevant sound. In other words, if a fish has a particular threshold for a pure tone in quiet and a background noise that contains energy in the same frequency range is introduced, this will decrease the detection of the biologically relevant signal. In effect, the threshold for the biologically relevant signal will become poorer.

The significance of this finding is that if background noise is increased, such as a result of human-generated (anthropogenic) sources, this may possibly make it harder for a fish to detect the biologically relevant sounds that it needs to survive. Similarly, if there is a strong background noise near a dam or other human-made object, any sound being used to modify fish behavior has to be louder to be detected by the fish and thus potentially effective in eliciting a response from the fish than if the noise were not present.

5.2 HOW DO FISH DETECT SOUND?

5.2.1 The Ear

Although fish have no external structures for hearing such as the human pinna, they do have an inner ear that is similar in structure and function to the inner ear of terrestrial vertebrates (Figure 5-2). Unlike terrestrial vertebrates, however, which require external structures to gather sound waves and change the impedance to match that of the fluid-filled inner ear, sound gets directly to the fish ear since the fish's body is the same density as the water. As a consequence, the fish ear and body move with the sound field. Although this might result in the fish not detecting the sound, the ear also contains very dense structures, the otoliths, that move at a different amplitude and phase from the rest of the body. This provides the mechanism by which fish hear.

The ear of a fish (Figure 5-2) has three semicircular canals that are involved in determining the angular movements of the fish. The ear also has three otolith organs, the saccule, lagena, and utricle,that are involved in both determining the position of the fish relative to gravity and detecting sound. Each of the otolith organs contains an otolith (a dense calcareous structure) that lies in close proximity to a sensory epithelium that contains specialized sensory cells that can detect the motion of the otolith (Popper et al. 2003).

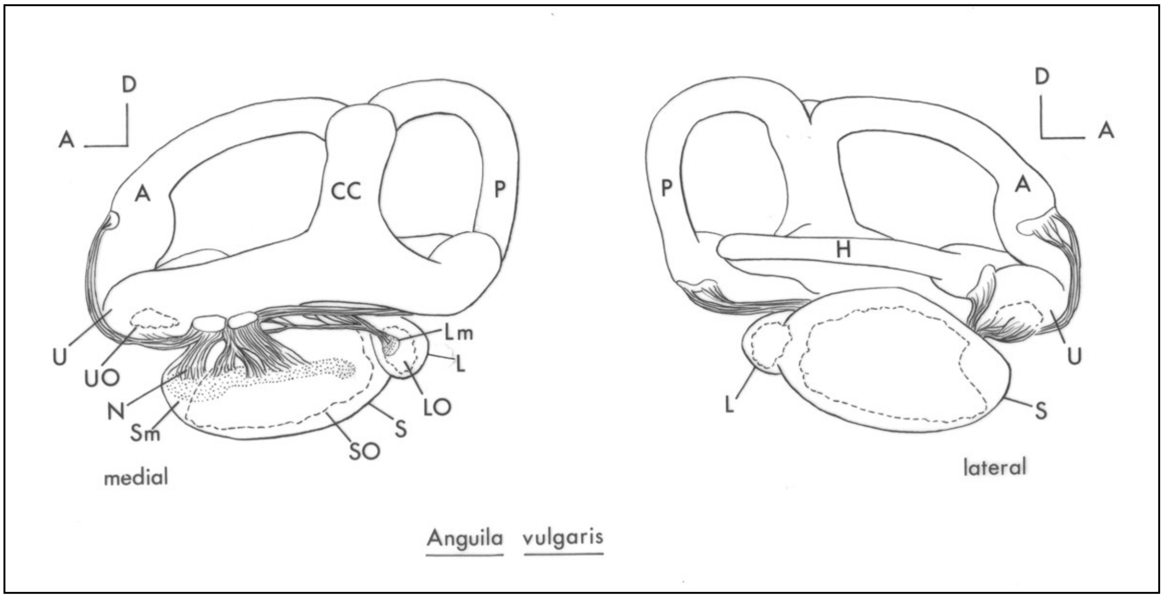

Figure 5-2. The ear of *Anguilla anguilla*. The ear of the European freshwater eel formerly known as *Anguilla vulgaris*.[20] . A is anterior and D is dorsal. The left side shows a medial view of the right ear while the right side shows a lateral view of the same ear. Each ear has three semicircular canals – the anterior (A), horizontal (H), and posterior (P), and these come together in a common crus commune (CC). There are three otolithic organs, the lagena (L), saccule (S), and utricle (U). Each otolithic organ is innervated by a branch of the eighth cranial nerve (N). Lm, lagena sensory epithelium (macula); LO, lagenar otolith; Sm, saccular macula; SO, saccular otolith; UO, utricular otolith. (Source: Retzius 1881)

5.2.2 Ancillary Structures for Hearing Specializations

All species of fish detect sounds by detecting relative motion between the otoliths and the sensory cells in the inner ear. However, some fishes, and most notably the hearing specialists, also detect sounds using the air-filled swim bladder in the abdominal cavity (Figure 5-3).

The swim bladder, because it is filled with air, is also of very different density than the rest of the fish body. Thus, in the presence of sound, the gas starts to vibrate. This is capable of reradiating sound to the ear and is potentially able to stimulate the inner ear by moving the otolith relative to the sensory epithelium. However, in hearing generalists, the swim bladder is quite far from the ear (Figure 5-3), and any reradiated sound attenuates a great deal before it reaches the ear. Thus, these species probably do not detect these sounds very well.

[20] The correct naming of this fish as *Anguilla anguilla* was found on www.fishbase.org.

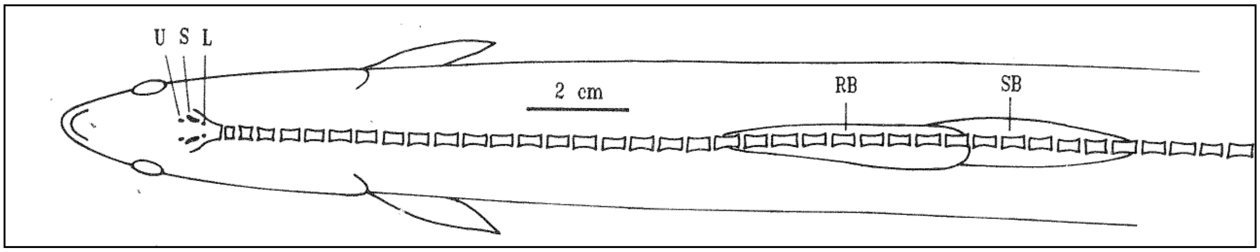

Figure 5-3. Swim bladder in European eel. Dorsal view of an *Anguilla* based on a radiograph of a live fish. The position of the swim bladder (RB and SB, the swim bladder is in two parts) is about 10-12 cm from the ear in a 50-cm fish. Anterior is to the left. U, utricle; S, saccule; L, lagena. (Source: Jerko et al. 1989.)

5.3 INFRASOUND

5.3.1 Infrasound Detection Capabilities

Detection of sound that is lower in frequency than 30 Hz was not investigated until fairly recently because most laboratory sound sources were unable to produce undistorted tones below 20-30 Hz. In addition, most earlier measures of fish hearing (audiograms as in Figure 5-1) indicated a steadily declining sensitivity toward lower frequencies (Fay 1988), suggesting that fish would not detect low frequencies. However, often the problem with measuring lower frequency hearing (e.g., below 50 or 100 Hz) was simply that the sound sources available (underwater loud speakers) were not capable of producing lower frequency sounds or the acoustics of the tanks in which the studies were conducted prevented lower frequency sounds from being effectively used.

Infrasound sensitivity in fish was first tested in the Atlantic cod (*Gadus morhua*) using an acoustic tube in order to have a highly controlled sound field (Sand and Karlsen 1986). The purpose of the study was to understand whether fish could, indeed, detect sounds lower than 50 or 100 Hz. The investigators demonstrated that Atlantic cod could detect sounds down to about 0.1 Hz and that the animal was sensitive to particle motion of the sound field and not to pressure. In a later study, Karlsen (1992a) used the same cardiac conditioning method to measure infrasound in the plaice (*Pleuronectes platessa*; Figure 5-4), a flatfish lacking a swim bladder, and showed similar thresholds to those of the Atlantic cod. In the plaice, the threshold at 0.1 Hz is about 4×10^{-5} ms^{-2} (Karlsen 1992a), which corresponds to the particle motion thresholds previously determined for this species between 30 and 150 Hz (Chapman and Sand 1974; Figure 5-4). Karlsen (1992a) also concluded that the receiving organ had to be the ear because the thresholds reported for plaice were well below the known sensitivity of the lateral line.

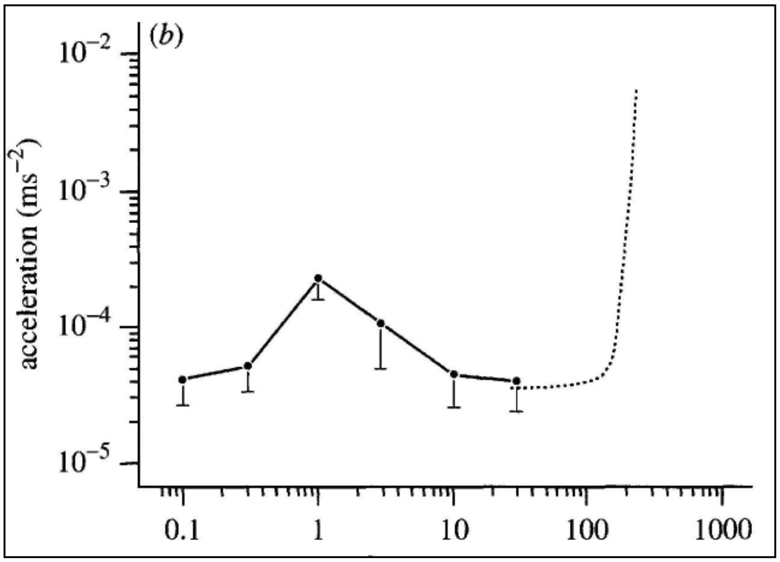

Figure 5-4. Hearing sensitivity in the plaice. The solid line shows cardiac conditioning data from Karlsen (1992a) with mean and standard deviation (n = 6). The dashed line shows comparable higher frequency hearing data from the same species from Chapman and Sand (1974). (Source: Sand and Karlsen 2000).

The acute sensitivity of at least some species of fish to infrasound may theoretically provide the animals with a wide range of information about the environment. An obvious potential use for this sensitivity is detection of moving objects in the surroundings where infrasound could be important in, for instance, courtship and prey-predator interactions. Juvenile salmonids display strong avoidance reactions to infrasound (Knudsen et al. 1992, 1997), and it is reasonable to suggest that such behavior has evolved as a protection against predators.

More recently, Sand and Karlsen (2000) proposed the hypothesis that fish may also use the ambient infrasounds in the ocean, which are produced by waves, tides, and other large-scale motions, for orientation during migration. This would be in the form of an inertial guidance system where the fish detect surface waves and other large-scale infrasound motions as part of their system to detect linear acceleration and in this way migrate long distances.

It has been suggested in all studies of infrasound that the detection system is the inner ear. This conclusion is based on experiments that reportedly temporarily interfered with detection by the lateral line and then went on to demonstrate that the infrasound-detecting species continued to respond to the sound. However, one concern with regard to this conclusion is that blockage of the lateral line was not done in every species tested for infrasound detection, and thus it is possible that although some species may use the ear, others may not. Although Karlsen and Sand (1987) showed in perch that the method they used will block both canal and superficial neuromasts in that species, the same approach will not work in salt water, and so it is not yet possible to test the relative contributions of the ear and lateral line in marine species.

A second issue relates to the distance at which infrasound is detected. Although there is no doubt that the signals are detectable by the species studied, the responses are always when fish are well within the acoustic near field of the sound source, and so it is likely that the response is to the particle motion component of the sound field. It needs to be kept in mind, however, that the lateral line is also responsive to such signals but only when the fish is within several meters of the sound source. Thus, without conclusive evidence that the whole lateral line has been "deactivated" experimentally, it can not be conclusively stated that the infrasound detector is the ear.

5.3.2 Use of Infrasound to Affect Behavior of Atlantic Salmon

The first species tested for infrasound detection and then tested to determine if infrasound could alter behavior was the Atlantic salmon (*Salmo salar*) by Knudsen et al. (1992). The investigators demonstrated that wild-caught and hatchery-raised salmon could detect infrasound and would show an "awareness response" at the sound onset, consisting of a decreased heart rate and opercular movements (respiration rate). The response was greater to a 10-Hz signal than to a 150-Hz signal. The authors concluded that this makes sense because predators are likely to produce infrasound signals (from swimming motions; see Moulton 1963), and so it would be advantageous for a fish to be more responsive to such signals than to higher frequencies.

In addition, the investigators placed salmon parr in a concrete pool with the infrasound source and found that fish would swim away from a 10-Hz signal. The authors concluded that the fish would respond to, and swim from, 10 Hz when the received signal was at least 10–15 dB above the animal's "awareness threshold" for that signal (equivalent to at least a particle acceleration of 10^{-2} m^{-2}). Interestingly, stimuli at 150 Hz did not evoke the same response even when the received signal was more than 30 dB above the "awareness threshold."

Subsequently, Knudsen et al. (1994) did experiments to determine if sounds could divert the movement of young wild Atlantic salmon smolt in a channel. They found that signals of 150 Hz, even when the received level was 114 dB above the threshold for the fish, did not affect fish behavior. However, they found a very statistically significant increase in fish diversion when the received level of a 10-Hz infrasound was 10 dB above the awareness threshold for that frequency (Knudsen et al. 1992), a distance of up to 3 m from the source. The authors were also careful to note that the diversion experiment was done in a small stream and that it is not known whether infrasound diversion would occur at larger sites. This issue is particularly relevant because the received sound levels at the fish had to be quite high and the fish had to be within 3 m of the infrasound source for it to be effective.

Most recently, Knudsen et al. (1997) investigated the effects of the same 10-Hz infrasound source used in Norway on the response in juvenile spring chinook salmon *Oncorhynchus tshawytscha* and rainbow trout *O. mykiss*. Fish were tested in a 3-m-diameter circular tank with a water depth of 1 m. The sound source was turned on for 5 s when the fish was within 1 m of the source. The authors found that during the first tests with each fish group, the fish always showed a strong flight response to the sound. However, after three to four tests with the same fish, the fish would primarily just swim away as far as possible from the source. This avoidance response did not habituate even after 20 trials.[21] In all cases, the fish avoided being within 1 m of the source for as long as it was on. The results of this study, albeit being in a relatively small tank, suggest that salmon may avoid a very intense infrasound source if they are close to it. However, these results also suggest that such a source is only effective over a very small area. Thus, diverting fish from a larger area would require many sources over the whole area being protected. A single large source is probably highly impractical due to the intensity of the signal that would be needed to exceed the awareness threshold at any significant distance from the source.

5.4 EELS AND HEARING

5.4.1 Sound Detection by Eels

Very little is known about sound detection by eels. The only data on the structure of the ear in *Anguilla* come from a set of classic and beautifully done drawings from Retzius (1881) (Figure 5-2). The ear as described by Retzius is quite typical of that of other fishes as described earlier. The only other data on the structure of the ear in any eel are for a member of the genus *Gymnothrax* (Popper 1979). Although *Anguilla* and *Gymnothorax* are in different suborders of the Anguilliformes, the gross structure of the ears is very similar. Based on the *Gymnothorax* data, the structure of the sensory cells of the ear involved in hearing in eels is likely to be similar to that found in other species.

The only study on eel hearing was by Jerko et al. (1989) in which the animals were tested in a specially designed standing-wave tube that enabled the investigators to measure sensitivity to both pressure and particle motion. Jerko et al (1989) presented the data for *Anguilla* along with several other species. The hearing range of *Anguilla* is from about 10 Hz to about 300 Hz, which is generally greater than for other species. It is important to note in interpreting these data one cannot suggest that *Anguilla* hear lower frequencies than other species. This is because of the species shown, only *Anguilla* were tested at this low frequency. Indeed, because it is now known that at least several other species, including salmonids and perch (Karlsen, 1992b), can detect infrasound (below 30 Hz; Section 5.3.1), it is possible that if their hearing were measured at 10 Hz, they would hear that frequency as well.

The actual data from Jerko et al. (1989) are shown in Figure 5-5. There are several important points to be made about these data. First, data were determined in a standing-wave tube in which the investigators were able to test hearing sensitivity, separately, to both pressure and particle motion.

[21] Note that Mueller et al. (1998) found infrasound habituation in several salmonid species.

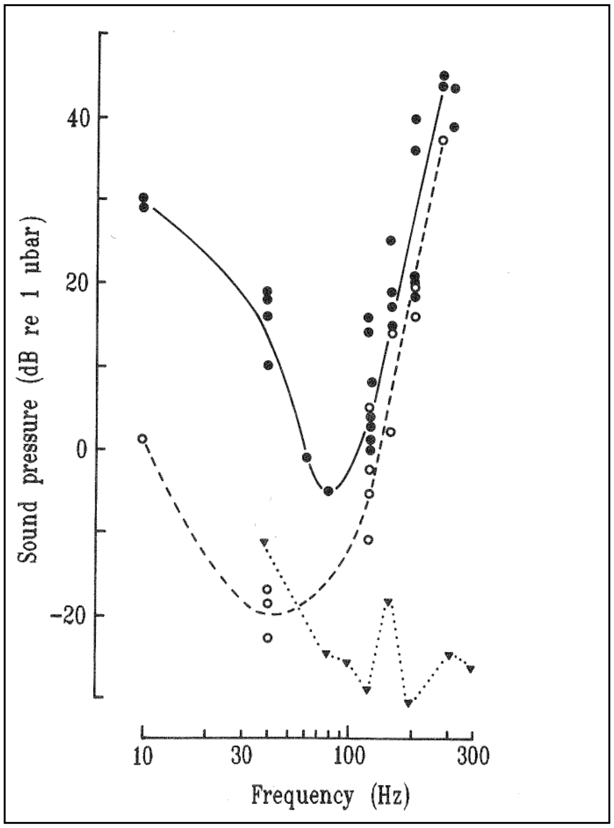

Figure 5-5. Sound pressure thresholds of *Anguilla anguilla*. Thresholds were measured in a standing-wave tube operating in pressure mode (●) and displacement mode (○). Background noise (▼), measured in one-third octave bands, was well below threshold. It should be noted that the values given in this figure are in terms of 1µbar, whereas data presented now are in terms of 1 µPa; to compare these values to more recent data, add 100 dB. (Source: Jerko et al. 1989).

Second, the investigators measured the noise levels in the tank to ensure that background noise did not hamper detection of the test signals. In all cases, the background noise was sufficiently low so as not to be a factor in the data presented.

Third, the results show that *Anguilla* can detect both pressure and particle motion signals. But the authors conclude that below around 100 Hz, the animals were responding to the particle motion component of the sound field, and it is likely that at frequencies below 100 Hz, this is the major stimulus used by the fish. Above 100 Hz, the thresholds are about the same for both pressure and particle motion, and the authors concluded that from about 100-300 Hz the fish are primarily responsive to the pressure component of the signal.

As discussed earlier, it is likely that hearing generalists, those species without a special connection between the swim bladder (the pressure receptor) and the inner ear, are primarily detectors of particle motion. In contrast, hearing specialists, those with connections between an air bubble and the ear, are primarily detectors of pressure. Jerko et al. (1989) concluded that *Anguilla* detects both particle motion and pressure at different frequencies and that some mechanisms are found in this species to couple the swim bladder motion to the ear in spite of a considerable distance between the anterior end of the swim bladder and the ear (Figure 5-3).

Finally, it should be noted that the pressure sensitivity of *Anguilla* is substantially poorer than that of other species studied (Figure 5-1). At the same time, it is hard to compare the particle motion data for *Anguilla* to that of other species because most other species were measured only for pressure sensitivity.[22]

5.4.2 Infrasound Detection by Eels

There has been only one study of infrasound detection by eels (Sand et al. 2000). This study involved both lab and field testing of the responses of the European eel *Anguilla anguilla* to an infrasound source. In the first part of the study, eels were placed in a standing-wave tube as had been done with several other species tested for infrasound sensitivity (e.g., plaice, Figure 5-4), and it was determined that the eels had about the same response thresholds to infrasound as other species.

In the second and more critical part of the study, the investigators examined the movement patterns of eels entering a narrow body of water in September and October 1997 using the infrasound device shown in Figure 5-6. The device was designed to be used in the field to produce an infrasound "fence" that could keep fish from going into unwanted areas. The device is able to generate a large near-field signal (i.e., particle motion) by using the movement of two symmetrical pistons in an air-filled cylinder with a 21-cm bore. The pistons are driven 180° out of phase by eccentric coupling to an electric motor (m in Figure 5-6), with a 5-cm peak-to-peak amplitude. The piston reaction forces are thus opposed, leading to vibration-free operation according to the investigators. The submergible infrasound source is operated freely suspended in the water mass. The signal emitted by the source was at 11.8 Hz and produced a particle acceleration that was about 0.01 ms^{-2} at a distance of 3 m.

The investigators placed a four-part net across the body of water and determined the distribution of the eels in the four net regions during emissions from the infrasound source compared to the distribution when there was no sound (control). In control experiments, the eels were trapped in equal numbers in all four parts of the net, whereas eels trapped during the sound exposure were, at a statistically significant level, in the net area furthest from the sound source.

Although the results from this experiment suggest that the eels moved away from the infrasound source, it must be noted that the distance moved was less than 10 m and that this work was done with silver eels. It is impossible to know from these studies whether the eels

[22] In a number of cases, such as the salmonids, it is likely that if the species had been tested for particle motion sensitivity in the same way as *Anguilla*, there would have been different low-frequency thresholds than those shown in Figure 5-1. However, calibration for particle motion is harder than that for pressure, and earlier investigators did not have such capabilities.

would have moved further from the source if the distance between the two riverbanks was greater than 10 m.

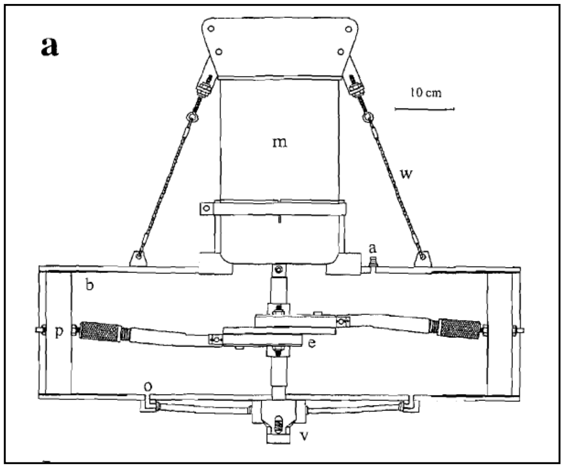

Figure 5-6. Infrasound source. Cross section of the design of the infrasound source used by the Norwegian group to test reactions of fish in the field to an infrasound signal: a, air inlet; b, bronze cylinder lining; e, eccentric disk; m, electric motor; o, air and water outlet; p, piston; v, one-way valve; and w, wire support. (Source: Sand et al. 2000).

5.5 USE OF OTHER SOUNDS TO CONTROL FISH BEHAVIOR

It is reasonable to consider using sound or water motions to control fish distribution in engineered environments because fish detect both sound pressure and hydrodynamic stimuli. The interest in having stimulus systems for control of free-ranging fish goes back several decades (Popper and Carlson 1998; Popper and Schilt 2008). The response of a fish or any animal to stimuli depends on many physiological, temporal, and environmental factors (Schilt and Norris 1997) such as sound, current, light, turbidity, and temperature. These may also include fish motivation and condition, hunger, and predation threat. The response may be specific not only to fish species but also to life stage, time of day and year, presence of predators, and countless other known and unknown variables. And because stimuli are presented against different backgrounds in different places, stimulus efficacy may be site specific. Habituation to a stimulus is also an important issue to consider in that if a fish is exposed to a specific stimulus for some period of time, the effectiveness of the stimulus may wane.

5.5.1 Fish Protection and Passage at Hydropower Dams and Other Industrial Sites

There is a history of successful and unsuccessful attempts at improving fish protection and passage at industrial facilities throughout the world (e.g., Haymes and Patrick 1986; Fletcher 1990; Jungwirth et al. 1998; Popper and Carlson 1998; Coutant 2001a; Pavlov et al. 2002;

Popper and Schilt 2008). In many cases, these efforts have attempted to use the natural responses of fish to signals in the environment (e.g., natural sounds).

Using fish ear- and lateral line-mediated behavioral responses to direct fish movement is appealing for several reasons (Schilt and Nestler 1997; Popper and Carlson 1998; Popper and Schilt 2008). However, attempts to reduce fish entrainment and impingement at industrial water intakes or to otherwise redistribute fish over long time periods using sound stimuli have largely proven to be unsuccessful (Popper and Carlson 1998). Positive results have been reported at one site (e.g., Hanson Environmental Inc., 1996; tests were conducted at a slough in California), but similar treatments do not work at other times and places (Ploskey et al. 2000). Unfortunately, in many studies involving sound and fish behavior, the stimulus and noise fields are poorly described if they are described at all.

Effective reductions of fish entrainment at power-generating sites have been reported for pneumatic guns (Haymes and Patrick 1986) and electronic sound sources (Hanson Environmental, Inc., 1996). Even in cases where a sound source is found to be efficacious at a given site, some sound-production systems, especially low-frequency impulse generators such as air and water “guns” and electric “sparkers” used in seismic exploration, there can be important dependability and (human) safety issues.

Finally, Patrick et al. (2000) reported that they did a short series of studies that demonstrated that a particular sound (indicated as being proprietary and so no information on its acoustic structure is available) did attract 70% of eels in a 5.5-m-diameter tank compared to control experiments where no sound was present. These tests were only done a few times with a few replicates of small immature eels as well as larger sized eels that might have been approaching maturity (no indication was given whether there was a better response of smaller or larger specimens). Clearly, this work holds some interest but would need considerable lab replication and extensive tests in the field to determine if there is any chance that sound could be used to attract young eels and thereby control their movement.

5.5.2 Use of Ultrasound to Control Fish Behavior

Although there generally has been little success in using sound to control fish behavior, one of the areas in which there has been considerable success has been the use of ultrasonic sound to keep herring in the subfamily Alosinae (family Cluepidae) from entering cooling-water intakes and large power plants. Ultrasonic sensitivity in an Alosinae herring (American shad, *Alosa sapidissima*) was discovered by Boyd Kynard when, in 1982, he was using ultrasonic (about 160-kHz) sonar to sample down-running (spent) adult American shad in a canal associated with Holyoke Dam on the Connecticut River, MA. Subsequent work at the site indicated that the sound field was effective at temporarily concentrating down-running adults but that the fish would finally pass through or perhaps under the sonar beam. Up-running (prespawning) shad were more successfully concentrated by the sound (Kynard and O’Leary 1990).

In 1989, net pen experiments were carried out on the upper Savannah River, GA (Nestler et al. 1992) in which captive adult blueback herring (*Alosa aestivalis*) were found to have significant avoidance responses for up to 15 min. Subsequent to this finding, ultrasound has been placed in operation to control the movement of several *Alosa* species (e.g., Dunning et al. 1992; Ross et al. 1993, 1996; Nestler et al. 1995; Ploskey et al. 1995). Gregory and Clabburn (2003) reported that the 200-kHz side-looking sonar with which they sample upstream-migrating Atlantic salmon (*Salmo salar*) must be turned off at intervals because it has the unforeseen consequence of stopping the concurrent upstream migration of the alosine twaite shad (*Alosa fallax*).

At the same time, it is also clear that ultrasound does not work for many other species, including many species related to the *Alosa* species (Clupeiformes). Work by Mann et al. (2001) has shown that only members of the Alosinae, a subfamily of Clupeiformes, are able to detect ultrasound. Thus, ultrasound barriers will only be effective for those species.

5.6 POTENTIAL NEGATIVE EFFECTS OF SOUND ON FISH BEHAVIOR, PHYSIOLOGY, AND MORTALITY

The literature on the effects of sound on fishes and other aquatic organisms is growing, but the greater portion of the work to date is highly equivocal, and often not very well done (see Hastings and Popper 2005 for an extensive review). The majority of the work suggesting mortality or substantial damage to fish has used very high intensity signals such as explosives (e.g., Yelverton et al. 1975) and pile driving (e.g., Caltrans 2001, 2004). In all cases, the signals are very high intensity (often over 200 dB re 1 μPa) and have very sharp onsets. The investigators have suggested that exposure to such signals might include death of the fish or damage to body tissues.

In contrast, other studies with high-intensity signals have reported no mortality or significant tissue damage to fish (e.g., Popper et al. 2005, 2007), although there is some evidence that long-term exposure to high-intensity sounds may produce some small amount of damage to sensory hair cells in the fish ear (Enger 1981; Hastings et al. 1996; McCauley et al. 2003). At the same time, it should be noted that these studies have been done with very few fish species, and there are insufficient data to provide any kind of model that would predict whether a sound will affect fish.

Without going into an extensive literature review (see Hastings and Popper 2005 for a review), it is reasonable to predict, based on current knowledge, that unless sounds used in attempts to control fish behavior are very extensive (directed at the fish) and long term (perhaps hours) and have sharp onset transients, there is unlikely to be a physiological effect on fish. Indeed, virtually all of the sounds that have been used to date in attempts to control fish behavior as well as sounds used in infrasound experiments are well below the levels that have affected the few species where damage has been shown, and none have onset transients typical of pile driving or explosives.

5.7 OTHER INVESTIGATIONS USING INFRASOUND

Although it is clear that some fish species can detect infrasound, only a few species have been tested to date and fewer have been tested to determine usefulness for the control of fish behavior. More importantly, the only demonstration that fish respond to infrasound sources has been on Atlantic and Pacific salmon and silver eels, all using the infrasound source from the Norwegian groups.

In contrast, infrasound sources have been tested by other groups, but data are limited as has been success. Most of these reports have not appeared in the peer-reviewed literature. However, a few of the most important are mentioned here.

Taft et al. (1996) reported that there were some responses to salmonids in a concrete tank to an infrasound device operating at about 10 Hz. These investigators also reported infrasound responses in several other species including white perch and possibly striped bass. However, detailed data were not provided in this report and so its applicability to understanding use of infrasound is very limited.

In 1997, the U.S. Army Corps of Engineers conducted an independent evaluation of two infrasound devices and strobe lights in cage tests at the Chittenden Locks near Seattle, WA (Ploskey et al. 1998). The infrasound devices included an Alden Laboratories particle-motion generator (PMG)[23] and a reciprocating piston device similar to that used by Knudsen et al. (1992, 1994) in Norway. The tests were designed to study the effects of these behavioral devices on young salmon.

The PMG operating between 10 and 50 Hz failed to elicit a startle response or directional avoidance by hatchery-raised yearling coho salmon and subyearling coho and chinook salmon. The piston infrasound device operating at 8.3 Hz did produce responses when subyearling coho and chinook salmon were within 1.2 m of the source. However, these responses were not as pronounced as those determined by Knudsen with salmon. Significantly, the investigators reported that there was a higher frequency signal accompanying the PMG infrasound device, and this signal was within the higher hearing range of salmonids. In addition, Ploskey et al. (1998) tested a higher frequency Argotech 215 transducer generating 300-/400-Hz "crescendos"[24] that were also ineffective with subyearling coho and chinook salmon and sockeye salmon.

Mueller et al. (1998) also investigated the effects of an infrasound device on several different species of wild and hatchery-raised young (40- to 60-cm) salmonids in a large tank. The stimulus was from 10-14 Hz and produced by a Simrad VDS with a 10-cm-diameter piston.

[23] Possibly the same device used by Taft et al. (1996), but this is not clear from the Ploskey et al. (1998) study.
[24] The "crescendo" was a signal designed by Loeffelman et al. (1991) based on presumed recordings from fish maintained in water bags held in air. The specific signal was considered proprietary by the investigators, but they claimed that it contained energy in the frequency range of sounds used by the species. This work has not been pursued because it was shown to be ineffective in several tests. Indeed, the author of this report did get to hear the sounds, and they were clearly not anything like those made by fish and included background sounds of automobile horns and other ambient sounds that were recorded when the bags of fish were held in air.

The investigators found that the juvenile salmonids (40-60 mm in length) detected the low-frequency, high particle acceleration sound fields of 10^{-2} m/s^2 produced by the Simrad device. They also reported that the fish reacted with a startle[25] and avoidance response that involved the fish moving to the bottom of the tank and then away from the source. The greatest response was in the wild chinooks, with less response in the hatchery raised individuals. The authors also reported that after a number of tests, both the wild and hatchery-raised chinook would actually swim to the infrasound-emitting device and also show habituation to the sound and no longer respond. On the other hand, rainbow trout did not show habituation but continued to exhibit the avoidance response.

The most important conclusion from the Mueller et al. (1998) report was that the fish were responding to the particle-motion component of the sound field as reported by Knudsen et al. (1992, 1994, 1997). Both groups also showed an avoidance response by several different salmonids. However, once the particle motion at the fish dropped below approximately 10^{-2} m/s^2, the response of the fish ended.

Finally, Amaral et al. (1998) tested responses of chinook salmon smolts to infrasound at the Roza Dam Screening Facility, WA. They used the aforementioned PMG infrasound source and found no response at all by the chinook salmon. However, they did report a strong response by three pikeminnow at all frequencies tested other than 20 Hz (although the authors do caution that no replicates were done with pikeminnow). Because there may be issues that the PMG device also produces a strong component of higher frequencies, as reported by Ploskey et al. (1998), it is possible that the pikeminnow were responding to higher frequencies than to the infrasound device.

5.8 FEASIBILITY OF EMPLOYING INFRASOUND TO GUIDE EELS AT IROQUOIS DAM

NYPA's request for proposals posed questions regarding several of the technologies and specified that responses be drawn from the review of findings. The following questions were established for addressing the feasibility of using infrasound to guide eels at Iroquois Dam.

- **What evidence exists to support the conclusion that fish, and eels in particular, can detect and respond to infrasound?**

[25] "Startle response" is a problematic term. It is often used by fish biologists to indicate a very specific response that involves the Mauthner cell (M-cell) of the hindbrain. Stimulation of this cell results in the fish bending its body into a "C shape" with the head away from the stimulus. At times, this is followed by the fish swimming in the direction that the head has turned. The problem with the term, however, is that other investigators use it in various different ways and often in a way that is analogous to a human showing a "startle" to a loud sound. It is significant to note that a "startle" response in fish does not necessarily mean that the fish will always move away from the sound. Instead, just as humans may "startle" to a stimulus and decide that it is not necessary to respond, fish may do the same thing.

The existing experimental data suggest that infrasound is not likely to be useful for the control of fish behavior. The data on use of infrasound to control eel movement are limited to a single paper (Sand et al. 2000), and those results have not been replicated either in the field or in the lab. The limited data on the response of fish to infrasound at this time do not appear to justify taking the technique from the lab into the field for complex and expensive tests.

There are a number of questions that would need to be answered before the suitability of this technology for fish control can be established. The Sand et al. (2000) study was conducted in a confined area about 10 m wide, and although the data suggest that eels moved away from the 11.8-Hz infrasound source, the narrowness of the area tested does not indicate if the eels would move further than 10 m. And because the fish were not allowed to swim past the infrasound source, it is not known whether they would continue to be displaced or whether they would return to their original paths once they got beyond the effective range of the source. The authors of the studies did not find any substantial habituation to the sound. Moreover, this study did not show how far individual fish might move from the infrasound source. In other words, it was not clear from Sand et al. (2000) whether the fish that wound up in the furthest trap (10 m from the source) were animals that detected the sound when they were very close to the source and then moved as far away as they could or whether the fish found at the furthest point detected and moved from the infrasound source even when the source was at its greatest possible distance.

Thus, the primary conclusion one can reach from the infrasound studies, including the one on *Anguilla*, is that some species detect infrasound, and there seems to be a trend for some species under certain conditions to move away from such sources. However, little more is known. For example, would fish avoid sources putting out different or multiple infrasound signals? Or what is the maximum distance from the source at which fish will show an avoidance response? And is the work reported by Sand et al. (2000) replicable with fish in North America or with the use of different infrasonic sources?

- **What are the most recent results on use of infrasound to guide eel movement?**

Dr. Damien Sonny, of Pro-Fish Technology, indicated that he was pursuing the application of his infrasound device to control eel movements at a 72-m-wide nuclear power plant intake in Belgium (e-mail to Dr. J. Boubée). The tests were planned for fall 2008. Dr. Sonny also reported that this work was in the early stages and that there are no data that replicate the Sand et al. (2000) study or go any further in demonstrating that infrasound can affect eel behavior, and he was uncertain if infrasound would be usable for eels for a large area (e-mail to Dr. A. Popper).

The most recent information from Dr. Damien Sonny indicates lack of success in use of the infrasound source to divert the movements of eels at a project site in France (e-mail to W. Richkus, April 2, 2009). It is not known if this is the same test referred to in his e-mail to Dr. Boubée. Dr. Sonny reported that there was no indication of success in controlling passage of eels at the experimental site. He indicated that some explanations for the lack of success may have been that there was less than adequate monitoring of eels (note, no specifics are provided in the email on the test site or the experimental approaches used), the distances between the sound sources and the eels may have been too large, or absorption characteristics of the bottom may have affected the sound field. Dr. Sonny proposes some additional experiments this coming summer and next year that he believes might provide more insight into the success, or lack of success, for the infrasound approach.

- **How applicable are the findings of existing studies to the use of infrasound for directing eel movements at Iroquois Dam?**

Although it might be useful and important to redo the infrasound experiments of Sand et al. (2000), particularly with *Anguilla rostrata*, the question arises as to the cost-benefit potential of doing this. There are a number of issues that must be taken into consideration. First and foremost, because both *Salmo* and *Anguilla* were only tested when they were close to the infrasound source and in narrow bodies of water, would these or other species respond in a much larger basin of water when the fish detect the sound[26] at more than the several meters from the source? Although data are very limited, the evidence suggests that infrasound is only effective very close to the source where the particle motion is well above the animal's threshold. Thus, the initial conclusion must be that infrasound is not likely be effective in a larger area or over larger distances unless many sources were used. In effect, it is likely that a system would have to be designed that is a continuous acoustic barrier that can keep fish away from an intake over its length and depth. In other words, to have a potentially effective infrasound barrier, it may be hypothesized that the sources would have to be close enough together. This means that there would need to be a large number of sources for a large body of water (Popper and Carlson 1998). Doing this at a larger scale is theoretically possible (Nestler and Davidson 1995) but only if there is far more work in the design of the sources and a wide range of elaborate studies is conducted to investigate the various responses of fish species to the sources.

Beyond the behavioral data, there are a number of other issues that argue against infrasound as a potential stimulus for eliciting avoidance behavior by fish at Iroquois Dam. First, the USACE results, using infrasound devices that were mechanically different than the Knudsen device, did not elicit a response (Nestler and Davidson 1995). This suggests that something very specific to the Norwegian device (perhaps the specific of the flow field-associated moving piston) elicited the responses and that this feature was not duplicated in other devices (also see Ploskey et al. 1998). Second, and far more important, the Knudsen group showed that infrasound elicits responses only when the fish are within 2 m of the flow field of the projector. Furthermore, the response range may be even shorter than the distance for other salmonids, or salmonids of different ages (e.g., Ploskey et al. 1998).

It must particularly be kept in mind that the sites used in Norway for the infrasound studies are very small areas that could be "protected" by one or a few infrasound sources. The data suggest, moreover, that the infrasound device is only effective in moving fish from the sound when the fish is within a few meters of the source. Thus, use of any larger site would

[26] Note that detection is different from actually making a response. In other words, a fish might detect (hear) a sound when it is just above threshold, but it may not respond to the sound until it is much louder. As an analogy, a human driver may detect the sound of a fire truck siren when it is not very loud, but only move to the side of the road when the sound is much louder.

require a full evaluation to determine the number of infrasound sources required to control fish behavior.

- **What are potential limitations to the use of infrasound to guide eel movements at Iroquois Dam?**

To date, the only data available on use of infrasound to guide fish is from small and highly controlled areas with, presumably, low water flow. In such situation, it takes only one or a few sound projectors to ensonify the area through which fish move, and the fish are all likely to be in the acoustic near field of the sound source. The issues for use of infrasound at Iroquois Dam are: (a) the large size of the area that would need ensonification; (b) the larger number of infrasound projectors that would be required (see the following question and response that presents information provided by Dr. Sonny) (c) the likelihood that there would be large expanses of water that are not within the near field of the sound; (d) the detectability of the infrasound source in the presence of natural background sounds that mask detection of signals; and (e) the absence of data on whether the currents and other water conditions at Iroquois Dam would have any impact on responses of fish to other stimuli in addition to infrasound.

Some of the issues raised for Iroquois Dam may be the very issues being encountered in France by Dr. Sonny, as described in the response to the question above, "What are the most recent results on use of infrasound to guide eel movement?" These include the consequence of areas in which there is no infrasound present and the impact of normal background noise on detection of the infrasound source.

In conclusion, based on studies over the past years, infrasound does not appear to be a viable method for guiding silver eel movements, particularly at large sites. Even if infrasound is ultimately proven useful at some sites, it will take a good deal more study to: define the signal parameters that will elicit responses; determine the best sound projectors to use; determine the specific species that show an avoidance to the signal; and ascertain the actual responses that the species will make.

- **Can cost for an infrasound barrier to eel movements at Iroquois Dam be estimated?[27]**

Dr. Popper's conclusion, drawn in response to the preceding question, was that it would require a good deal more study before any potentially feasible infrasound barrier could be designed for installation at Iroquois Dam. Studies would be required to define the signal parameters that will elicit responses from eels at such a site, determine the best sound projectors to use, determine the specific species that show an avoidance to the signal (e.g., assess the unintended consequences to other species, and ascertain the actual responses of eels at the site).

[27] The response to this question was not prepared by Dr. Popper; it is based on a response from Dr. Damien Sonny to a request from Mr. Greg Allen, Alden, Inc., Dr. Sonny's response has been edited and expanded by Dr. William Richkus, Versar. This text has been merged with Dr. Popper's text for editorial purposes but is not attributable to Dr. Popper.

Dr. Damien Sonny of ProFish Technology has been conducting studies of infrasound as a fish diversion device, and Versar concluded that he might be able to provide some general cost information for such devices that might be informative. A request was made to Dr. Sonny through Mr. Greg Allen of Alden, Inc., and, in response, Dr. Sonny provided his estimates of cost of a hypothetical installation of infrasound emitters for the purposes of diverting eels moving downstream at Iroquois Dam (November 2007). The following material is based primarily on the information provided by Dr. Sonny. The costs were based on those of an infrasound fish-diversion model installed by ProFish Technology at a nuclear power plant in Belgium in 2008, presumably for the studies that were referred to in response to an earlier question. Dr. Sonny was provided with dimensions of Iroquois Dam to use in providing his cost estimates.

The basic infrasound unit is composed of two symmetrical pistons in an air-filled cylinder (Figure 5-7). A unit has a vertical height (motor compartment) of 80 cm with the horizontal piston/membrane element 55 cm in length. The pistons are driven by a high-precision mechanical transmission coupled to an electric motor. Each unit weighs about 85 kg, but external weight is required to sink the unit (global weight of 110 kg). The frequency range of a unit is 1-16 Hz and is adjustable in 0.1-Hz increments. The voltage is 3 × 380 V, with the power and the amperage being strongly dependent on the frequency. At 10 Hz, the amperage is around 2.5 A, and the power is around 1.5 kW. At 16 Hz, the amperage is around 6 A and the power is around 3.5 kW; the recommend frequency is in the 10- to 15-Hz range.

Dr. Sonny suggests that the unit described is capable of creating an effective field extending about 12 m from the unit for small fish and about 6 m for larger fish. However, Dr. Popper's preceding review illustrates that the effective field for migrating silver eels is not known. Dr. Popper also indicates that a basic issue is whether wild *Anguilla* would respond to the infrasound source, since while there are some data that *Anguilla* can detect and respond to infrasound, whether this would be applicable in the wild is not known. Thus, Dr. Sonny's design is based on an assumed effective field size.

For Iroquois Dam installation, Dr. Sonny recommended installation of an infrasound unit every 10 m. Although a single control system could operate up to 20 units, distance limitations for the cables limit a deployment to 16. Each section would be 150 m long (Figure 5-8). At the mid-length of the section, a floating platform of 5 m × 5 m (approximate size) is equipped with the switchgear cubicle and the air compressor. From there, electrical cables and air tubes are run along a floating line. Each floating control platform must be supplied with 64-kW power (3 × 380 V). Each unit is suspended from the surface by a buoy. Buoys are linked by a cable with electrical wires wound around it. A 150-m section would have to be strongly anchored at both ends.

Figure 5-7. A ProFish Technology infrasound unit and its operating system (Photo courtesy of Dr. Damien Sonny, ProFish Technology)

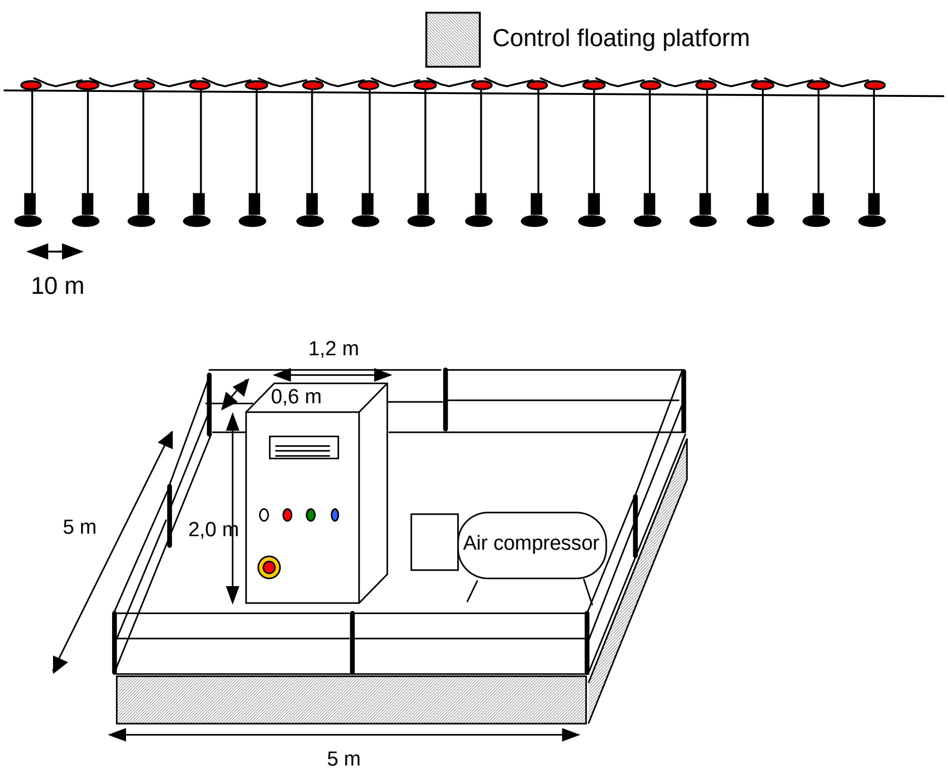

Figure 5-8. Floating section (150 m, 16 units) and its control system (Source: D. Sonny, ProFish Technology)

A diversion array at Iroquois Dam would have to be inclined to the river axis. The appropriate angle would have to take into account signal propagation, water velocity, and eels' behavior. Figure 5-9 shows a conceptual 600-m-long diversion array (4 sections of 16 units each, 64 units in total) with an angle of 20° to the dam axis. A decrease in the angle relative to the current direction would require more units and an array of greater length. Dr. Sonny's conceptual design using an angle of 20° to the dam axis is inconsistent with most of the mechanical and behavioral barrier studies with eels, as were described in Section 3 (Mechanical Barriers) and Section 6 (Light Barriers). Most studies with outmigrating silver eels indicate that diversion barriers at an angle of 30° or more to the direction of river flow (or in this case, to the dam axis) would be required for success in diverting migrating eels, particularly in rivers with high flows. Thus, Dr. Sonny's conceptual design is likely to provide an underestimate of the potential cost for an infrasound barrier, since the barrier would most likely have to be much greater in length than was assumed in his design.

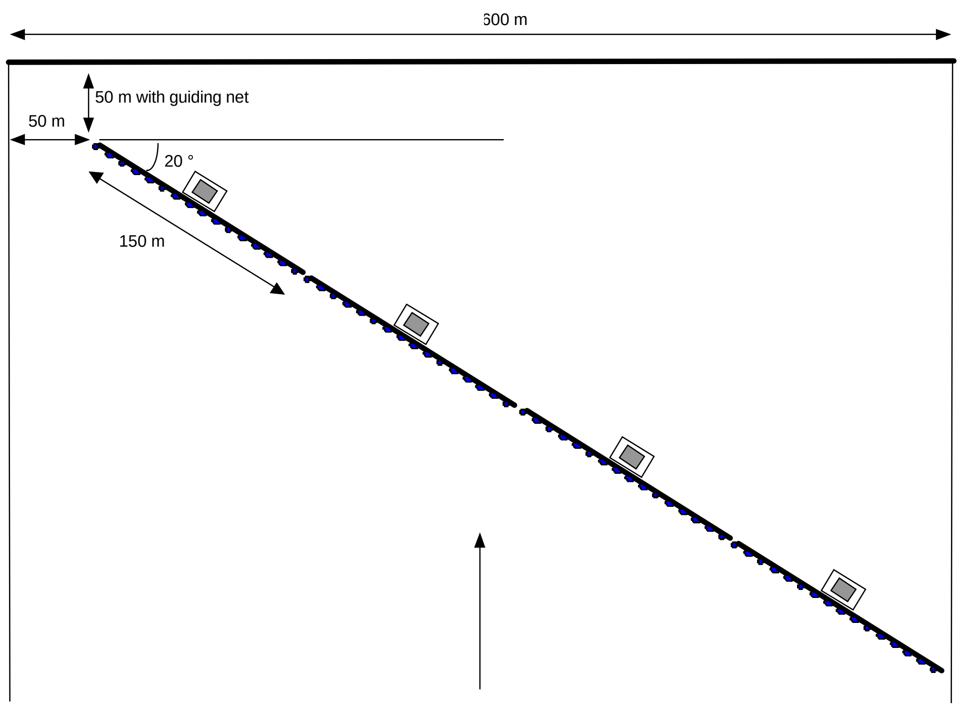

Figure 5-9. Conceptual design of an infrasound array at Iroquois Dam (Source: D. Sonny, ProFish Technology)

Table 5-1 presents the estimated cost of multiple infrasound units. The per unit price of 50,000 € for a validated system is an estimate ± 10-20%.

Table 5-1. Infrasound unit cost estimates, in 2007 U.S. dollars (Source: D. Sonny, ProFish Technology)

Number of units	Cost EURO	Cost U.S. $	Cost/Unit U.S. $
1	50,000	72,880	72,880
10	460,000	670,496	67,050
20	676,000	985,338	49,267
50	1,582,500	2,306,652	46,133
75	2,313,000	3,371,429	44,952
100	2,976,000	4,337,818	43,378

For the 600-m-long fish fence, Dr. Sonny estimated the cost would be $2,952,512 (2007 U.S. dollars). This cost estimate includes shipment and delivery to the site, a year of maintenance and warranty, the floating line to hang the units and setup of the whole fish barrier. It does not include the adapted anchoring system, the floating platform, or the cost of providing the required electric power at each floating platform. Annual maintenance costs are estimated at about 10% of the purchase cost. However, as noted earlier, the barrier would likely have to be a greater length than estimated in Dr. Sonny's conceptual design, and thus a greater number of units would be required, increasing the cost estimate. In addition, his estimate of a 10-m distance between sources is based on data determined for other species, and whether those data could be extrapolated to outmigrating eels is unknown. Thus, a closer spacing of units might be required, which would add additional costs. In addition, the high debris loading of equipment installed under water from SAV is likely to require that maintenance be nearly continuous so as not to impact sound emissions. Thus, the 10% annual maintenance cost does not appear sufficient to account for that requirement. Overall, we conclude that while Dr. Sonny's information on unit cost for the infrasound emitters is reliable, the potential effectiveness of his conceptual design for an infrasound barrier is likely to be poor. As concluded by Dr. Popper in the preceding response, there is currently insufficient data and information from which to create a potentially effective design and thus a reasonable cost estimate for an infrasound barrier at Iroquois Dam.

5.9 RESEARCH NEEDS

In 1998, Popper and Carlson concluded that, other than for Alosinae clupeids, there are no replicable data to show that sound at any frequency can be used to control the movement or behavior of fish. Although there have not been extensive studies since then, it is likely that the conclusion reached in 1998 still stands today. Moreover, of the data suggesting that sound might be an effective barrier to keep fish from entering undesirable locations, it must be noted that the data are highly equivocal. More specifically, there are some data from some sites and for some species suggesting that under certain conditions, certain sounds may control the movement of some fish. Importantly, these data are limited, rarely have been subject to thorough peer review, and have not been replicated. In effect, even the few reported "successes" can only be useful at the site of experiments and for the precise conditions under which the tests were run. Exporting these results to other sites is, with the exception of use of ultrasound on members of the genus *Alosa*, not possible.

Indeed, anyone wishing to use sound to control fish behavior, whether the sound be sonic or infrasonic, needs to virtually "start from scratch" in experimental design. And the experimental design needs to take into consideration a substantial range of variables in each part of the study. For example, not only is the particular species of consideration but also the hearing capabilities and behavior of each species at different life stages.

In addition, one has to ask what kind(s) of sound might be most effective in eliciting responses from a fish. Because the sounds that fish most likely attend to are those of conspecifics (for those that make sounds), predators, and prey and from the environment, any experiments must first determine which sound(s) are potentially of "interest" to a particular species (and life stage).

Other potentially important variables are, for example, water temperature, time of year, fish motivation, and innumerable other environmental and physiological conditions that may alter the response of fish to sounds. The "bottom line" is that to find a stimulus (or stimuli) that elicits a desired reaction of a species (e.g., avoidance, attraction), the signal must not only be detectable by the fish, but the signal also needs to be effective over many different environmental and physiological conditions.

Thus, determination that any sound could be useful in affecting fish behavior is complicated and requires an extensive set of studies that might start in the lab to determine what sounds fish can detect and potentially respond to in a positive or negative way. This has to be followed by field studies under widely different conditions to determine if the behavioral responses to sound seen in the lab actually occur in the wild. Moreover, one must keep in mind that there may be sounds in the wild that could elicit responses from fish, but the same sounds are not effective in the lab where fish are in relatively small tanks with very complex acoustics, and vice versa.

As discussed above, there are several suggestions that infrasound might be effective to move some fish species away from a protected area. However, the number of studies are few and have yet to be successfully replicated using any infrasound device other than that developed by the investigators on the papers that described the responses. Thus, before there can be any consideration of the use of infrasound to affect fish behavior, there have to be studies that take into consideration: (a) the device, (b) replication of studies showing that infrasound is useful, and (c) an analysis to determine if the response to infrasound is sufficient to work at all but in a very small area. Each of these analyses needs to be done if one is to even consider use of infrasound.

A related issue is the sound level of the transducers. In a quiet area, it is possible that the transducers could be kept at a relatively low sound level and still be detectable by fish. However, in a noisy environment, such as near a hydropower facility and/or an area with rushing water, the sound level of the transducers would have to be higher to be detectable by the fish over the background noise. But a related consideration that has yet to be made is the sound field generated by a large number of transducers and the effects this would have on other species in the area, including the humans running the facility. In effect, the sound levels from the infra-sound transducers may have to be so loud that they are detectable in air as well as under water.

Based on current knowledge of the use of sound to control fish behavior, and the limited data on the potential use of infrasound to affect the behavior of eels, it is concluded by the author of this report that this is not yet a viable method for the control of eels or any other fish species. Moreover, if there are reasons to continue examination of the potential use of infrasound for control of eels, initial approaches should look at the most basic questions of the detectability of infrasound by eels of appropriate ages, followed by testing with the potential infrasound source. The initial studies would use physiological and/or behavioral methods to determine if the fish detect infrasound and the sound levels needed to elicit a response.

If and when it is determined that these fish are able to detect infrasound and at what sound levels, an engineering model should be developed using an "ideal" infrasound detector to determine if it would be technically and economically feasible to use such a source at the proposed site to produce sounds detectable by the eels. Part of this evaluation should include an analysis of the impact of the infrasound not only on eels but also on other organisms in the area.

Only after such an analysis is made would it be worth continuing experiments to develop a real source and to determine if and how eels would respond in their normal habitat.

Taking these issues into consideration, there are several studies that would need to be done to test whether infrasound could be used to control fish movement.[28] These include:

- determining that eel actually detect infrasound;
- determining hearing thresholds (lowest sound level detected) for infrasonic frequencies;
- determining responses to the specific infrasound source;
- testing responses of eels to different infrasound characteristics (e.g., pulsed, frequencies) to find the signals that are most readily detected and that elicit the strongest responses;
- determining the response characteristics including the behavior of eels to the sound source;

[28] Although these recommendations specifically refer to eels, comparable studies and studies on detection and responses at different life stages would be applicable to other species as well.

- determining sound level and distance thresholds over which eels will show the desired behaviors;
- determining whether eels will respond to the infrasound source in the wild and with the presence of background (masking) sounds;
- ensuring that high levels of infrasound, even if they elicit appropriate behaviors, do not damage eels and other fish species in the same area and thereby decrease survival;
- determining whether the levels of infrasound used to affect eel behavior have any impact on other organisms in the environment including fish, invertebrates, and humans; and
- doing an engineering analysis of the costs (including electrical) of operating the appropriate-sized infrasound barrier, possibly using the information provided by Dr. Sonny as a starting point.

6.0 TECHNOLOGIES FOR USING LIGHT TO INFLUENCE THE MOVEMENTS OF OUTMIGRATING EELS

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Light arrays or barriers are the most extensively documented of the various technologies being evaluated for their potential for guiding the movements of outmigrating eels at Iroquois Dam. Evidence that light can be used to alter the movements of outmigrating silver eels dates back to the early 1900s and probably much earlier. Petersen (1906) reported that fishermen in Northern Italy lit bonfires along canals to temporarily halt the run of eels while they worked their fishing gear, and Petersen's own studies using a light projector demonstrated eels' strong avoidance of artificial light. Lowe (1952) also reported that Irish fishermen set turf fires along the banks to stop the run of eels while they emptied their nets. She conducted several classic experiments that demonstrated that the downstream migration of silver eels could be interrupted or delayed by setting artificial lights across their path.

An example of the effect of light on eels' movements was observed more recently in a fishery at the Killaloe eel weir in Ireland. Fishermen suspend their nets from steel frames on a bridge. To facilitate boat movements at night, floodlights were installed in the center of the bridge where the currents were strongest, and catches normally were largest. The maximum catch in the center nets decreased from 1.5 tons on unlighted nights to 0.3 tons on lighted nights (Nolan et al. 1986). A more rigorous study of this effect reported by Cullen and McCarthy (2000) is discussed later in this section. These anecdotal reports along with general observations that eels tend to run during the dark of the moon served as the impetus for studies during the past century in which lights were used to attempt to control eel migration (Eales 1968; Cairns and Hooley 2003). The primary motivation for these studies was to increase capture efficiency in fisheries (Wickham 1973; Ben-Yami 1976). Only more recently has interest arisen in using light to divert eels away from potential sources of injury or mortality at hydroelectric projects and cooling water intakes for power plants.

Section 2 described the general procedures used to search for relevant literature and information. Appendix A lists all of the eel researchers contacted during this project and identifies the various technologies and topics for which they provided some input. All researchers who had published papers on the use of light to guide eels were contacted to identify any other researchers currently studying that technology. This review of the effect of light on outmigrating eels was initially intended to focus on studies that have been conducted since 2000, because EPRI reviewed studies conducted prior to 2000 in a comprehensive report on technologies for guiding the movements of migrating silver eels (EPRI 2001a). No researchers were identified who had conducted studies using lights to guide migrating silver eels since 2000; therefore, studies performed by NYPA in 2002 are the most current work on this technology. NYPA's work, which is reviewed in detail later in this section, is the only large-scale, in situ investigation of the effects of light on the behavior of outmigrating eels in a large river system. Given the absence of more current studies, this section summarizes and synthesizes information from earlier studies reviewed previously by EPRI (2001a) with some additions and elaboration; a review of NYPA's studies of light guidance follows. A brief discussion of photoreception in eels and how detection of and sensitivity to light changes as non-migratory eels transform into the sexually mature, migratory life stage precedes the review of literature.

6.1 PHOTORECEPTION IN EELS

The characteristics of light and the sensory mechanism through which eels perceive it determine how outmigrating silver eels respond to light. Fish of various species often have optical sensitivities attuned to the particular spectral irradiances of their habitats (e.g., Lythgoe 1979). Eels reside in dramatically different habitats during different periods of their lives. Yellow eels reside in yellow- or red-stained fresh waters or green estuarine waters; in their silver stage, eels move through blue waters of the deep ocean (Archer et al. 1995). The maximum response of eels' photosensitive receptors occurs at wavelengths of 500 nanometers (nm) for twilight receptors (rods) and 560 nm for daylight receptors (cones; Protasov 1970 as cited in Hadderingh et al. 1992). One adaptive feature of eels' relatively unique life history is an enlargement of the eyes and a change in their photoreceptive characteristics that occurs at the onset of sexual maturation. During sexual maturation, which typically is completed before migration from rivers to the deep sea, the visual pigment in the rods shifts from one that is most sensitive to green light (523 nm) to one that is most sensitive to blue light (approximately 482 nm; Carlisle and Denton 1959). Both American and European eels exhibit this shift (Beatty 1975). The change in sensitivity to particular colors of light involves the synthesis of a new protein (i.e., the visual pigment opsin) that is inserted into the outer segments of the rods as eels mature. This change appears to be induced by hormonal shifts during maturation and can be duplicated in the laboratory by treating immature eels with hormones that stimulate maturation (Hope et al. 1998), as shown in Figure 6-1. In the laboratory, changes occur very rapidly, beginning within six hours of injection of the hormone (Hope et al. 1998). The difference in spectral sensitivity of the eyes of yellow and silver eels was also demonstrated by Andjus et al. (1998), who reported peak sensitivities nearly identical to those found by Hope et al. (1998).

Knowledge of when maturing eels' eyes begin to change, how rapidly the change occurs, and how the change affects sensitivity to light of different wavelengths is particularly relevant to this project because of the extended period over which eel migration occurs in the St. Lawrence River in the vicinity of Iroquois Dam (generally June through September; McGrath et al. 2003b). Determining if the physical and physiological characteristics of eels' eyes vary substantially over time during migration past the dam would be relevant for designing any system that attempts to use light to modify eels' behavior.

Pankhurst (1982) indicated that enlargement of the eyes and the structural changes associated with the change in color sensitivity are essentially complete in both sexes when migration begins; however, the eels that Pankhurst studied were from migrations typically observed in small rivers and streams. Those brief, episodic, fall migrations differ substantially from the migration in the upper St. Lawrence River, which takes place during approximately three months throughout the summer and early fall (EPRI 1999). Eels participating in that extended migration appear to be undergoing transformation of the eye during migration (McGrath et al. 2003b). McGrath et al. (2003b) reported an ocular index as one of several metrics that can be used to differentiate between mature and immature eels in the St. Lawrence River. Figure 6-2 presents data collected in the St. Lawrence River in a study conducted in 2002 suggesting that the size of the migrating eels' eyes gradually increased over the two-month study period; however, the data are highly variable.

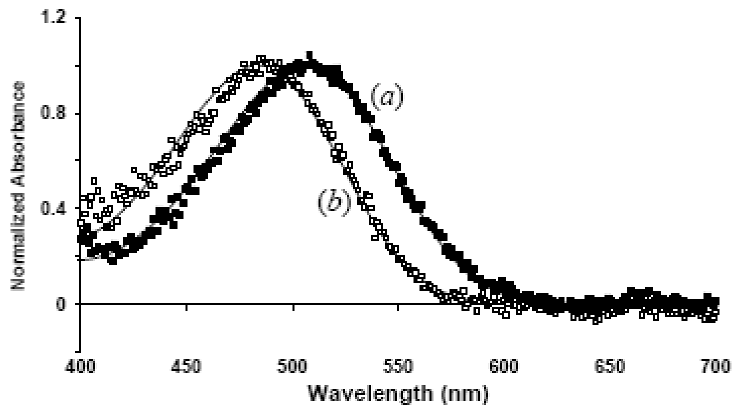

Figure 6-1. Normalized average absorbance spectra of visual pigments measured from rods of untreated (a) and hormone-treated (b) European eels (Source: Hope et al. 1998)

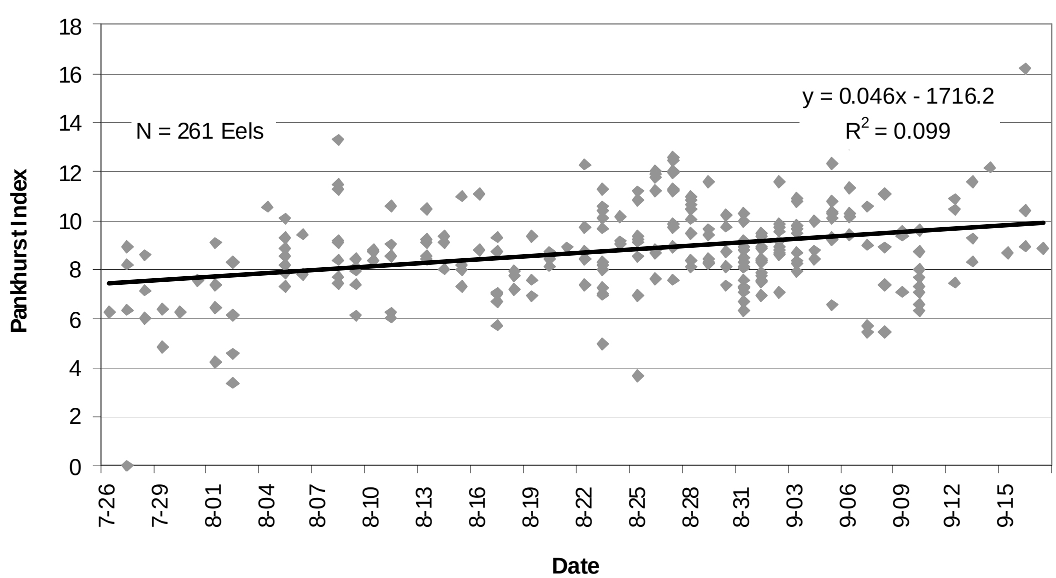

Figure 6-2. Pankhurst's (1982) eye index for eels captured in stownets in the St. Lawrence River during a light-avoidance study conducted from July 24 to September 17, 2002 (data provided by K. McGrath, NYPA)

Although the shift in peak sensitivity to different wavelengths of light as eels mature is interesting, its importance for determining how to use light to guide or concentrate eels may be somewhat limited. Unless eels use color vision to direct some aspect of their migratory behavior, the spectrum of light emitted from an artificial source is likely to be important only to the degree that eels perceive some emissions to be brighter than others (J. Patridge, pers. comm., November 2007). The relatively broad and overlapping range of spectral sensitivity of the eyes of immature and mature eels (Figure 6-1), and the fact that the peaks are separated by only 41 nm or less suggest that eels would detect light at reasonable intensities over a relatively large range of wavelengths. The fact that eels responded to the light of fires and other sources that emit light in the yellow range (around 570 nm) further suggests that wavelength might not be the most critical factor in eliciting responses. This suggestion is supported by the findings of Hadderingh et al. (1992), who conducted laboratory experiments with eels in a flume (described in more detail below) using three kinds of lamps (i.e., incandescent, sodium, and mercury). The eels were released approximately 3 m away from two downstream compartments, one lighted and one dark. Eels consistently avoided the lighted compartment and selected the dark one. The authors indicated that the incandescent lights had a continuous spectrum that included wavelengths of 500 nm and 550 nm and that both of those wavelengths were present as low peaks in the spectrum of the sodium lamp. The spectrum of the mercury lamp lacked a 500-nm peak but had a high peak at 550 nm. Despite the differences in the spectra of light emitted by the three kinds of lamps, no difference was found in the eels' responses in test chambers with light intensities ranging from 0.1 lux to 55 lux. In all three tests, at least 92% of eels selected the dark chamber. The authors concluded that all three kinds of lamps would be suitable for deflecting eels.

Sources that produce light with wavelengths outside the range of sensitivity of both mature and immature eels (i.e., less than 400 nm or greater than approximately 550 nm) are unlikely to affect eels' behavior. For example, Patrick et al. (1982) found that yellow eels strongly avoided a strobe light emitting light at wavelengths of 400-470 nm but did not respond to red strobe light (600-700 nm). This finding is consistent with the spectral sensitivity data shown in Figure 6-1. Light at wavelengths that eels do not appear to detect could prove useful for observing their behavior under otherwise "dark" conditions, such as in laboratory studies.

Water quality would be important in determining if light could be useful for altering the movements of eels because changing characteristics of the water could result in changes in wavelength and attenuation of the intensity of light with distance from the source. None of the literature reviewed addressed the importance of potential interactions between eye development, light wavelength and intensity, and their interactions with water quality characteristics in affecting the behavior of adult eels. Given that the eels moving past Iroquois Dam will vary in their developmental stage, any guidance device based on light that is installed at that site would have to be designed to be effective for eels over the range of stages of development observed there. Wavelengths in the range of 450 to 550 nm have the greatest likelihood of affecting behavior.

6.2 REVIEW OF LIGHT GUIDANCE STUDIES CONDUCTED PRIOR TO NYPA'S STUDIES IN THE ST. LAWRENCE RIVER

In 2001, EPRI published a comprehensive review of studies that had investigated the use of lights for guiding the movements of silver eels. The review presented in this report expands upon the information presented in EPRI's report by including additional studies conducted after 2000 (EPRI 2001a). Additional information from the major studies conducted prior to 2000 that was not included in EPRI's report also is included to provide sufficient background and context for discussing the more recent studies. The literature search and networking described in Section 2 resulted in the discovery of only a few additional studies. The most recent new paper was based on work done in the late 1990s (Cullen and McCarthy 2000). No studies of light guidance appear to have been conducted since NYPA conducted its proof-of-concept study of using light to guide eels on the St. Lawrence River in 2002. As discussed below, controlled and *in situ* experiments indicate that both American and European eels exhibit a strong avoidance reaction to light; however, the reaction is not consistent and can be influenced by many factors. None of the studies reviewed here provided information about costs; moreover, most of these studies were performed so long ago that their costs are not likely to be representative of the current costs of similar work.

6.2.1 Studies Conducted Before 1990

Lowe (1952) conducted extensive studies in which she attempted to use light as a barrier to migrating silver eels in laboratory flumes and at six field sites in England during the 1940s. All of the field sites were small streams; the greatest cross-stream distance was 45.7 meters, and the streams at several sites were only 9.1 to 18.2 meters wide. Lowe's lights for field studies were submerged and directed downward in the water column because of black-out restrictions during World War II. Lights were mounted in 91.4-cm-long, metal tubes suspended from hooks at intervals of 61 to 91 cm on wires that spanned the stream. A portion of the tube was submerged, but the suspension method allowed the tubes to swing so that branches and debris could move past without snagging. Caps on the tops of the tubes directed the light beams

Units of Measure of the Intensity of Light

Units of measure of the intensity of light used in the reported studies vary in kind and designation. **Candlepower** is the light density within a very small, solid angle, in a specified direction. Candlepower often is measured at various angles around the source, and the results are plotted to give a candlepower distribution curve. Such a curve shows luminous intensity (how "bright" the source seems) in any direction. The unit of measure of luminous intensity is the **candela**. In modern standards, the candela is the basic measurement of light, and all other units are derived from it. The **lumen** is a measure of light flux irrespective of direction (i.e., the total output of a source, output within a specific angular zone, amount of absorbed light). Candle power, then, is the total number of lumens from a surface emitted in a given direction. Illumination is the density of luminous flux on a surface, which is a measure of how "bright" the surface appears to the human eye. The appropriate units of measure are foot-candle and lux. One foot-candle is the illumination produced by one lumen uniformly distributed over one square foot of a surface, or the illumination at a point one foot from, and perpendicular to, a uniform point source of one candela. So, foot-candles incident on a surface=lumen/area (sq.feet). The International System uses **lux** (lumen/sq. meter). One lux=0.0929 foot-candles, or 1 f-c=10 lux (definitions of terms taken from http://www.highend.com/support /training/lightingfaq .asp). None of these older studies used **quantum flux** ($uE/m^2/s$), a more precise measure of light intensity, but it would be the preferable unit of measure of luminous intensity in any future studies.

down into the water. Sources of light were 6-V or 12-V (3 or 4 W) incandescent bulbs. The apparatus produced strips of light along the river bottom that ranged from 30.5 to 91.4 cm wide, depending on the depth of the water. Light intensity from the lamps ranged from 0.25 to 5.3 candlepower (cp). The wavelengths of emitted light were not documented. Lights were deployed in V-formations with traps in the center of the stream or in angled, cross-stream arrays with traps positioned on the banks at each terminus of the arrays. Arrays were deployed at angles of 35º or 12º to the direction of flow. The angle of the array in relation to the direction of the current influenced its effectiveness for diverting eels: a short string of lights angled at 35º was more effective (73% to 75% diversion) than a longer array at an angle of 12º (65% to 69% diversion). Diversion percentages in many of the individual studies were high (i.e., 72% and 92% of captured eels taken in the dark side at two test sites) in a variety of conditions; however, diversion most commonly ranged from 50% to 70% across all tests. Diversion effectiveness was low during floods, when water was turbid, and with several specific arrangements of the lights. Effectiveness appeared to be particularly high for configurations in which the lights were directed upstream. Lowe speculated that lights so directed appeared to the eels as “bright blobs” rather than as a continuous path of light, and that the blobs would give eels a longer warning of the barrier as they approached in fast moving currents than the continuous path of light produced by the perpendicular (to flow) configuration. These studies were performed in relatively small rivers; consequently, in most cases the entire width of the river could be trapped. Lights with intensities of 5 and 0.7 cp were effective in waters up to 1.3 m deep, with current speeds of 76 cm/s.

Lowe (1952) conducted laboratory studies in an “artificial river” consisting of an oblong concrete tank divided into two channels by an oblong partition around which water flowed in a continuous steam. The two straight channels were 4.6 m long; one was 0.6 m wide, and the other was 0.9 m. wide. Water was maintained at a depth of 38 cm, and velocity during the studies was varied from 15.2 to 30.4 cm/s. The light barrier tested in the flume consisted of 12 incandescent bulbs (12 V, 10 W) placed in a string just below the surface of the water. Flume studies were terminated after only five tests. Eels tended to swim upstream against the artificial current, particularly at high velocities. Light barriers were ineffective in the flume; eels readily swam upstream through each tested barrier. Lowe concluded that eels were influenced too much by abnormal conditions in the flume for results to be applied to natural conditions.

Lowe’s work was comprehensive but was conducted in very small streams and rivers where conditions were quite dissimilar to those in the St. Lawrence River. The size of the streams constricted eels’ movement and maximized their exposure to the light arrays. The configurations that appeared effective for diverting eels in those test streams may not be relevant for the St. Lawrence River at Iroquois Dam because of the vastly different dimensions and characteristics of the sites. Although the maximum effectiveness in some of Lowe’s tests was as high as 90% diversion, diversion rates were more commonly in the range of only 50% to 70%, even in the small, confined streams.

Hadderingh and Kema (1982) used artificial illumination to reduce fish impingement at the Bergum steam electric power station in the Netherlands. European eel was among the species recorded. Intake velocities were on the order of 14 cm/s. The plant intake had an inside length of 29 m, with water depth of 3.5 m. Intake velocity was 14 cm/s, but only 7 cm/s in areas adjacent to the intake. Lamps were installed in six locations around the intake. Locations 2 and 3 were at the intake, and the other locations were on either side of the intake. Twelve lamps were positioned above the surface of the water and four beneath it (Table 6-1). Light sources were high-pressure, mercury vapor lamps that produce light in the violet, blue, green, yellow and orange ranges, with peaks at approximately 540 nm (green) and 580 to 600 nm (yellow). Surface illumination when the lights were on was as bright as 700 lux) at Locations 2 and 3, directly in front of the intake. Illumination underwater was not measured. Night illumination without the lights was measured at 0.2 lux. The effectiveness of the illumination for reducing entrainment of eels was relatively low for juvenile yellow eels (-31%[29] to 60%, 21% average) but much higher for silver eels (-4% to 73%, 54% average). The authors noted that the effectiveness of the lights would be significantly influenced by water clarity; they expected the lights to be less effective in turbid waters.

Table 6-1. Location of lamps at the Bergum Power Station intake, Netherlands (Source: Hadderingh and Kema 1982)

Location	Number of Lamps	Capacity per Lamp(W)	Distance Above (a) or Under (u) the Water (m)
1	2	2000	11.5 (a)
	2	2000	-17 (u)
2	2	2000	9 (a)
	1	400	-1 (u)
3	2	2000	9 (a)
	1	400	-1 (u)
4	2	2000	17
5	2	2000	17
6	2	2000	17

Diverting eels away from cooling water intakes might be easier than diverting them from the intake at a hydroelectric facility because cooling water intakes typically draw water from the side of the river in which water flows past the intake; therefore, eels can be diverted into the main river flow, which is likely to be their preferred migration path. Another difference is the flow or intake velocities in front of each generating unit/turbine. In once-through-cooling facilities, intake velocities typically average approximately 0.2 to 0.3 m/s, whereas flow velocities at hydroelectric stations typically exceed 0.5 m/s. In large rivers many eels may pass cooling water intakes at points that are beyond the area of hydraulic influence of the water withdrawal, unlike the situation at hydroelectric facilities, where all eels moving downstream encounter the facilities.

[29] Negative effectiveness means that more eels were taken with lights on than with lights off.

6.2.2 Studies Published After 1990

Hadderingh et al. (1992) provided a summary and synthesis of findings from light guidance studies conducted under both laboratory and field conditions. For their laboratory studies, the authors used silver eels caught in a commercial fishery the night before the experiment. The experimental flume was 5.35 m long and 1.36 m wide. The test portion of the flume was 2.7 m long and 1.36 m wide and was filled to a depth of 20 to 26 cm.[30] Water velocities during the study ranged from 6 to 25 cm/s. Light in the experimental flume was provided by an incandescent lamp with a tungsten filament that produced a continuous spectrum of light. Findings of the laboratory and field studies were as follows (summarized from Hadderingh et al. 1992):

- In the laboratory, light intensities as low as from 1 to 10 lux induced a significant avoidance response (64% to 90% avoidance).

- During studies at the Bergum power station in 1987, lights were placed in front of one of two units; the unlighted intake was the control. Two different light arrays were tested. One consisted of high-pressure mercury lamps placed 1 m above the surface of the water. That arrangement did not divert yellow eels and diverted only 6% of silver eels. A second experiment tested a combination of high-pressure mercury lamps placed above the water and incandescent lamps (tungsten filament, continuous spectrum) deployed on the bottom of the river. That arrangement diverted 51% of yellow eels and 25% of silver eels. The authors concluded that the turbidity of the lake water was probably the reason that only underwater lights were effective.

- In 1988, a light array was installed 4 m away from the intake at the De Haandrik hydroelectric power station, where the river was approximately 40 m wide. Lights were spaced over a lateral distance of 4.5 m. The array consisted of 9, 200-W incandescent lamps laid on the bottom (2.6 m deep) and 2, 2000-W, high-pressure, mercury lamps placed 1.5 m above the surface of the water. Water velocity at the barrier was 59 cm/s. The majority of the eels taken in this study were silver eels. The reduction in eel passage with lights on was 66% (Figure 6-3).

- Additional studies of the effectiveness of light barriers were conducted in conjunction with a commercial eel fishery that used fyke and barrage nets in a small river (33 m wide, 3 m maximum deep). Twenty-eight, 200-W lamps were placed on the bottom of the stream over a distance of approximately 33 m at a 45º angle to the river flow, which varied widely from near 0 to 60 cm/s. Maximum lamp capacity was 10 lux.[31] Diversion ranged from 73% to 85% at maximum intensity. Diversion decreased to 30% at 0.6 lux, a response quite different that that observed in laboratory studies described above.

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[30] This same flume apparently was used in all of the laboratory work.

[31] The location at which this light intensity was measured was not specified. The lights were directed upward; therefore, the measurement may have been taken directly above the lights.

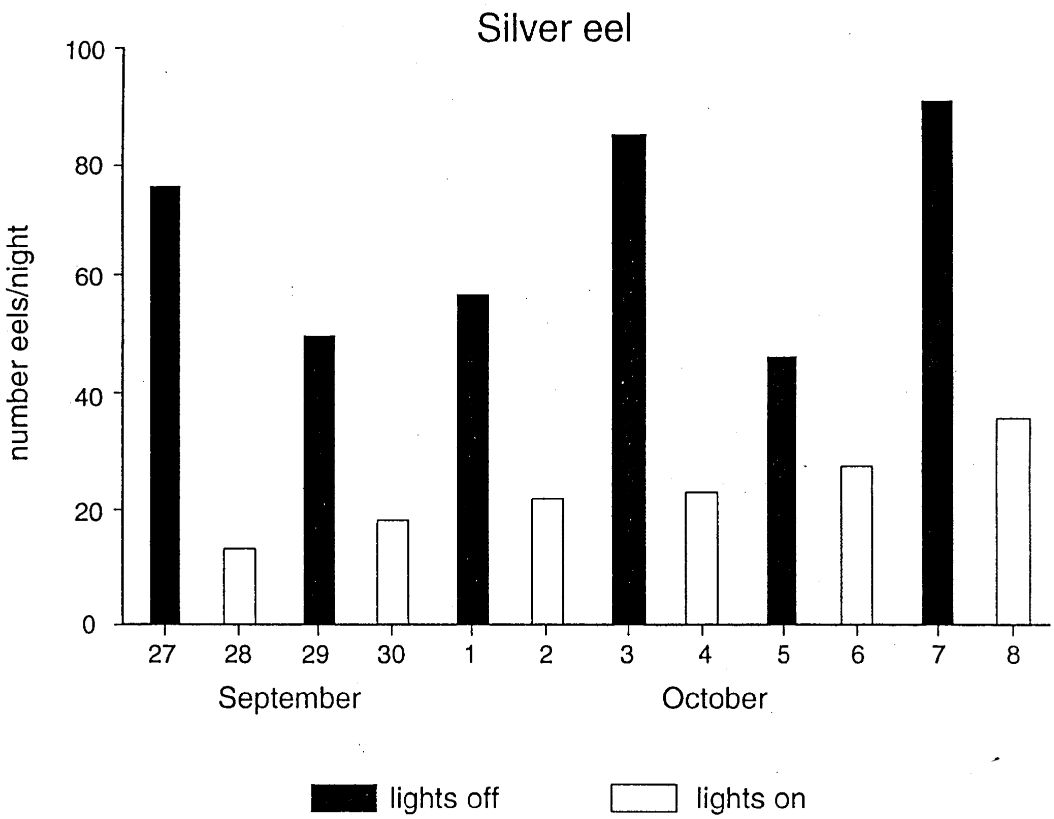

Figure 6-3. Number of silver eels caught behind the light barrier at Haandrik Hydropower Station, Netherlands (Source: Hadderingh et al. 1992)

Hadderingh and de Potter (1995) and Hadderingh and Smythe (1997) reported similar findings regarding light diversion. Table 6-2 shows that light was effective in diverting eels in the experimental flume even at illumination as low as 0.007 lux (for florescent), and regardless of the kind of lamp used. Turbidity in the flume was near zero. They also noted that the effectiveness of light for diverting eels was related to water velocity; diversion effectiveness decreased with increasing water velocity. This may be associated both with the preference of outmigrating eels for swift currents and with the possibility that the period of exposure to the lights decreases when eels are in fast-moving water. In addition, high velocities in small streams and rivers often are associated with significant rain storms, which result in increased turbidity and decreased transparency. Such changes in water quality could reduce the effective range of a light barrier, as suggested by Lowe (1952).

Table 6-3 summarizes the results of several studies of the diversion effectiveness of light barriers at steam electric station intakes, hydroelectric facilities, and fishing net arrays. The low percentage diversion at the Dietfurt hydroelectric station (8%) should be considered unreliable because of the small number of eels observed in that study (39), and the fact that water velocity at the bypass entrance was slow (3-4 cm/s), while velocity at the light barrier was much faster

(15-20 cm/s). Average flow at the Dietfurt station was 16m^3/s, and river width was approximately 110 m. Hadderingh and Smythe (1997) recommended placing light barriers at a small angle between the light barrier and the direction of flow (i.e., river axis) to enhance diversion effectiveness, so that when eels recoil from the angled line of lights, they are directed toward the entrance to a bypass.

Table 6-2. Reaction of silver eels to light from three kinds of lamps in an experimental flume (Source: Hadderingh and Smythe 1997)

Kind of Lamp	Illumination (lux)	Water Velocity (cm/s)	Number Eels			Statistical Probability (p–value)	Diversion Percentage (%)
			Total	Dark Compartment	Illuminated Compartment		
Incandescent	10.4	10	20	18	2	≤0.001	80
	10.4	44	19	13	6	n.s	37
	1.4	10	42	33	9	≤0.001	57
	1.4	22	22	19	3	≤0.001	73
	1.4	33	22	14	8	n.s	27
	1.4	44	21	16	5	≤0.025	52
Fluorescent	1.5	11	33	30	3	≤0.001	82
	1.5	33	67	47	20	≤0.001	40
	1.5	44	69	44	25	≤0.025	28
	1.5	11	40	34	6	≤0.020	70
	7×10^{-3}	11	40	35	5	≤0.020	75
Strobe	80×10^{-3}	11	70	65	5	≤0.020	86
	3×10^{-3}	11	40	29	11	0.020	45

Table 6-3. Reduction of the passage of silver eels using light barriers at thermal and hydroelectric power stations and at commercial eel fisheries (Source: Hadderingh and Smythe 1997)

River	Year	Location	Water Velocity (cm/s)	Kind of Lamp	Number of Nights (Total Eels)	Deflection
Bergum (lake)	1987	Bergum thermal power station	30	incandescent + high pressure mercury	10 (6,030) 10 (610)	51% 25%
Vecht	1988	Haandrik hydropower station	59	incandescent + high pressure mercury	12 (543)	66%
Regge	1988	commercial eel fishery	0-60	incandescent	52 (3,021)	85%
Regge	1989	commercial eel fishery	0-60	incandescent	12 (194)	76%
Vecht	1990	commercial eel fishery	0-60	incandescent	126 (2,356)	73%
Amer	1995	Amer thermal power station	50	fluorescent	17 (513) 17 (308)	62%* 74%**
Altmüh	1996	Dietfurt hydropower station (Germany)	20	fluorescent	1 (39)	8%

* yellow eels
** silver eels

Hadderingh et al. (1999) reported other positive diversion results from laboratory studies with silver eels. Eels were captured in fyke nets and maintained in the laboratory with a controlled natural photoperiod for four months before experiments were initiated. The fluorescent lamp used (36 WE, Pl-L Philips) emitted light ranging from approximately 350 nm to 725 nm, with peaks at 360, 410, 430, 540, and 620 nm. In the same flume described previously (Hadderingh et al. 1992), 50% to 65% of silver eels could be diverted at an illumination level of approximately 0.003 to 0.005 lux, and 75% of silver eels preferred the swimming route that offered the fastest water velocity (25 cm/s). When eels were offered choices among combinations of velocity and illumination, the tendancy to avoid light was stronger than the attraction of the faster water velocity, although the efficiency of diversion was less at the faster velocities (e.g., 50% diversion from the test channel with faster velocity). The authors noted that the magnitude of diversion in these studies was less than in their previous work. One factor that may have lessened diversion efficiency was the configuration of the test chamber (i.e., the short distance between location of release of the eels and the entrance to the chambers between which the eels had to choose). The authors noted that eels probably would pass through a light barrier extending across a downstream migration route in a current after multiple encounters with it. They recommended a small angle (approximately 25º) between the light barrier and the direction of flow (i.e., river axis) in order to deflect a reasonable proportion of eels to a bypass at the end of the barrier.

Cullen and McCarthy (2000) reported the effects of lighting on migratory movements of silver eels at the Killaloe eel weir in the lower Shannon River, Ireland, during the silver eel fishing seasons of 1992–1993 and 1993–1994. The weir consists of a metal walkway that supports a series of steel wattles and hydraulic frames; the wattles and frames are used to set and lift a series of nets. Circular nets with a circumference of 10 m and a length of 8 m are mounted on square frames. Up to 34 nets may span the river, each set in one of the eleven arches comprising the weir support. Water at the weir is approximately 3.2 meters deep, and the river is approximately 440 m wide at that point. Arch 3 in the weir extends over a navigational channel that is illuminated by 2, 400-W, sodium spotlights mounted approximately 4 m above the water's surface. These spotlights facilitate nighttime boat traffic, which the nets do not impede. Catches were monitored, and the distribution of catch across the arches was documented with and without lights. Figure 6-4 shows a decrease of approximately 50% in eel catch in the navigation channel when the lights were on. The data plotted are percentages of the total catch of eels during a season. The decrease in the percentage captured at Arch 3, therefore, is equal to the sum of the increases in catch at other arches (i.e., 1, 2, 5, and 6). No data were presented on wavelengths emitted by the sodium spotlights, but such lights typically produce predominantly yellow light. No data were presented on light intensity at or beneath the surface of the water.

6.2.3 Studies That Showed Little or No Response

In contrast with results suggesting that light may be an effective technology for diverting eels, Adam and Schwevers (1997) found that silver eels did not avoid strobe lights in an experimental channel. Their "hydraulic channel" was 30 m long, 2.0 m wide and 1.2 m deep. Water was maintained at a depth of 0.75 m. Maximum flow through the channel was 950 l/s, which generated a maximum velocity of 0.63 m/s. They used a xenon lamp strobing at the rate of 150 flashes per minute. Eels 60 to 70 cm long were caught by a professional fisherman or by electrofishing and maintained in the laboratory. The investigators reported that the eels did not react to the strobe light and that some individuals lingered in front of the lamp at eye level. The authors offered no definitive explanation for the failure of the xenon strobe to elicit the strong response observed in other cases (Lowe 1952; Hadderingh et al. 1992), nor did they discuss how the experimental conditions may have influenced the eels' behavior. They speculated that the failure of the light to induce an avoidance response was due to the shift in spectral sensitivity of eels' eyes to enhanced perception of blue wavelengths that occurs during metamorphosis. Another possible explanation is that the flash rate was too slow to elicit a response. Studies of the responses of gizzard shad to strobe lights set at different flash frequencies ranging from 50 to 1000 flashes/minute revealed that avoidance response occurred only when the flash rate exceeded 200 flashes/minute (P. Patrick, pers. comm., 2007).

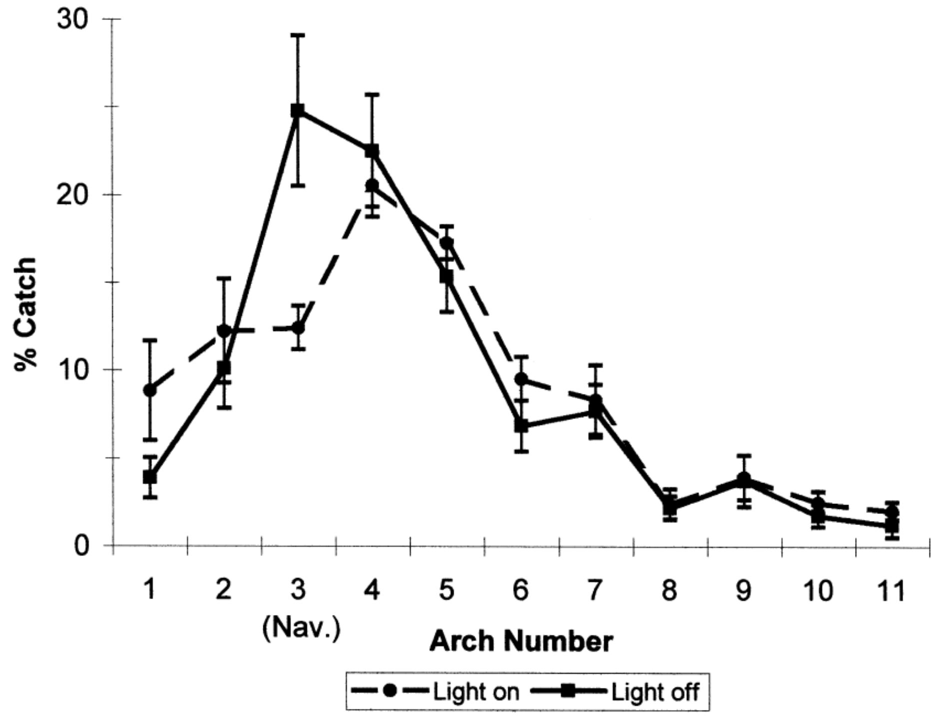

Figure 6-4. Average percentage (±1 SD) of daily catch of eels recorded at 11 arches at the Killaloe weir without lights at the navigation arch (1992–1993 season) and with lights at the arch (1993–1994 season). The navigation arch (Arch 3) is marked 'Nav.' on the x-axis of the graph (Source: Cullen and McCarthy 2000).

Schultze (1989; as cited in Thon 1999), also reported no response of silver eels to strobe light in an experimental flume. If eels' responses to light vary with the changes in the size of their eyes and the spectral sensitivity of the rods that occurs during metamorphosis, recording and reporting eye diameter in future behavioral studies would allow spectral sensitivity to be evaluated in investigating discrepancies in experimental results. Many telemetry studies have noted that eels in the silver stage are especially sensitive to capture and handling (e.g., Haro and Castros-Santos 1997 and Section 8 of this report). Stress due to handling during experimental procedures could influence eels' response to light in laboratory studies. Some eels in the study conducted by Adam and Schwevers (1997) were taken by electrofishing, which could cause considerable stress. Reynolds and Hollman (2004) documented extensive injury among electro-shocked eels and suggested that this species is at high risk for injury because of its large size and many vertebrae.

Hadderingh et al. (1992) reported that Berg (1985) experimented with underwater lights at a hydroelectric station in the river Neckar, a tributary of the Rhine. Thirty-three lamps were installed at different depths at the intake of a newly installed turbine. In this case, the light barrier was not successful, probably because, in the author's opinion, the lamps were placed too close to the intake, and the light levels produced by the lamps were too low. No further details were available about Berg's study or the site. Halsband (1989 as cited in Thon 1999) attempted to guide silver eels away from the turbines at a hydroelectric facility using a light barrier of 20, mercury-vapor lamps (500 W each) suspended above the water but apparently was unsuccessful. Therrien and Verreault (1998) reported a low percentage of diversion for a light diversion array at a small hydroelectric facility (3.74 MW) on the Rimouski River, a tributary of the St. Lawrence River. The light array was placed behind trash racks such that the vicinity of the trash rack was illuminated to approximately 20 lux, and a small bypass (0.3 m by 0.6 m) provided for passage around the single turbine entrance. The percentage of eels diverted to the bypass when the light system was operating ranged from 0% to 12.5%. The authors speculated that this low effectiveness may have been related to the fact that flow was abnormally low and provided very low bypass attraction flows. They also noted that the lights were positioned such that dark areas occurred in some portions of the trash rack, providing possible passage routes through the racks. The very small size of the bypass opening also could have been a contributing factor.

Thon (1999) concluded that barrier systems based on light are ineffective at hydroelectric power plants. The fact that several studies demonstrated their potential effectiveness and that some did not work due to deficiencies in their deployment suggest that Thon's conclusion may be incorrect. Hadderingh et al. (1999) suggested that a row of underwater lights (e.g., a light screen) could be used to deflect eels in the direction of a bypass, but that deploying the screen such that the angle between it and the direction of flow (i.e., the river axis) is as small as possible (approximately 25°) is very important. Such a small angle would allow eels to respond to the light and still take advantage of the directing water current. The researchers also noted that the depth and dimension of the entrance to the bypass should correspond to the position of the eels in the water column. Lowe (1952) demonstrated that the effectiveness of lights for altering eels' movements decreases substantially with decreasing water clarity.

6.3 NYPA'S PROOF-OF-CONCEPT STUDY OF LIGHT AVOIDANCE

EPRI's (2001a) review suggested that light and infrasound appeared to be capable of altering the movement patterns of outmigrating eels and that the most substantial body of literature supported the effectiveness of light. Based in part upon EPRI's review and consultation with the Eel Working Group (EWG), NYPA initiated studies to examine if a light system might be useful for concentrating eels so that they could be collected to be passed or transported downstream of Moses Saunders Power Dam. Initial investigations were conducted in an enclosure constructed in an ice sluice downstream of the dam. Underwater lights were deployed at one end of the enclosure, and the responses of eels to light were recorded with and without the underwater light. Test specimens were from the downstream commercial fishery. They were transported a considerable distance before being used in the study; consequently, they experienced the stress of capture in the commercial fishery, transportation, then handling during the actual study when transported from holding tanks to the test facility. In this preliminary study, light did not alter the behavior of eels, but the researchers concluded that other factors (e.g., the stress of handling and holding, noise from dam operations, slight water currents in the enclosure) may have influenced the eels' behavior (K. McGrath, NYPA, pers. comm.).

NYPA conducted a much larger proof-of-concept study of light guidance in 2002 (McGrath et al. 2005). The objective of the study was to determine if naturally outmigrating eels in the St. Lawrence River avoid artificial light. The light array used in the study included underwater lights suspended from an 80-m floating platform set at an angle of 30º to the direction of current in the St. Lawrence River above Iroquois Dam (Figure 6-5). Eighty-four, 1,000-W, halogen lights were attached in groups of 3 to 28 poles. Poles were 7.9 to 10.7 m long; the length of the pole depended on bottom depth at the pole's location. The array was designed to create a "wall of light."

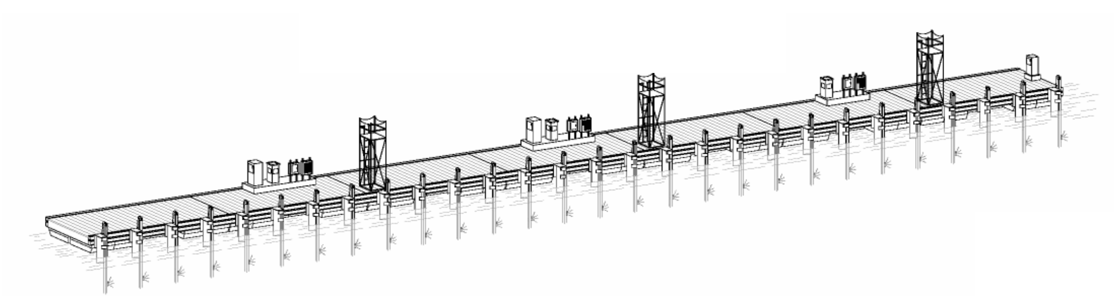

Figure 6-5. Diagram of the light platform used in NYPA's light-avoidance study illustrating the segmented construction, location of power connections and observation towers, and light poles extending underwater to the river bottom (Source: K. McGrath, NYPA)

The light platform was anchored in an area approximately 9 m deep where river velocities were 0.6 to 0.9 m/s. Figure 6-6 illustrates the change in intensity of the light field generated by the light array with distance. At 1 m from the platform, the maximum light intensity was 7,994 lux (immediately in front of lights), and the minimum was 105 lux (between the poles). At a distance of 10 m from the platform, the light was less intense and more diffuse, measuring a maximum of 196 lux and a minimum of 148 lux. The lamps and the voltage of the power supply were selected to emit wavelengths of 450 to 550 nm, corresponding to the peak spectral sensitivity of silver eels' eyes (Andjus et al. 1998). Maintaining consistent voltage was critical because changes in voltage can change the emission spectrum of a light (K. McGrath, NYPA, pers. comm.). Turbidity of the water at the study site was low and relatively constant over the course of the study, at approximately 0.4 NTU (Nephelometric Turbidity Units).

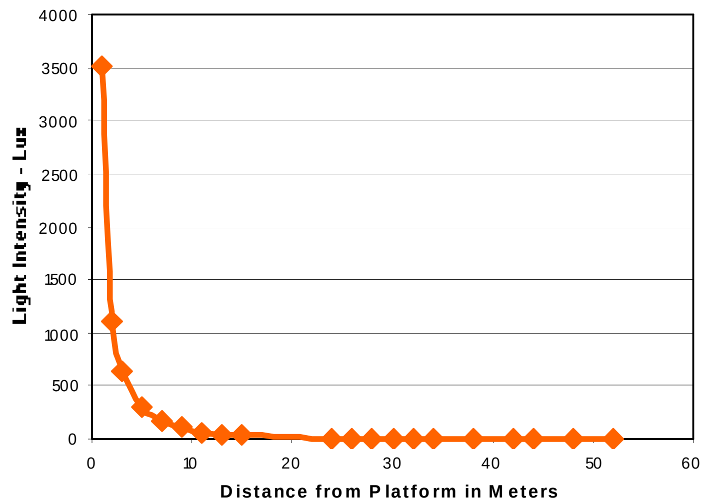

Figure 6-6. Light intensity as a function of distance from the light barrier (Source: K. McGrath, NYPA)

Stownets, which are modified, anchored mid-water trawls, were employed in this study. Two different net configurations were employed, with nets strategically positioned parallel to each other across the river, downstream of the platform, so that the one directly downstream of the platform would collect eels that passed through the light array and the other(s) located downstream of the end of the platform or further from the platform end would collect eels that avoided or were guided away by the light. In the first configuration, the Treatment Net was anchored directly downstream of (i.e., behind) the platform, and Deflection Net 1 was anchored at the downstream terminus of the platform, adjacent and parallel to the Treatment Net but not behind the barrier. These two nets were in place for the entire study period, (July 24 to September 17). In the second configuration, a third net (Deflection Net 2) was installed adjacent and parallel to Deflection Net 1 and, thus, farther from the light field. This three-net configuration remained in place from August 20 through September 17. During the study, eels were captured under two conditions: lights OFF (control), and lights ON (treatment). These two conditions were alternated randomly throughout the study period. The data from the two-net configuration for the period July 24 to September 17, and the data for the three-net configuration for the period August 20 to September 17 were analyzed separately. The two-net trials consisted of 28 random control replicates (lights OFF) and 25 treatment replicates (lights ON); trials with three nets consisted of 14 replicates of each condition. Trials performed on July 25 and 28 were excluded from the analysis because of logistical difficulties with the gear. The standard unit of fishing effort during each trial was one "trap-night."

Table 6-4 presents the numbers of eels captured with the two-net configuration. Table 6-5 presents the numbers of eels captured with the three-net configuration. In addition to the eels captured in the nets, the responses of 111 eels to the light field were observed visually and documented.

Table 6-4. Total number of eels captured per net with the two-net configuration from July 24 to August 19, 2002

	Number of Eels Captured		
Conditions	**Treatment Net**	**Deflection Net 1**	**Total**
Control – Lights Off (28 Replicates)	30	134	164
Treatment – Lights on (25 Replicates)	6	57	63

Table 6-5. Total number of eels captured per net with the three-net configuration from August 20 to September 17, 2002

	Number of Eels Captured			
Conditions	**Treatment Net**	**Deflection Net 1**	**Deflection Net 2**	**Total**
Control – Lights Off (14 Replicates)	13	64	25	102
Treatment – Lights on (14 Replicates)	2	41	36	79

The estimated overall probability of avoidance of the lights was 77.6% with the two-net configuration and 84.6% with the three-net configuration. These probabilities are not statistically different ($P > 0.10$). The three-net array provided additional information about the movement of eels in response to light. Comparing the mean number of eels captured in Deflection Net 2 during control periods (lights OFF; 25 eels) and treatment periods (lights ON; 36 eels) reveals that 44% more eels were captured when lights were on than when lights were off. A similar comparison for Deflection Net 1 shows a very different result. Sixty-four percent fewer eels were captured when the lights were on. The light array appears to have deterred eels from entering both the Treatment Net positioned directly downstream of the light array and, to a lesser degree, Deflection Net 1 positioned at the downstream terminus of the light array. In contrast, eels deterred from entering the other two nets were being deflected further away from the platform and collected in Deflection Net 2.

During the latter portion of the study, trained observers were stationed in towers spaced along the length of the light platform to observe and document eels' movements. Observations of behavioral responses were expected to contribute to interpretation of net-capture data. Visual observations were possible because of the clarity of the water at the study site. Eels were observed as they approached the light array during the treatment condition (lights ON). No observations were possible during the control condition (lights OFF). Eels' behavior was classified into one of three categories:

- Deflected Away: Eels moving downstream entered the field of light as they approached the light platform, then turned and swam away from the platform, across the direction of the current.
- Deflected Parallel: Eels moving downstream entered the field of light approaching the light platform, then turned and swam parallel to the light field, now moving at a 30^o angle to the direction of current, until they reached the downstream terminus of the platform.
- Through: Eel entered the field of light and went through the light array.

Twenty-six (23.4%) of the 111 observed eels were deflected away, 68 (61.3%) were deflected parallel, and 17 (15.3%) passed through the light array. The combined percentage of eels visually observed to be deflected (84.7%) is consistent with the percentage deflection documented from the net captures. Most of the eels that were deflected away altered their course at a distance of 5 m or more from the light platform. Most of the eels that were deflected parallel maintained a distance of at least 5 m from the platform. The range of visibility was approximately 22 m, and eels were observed moving away from or parallel to the array even at that distance. Based on data shown in Figure 6-6, eels responded to light intensities of approximately 250 lux at 5 m from the array and to very low intensities, perhaps fractions of a lux, at the 20 m distance.

6.4 OVERVIEW

Most of the studies summarized here demonstrate that eels respond to light fields and tend to avoid light, although not necessarily in a consistent manner. Lowe (1952) conducted some of the most comprehensive field studies ever performed, and the extensive work by R. Hadderingh and colleagues expanded upon Lowe's and others' work to explore the potential of light barriers for protecting eels from injury or mortality caused by passing through turbines. Most of the studies reviewed were conducted in very small streams and rivers and at specific facilities (e.g., a power plant intake) where the objective did not require preventing all eels from moving through a system. Some laboratory studies confirmed that eels will avoid light, but eels' behavior in laboratory flumes was inconsistent and often was influenced by other stimuli in the test chambers, which raises questions about the applicability of laboratory observations for designing systems for use in the field. NYPA's proof-of-concept study of light avoidance was the only one performed in a large, unconstrained river system, and the only one that used a surface-to-bottom light field in deep water.

NYPA used light sources that produced the highest luminous intensities reported and was the only field study in which light intensities in the vicinity of the light array were rigorously quantified. Most of the field studies did not document the spatial dimensions of the light fields generated by the light arrays. Luminous intensity would have decreased with increasing depth in the water, but most researchers did not measure luminous intensity below the surface. Most studies documented that light at very low intensities or fields generated by very low wattage sources elicited avoidance responses among eels. On the whole, the literature suggests that very dim light can elicit avoidance responses.

Multiple studies confirmed that water velocity influenced how eels would or could respond to light fields such that light was less effective for diverting eels in the presence of swift flows. In some field studies, however, this observation was confounded by the fact that water turbidity increases with increased river flow, and increased turbidity decreases the effectiveness of light for diversion. In many studies, researchers felt that eels may not have had sufficient time to respond to light barriers because of high flow velocities and the distance at which an avoidance response is required to achieve effective diversion (e.g., Hadderingh et al. 1999). High flow velocities in combination with swift downstream movement of the eels as they approached a barrier afforded the eels less time to move to avoid a light array. Another possible interpretation of this phenomenon is that a strong behavioral attraction to higher velocities (Section 4) overrides some of the repelling effect of light. All studies consistently indicated that the angle of the light field relative to the direction of flow influenced the efficiency of diversion. Arrays positioned perpendicularly to the river axis had a temporary, if any, affect on eels' movements, and arrays at shallow angles to the river axis generally were the most effective (e.g., Hadderingh et al. 1999); however, some studies reported that longer arrays, which would be the result of shallow angles, were less effective for diverting eels (e.g., Lowe 1952). Such a response could be caused by habituation of the eels to the light field over a somewhat extended exposure.

6.5 FEASIBILITY OF USING A LIGHTED GUIDANCE STRUCTURE AT IROQUOIS DAM

NYPA's request for proposals posed questions regarding each of the technologies and required responses to be drawn from review findings. NYPA posed the following questions regarding light guidance technology:

- **Are there regulatory, engineering, or environmental encumbrances that would preclude deployment of a light array at Iroquois Dam?**

Regulatory Issues – NYPA's Kevin McGrath and Tom Tatham discussed the status of American eel populations in the St. Lawrence River watershed and the concept of installing a collection facility at Iroquois Dam with Mr. Mark Colosimo, United States Section Engineering Advisor for the International Joint Commission (IJC), in May, 2007, to determine if the IJC would have any concerns about construction of passage facilities and to identify permitting requirements or restrictions. Mr. Colosimo indicated that the IJC would be concerned only if any modifications of Iroquois Dam associated with passage facilities would affect flows or water levels or could cause flooding; otherwise, the IJC would have no issues. He noted that if a project proceeds to the design stage, NYPA will have to advise the St. Lawrence River Board of Control of the plans and request a review and opinion. A waterway permit from the United

States Army Corps of Engineers (USACE) would be required for any facility constructed in the St. Lawrence River within United States waters (most of Iroquois Dam is in U.S. waters). The United States Coast Guard (USCG), Ninth District Office, Cleveland, Ohio, is responsible for the Great Lakes Region and the St. Lawrence River (Mr. Doug Sharpe, USCG, pers. comm.). A copy of an application for a permit filed with USACE for any structure proposed for the St. Lawrence River should be submitted to the USCG for review. The USCG's review would focus on determining if the proposed structure would impede navigation and on the kind of lighting to be used to mark the structure. USCG would submit its comments and recommendations to the USACE for inclusion in the required permit.

Engineering Issues **–** Construction of a lighted structure for diverting eels to a capture device at Iroquois Dam poses many engineering challenges. High water velocities, the large load of debris from submerged aquatic vegetation, and the large size of such a light array all are factors to be accounted for in the design and in estimates of the capital and operational costs of such a project. Kleinschmidt's (2006) conceptual design for a lighted guidance structure in the St. Lawrence River is useful for illustrating how conditions at Iroquois Dam influence the design and cost of such a structure. The design details presented here are taken directly from Kleinschmidt's (2006) white paper. The conceptual design is the same as for the physical barrier discussed in Section 3.4 and illustrated in Figure 3-17: angled arrays of lights deployed at 15º, 30º, and 45º to river flow in a V-shaped configuration with its vertex pointing upstream and its arms terminating at sluiceways containing collection facilities. The lengths of the arrays deployed at each of the three proposed angles would be the same as indicated for the physical barriers.

This device would cover the entire water column and consist of lights mounted on a framework spanning the distance between each support pier. The number of lights required to provide a complete wall of light was estimated based on a modeling exercise, and the conceptual design assumes the use of halogen lights. A trash rack would prevent large debris from damaging the lights. The conceptual design assumes an average water depth of 14 m. Piers to support the structure would be spaced at 18-m intervals, and the structure would include an 8-m-wide deck to provide acess to equipment and the trash rakes.

Kleinschmidt (2006) identified several advantages and disadvantages of its proposed light barrier. The barrier would span the entire river (except for sluiceways that may have to remain unblocked to allow for recreational boating traffic), but it would not interfere with commercial navigation on the St. Lawrence. NYPA's proof-of-concept study demonstrated that migrating eels in the St. Lawrence River exhibit an aversion to light; however, the effectiveness of a light system for directing eels on a large scale has not been demonstrated and tested. Downstream migrants from Lake St. Lawrence and Lake St. Francis would not be collected using the light barrier at Iroquois Dam. The severity of debris loading is unknown, but the presence of SAV could significantly and regularly impede the effectiveness of lights for diverting eels. Lights would be effective only at night (approximately 75% of the eels move at night). Maintaining lights would be very labor intensive. Lights could attract some nontarget species and affect bycatch, and biofouling by zebra mussels could substantially increase the cost of operation and maintenance.

Constructing a light array as described above is feasible but would be even more complex than constructing a physical barrier (Section 3.4). Designing the lights and other electrical components would require significant research and development because no suitable "off the shelf" components exist at this time. Research on the characteristics of debris loading would be needed, and an appropriate debris handling system would need to be designed to minimize turbidity and keep the lights functional. The time frame for construction would be similar to that described for the physical barrier.

Kleinschmidt (2006) calculated capital costs as cost per linear meter and then extrapolated based on the length of the structure. More details on cost are provided in Appendix A of Kleinschmidt's report. Annual operation and maintenance costs consider that the panels of the light array would be removed each year to avoid ice damage and reinstalled after the threat of freezing has passed. Annual costs also include daily operation and electricity. Depending on the size of the structure, four to eight full-time employees would be required to operate it. Table 6-6 shows the total estimated costs for installation and operation and maintenance of a light array and two traps[32] at Iroquois Dam. For consistency of comparison among the different technologies evaluated in this report, the 2005 Canadian dollar cost values in Kleinschmidt's report (2006) were converted back to U.S. dollars using an exchange rate of 1.23 (Canadian/U.S.) and adjusted to 2007 dollars using a multiplier of 1.06.

Table 6-6. Estimated costs (2007 U.S. dollars) of installing and operating and maintaining a V-shaped light array to guide eels at Iroquois Dam for three possible angles of installation in relation to river flow (Source: Kleinschmidt 2006)

Angle (length in meters)	**Cost of Installation***	**Annual Cost of Operation & Maintenance**
15º (2,120)	$242,895,122 ± 50%)	$ 8,773,008 ± 50%)
30º (1,098)	$132,508,618 ± 50%)	$ 5,575,772 ± 50%)
45º (776)	$97,166,667 ± 50%)	$ 4,610,569 ± 50%)

*Costs adjusted to 2007 U.S. dollars.

As part of the current project, Alden, Inc., (2007) reviewed the conceptual design and cost estimates presented by Kleinschmidt (2006). Alden concurred that the light array should include a trash rack to protect the lights from large debris and recommended spacing bars at 30.5-cm intervals and removing both the light array and the trash rack each winter to limit ice damage. A hydraulic study would be needed to determine the potential for the structure to create ice jams. Alden generally agreed with the overall magnitude of Kleinschmidt's cost estimates but could not comment on the estimated cost of lighting units because of lack of familiarity with the kind of lights proposed. Alden considered the estimates of the costs of operating and

[32] Kleinschmidt (2006) estimated cost for a single trap at $4.8 M (2007 U.S. dollars); Section 8.2.4.3 of this report presents an estimate of the cost to install a modular inclined-screen trap at Iroquois Dam ($12.6M in 2007 U.S. dollars).

maintaining the light array and trash rack to be reasonable. Kleinschmidt's (2006) estimate included the cost to replace lights three times a season; however, estimated costs did not appear to include replacing other components, which would include periodically repairing or replacing major components such as trash racks, trash rakes, cranes, transport vehicles, etc. Alden recommended including the cost of replacing major components every 10 years, which would significantly increase the estimated operation and maintenance costs.

Environmental Issues – The primary environmental issue is the possibility that a large light barrier would adversely affect aquatic species other than outmigrating eels or immature yellow eels that may be moving upstream in the vicinity of Iroquois Dam. Diverting non-target species into a collection facility from which they would have to be removed and sorted before release could cause handling stress and mortality, as well as alter their normal behavior and movement patterns. Lights might attract non-target species, altering their natural behavior and making them more vulnerable to predation. For example, in studies conducted in the forebay of the Nanticoke Fossil Plant, large numbers of juvenile gizzard shad were attracted to mercury vapor lights (Haymes et al. 1984). A large nocturnal light field conceivably could affect the behavior of insects and birds as well as fish. The likelihood of such effects cannot be predicted because an underwater light barrier of the size considered here has never been installed anywhere in the world.

- **In a general sense, what are the prospects that light can be used to guide eels to a collection facility on the St. Lawrence River in the vicinity of Iroquois Dam?**

NYPA's proof-of-concept study is the only research that provides information that is directly relevant for evaluating the potential efficacy of light barriers for guiding eels' movements at Iroquois Dam. No other study was conducted in an environment comparable to the upper St. Lawrence River, and eels' responses in laboratory flume studies do not appear to reliably represent their responses in field situations. NYPA's light barrier elicited responses among and altered the downstream migration path of most migrating eels that encountered the barrier; however, the barrier did not ensure that all eels moved in a particular direction or to a specific location. The reported 77.6% to 84.6% diversion represented responses to an 80-m long platform/light field, at a 600-m-wide location in the river. The eels' downstream path was shifted laterally to a maximum distance of approximately 80 m (the width of the two deflection-net wing openings). The results could be interpreted as a demonstration that eels can avoid an obstacle in their path, which is quite different than guiding eels in a specific direction over a long distance. Despite uncertainty about the many factors that could influence the diversion efficiency of a light barrier, theoretically light could be used to guide eels to a collection facility, but the distance over which their movements can be altered effectively cannot be predicted.

- **What configuration (angled to the flow or perpendicular) of an array would be most appropriate based on the information collected?**

All the field studies reviewed indicate that a light barrier deployed at an angle to the direction of flow is more effective than a perpendicular barrier for directing eels to or away from a particular location. Based on his numerous studies, Hadderingh recommended an angle of 25º to the direction of flow; however, he did not do an exhaustive study to determine how diversion percentage would vary with barrier angle. Lowe (1952) reported highest effectiveness for a 35º angle to flow.

- **What intensity of light and what wavelength would work best to guide eels?**

The studies reviewed documented that most eels were diverted by light at a wide range of intensities, often as dim as a fraction of a lux. The literature lacks comprehensive quantitative measurements of light intensities as a function of distance from the source especially in the vicinity of the areas from which eels were to be diverted. Secondly, the units of measurement are not precise; all studies measured lux or illuminance (engineering unit) rather than quantum flux ($uE/m^2/s$), which is a more meaningful measurement for assessing the response of aquatic organisms to light.

Generally, the distance at which eels are first able to detect light would increase with increasing intensity of the source. Lights of high intensity would appear to be most appropriate for creating barriers in large bodies of water. Despite the shift in the spectral sensitivity of eels' eyes to the blue range as they become sexually mature, the fact that lights emitting a relatively broad range of wavelengths were shown to affect eel behavior suggests that specific wavelengths may not be critical within the range of 450 to 550 nm, except perhaps in terms of light penetration through the water column.

- **Would habituation to light be a problem and under what circumstances? Can habituation be prevented or minimized and, if so, how?**

Lack of response to light fields in the laboratory in some studies suggest that eels may become habituated to the light (e.g., eels remaining in the vicinity of strobe lights in Hadderingh's studies); however, none of the reviewed field studies investigated habituation or discussed the topic specifically. One means of addressing this question is to use data from existing studies to estimate the length of time during which migrating eels might be exposed to light from a barrier.

NYPA's telemetry studies in the vicinity of Robert Moses Power Dam (McGrath, 2007) documented eels moving downstream at approximately 0.4 m/s faster than the velocity of the water. Water velocity above Iroquois Dam in the vicinity of the light barrier platform is approximately 0.6 to 0.7 m/s; therefore, eels would be expected to move downstream through this area at an average speed of approximately 1.0 m/s. Habituation would occur only if eels were to remain exposed to a continuous level of light for some period of time. Kleinschmidt's (2006) conceptual design for a light barrier at Iroquois Dam described the lengths of the legs of a V-shaped barrier for different configurations. Based on existing studies, the configuration in which the legs of the V are positioned at a 30º angle to the direction of flow could reasonably be expected to be effective. Such a barrier would have legs measuring 539 m long. An eel's rate of downstream movement might be somewhat slower as it moved at an angle to the leg of a barrier, but assuming the average rate of 1.0 m/s even while moving cross-current at some set distance from the barrier, an eel would take approximately 9 minutes to travel the length of the 539-m barrier leg. Habituation would be unlikely in such a short period of time. If eels were to habituate to the dimmer light at some distance from the source, the increasing gradient of luminous intensity as eels moved closer to the source probably would counteract the tendency toward habituation. Barriers at greater angles would reduce the rate of downstream movement (i.e., a major portion of the eels' swimming speed would be directed laterally), which might afford greater opportunity for habituation. No studies documenting habituation rates of silver eels' eyes to light were identified during the literature search for this report.

- **What guidance efficiency would be expected and under what conditions?**

No light barrier of the size that would be required at Iroquois Dam has ever been constructed, nor has the effectiveness of light barriers been studied thoroughly under the prevailing conditions in the St. Lawrence River (e.g., high velocity, high debris); therefore, the guidance efficiency of such a structure cannot be estimated reliably. NYPA's proof-of-concept and telemetry studies provide information that can be used to speculate about potential guidance efficiency. Such an informed speculation can account for various factors that could influence guidance efficiency but, nevertheless, is still only a back-of-the-envelope assessment based on a very simple spreadsheet model. The spreadsheet accounts for day-night migration percentage, guidance efficiency as a function of barrier length, and the anticipated length of a barrier at Iroquois Dam.

NYPA's telemetry studies in the vicinity of Robert Moses Power Dam documented that approximately 75% of eels passing downstream move at night; therefore, the maximum percentage of migrating eels available for diversion by light barriers would be 75%. In NYPA's proof-of-concept study in the St. Lawrence River, the avoidance attributable specifically to the 80-m long "wall of light" was on the order of 78%. If this avoidance could be maintained for an extended period of time (i.e., 8-10 minutes without habituation) and over an extended distance (539 m, the length of an arm of the conceptual barrier), a surface-to-bottom "wall of light" might be capable of diverting 78% of night-migrating eels, or 58.5% (75% X 78%) of the total migrating population.

The percentage of eels that would be diverted by a light barrier might be expected to decrease (i.e., decreasing diversion efficiency) with increasing length of the barrier due either to habituation or to increased motivation to move downstream as the eel is diverted from it's preferred downstream path. Specifically why 22% of the eels were not diverted by the NYPA light barrier is not known. Assuming that eels moving downstream are distributed homogeneously across the width of the river as they approach a barrier, 78% of eels that encounter each 80-m section of the barrier would be diverted to the next 80-m section downstream, and so on across the length of each arm of the barrier; consequently, the group of eels that encountered the furthest upstream sections of the barrier might be expected to exhibit a cumulative decrease in percentage diversion as they continued downstream along the barrier. Assuming an inverted-V barrier with legs 539 m long positioned at a 30º angle to the direction of flow, seven 80-m sections would be required in each arm of the structure to span the river at Iroquois Dam. Simple calculations based on these assumptions and the observation that only 75% of eels move at night suggest that the diversion efficiency of the total structure would be on the order of 13%.

Based on these very rough calculations and the limited information available from NYPA's proof-of-concept study, the percentage of all eels migrating down the St. Lawrence River at Iroquois Dam that might be diverted by a light barrier similar to Kleinschmidt's conceptual design might be somewhere between 13% and 58.5%.

- **What would be the relative efficiency by having lights low in the water column (guiding eels toward surface) compared to lights high in the water column (guiding eels toward bottom)?**

The 600-m width of Iroquois Dam implies that simply shifting the vertical position of eels' path up or down in the water column would not reduce the required size of a diversion barrier (i.e., if a system moved eels to near the surface, capture structures still would be required at all 32 gates). The potential for a capture system at the dam might be greater if lighting most gates would divert eels through a few unlighted gates into a collection system. Assuming that strategy, the relevant question would be if bottom-mounted or surface-mounted lights are capable of diverting eels laterally from a cluster of lighted gates to an unlighted gate or gates.

No information is available from which to deduce how eels moving through the entire water column in water approximately 10 m deep would respond to a light gradient being emitted from the river bottom or the water surface. Some of the studies reviewed in this report employed lights mounted on the river bottom and pointed upward, or suspended above the water surface and pointed downward, rather than suspended in the water column as in NYPA's proof-of-concept study. The benefit of surface-mounted and bottom-mounted configurations is that the amount of structure in the water column that could be susceptible to fouling by floating and suspended debris would be minimal. Observed diversion in response to both bottom-mounted and surface-mounted lights shows that the direction from which light is emitted may not be a critical feature of an effective light array; however, the waters in which those studies were conducted were much shallower than the St. Lawrence River at Iroquois Dam (i.e., approximately 10 m). Hadderingh conducted one light diversion project in which maximum depths were 3 m, the greatest depth in all of the reviewed studies. Bruijs et al. (2007) described a bottom-mounted, fluorescent light barrier proposed for use on the Meuse River. A firm in the Netherlands has initiated a study of such an underwater light system using strobing LED lights, a source that has not been tested previously (M. Bruijs, pers. comm., 2007). Both bottom-mounted and surface-mounted lights could be effective in directing eels away from the light source. The magnitude of the diversion of the eels' migration path (i.e., how far vertically or laterally it might be shifted) probably would depend on the intensity of light at various points within the water column. It is interesting to note that Lowe (1952) obtained her highest diversion rates in one test series in which lights were pointed upstream. No other studies have investigated the relative effectiveness of different orientations of the individual lamps within a light array, but directing lights upstream might enhance the diversion effectiveness of a light barrier deployed at Iroquois Dam.

Most of the studies and the professional opinions of experienced researchers indicate that light barriers that extend across water bodies perpendicular to river flow are relatively ineffective at stopping downstream movement of eels, particularly at relatively high river flows. Cullen and

McCarthy (2000) showed, however, that illuminating a portion of the downstream migration path could shift eels laterally to other sections of that path. Illumination was provided by 2, 400-W, sodium spotlights mounted approximately 4 m above the water's surface (width of the river and depth were not provided in the paper). The effectiveness of such a system at Iroquois Dam would depend on light intensity, the width of the light field, and water velocity. Eels would have to be able to detect the light field at a sufficient distance to allow them to move laterally to avoid it. Considering these factors, the concept of illuminating a subset of gates at Iroquois Dam and leaving other gates darkened appears to have potential for concentrating downstream migrating eels at certain gates and could be studied easily. The major question is how many of the 32 gates could be illuminated before the width of the light barrier becomes so large that eels are unable to move laterally to avoid it and pass through instead.

- **How would guidance efficiency be affected by current velocity and/or angle of a light array?**

Several studies have suggested that the effectiveness of light barriers decreases as flow velocity increases. One possible explanation for that result is that eels moving at higher velocities have less time and space (i.e., distance from the source) in which to respond to the light field after first detecting it. Visual observations of eels moving into the light field in NYPA's proof-of-concept study showed that the greatest percentage appeared to move along a trajectory over which the light intensity would be expected to remain fairly constant (i.e., maintain a constant distance from the light source). Those eels had to move only a relatively small distance laterally to remain at the preferred light intensity level when the barrier was placed at a 30º angle to the current. A barrier at a much larger angle to the direction of the current would require eels to move laterally at a greater speed and simultaneously to move against the current to avoid passing through the barrier. This phenomenon would explain why older studies showed that barriers placed at small angles to the direction of current were more effective for diversion than barriers placed at closer to perpendicular to the direction of flow. The smaller the angle between the barrier and the direction of flow, the longer the structure required to span a particular cross-section of the river; therefore, the feasibility of construction and cost become important factors in selecting the appropriate angle.

7.0 COMBINATIONS OF TECHNOLOGIES

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Sections 3, 4, 5, and 6 evaluated the potential effectiveness and limitations of four different technologies for guiding the movement of outmigrating silver eels in the St. Lawrence River at Iroquois Dam. In areas where the target species (i.e., outmigrating American eel) is difficult to divert because of site conditions (e.g., high flow velocity), behavioral characteristics, or environmental issues (e.g., effects on other species), a "multisensory" approach that combines several technologies might be more effective than a single system. For example, the reduced effectiveness of light with increasing turbidity might be counteracted by using another deterrent in combination with a lighting system. A strategy that combines technologies could include both behavioral and physical systems. For example, passive or active devices for directing flows might be used effectively in small areas to enhance the performance of physical guidance systems such as louver arrays or bar racks (C. Coutant, pers. comm.).

Several examples in the literature demonstrate that combining technologies improves diversion efficiency for some species (e.g., Patrick and Sim 1985; McCauley et al. 1992); however, none of those examples involved eels, and they typically took place at once-though-cooling plants rather than hydroelectric facilities. For example, the effectiveness of a barrier of air bubbles for diverting alewives away from a cooling-water intake was enhanced when the bubble barrier was illuminated with strobe lights. On average, the effectiveness of the combined strobe light/air bubble system ranged from 90% to 98% depending on current and turbidity (increased from 38% to 73% for bubbles alone). Similarly, a 50% increase in effectiveness for diverting menhaden (a marine pelagic species similar to alewife) was observed when a strobe light was used in combination with a bubble barrier. At the Lambton Fossil Plant on the St. Clair River, which extends from Lake Huron to Lake St. Clair along the border between the United States and Canada, a system that combined acoustic and light technologies was designed to reduce the number of gizzard shad that entered the heated discharge plume during the fall and winter (Patrick et al. 2005). The effectiveness of the system was evaluated by operating it in three different modes (i.e., control, acoustics alone, and acoustics combined with strobe lights). Based on impingement records and sonar data, the combined system was the most effective for reducing impingement of fish at the station.

Bruijs (2007) explored the concept of combining systems for protecting fish in an evaluation of several systems that might be applied at the Alphen and Linne hydropower stations on the Meuse River in the Netherlands. The river immediately upstream of both projects is approximately 250 m wide. Owners of Dutch hydroelectric projects are required to identify which fish-protection system constitutes Best Available Technology (BAT). The identification of BAT must account for cost and effectiveness. The maximum allowed cumulative mortality for target species, including eel, is 10%. Cost effectiveness of each of the evaluated systems was expressed as the cost of a technology or combination of technologies per reduced amount of fish mortality (Euros per kg of fish lost without protection/ % avoided fish mortality). The systems were ranked in order of cost effectiveness. Four of the 11 fish-protection systems that Bruijs evaluated are potentially relevant for diverting eels at Iroquois Dam: a bio-acoustic fish fence (BAFF, a technology developed by the firm KEMA), fluorescent light, strobe light, and a combination of light and sound. Eel mortality without diversion was estimated to be 18.1%. Mortalities with diversion were estimated at 18.1% for the BAFF alone, 10.9% to 3.6% for light (both fluorescent and strobe), and 10.9% to 2.7% for light and sound combined. Considering cost effectiveness and specific operational and construction features in addition to fish mortality, the combined system ranked second among the 11 systems; however, all the effectiveness values were based on estimates of both costs and mortality, and the combined system was not deployed or tested. These results, nevertheless, illustrate the potential for combined systems to enhance fish protection.

One result of NYPA's proof-of-concept study of using light to divert eels (Section 6.3) may be relevant for designing a system that combines guidance technologies. During NYPA's study, diversion efficiency attributable solely to the effect of light ranged from 77.6% to 84.6% (Section 6.3, Tables 6-4 and 6-5). Examining captures only during the control periods (lights off) suggests that eels avoided the light platform itself when the lights were off. During control periods with the two-net configuration (i.e., Treatment Net and Deflection Net 1), Deflection Net 1 captured 134 of 164 eels (81.7%); with the three-net configuration, Deflection Nets 1 and 2 captured 89 of 102 eels (87.3%). The use of light increased the diversion percentage. The percentages of eels taken in the deflection nets were 90.5% for the two-net configuration and 97.5% for the three-net configuration when the lights were on. One explanation for this result could be that some characteristic of the bathymetry or velocity at the site caused the normal path of migrating eels moving past that location to bypass the platform. This hypothesis could be tested only by conducting an experiment to compare net captures with the platform in place with captures without the platform; however, that experiment would be nearly impossible to conduct because of the logistical difficulty of securely anchoring and removing the platform in the high river flows at the site. The results also could be interpreted to mean that some sensory cue other than artificial light contributed to the eels' detection and rapid avoidance of the platform. Visual observations of eels exhibiting the "deflected away" behavior during control periods seem to support that theory (Section 6). Examples of cues that might have alerted eels to the presence of the platform when the lights were off include vibration from its moorings and the light poles, or a shadow cast in the very clear water by moonlight or starlight striking the platform. No data were collected during the light-avoidance study that would support an investigation of the effects of other potential cues (e.g., sound, visual appearance, water turbulence); nevertheless, the finding supports the contention that a multi-sensory approach employing combined behavioral or behavioral and physical systems merits consideration.

The cost to deploy two different guidance technologies in combination at Iroquois Dam probably would be less than the sum of the costs to deploy each technology individually. All of the technologies reviewed in the preceding sections require the installation of support structures in the river. The same structures probably could be used to mount two different technologies, which would result in some cost savings. The magnitude of the cost savings would be a function of the cost of the technologies themselves (e.g., light arrays, infrasound emitters) and the cost of installing and maintaining the support structures. The effectiveness of combined technologies for guiding the movements of outmigrating eels in the St. Lawrence River has not been studied; consequently, no information is available about the incremental increase in diversion efficiency that might be possible. The combination of light and sound investigated by Bruijs (2007) was estimated to result in only a very small improvement in diversion of eels, which suggests that the total cost to deploy combined technologies still could be greater than a marginal increase in guidance efficiency would warrant.

8.0 METHODS FOR COLLECTING, HOLDING, AND TRANSPORTING OUTMIGRATING EELS

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Sections 3.0 through 7.0 described and evaluated technologies that could be useful for altering the movement of outmigrating eels in the vicinity of Iroquois Dam and directing them into a collecting structure. This section focuses on methods for collecting the eels, holding them as long as is necessary, and transporting them downstream of the Beauharnois Generating Station, thus ensuring that the eels avoid passing through turbines at two hydroelectric facilities. Successful and profitable fisheries for migratory species, including eels, have lead to the development of efficient technologies for capturing, holding, and transporting live fish. Historically, fishers in North America and Europe often were offered higher prices for eels delivered alive, which generated much interest in developing methods for holding and transporting eels that minimized injury and mortality. Modern eel fisheries also place great value on live eels, and the methods used to hold and transport them have improved dramatically since the early 20th century. Past and current methods used in commercial eel fisheries are reviewed here to assess their feasibility and applicability for a trap-and-transport program for eels on the St. Lawrence River.

Although no major trap-and-transport programs to mitigate the effects of hydroelectric projects on migrating eels currently exist in North America, many large-scale programs address similar issues for other downstream migrants, most commonly various species of salmon smolts. Several programs being used on large river systems are reviewed here to provide insight about methods, required facilities, logistical requirements, costs, and pros and cons, all of which might be relevant to designing a large-scale program for trapping and transporting outmigrating eels in the St. Lawrence River. Several trap-and-transport programs for outmigrating eels currently being implemented in Europe also are described in this section.

Section 8.1 reviews a wide range of systems that could be used to collect eels. Barriers have been conceived (i.e., conceptual designs for mechanical and light barriers described in Sections 3.0 and 6.0, respectively) to divert outmigrating eels from their usual path toward collection devices installed in two sluiceways at Iroquois Dam. After reviewing all potential collection methods, the Project Team concluded that an inclined-screen trap is the most appropriate kind of collection device for use in conjunction with diversion barriers at the dam. Section 8.2 reviews various applications of inclined-screen traps to provide an overview of different kinds of installations, logistical issues, and methods of operation that would have to be addressed if an inclined-screen trap is to be used at Iroquois Dam. Section 8.2 also presents a conceptual design for a modular, inclined-screen trap that could be installed in a sluiceway at Iroquois Dam along with an estimate of the cost of such a trap. Section 8.3 reviews methods for holding and transporting migratory fishes. Section 8.4 reviews active trap-and-transport programs for other species, and Section 8.5 reviews active programs for eels. Section 8.6 reviews the regulatory context for transporting eels across international borders, which might be a component of a trap-and-transport program for outmigrating eels in the St. Lawrence River.

One issue in any trap-and-transport program for a migrating fish is whether capturing, holding, and transporting fish adversely affects their health or behavior, or precludes them from successfully completing their life cycle. These issues have been assessed for other species, in particular salmon smolts, but not for *Anguilla* eels. The possibility that collecting, holding, and transporting outmigrating eels may affect the process of sexual maturation so that they are unable to reproduce successfully is a particular concern. Section 8.7 reviews the literature relevant to this issue to provide some insight into the likelihood of such adverse effects.

Methods employed to collect the information synthesized here are described in Section 2. Information reported in this section was obtained largely through personal contacts with fishermen, eel wholesalers, and seafood dealers.

8.1 TECHNIQUES FOR COLLECTING EELS

An initial objective of this element of the project was to document as comprehensively as possible all of the numerous methods that eel fishers throughout North America and Europe have used to capture, hold, and transport eels, including methods used in fisheries for yellow and silver eels and those used in small streams as well as in large rivers and estuaries. All of the information acquired in that comprehensive search was reviewed to distinguish methods and techniques that could be deployed in large bodies of water, such as the St. Lawrence River, from those that clearly are inappropriate for such an application. Those considered most appropriate for capturing eels in the vicinity of Iroquois Dam could be installed in large water bodies and could be fished continuously for extended periods of time. Methods that met those criteria are evaluated here for their usefulness in capturing eels from the width and depth of the St. Lawrence River at Iroquois Dam and for their potential to affect collected eels adversely. Information about methods considered to be unsuitable for deployment in the St. Lawrence River may still be of some interest to stakeholders and is included in Appendix C.

Of all the available sources of information about techniques for collecting eels, Eales (1968) provided the most comprehensive overview, from a fisheries perspective, of the wide range of nets and technologies available, including illustrations and costs. Nearly all eel research programs reviewed in this report used one or more of the methods described by Eales. Electrofishing is the only sampling method used in research programs that is not used in large-scale commercial fisheries. The summary presented here draws heavily from Eales' comprehensive review for basic descriptions of methods, and expands the discussion to identify other sources that reported using the same or similar gear.

8.1.1 Stownets

Design Characteristics. Stownets are distinguished from other gears in that strong water currents are required to keep the nets open. A stownet consists of a conical net with a single large opening at the base of the cone (Klust 1971; Figure 8-1). The opening of the net often is rectangular and encircled by a rope frame connected to stakes (wood or iron) at all four corners. The net is attached to the stakes with steel-wire rope or metal rings. Stownets also can be held in place by anchors either with or without a ship or used with wooden or metal otter boards. Beginning around 1970, stownets were made of polyamide filament netting yarns (Klust 1971). This material is waxy, can float, accumulates little dirt, and is relatively easy to clean. Mesh-size depends on the target species.

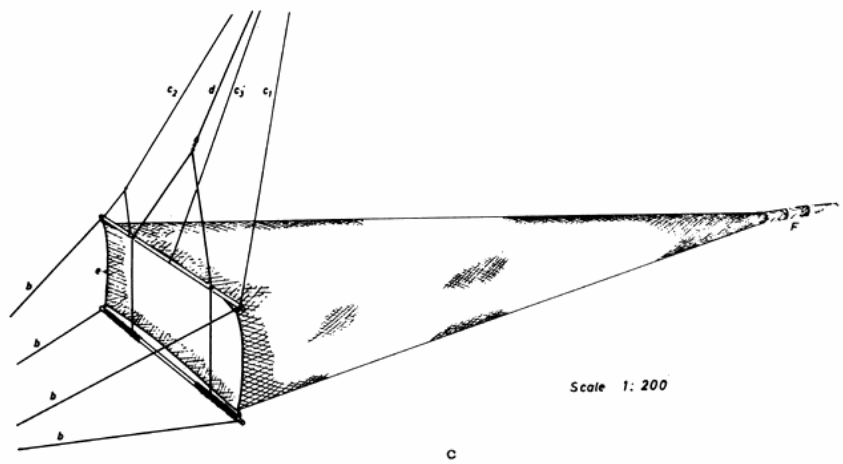

Figure 8-1. General design of a stownet. This particular design was deployed on the Rhine River in Germany. Lines extending from the front of the net go to anchors; lines extending upward go to a tender boat situated above the net (Source: Klust 1971).

Stownets typically are set close to the water surface (Klust 1971). The typical dimensions of the opening of a stownet are 6.3 m X 3.3 m or 4.5 m X 3 m. Nets are approximately 18 to 20 m long. Stretched mesh[33] at the entrance is about 80 mm long. The cod-end of a stownet, at the apex of the net where the captured fish are held, may be composed of either one or two funnels. The opening of a stownet faces upstream; consequently, the net may become clogged with leaves and other detritus.

Design Variations. Stownets at anchor may be set without a vessel (Figure 8-2; Klust 1971). In this case, the stownet has a four-sided frame typically made of wood. Steel-wire ropes connect the four corners of the frame to an anchor at the bottom of the river. This method was

[33] The term "stretched mesh" is a standard term for describing the dimensions of the mesh size of the net; it is the length of a single net mesh opening when that opening is stretched from one corner to the opposite corner.

historically used in Germany in deep waters and hard bottom habitats where stakes could not be used. Stownets without vessels are not commonly used in large rivers due to their stationary nature.

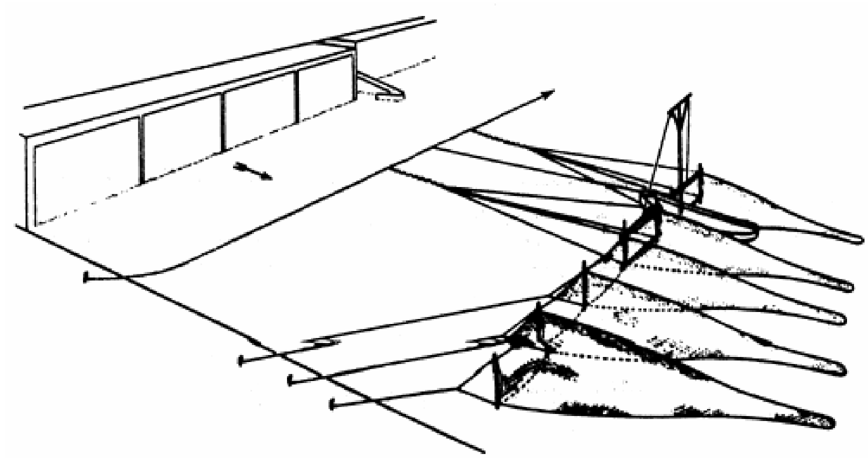

Figure 8-2. Stownet anchored without a vessel. This particular design used on the Moselle River in Germany employs 5 gears behind an artificial barrier built across the river to prevent flooding (Source: Klust 1971).

Stownets at anchor also can be associated with a vessel (Figure 8-3; Klust 1971). In smaller rivers, the vessel often is deployed without an engine because its primary functions are to hold the fishing gear, to serve as a work platform, and possibly to provide lodging for workers. Two ropes connect the vessel with the river bank and gear. Lengthening or shortening the ropes can shift the position of the vessel somewhat. In larger rivers, vessels 12 to 18 m long with 60 to 120 hp engines are used.

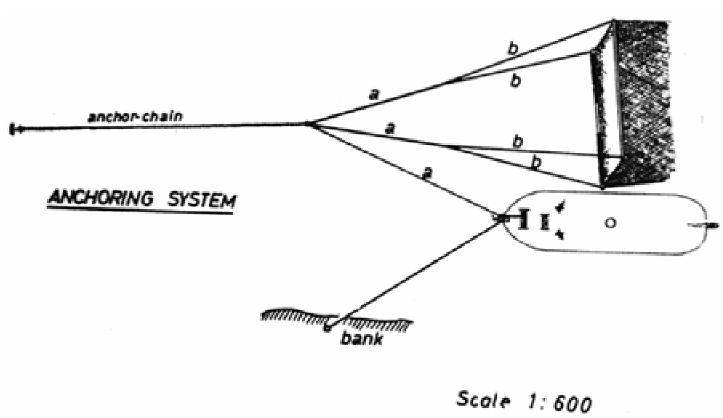

Figure 8-3. Stownet anchored in association with a vessel (Source: Klust 1971)

Stownets associated with otter boards are the most effective variation for catching migrating eels (Figure 8-4; Klust 1971). Otter boards are devices attached to the net bridle that help to keep the net open and the wings at their maximum extension. The net is about 32 m long with an opening that measures 16 m x 3 m and has two wings that measure 20 m to 25 m long. The whole net is associated with a floating otter board. No vessel is required if the two main ropes can be anchored on the banks. The gear may be left in the water in an inoperative position during the entire fishing season.

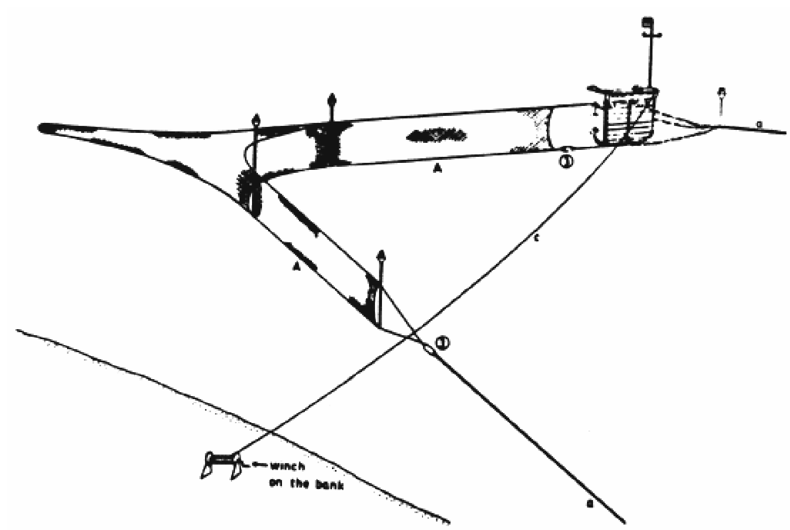

Figure 8-4. Stownet associated with an otter board operated from the bank of a river without a vessel (Source: Klust 1971)

Examples of Use and Efficiency. Historically, stownets were used to capture silver eels from rivers in Germany for commercial purposes (Klust 1971). NYPA used stownets in their light barrier studies in the vicinity of Iroquois Dam, as reviewed in detail in Section 6.

A decision analysis carried out by Grieg et al. (2006) considered stownetting to be a potential means of collecting eels in the St. Lawrence River-Lake Ontario region in a trap-and-transport program to move eels past the two dams on the St. Lawrence River. Discussion during the decision-analysis process indicated that stownetting would be more useful if eel densities increase but might not be cost effective while densities are low (Grieg et al. 2006).

8.1.2 Pound Nets

Design Characteristics. A pound net is composed of three main sections (Figure 8-5; Gunderson 2004; H. Wickstrom, pers. comm.). The first is a pound or crib. This section is enclosed and is where fish become entrapped. The second section, called the heart, is a heart-shaped net that funnels fish into the pound. The third section is a leader or hedger which is a long straight net or a series of nets that guide fish from the shore toward the pound. Captured fish can then be removed from the pound using a variety of methods.

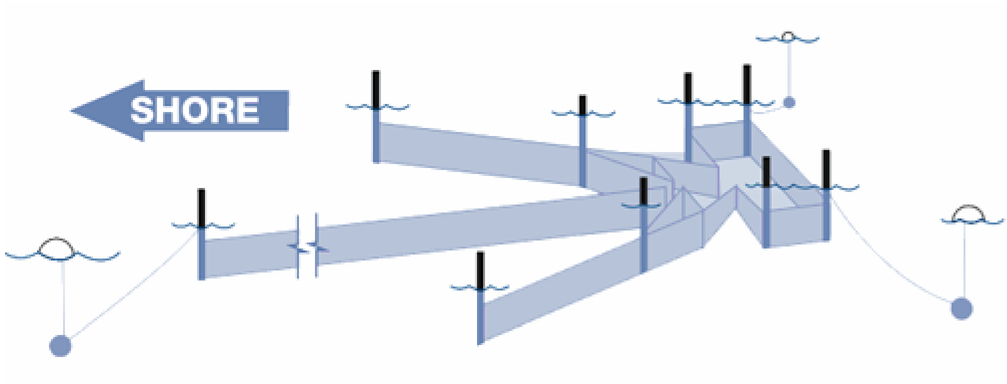

Figure 8-5. General design of a pound net; the “pound” is to the right in the figure, with the “heart” immediately to the left of the pound; the “lead” nets extend from the heart toward shore (Source: Gunderson 2004).

Deployed in about 3 m of water, the nets are either fixed to the bottom using poles in soft bottom habitats or supported by floats secured with anchors. The trap and its leaders are oriented toward the shore. Depending on the distance of the pound from the shore, anywhere from 100 m to 1000 m of leaders may be used (Larsen 1970).

Examples of Use and Efficiency. Pound nets are used in eel fisheries throughout Europe including fisheries in the Baltic Sea and in large managed lakes in Denmark (Berntsson 1970; Larsen 1970; H. Wickström, pers. comm.). Silver eels have been captured using pound nets in the lower Potomac River, although most likely as a by-catch (A.C. Carpenter, pers. comm.). Because pound nets are fished in relatively shallow, near-shore and low velocity waters, they would not be capable of intercepting and capturing outmigrating eels that moved downstream in deep, high velocity channels of river systems, such as the St. Lawrence River.

8.1.3 River Weirs

Design Characteristics. Eales (1968) described river weirs as consisting of two solid walls aligned in a V-shape with its apex pointing downstream (Figure 8-6). The walls allow water flow to carry fish toward and through the apex. One or a series of boxes set beyond the apex of the V retains the fish while allowing water to flow through. A flume of lathes may aid this process. A single collection box made of netting may be V-shaped with the wide opening of the V opening toward the walls of the weir. The apex of this box then may lead to a cylindrical net that is closed at the far end. A hoop provides the support structure for this cylindrical net (Figure 8-6).

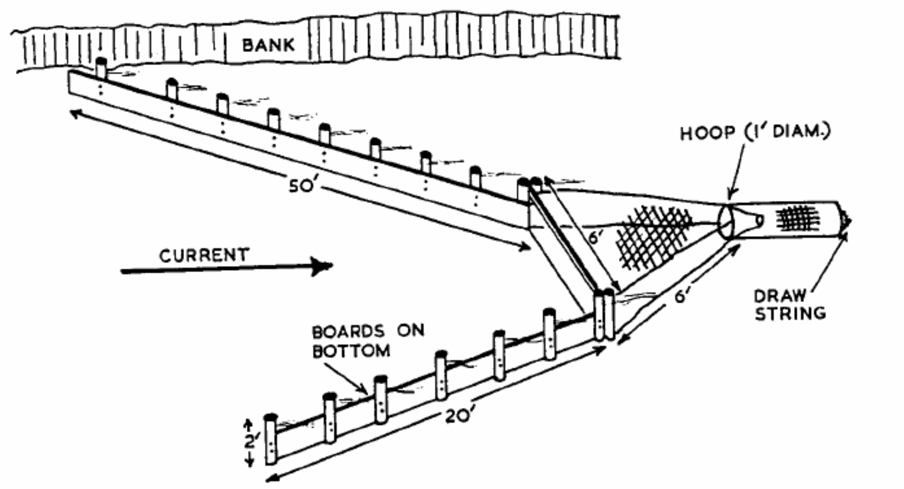

Figure 8-6. General design of a river weir (Source: Eales 1968)

Multiple V's may be used together in the case of wider streams and rivers typically leaving up to 25% to 33% of the river unobstructed (Eales 1968). Weirs are easiest to construct during the low-water period of summer. A useful strategy is to set the weir at a location where the river broadens into shallow water of about 60 to 90 cm deep or below rapids or small falls. Weirs often are set on rocky bottoms where flow is good or where a natural V occurs in the river's path.

The walls of the V may be composed of stones facing wooden posts on the upstream side that may be interwoven by wattle or brushwood (Eales 1968). V's made of rocks alone or wooden planks may also be used. Periods of high flow increase both the pressure against the walls and the velocity at which fish are carried through the apex of the V. Fish move into a cone-shaped net located beyond the apex of the V at its wide end. From there, fish move into the collecting box from which they can be retrieved.

Operation Time. This collection method takes about 3 to 4 hours per day to maintain (Eales 1968). River weirs and all other fishing gears described by Eales (1968) typically have been deployed during the fall migration, usually on dark, moonless nights with increased water level or increased flow. In eastern Canada in particular, river weirs historically were fished in August, September, and October.

Cost. In 1968, the cost of construction of one of the largest weirs in existence was estimated at $100,000.[34] Adjusting the 1968 cost for inflation using the Consumer Prince Index, results in an estimated cost of $630,000 in 2007 dollars to construct that same weir. This

[34] The location of this weir was not identified; Eales' (1968) costs estimates are in Canadian dollars; as of June 11, 2008, $1 Canadian was equivalent to $0.98 U.S.; however, as of March 27, 2009, $1 Canadian was equivalent to $0.81 U.S.

estimate appears unrealistically high, but no recently constructed weirs could be identified from which to verify current costs. Eales estimated maintenance costs of $2000 to $5000 per year ($12,600 to $31,500 in 2007 dollars) for a river weir.

Examples of Use and Efficiency. Weirs are one of the oldest eel harvesting methods used throughout the range of this species. Relic stone weirs can be found throughout the United States on small streams and large rivers (F. Campfield, pers. comm.). Weirs are designed specifically to capture downstream migrating fish; therefore, their primary target traditionally has been silver eels. Eales (1968) documented extensive use of weirs in Canada. Historically, weirs on many small rivers in Canada typically yielded 100 eels in a single catch and on the order of 2.3 metric tons of eels per year. Weirs were responsible for 7% of eel catches in the Maritime Provinces during the fall of 1964 (Eales 1968). Historical long term data indicate that a single Canadian weir brought in catches of 46,000 metric tons per year in some years between 1868 and 1968. Weirs also have been useful in research studies elsewhere because they offer one of the most consistent sources of silver eels during the migration period. River weirs are used in research and mitigation programs for other fish species. For example, a weir currently in operation in New Brunswick (Energie NB Power) is operated as part of a trap-and-transport program for salmon.

Eel fisheries in Europe reportedly caught up to 300,000 eels (63.5 metric tons) per year using weirs during the 20th century (Bertin 1956). Weirs are still used extensively; however, the term "weir" as used in some cases in Europe refers to structures very different than the stone and wood weirs described by Eales (1968). For example, coghill nets are used to capture eels at the Killaloe eel "weir" on the Shannon River in Ireland (Cullen and McCarthy 2000, 2003). The river in the vicinity of Killaloe is approximately 10 m deep and 110 m wide with average flow of 10 m^3/s. Such dimensions would preclude the construction of a weir made of stone and wood. At Killaloe, the "weir" is a bridge from which the coghill nets are raised and lowered into relatively deep and swift water. Some of the eels taken at the Killahoe weir are transported downstream and released as part of a trap-and-transport program to avoid turbine mortality at hydroelectric projects located downstream (D. Doherty, pers. comm.).

8.1.4 Estuary Weirs

Design Characteristics. Estuary weirs are similar in concept to river weirs; however, estuary weirs generally do not extend across an entire body of water, and they take advantage of tidal water flow and shallow tidal flats. These weirs consist of a set of leaders or wings that lead fish to either a single trap or several consecutive traps (Figure 8-7). The trap(s) is a cone-shaped net whose apex leads into a retaining box. The leaders or wings may be constructed of wire or brush and may be up to 900 m long and up to 3 m tall depending on tidal fluctuations. Eels move with the tidal flow and encounter the leaders, which redirect their movements. Eels follow these leaders toward the weir, where they become trapped in the weir net. Nets may be set in areas with different kinds of substrate ranging from rocky to muddy and can be placed where some vegetation is present (Eales 1968). Historically, in Canada, estuary weirs were set from June through November, and the greatest catches occurred from late August through October.

Catches were reported to be greater at night, when there was a shoreward wind, and just after a storm. The weir design illustrated in Figure 8-7 is used in the tidal region of the St. Lawrence River between Montmagny and Lotbiniere (about 60 km downstream and about 65 km upstream from Quebec City, respectively).

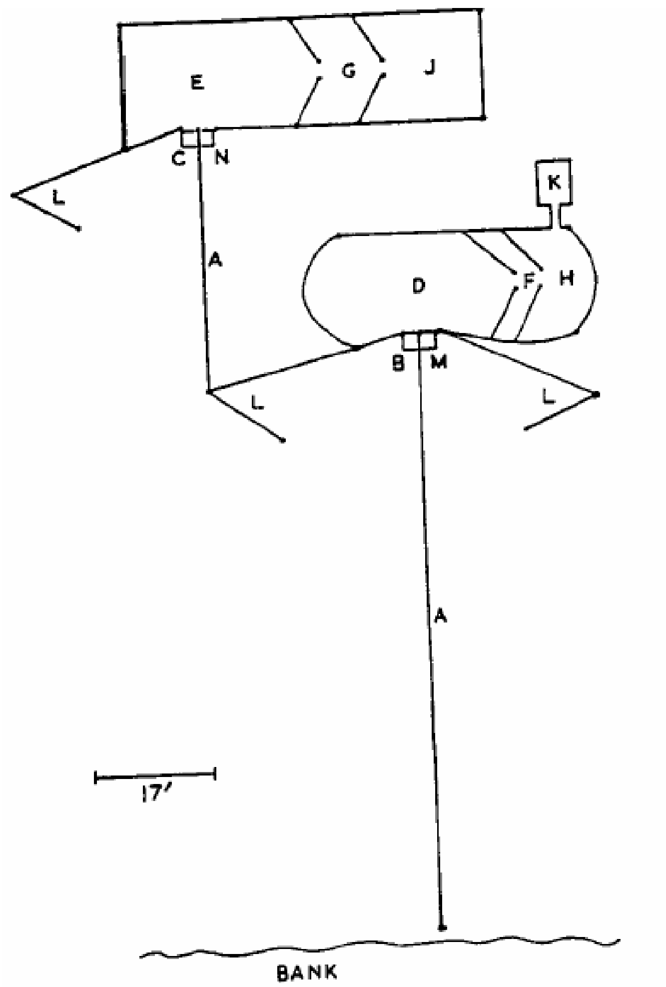

Figure 8-7. General design of an estuary weir (Source: Eales 1968). On the incoming tide, eels are guided with fences or wire brush (A) to ramps (B and C) at openings that lead into large chambers (D and E). Eels move through chambers F and G into smaller chambers (H and J). Eels may then pass into a collecting box (K). On the outgoing tide, eels encounter the fences (A) and swim to the ramps (M and N) at the openings to chambers D and E, where they become trapped.

Construction Time. Estuary weirs typically are removed and stored in sections or re-constructed anew for each season. An estimate from 1968 indicated that it took two men working three to four hours a day during low tide one month to construct an estuary weir (Eales 1968).

Operation Time. Operating a single weir takes 2 to 3 hours a day, including two trips during diurnal low tides to collect eels (Eales 1968).

Cost. Purchase cost for an estuary weir in 1968 ranged widely between $300 and $7,000 ($1,890 and $44,100 in 2007 dollars) with most structures costing between $1,000 and $2,000 ($6,300 and $12,600 in 2007 dollars; Eales 1968). Additional upkeep costs range from $50 to $2,000 per year ($315 to $12,600 per year in 2007 dollars). A successful weir on the St. Lawrence River during this time period cost $900 ($5,670 in 2007 dollars) to build and $200 ($1,260 in 2007 dollars) per year to operate. Weirs that use netting are more expensive to maintain. Additional costs may arise from withdrawing captured eels from the trap. Availability of modern netting and support material may result in lower current costs for structures such as these.

Examples of Use and Efficiency. Like river weirs, estuary weirs have been a common mode of eel fishing. Most Canadian fishers operating weirs in estuarine waters reported catching up to 4.5 metric tons of eels per year, although some reported catching as much as 15.8 metric tons per year (Eales 1968). Historically, catches have varied seasonally; peaks occurred during the height of migration, which occurs in the early fall in eastern Canada (Figure 8-8). More recently, Caron et al. (2003) estimated that the estuarine fisheries in the St. Lawrence River captured eels at rates of 19% and 24% in 1996 and 1997, respectively.

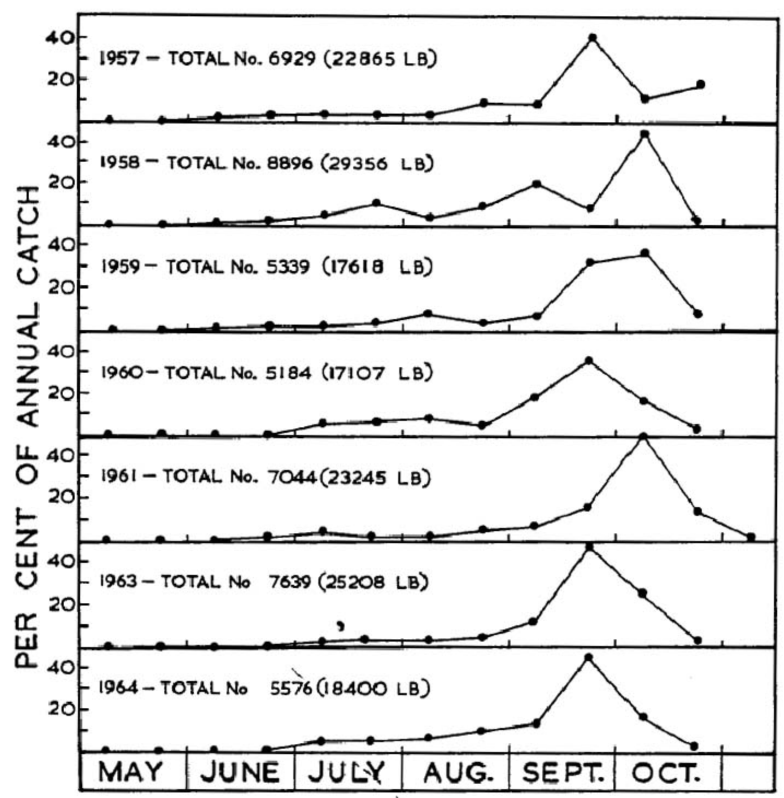

Figure 8-8. Catches from an estuary weir at St. Vallier, Quebec, between 1957 and 1964 (Source: Eales 1968)

8.1.5 Hoop Nets

Design Characteristics of a Generalized Hoop Net. Hoop nets consist of a large cone of netting that encloses a series of smaller tapering cones of netting (Eales 1968). Each inner cone is encircled by a rigid hoop and the mouth of each inner cone may range from 0.3 m to more than 1 m in diameter. From the mouth, each inner cone tapers toward the apex where a small opening leads into the next cone. Fish swim into the wider ends of the cones and become trapped in the netting. The hoops provide structural support and can be made of a variety of materials including wood and aluminum. The nets are made of cotton, hemp, monofilament, or nylon with desired mesh size typically ranging from 6.7 to 12.3 mm. Multiple nets may be set in combination to increase catch. Designs vary in the number and size of hoops and leaders. Two common types of hoop net are *wing nets* and *fyke nets*.

Wing Net Design Characteristics. Wing nets use the basic construction of hoop nets with the modification of having two wings that precede the mouth of the net (Figure 8-9; Eales 1968). The wings, joined by up to 91 m of netting and held in place by stakes, approach the main net an angle, acting to guide fish toward the main net. Eales (1968) noted that knowledge of habitat use and strategic placement of nets may be helpful for enhancing capture efficiency (Figure 8-10).

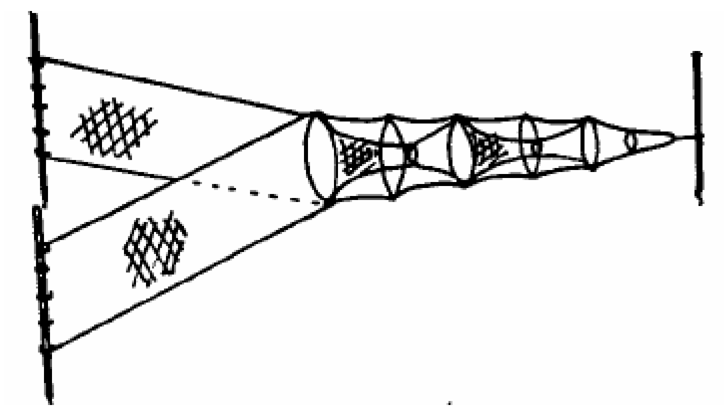

Figure 8-9. Wing net design (Source:Eales 1968)

Fyke Net Design Characteristics. Fyke nets also use the basic construction of hoop nets but, in contrast to wing nets, have only one leader of netting (Figure 8-11; Eales 1968). The mouth of a fyke net typically ranges from 0.3 to 1.2 m in diameter. The main net and leader netting are placed at a right angle to the shoreline, and the leader netting is held in place by stakes. The head rope running horizontally along the top of the leader netting is usually drawn taught, and the foot rope is left slack on the bottom and can be weighted down. The mouth of the net also can be weighted down if the bottom is uneven.

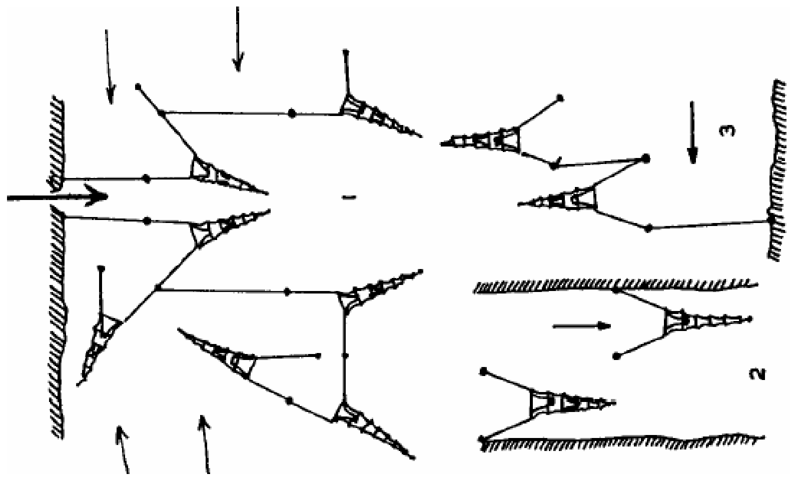

Figure 8-10. Methods for setting wing nets (Source: Eales 1968). Small arrows represent direction of eel movements. Large arrow represents the direction of flow of a stream entering a lake.

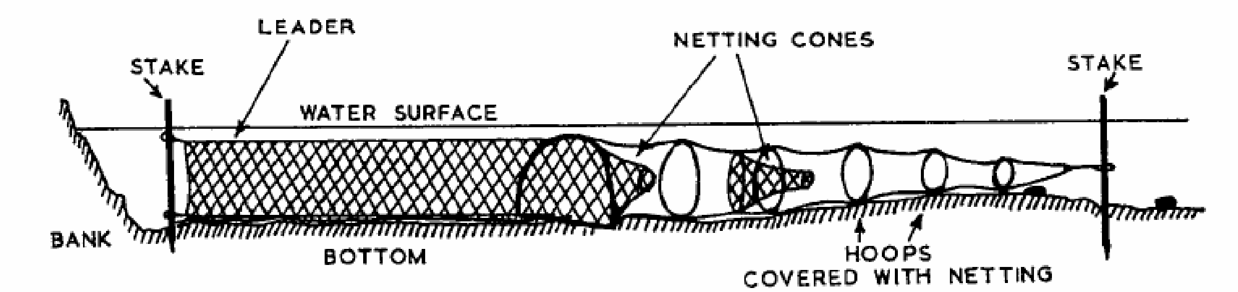

Figure 8-11. Fyke net design and general method for setting (Source: Eales 1968)

Fyke nets themselves may also be modified in various ways. For example, a single hoop fyke net consists of a hoop attached to a 1.5 to 2.7 m cone of netting that is tied at the far end. The eel fisheries in Queensland, New Zealand, use a fyke net that opens through a funnel into a rigid cage where eels are retained until removal (Figure 8-12). The dimensions of such traps are approximately 2.0 x 2.0 x 0.6 m when set (1 m diameter and 0.6 m height for a round trap). Rigid material is required for the frame of the trap, which is covered by nylon netting with mesh size of approximately 25 mm.

Operation Time. For commercial purposes, maritime fishers in Canada typically set 2 to 5 nets; a small number set up to 10 to 40 nets. On average, operation of hoop nets takes 3-5 hrs per day; a range of 1 to12 hrs has been reported, depending upon the number of nets (Eales 1968).

Cost. In the 1960s, a hoop net cost anywhere from $25-$400 ($158-$2,520 in 2007 dollars). Maintenance costs were estimated to be $300-$400 ($1,890-$2,520 in 2007 dollars) to maintain over 30 nets at that time. Eales (1968) noted that even though hoop nets are vulnerable to damage during storms, a high quality net should last for 10 years.

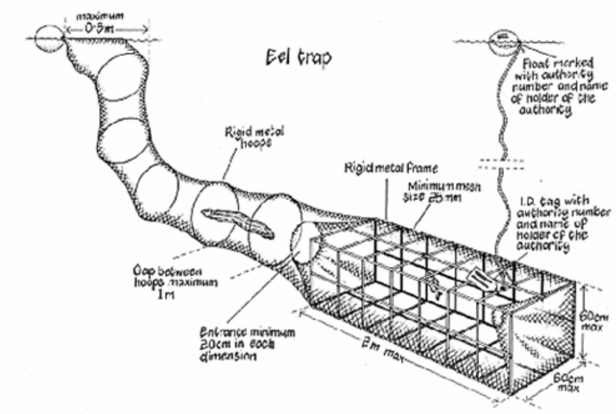

Figure 8-12. Fyke net attached to a box trap used in a fishery for adult eels in Queensland, New Zealand. The trap is connected to a buoy at the surface by a rope. (Source: http://www2.dpi.qld.gov.au/fishweb/15891.html).

Examples of Use and Efficiency. Both wing and fyke nets are commonly used in eel fisheries around the world. Historically, eel catches in Canada were as high as 20,000 eels (both yellow and silver) per year by fishers using an average of 20 nets (Eales 1968). Fyke nets currently are used in the adult eel fishery in Queensland, New Zealand, where fishing generally is limited to impoundments created by dams. In addition to their commercial application, fyke nets have been employed for research and mitigation strategies at hydroelectric dams. Fyke netting is used as part of a trap-and-transport operation to protect large, highly fecund migrating female eels from turbine mortality at a hydroelectric dam in the vicinity of Manapouri Lake and Te Anau Lake, as discussed in more detail in Section 8.5.2. In another example described in Section 8.5.1, a German utility company operates a trap-and-transport program in which silver eels are caught in tributaries upstream of a series of dams on the Moselle River and transported downstream, where they are released into the Rhine River (Suzanne Teggers-Junge, pers. comm.). Nets are set in relation to moon phase and water discharge rates. Hoop netting also has been investigated as a method for collecting fish in the vicinity of Moses-Saunders Power Dam in Canada. That work is explored in detail in Section 9.6.3 of this report.

8.1.6 Applicability of Capture Gears for Use in the St. Lawrence River Near Iroquois Dam

All of the gears described were assessed for their potential value for capturing eels in the St. Lawrence River near Iroquois Dam because they could be installed in large water bodies and could be fished continuously for extended periods of time. Even deploying multiple units of any of these gears, however, would probably result in capturing only a small proportion of the eels migrating past the dam. For example, fyke nets used in the trap-and-transport program in New Zealand are set along the shoreline of a large impoundment and are estimated to capture only between 5% and 10% of migrating eels (Section 8.5.2). Capturing a small proportion of migrants might be sufficient if the objective were to sample eels or to collect eels for use in studies, but the objective at Iroquois Dam is to intercept and capture the majority of migrating eels in order to transport them past the hydroelectric facilities. To accomplish that objective in the absence of any technology that could result in guiding or concentrating the migrants, multiple units of any of the gears described here would have to be installed such that they sampled virtually the entire cross section of the river, or at least the main channel. NYPA's telemetry studies indicated that migrating eels generally travel with the highest velocity currents, in the main river channel. In contrast, in the New Zealand example, migrating eels probably move along the shoreline of the impoundment searching for a discharge outlet. The logistics and cost of deploying multiple units of any gear in the main channel of the St. Lawrence River make such an approach unrealistic. In addition, site characteristics (e.g., depth, high water velocities, substrate unsuitable for anchoring gear) would preclude the use of most of the gears in the river channel. Further, NYPA's studies in Lake St. Lawrence (Section 9.6.3) showed that hoop netting captured primarily non-migratory, yellow eels rather than the outmigrating eels targeted for capture and transport.

Given these factors, the only potentially feasible method of capturing a large percentage of outmigrating eels at Iroquois Dam would be to use some kind of barrier (e.g., light, physical) to divert them to a collection facility. The conceptual designs for a physical barrier and a light barrier at Iroquois Dam (Sections 3.0 and 6.0, respectively) include the installation of a collection facility in one or more gates of the dam. An inclined-screen trap appears to be ideally suited for collecting eels at the gates at Iroquois Dam. The following section describes examples of inclined-screen traps and provides a conceptual design for, and estimate of the cost to install, a modular, inclined-screen trap at Iroquois Dam.

8.2 INCLINED SCREENS

Inclined-screen traps are addressed in this review because they appear to be a particularly suitable system for capturing outmigrating eels at Iroquois Dam when used in combination with some kind of migration barrier. The suitability of inclined screens is the result of site-specific characteristics at the dam, including high water velocities and the availability of existing structures to support such traps. The following is a summary of the use of various inclined-plane-screen traps for collecting downstream-migrating fish, generally salmon smolts and a detailed overview of EPRI's studies of a modular inclined screen at the Green Island Hydroelectric Project on the Hudson River in New York (EPRI 1994). The summary of the EPRI's tests includes a detailed description of the experimental test facility and the results of hydraulic and biological testing.

8.2.1 Fish Trapping Applications

Biologists have used inclined-plane-screen traps to capture migrating juvenile salmonids from medium and large streams (Schoeneman et al. 1961; Seiler et al. 1981) and from small tributary streams (Solazzi et al. 2000). These traps are used widely in the Pacific Northwest, especially for monitoring the migration and survival of juvenile salmonids. Following a brief overview of inclined-plane-screen traps, several examples of the use of these traps in the Pacific Northwest and elsewhere are described.

When an inclined-plane-screen trap is lowered into the current, water is strained through the screens, and downstream migrants are swept up the inclined screen and deposited into a live well that has solid sides and a solid floor. The velocity of the water moving through the trap must exceed the swimming speed of the target species to capture and retain fish in such traps (Volkhardt et al. 2007). Swimming speed is directly related to body length; therefore, greater flow velocities are required to trap larger species. At less-than-optimal velocities, larger fish can avoid or swim out of the trap. Velocity requirements can be reduced by using a traveling-screen trap because the screen can be fitted with baffles or perforated, L-shaped cups to help carry fish to the live well and reduce the chance of escape. As velocity increases, the volume of water and suspended debris passing through the trap also increases, requiring more frequent inspection and cleaning of the trap and live well.

Flow into the trap is regulated by altering the lateral and longitudinal position of the trap in the stream and by adjusting the level and angle of the inclined screen (Volkhardt et al. 2007). A smooth flow over the apex of the incline into the holding chamber and water depth of 1.5 cm to 2 cm over the apex indicate proper adjustment of the trap. As debris accumulates on the screen, its ability to pass water decreases, and the depth of water and velocity of flow over the incline increase, resulting in turbulence in the holding chamber. Debris load is affected by vegetation on the bank of the stream, weather, and most importantly, river discharge. On smaller rivers that may be subject to storm-related fluctuations in flow, operating the trap through a freshet requires monitoring the screens carefully, cleaning them regularly, and removing the catch from the live well frequently. In the St. Lawrence, the loading from SAV probably would require relatively continuous cleaning.

The design of inclined-plane-screen traps permits applications over a range of river velocities and depths (Volkhardt et al. 2007). The basic design is simply a wedge-shaped, screened, rectangular tube suspended from a pontoon barge, but many permutations of the basic design are possible. The screen section typically is constructed of galvanized, woven wire mesh or perforated aluminum sheet metal riveted to a frame. All seams are coated with a sealant to cover sharp metal edges that might injure fish. The trap typically is suspended on floats or inside a pontoon barge from support winches at the corners of the fore and aft decks (Figure 8-13). The position of the trap is fixed using anchor lines that extend from each pontoon to shore, a fixed structure (e.g., bridge), or a high lead that extends across the river.

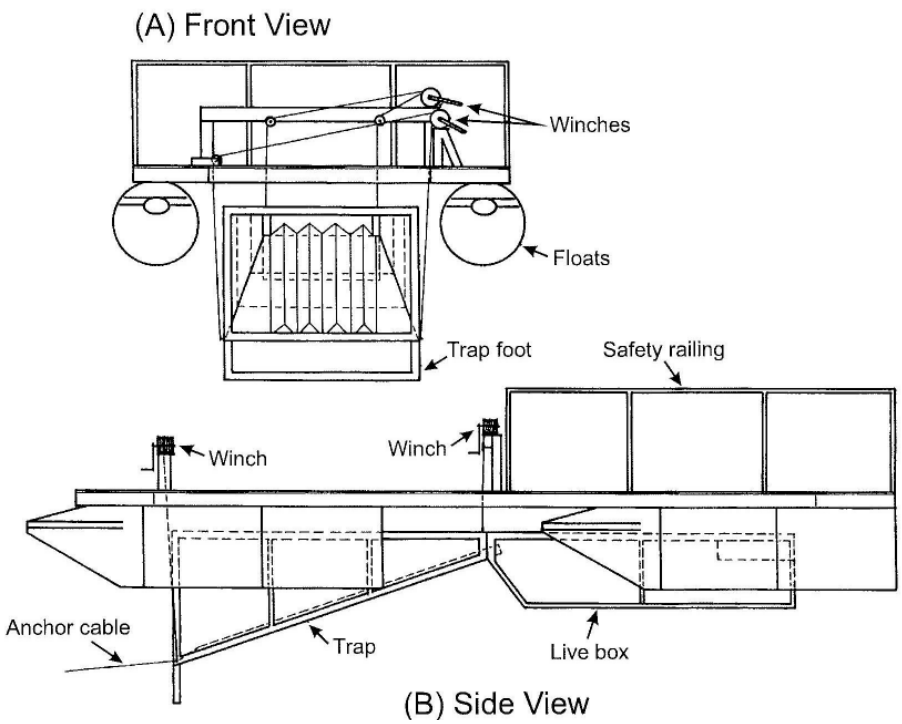

Figure 8-13. Front and sides of an inclined-plane trap and floating platform used for sampling salmon smolts (Source: Todd 1994)

Other trap designs have been developed to reduce the accumulation of debris on the trap and to adapt to specific site characteristics. For example, the Humphreys trap, uses a traveling screen instead of a fixed screen along with a trash drum at the back of the live well (McLemore et al. 1989). The basic Humphreys trap uses a paddle wheel and gear assembly attached to one or both pontoons supporting the trap to power the traveling screen and trash drum (Volkhardt et al. 2007). Another variation of the fixed-screen design involves having the upstream end of the inclined-plane screen attached to a low-head dam or weir; this version collects fish passing over the structure (e.g., DuBois et al. 1991). A lightweight inclined-plane trap for sampling salmon smolts has been used in Alaska (Todd 1994).

The Oregon Department of Fish and Wildlife (ODFW) uses an inclined-plane trap to capture and sample salmon smolts as part of its annual monitoring of the migration and survival of juvenile salmonids in the Umatilla River, (White et al. 2003). The width of the river near the trap is about 64 m. Average monthly discharge within the lower river varies from 0.7 m^3/s during summer months to about 31 m^3/s during spring runoff (typically in April). The trap fishes from near the surface to the bottom (approximately 5 m deep) and samples between 1% and 30% of the total flow through the canal (Josh T. Hanson, Fish Habitat Biologist, ODFW, pers. comm.).

ODFW's inclined-plane trap consists of diversion screens that direct fish into a bypass channel, through a dewatering plate, and across a fish separator. Large fish (> 400 mm) pass over the separator, into a down well, and back to the river through a 61-cm diameter bypass pipe. Small fish (< 400 mm) fall through the separator and pass through a PIT-tag detection system as they exit the separator back to the down well. Fish are sampled using a pneumatically actuated gate set at timed intervals according to the number of fish moving through the trap. When sampling, fish are diverted into a 2.8-m^3 holding tank equipped with a crowder, divider, and lift basket. Fish are crowded into the forward half of the tank and separated from incoming fish by lowering the divider. Fish are held for up to 48 hours prior to sampling. Traps generally are checked and cleared of debris once a day. The inclined-plane trap is effective for capturing juvenile salmonids; almost 34,000 fish were caught during the 2001 sampling season.

Washington Department of Fish and Wildlife (Kiyohara and Volkhardt 2007) and Califorinia Department of Fish and Game (Ricker 2005) also have used inclined-plane-screen traps in their juvenile salmonid monitoring programs. Some important details about those efforts (e.g., hydraulic conditions at the locations of traps, proportion of flow sampled, and depth of trap opening) were not available for this review.

Inclined-plane traps have been used to assess populations of outmigrating sockeye salmon on the Kenai Peninsula in Alaska since the early 1980s (Kyle 1992; Todd 1994). A 1.5-m wide, inclined-plane trap has been used extensively to capture juvenile salmon in the large and turbid Kasilof River (83 m wide and 1 m deep; discharge ranges from 10 m^3/s to 62 m^3/s). Smaller versions of these traps have been used successfully in other waterways in Alaska, including Quartz Creek (a small Clearwater tributary on the Kenai with discharges ranging from 5 m^3/s to 18 m^3/s; Flagg et al. 1986) and the Crescent River on the west side of Cook Inlet (Kyle 1983).

Richkus (1974) employed a modified-Wolf, inclined-screen trap in studies of out-migrating juvenile alewives (*Alosa pseudoharengus*) in a small stream in Rhode Island. The trap was installed in a Denil fishway and consisted of a galvanized, wire-mesh trough attached to a wooden frame suspended from baffles in the fishway. The upstream edge of the inclined trough was in contact with the bottom of the fishway and spanned its full width. All water entering the fishway passed through the trough, which terminated in a catch box with wire-mesh floor panels. A barrier net installed across the width of the stream at the fishway forced all downstream migrating fish to pass into the fishway. During the course of this study of alewives, the trap also captured large numbers of outmigrating silver eels; Winn et al. (1975) reported findings concerning eels.

8.2.2 EPRI's Tests at Green Island

EPRI patented a new fish-diversion concept known as the modular inclined screen (MIS) in 1991. EPRI evaluated a prototype MIS installed at Niagara Mohawk Power Corporation's Green Island Hydroelectric Project in New York State in 1995. The prototype MIS was designed by Stone & Webster, fabricated by Steel-Fab, Inc., and installed by Steel Style Inc. The test facility was adjacent to USACE's dam and auxiliary spillway on the Hudson River, just north of Albany, New York. The MIS is a fish-diversion screen for use in high-velocity waters that was developed during hydraulic model studies and biological testing conducted by Alden in 1992 and 1993. Laboratory tests indicated that fish diversion success approached 100% at velocities up to 1.8 m/s for nearly all fish species tested; diversion efficiency and survival of some species remained high up to flow velocity of to 3 m/s (EPRI 1994).

An existing ice-sluice gate at the Green Island Project offered a means to control flow rates through the prototype MIS. The main spillway is 179 m long, includes a 0.6-m-tall inflatable dam, and has a crest at elevation 5 m when the rubber dam is inflated. The fixed-crest auxiliary spillway is 204 m long and has a crest at elevation 5 m. The 7.3-m-wide ice sluice gate is adjacent to the auxiliary spillway and forebay entrance. Flow in the Hudson River averaged 270 m^3/s during the months of testing. The project has a hydraulic capacity of 170 m^3/s. The main spillway also has a capacity of 170 m^3/s when the rubber dam is deflated and the water level is at the elevation of the fixed-crest spillway. The test facility was designed for over-topping at headpond elevations greater than 5.8 m. The test facility had a negligible effect on hydroelectric operation because the ice-sluice gate and the MIS had a maximum flow of about 5.4 m^3/s or only 2% of total river flow. The location of the MIS structure adjacent to the bulkhead structure did not affect flow patterns to the plant intake and reduced the length of the fixed-crest spillway by only approximately 5%.

The prototype MIS at Green Island consisted of a streamlined entrance with a trash rack, upstream and downstream isolation gates, a wedge-wire screen set at a shallow angle to flow, and a bypass for diverting fish to a transport pipe or holding facility. The module was completely enclosed and was designed to operate at water velocities from 0.6 to 2.4 m/s. The MIS structure was about 3 m wide, 12.2 m long, and fabricated of steel plate and various structural steel shapes (Figure 8-14). A 3-m-wide trash rack (bar spacing of 20.3 cm) was located at the upstream end of the module (Figure 8-15). The trash rack had a 1:5 (horizontal to vertical) slope extending from the module to the deck level. A uniform flow distribution through the screen that reduced potential for fish impingement or injury was created because this slope provided a flow area under the screen at the bypass equal to the flow area immediately upstream of the screen.

A bypass sluice directed fish laterally across the module to the bypass and into the collection area. Bypass flows were controlled by a 0.3-m-wide, bottom-drop gate installed at the end of the fish-bypass sluice. Bypassed fish were collected in a hopper located immediately downstream of the bottom drop gate. The hopper was 1.2 m wide, 1.8 m long, 2.4 m deep, and could contain about 0.45 m^3 of water in the bottom when the fish were being lifted. The hopper was designed to collect fish discharged over the bottom drop gate (Figure 8-16). A manually operated gate was installed on one end of the hopper to discharge the fish into holding pens. An electric hoist was used to rotate the MIS between the fishing position and the screen-backwashing position (hoists were also used to raise and lower the collection net and hopper). The hopper also was hoisted from the bottom-drop gate to the sorting table. The gates and the screen could be operated either manually or with a portable electric motor. The pump system in the collection area included a flow-control valve that was used to monitor the bypass flow level continuously. To maintain the required head differential necessary for the various test conditions, the bypass flow from the MIS entered the collection area where it was pumped and discharged over the auxiliary spillway.

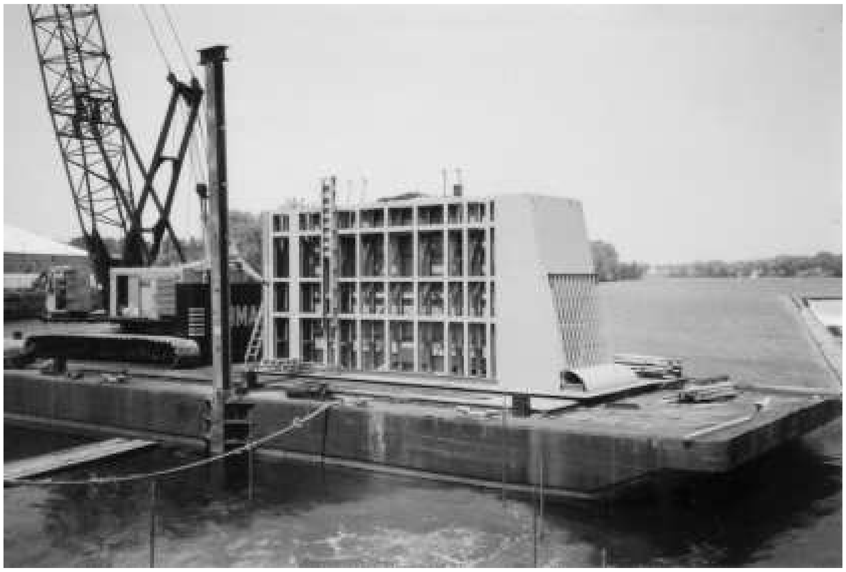

Figure 8-14. Photograph of the MIS prior to installation at the Green Island Hydroelectric Project, New York (Source: EPRI 1994)

Figure 8-15. Photograph of the entrance to the MIS module showing the trash rack (Source: EPRI 1994)

Hydraulic testing of the MIS at Alden's test facility indicated that flow ranged from 1.13 m^3/s to 4.39 m^3/s with the normal forebay water level at elevation 4.97 m (i.e., the top of the fixed-crest spillway). At normal forebay levels this range of flow corresponded to a minimum approach velocity of 0.61 m/s and a maximum approach velocity of 2.29 m/s maximum with respect to the screen. The minimum flow in the MIS was determined by the leakage around the closed, ice-sluice gate. The maximum flow in the MIS was achieved when the ice-sluice gate was in the full open position.

Figure 8-16. Photograph of fish collection hopper. Fish diverted by the screen into the bypass flow are collected in the hopper (Source: EPRI 1994).

Biological tests in the field indicated that, under most test conditions, the rates of diversion and survival of golden shiners and rainbow trout approached 100%. River conditions and the low numbers of fish that naturally entered the MIS limited the results for blueback herring. Rates of diversion and survival appeared to be related to test velocity in both natural and fish-injection tests. Greater velocities resulted in smaller rates of diversion and survival. In general, diversion efficiencies were high at velocities up to 1.22 m/s. Survival rates ranged from 70% at 1.22 m/s to 95% at 0.61 m/s.

Debris accumulated on the screen relatively slowly throughout most of the tests. Typically, less than one liter of debris collected in the net following backwashing of the screen; however, increased impingement of fish on the screen during two tests appeared to be the result of accumulation of debris. Debris comprised equal amounts of deciduous leaves and aquatic macrophytes. Debris entrainment into the MIS appeared to be minimal because of its submerged design. The volume of surface debris observed on the river during much of the study period was large compared to the volume of debris collected following backwashing. Due to the observed impingement events, the authors noted that frequent backwashing of the screen should be considered in riverine applications of the MIS, especially during high-flow periods when accumulation rates are likely to increase.

8.2.3 Applicability of Inclined Screen Traps at Iroquois Dam

The inclined-screen traps described above were designed for use at much smaller scales than would be required at Iroquois Dam. Most examples were in minor waterways with minimal flow compared with flow in the St. Lawrence River. As a result, the relevance of those studies for determining the potential applicability of inclined screens for diverting and collecting outmigrating eels in the St. Lawrence River is limited. EPRI's (1994) evaluation of the MIS at the Green Island Hydroelectric Project provides somewhat more insight into the potential viability of this technology for collecting eels at Iroquois Dam. The general scale of the Hudson River at the MIS test site is more comparable to the St. Lawrence River at Iroquois Dam in terms of size and hydraulic characteristics than the other applications. Survival rates approaching 100 % for golden shiners and rainbow trout under most test conditions indicates that the MIS can be fish-friendly for some species. Those species, however, are poor surrogates for silver eels because their body shapes and modes of locomotion are very different. As a consequence, the survival rates of fish in the Hudson River evaluation provides little information about how eels might survive passing through an MIS on the St. Lawrence River. The MIS structure on the Hudson River sampled only 2% of the total river flow during the evaluation. At Iroquois Dam, with its 32 identical gates, a trap installed in a single gate would sample only approximately 3% of the total flow of the St. Lawrence River. If only inclined-screen traps were to be used to collect eels at the dam, a trap would be needed in each gate (except for several that probably would have to be left open to allow for recreational boat traffic). Alternatively, inclined-screen traps could be used in combination with some kind of migration barrier, as described in conceptual designs for physical and light barriers in Sections 3.0 and 6.0. Floating and submerged debris, particularly submerged aquatic vegetation, is typically dense in the St. Lawrence River and is likely to foul screens continuously, posing the greatest obstacle to successful use of this capture technology. Screens clogged with debris would increase the likelihood that eels and other fish species would be impinged on the structure; consequently, frequent maintenance would be required to keep the screens operating effectively.

8.2.4 Design and Considerations for an MIS at Iroquois Dam

Alden was asked to provide a conceptual design and estimate the cost for an MIS that would be suitable for installation at Iroquois Dam (Alden 2007). The MIS at Iroquois Dam would be located behind one sluiceway and designed to collect and transport eels guided to the trap by some kind of diversion barrier. Modules would be used to screen the flow. The screen modules would be stacked vertically in two layers of three modules each, (Figure 8-17). This layout would provide MIS entrances at the top and bottom of the water column and would minimize reductions of flow capacity at the existing gate. Isolation walls would be constructed between the MIS structure and the sluiceway to prevent eels from bypassing the screens. A top pad would be constructed over the top of the modules to prevent eels from passing over the top of the modules and to support a trash rack cleaning system and a fish collection system.

Each module would have a 4.3-m, square entrance and approach area in a vertical plane upstream of the inclined screens. The entrances would have curved sides to create optimum flow distribution and acceleration approaching the screens. A trash rack with bars spaced at 30.5 cm on center would span the entrance of the collection facility to prevent large debris from impacting on the screen or entering into the fish bypass. Each screen would be about 20.4 m long and angled 10º off horizontal (Figure 8-18). The screens would be made out of stainless steel wedge-wire with 0.64-cm openings. Isolation gates would be located upstream and down-stream of each screen to allow dewatering for inspection and maintenance. A fish bypass entrance would be located at the downstream end of the screen and would transition from the full width of the screen down to a 45.7-cm-diameter pipe to a common, 60.7-cm-diameter manifold (Figure 8-19). The velocity in the bypass pipes would be about 3.0 m/s to quickly transport the eels and other fish to the collection area.

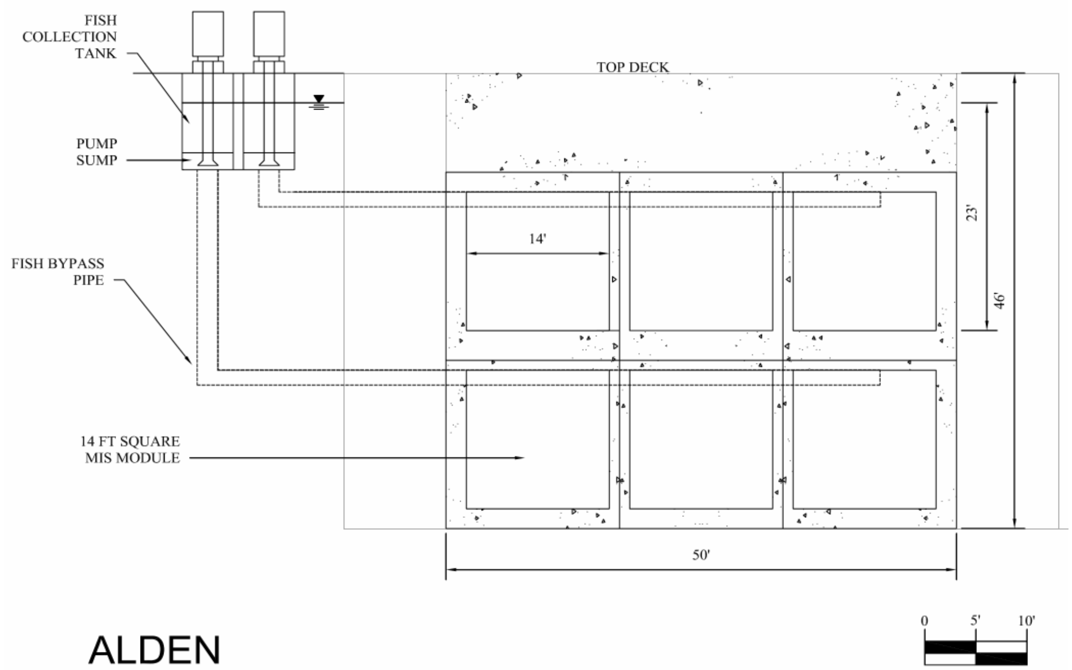

Figure 8-17. MIS for one sluiceway at Iroquois Dam – sectional view looking downstream

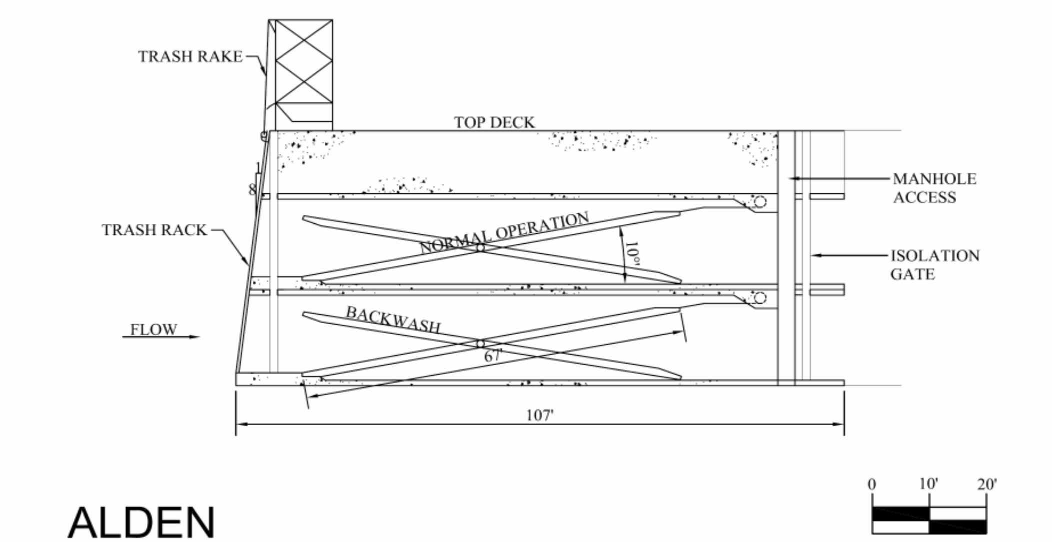

Figure 8-18. MIS for one sluiceway at Iroquois Dam – sectional view looking across the channel

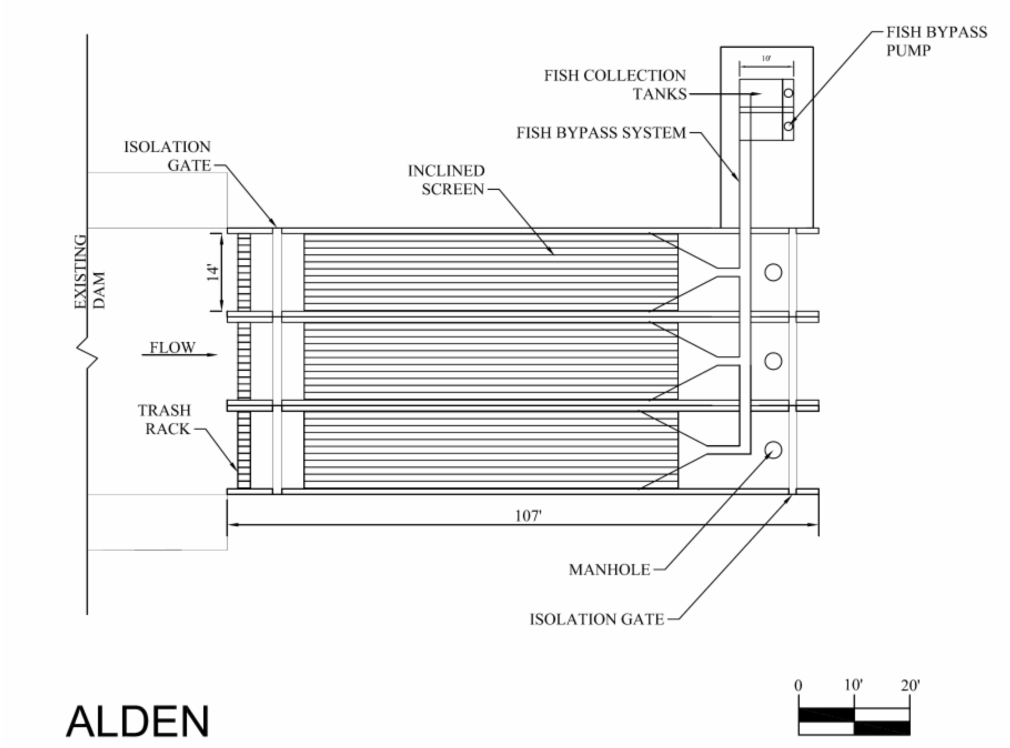

Figure 8-19. MIS for one sluiceway at Iroquois Dam – plan view looking from the top

The MIS and support structure would be designed to account for debris, ice, and hydraulic forces and to permit maintenance activities. Cleaning of the trash racks and screens would be necessary to maintain the passage efficiency of the screens and to prevent additional head losses. An automatic trash rake would be used to clean debris on the trash racks at the entrances to the screens. The inclined screens would be designed to rotate for back flushing of debris off the screen face, as needed. Debris removed from the inclined screens during back-washing would flow downstream. The screen facility would be designed to be operational year-round; however, the screens could be left in place in a horizontal position when eels are not present and during the coldest months to prevent plugging by ice.

8.2.4.1 Biological Considerations

Although the MIS has never been evaluated for diverting eels, lab and field studies with other species have consistently shown high bypass efficiencies (typically greater than 90%, depending on species and approach velocity). An Eicher screen positioned in a conduit down-stream of an experimental turbine effectively diverted juvenile American eels (99% diversion and survival of fish 30.5 cm – 45.7 cm long; Cook et al. 2003). Eicher screens, like an MIS, have inclined wedge-wire panels and produce rapid approach velocities that divert fish to a bypass at the downstream end of the screen.

Only MIS modules with 2-mm slot openings have been tested to date, and that configuration appears to be effective for guiding all but the earliest life stages of fish. Such a small slot size probably is not necessary for fish as large as silver American eels; therefore, a 0.64-cm slot size was selected for the conceptual MIS for Iroquois Dam because it would reduce head loss through the screens and should be sufficient to divert silver eels.

Given the ability of inclined, wedge-wire screens to divert fish effectively, the MIS concept is considered a viable alternative for collecting outmigrating American eels at Iroquois Dam; however, MIS has not yet been used in a full-scale, permanent application. Pilot-scale testing, a post-installation evaluation, or both would be needed to ensure optimum design and hydraulic conditions are being used for effectively diverting outmigrating eels to a collection area at Iroquois Dam.

8.2.4.2 Technical Considerations

Each MIS module would include a 4.3-m-wide by 20.4-m-long rectangular, wedge-wire screen inclined in the downstream direction at an angle of 10º from horizontal. The bars would be arranged parallel to the direction of flow. The screen panels would have a uniform porosity of 75% with 0.64-cm slots along the entire length. The panels would be supported by a steel frame designed for a 1.5-m differential pressure that could result from debris accumulation. The screens would be rotated by a motor operator to backwash debris from the screen face. At the average water depth of 13.1 m, the bottom of the top row of MIS modules would be about 7.0 m below the water surface. This submergence is several times the submergence required to prevent the formation of a vortex.

The fish bypass entrance at the downstream end of the screen would be the full width of the screen and would transition into a 0.46-m-diameter transport pipe. The velocity within the bypass pipes would be about 3.0 m/s to prevent eels from swimming against the flow and escaping upstream. Flow into the fish bypass would be provided by two pumps with screened suctions off the collection area. The eels would be collected from the collection area by draining the tank or crowding the eels into a lifting basket.

Construction of the modules and installation of screens would take approximately 15 months of active construction time over two years. During the first year, the MIS modules would be constructed on-site. Alden has assumed that the modules could be constructed two at a time to reduce the time required for construction. During the second year the installation sluiceway and an adjacent sluiceway would be closed to shelter and minimize turbulence in the project area. A temporary cofferdam would be constructed downstream of the gates to allow the construction area to be dewatered. Once the cofferdam is complete, the area behind the sluiceway would be inspected and excavated as needed to install a level foundation anchored to existing bedrock. After the completion of the foundations the MIS modules would be lowered into place. The top deck, trash rake, fish bypass and collection tank would be installed once the screen modules are in place. After the installation is complete the cofferdam would be removed, and the sluice gates would be opened to allow flow through the screens.

The MIS facility would not significantly affect current operations of Iroquois Dam. Flow capacity through the gated structure is expected to be reduced due to the added head losses associated with the screening facility. Typically MIS modules are designed for applications where flow is induced through the module by an existing head differential typical at hydropower stations. At Iroquois Dam the available head differential through the existing gates is limited. Based on that head differential, Alden estimated an approximate velocity of about 0.61 m/s approaching the MIS. This is an approximate estimate based on river flow, screen slot size, and assumptions of head differential through the existing gates. Daily monitoring and cleaning of the trash rack and screens probably would be necessary to maintain hydraulic conditions that are most conducive to effective diversion. The time required to monitor and clean the trash racks and screens has been estimated to be about one hour per day when the screens are in position for fish diversion. Power to operate the trash rake and inclined screens would be about 1,759 kWh per year, assuming that the trash racks would need to be cleaned weekly, and the MIS would need to be rotated daily. Operation of the bypass flow pumps would require approximately 657,000 kWh per year. In addition to daily cleaning, the MIS modules and bypass systems would need to be thoroughly inspected once a year.

8.2.4.3 Costs

Alden (2007) estimated order-of-magnitude installation, operation and maintenance, and power costs associated with installing an MIS at Iroquois Dam. The costs were estimated using quantities developed from a conceptual MIS design and cost data from other projects that were adjusted for identifiable differences in project sizes and operations and were considered to be sufficient for planning proposes. The cost estimates do not include such ancillary costs as those to perform additional laboratory or field studies that may be required, those for administration of project contracts and for engineering and construction management, those for permitting, and those for price escalation. The estimated capital cost of the conceptual MIS for Iroquois Dam is $12.6 million (2007 U.S. dollars), with annual operating costs of $220,000, all costs ± 50%.

8.3 TECHNIQUES FOR HOLDING AND TRANSPORTING EELS

This review was as comprehensive as possible and included all of the numerous methods that eel fishers throughout North America and Europe have used to hold and transport eels in large and small operations for both yellow and silver stages. All of the information acquired was reviewed to identify methods and techniques that could be effective for a capture and transport program. Many of the methods identified clearly would be inappropriate for such a program, primarily due to the potential for injuring eels. Such potentially injurious methods are described in Appendix C despite being considered inappropriate for NYPA’s purposes, to illustrate the wide range of devices that have been used to hold and transport live eels of all life stages.

Many factors must be considered in determining which methods for holding and transporting eels are most appropriate for a large-scale capture and transport program. If eel abundance and daily capture rates are low, captured eels may have to be held for an extended time to accumulate sufficient numbers to make transporting them economically feasible. In such circumstances, holding conditions that prevent injury, create the least stress, and maintain eels in the most natural conditions would be desirable. If eel abundance is high, providing adequate space and a constant supply of aerated water is essential. Eales (1968) reported that 2,832 liters of water is an appropriate volume for holding 680 kg of eels, if a constant supply of aerated water is available. He recommended decreasing the number of eels per unit volume substantially when water is limited. A container with smooth interior edges helps to prevent physical damage, particularly damage due to loss of slime from the skin (Eales 1968; M. Feigenbaum pers. comm.). If mortality occurs, dead eels must be removed immediately (Eales 1968). Creating flows in the holding container and discharging water from the container should be avoided due to the eels' tendency to attempt to escape from containment (M. Feigenbaum, pers. comm.).

8.3.1 Holding Tanks

Tanks are used commonly in commercial fisheries to hold silver eels between the time of capture and the date of sale. Table 8-1 provides detailed information collected during interviews with commercial fishers and fish distributors about their methods for holding eels. In general, tanks ranged from 1000 to 2000 liters in volume and held between 100 and 300 eels. The water temperature inside the tanks was maintained within the range of 4ºC to 15ºC. Many correspondents reported using compressed air to aerate the water. The minimum reported holding time was 4 days, and the maximum was 11 months. One fisher reported using indoor swimming pools filled to a depth of 46 cm (J. Paquet), and another reported that he retains his catch in a fishing weir until a buyer arrives (F. Campfield).

In a trap and transport study conducted by Stanley and Pope (2008), large yellow eels captured for transport below the two hydroelectric dams on the St. Lawrence River were kept in flow-through livewell facilities or in wire-mesh holding pens in local waters prior to being transported. More detail on this study is presented in Section 8.7.3.

8.3.2 Barges

Another approach is to store eels on a barge, which could serve as a transport facility as well as a holding facility. For example, Messrs Aldous Successors Ltd. (Brightlingsea, Essex, England) constructed a containment barge for the Live Eel Supply Company, Ltd. (Malden, Essex, England). The barge measured 32.6 m by 5.6 m, had a draft of 1.4 m, and could hold 500,000 eels (0.9 kg each). The bottom of the barge was made from perforated steel plates through which water could flow from the outside. Two buoyancy tanks located fore and aft kept the barge afloat. The holding tanks were aerated using a diesel-driven compressor located in the center deckhouse. The deckhouse also contained a pump that used 72 jets to pipe aerated water into the tanks and a power generator to supply electricity. Eels were kept for "long periods" in a British canal using this method (Eales 1968). Occasionally, the barge was moved out to sea for 24 to 48 hours to invigorate the eels and prevent them from losing their "wriggling characteristics." Such trips were brief because prolonged exposure to seawater increased mortality

Table 8-1. Holding facilities for silver eels used by commercial fishers and distributors (n/r = none reported)

Data Source	Holding Facility	Tank Size	Water Temp (^{o}C)	Water Aerated (Y/N)	Water Treatment	Holding Time	Eels Per Tank
D. Witten[a]	[b]Box→ plastic barrel→ truck tank→ holding tank	n/r	~9	n/r	n/r	About 1 week	n/r
A. Gagné[b]	Tanks	n/r	4-15; tank is insulated	Y	water changed 3X per week; chlorinated	Up to 3 months	200-300 (~454kg)
C. Guy[a]	Tanks	4 X 1000 L & 2 X 2000 L tanks	12-15	Y	n/r	5 d	~200 (250 kg)
G. Dionne[a]	Tanks	8 X 1000 L tanks	n/r	Y	water changed every 2 d	n/r	250-300 (~600 kg)
J. Paquet[a]	Indoor swimming pools	Water depth = 46 cm	12-15	Y	freshwater changed every 3 d; NaCl added to water only when some eels contract yeast infection	Up to 4 months	n/r
G.-H. Lizotte[a]	Tanks[d]	8 X 1000 L tanks	6-13	Y	water changed every 2 d;	4-10 d	~200 (225 kg)
B. Ouellet[a,c]	Tanks	6 X 1000 L tanks	6-15	Y	water renewed every 2 d;	~4 days	~100 (150 kg)
F. Campfield[a]	Weir	n/r; uses tanks on trucks to transport (2.1 m width X 0.6 m depth)	n/r	n/r; transport tanks, Y	n/r	Until buyer comes; or up to 1 yr in his own large tanks	n/r

[a] Commercial fisher

[b] Plastic barrels are smooth-sided, which prevents disturbance of the eels' skin slime. Tanks on trucks deliver the eels to holding tanks. Eels are stored until a sufficient number to sell are caught. In the case of a large catch and insufficient room in the tanks, eels may stay in the tank for only one or two days before a buyer arrives. On occasion, eels are stored over winter from September to July.

[c] Fish distributor

[d] Early in the season when catches are low, eels may be kept in a holding box on muddy flats in brackish estuarine habitat for up to 30 days.

rates for both silver and yellow eels. Eales (1968) reported that eels were maintained in these confined quarters for several months and noted a 20% decrease in weight during holding. He also noted that weight loss was more rapid among yellow eels than among silver eels.

Custom-made barges also have been used to transport eels by sea for fisheries in the U.K. and across Europe. For example, Horne and Birnie (1970) described steel "tank crafts" with perforated sides and bottoms. The perforations were 10 mm in diameter and occurred at 20 mm intervals. Water in the tanks was pumped continuously and aerated with an air compressor. Nine-hundred-seven kilograms of water was used to house 907 kg of fish. Dutch fishers also transported eels by ship around 1968 (Eales 1968). For example, the Helene was a 116-ton vessel with a perforated hull. A double deck and diesel oil tanks maintained the buoyancy of the vessel. Another example is the 300-ton Mercurius. Operating in eastern Canada, the Mercurious maintained continuously circulated seawater in its tank holds. One disadvantage cited by Eales (1968) is that eels were exposed to pollutants and contaminants in the surrounding water, which could cause mortality. This problem resulted in the loss of a shipment of eels from Quebec in the St. Lawrence due to polluted waters.

8.3.3 Trucks

Commercial eel fishers in the United States and Canada frequently transport their catches to a secondary location for sale or long-term holding (Table 8-2). During telephone interviews, one fisher reported using a truck with a large cattle stock tank to transport eels. Another reported that he transports eels in water, on wet ice, or in bags of water and pure oxygen, depending on his customer. Fishers commonly reported transporting eels to a broker located in a major city, who then distributes the eels to markets in Europe, Asia, and North America. Other destinations included a restaurant and a power company.

Horne and Birnie (1970) reported that large numbers of eels from Northern Ireland and elsewhere in Europe were shipped aboard road vehicles or ships outfitted with special tank facilities in the U.K. To transport eels by road, vehicles contained sectional tanks in which water was circulated continuously via a circulation pump and aerated by an air compressor during travel. Nine hundred seven kilograms of eels were transported in 907 kg of water. Eales (1968) also reported that tank-truck trailers were used to transport eels from Northern Ireland to southern England. Each trailer carried between 12 and 14 tanks that measured 0.9 m x 0.9 m x 0.9 m. Each tank held 453 kg of water and 453 kg of eels. The trailer also contained an air compressor that was operated alternately by one of two small diesel engines to aerate the water in the tanks. Tanker trucks have also been used to transport eels throughout eastern Canada (Eales 1968).

Eels are also trucked for non-commercial purposes. The Electrical Supply Board (ESB) of Ireland uses trucks outfitted with large transportation tanks to move some eels a few kilometers downstream of a dam on the Shannon River (D. Doherty, pers. comm.). Eels to be relocated are taken directly from capture nets to a 200-liter tank aboard a truck for transport. The

Table 8-2. Modes of transport and destinations for silver eels reported by commercial fishers and dealers (n/r = none reported; n/a = not applicable)

	Mode of Transport	Distance	Market	Other Information
D. Witten[a]	Truck	n/r	G. Grommet[b], Florida Power & Light, Alden Laboratories	n/r
A. Gagné[b]	n/r	400 km	Toronto for Korea, Taiwan	n/r
C. Guy[c]	n/r	n/r	Pecheries Gagné [b]	n/r
G. Dionne[c]	n/r	n/r; to Toronto	Toronto for Asia	n/r
J. Paquet[c]	n/r; in insulated tank; 8-15 °C	n/r; to Toronto	Toronto for N. America, Asia	n/r
G.-H. Lizotte[c]	n/r	n/r; to New Brunswick	Shore Trading Co.[b]	n/r
B. Ouellet[b,c]	No transport	n/a	n/a	n/r
F. Campfield[c]	Truck with cattle stock tank (210 cm w X 60 cm d)	To his storage facility	restaurant	n/r
M. Feigenbaum[c]	n/r	n/r	n/r	In water; on wet ice; in bags of water with pure oxygen gas

[a] Environmental consulting company specializing in fish passage systems
[b] Fish distributor
[c] Commercial fisher

tank is aerated with bottled oxygen. Approximately 10% of the captured eels are released in this manner, but the percentage transported daily varies during a migration season; the remaining 90% of eels are harvested by the cooperating fishermen. In the trap and transport study conducted by Stanley and Pope (2008), large yellow eels were transported via truck in fish totes with raw water aerated with compressed oxygen. Water temperatures were monitored continually, and if temperature rose more than 2 °C during transport, ice was added to stabilize temperature. The temperature of water in the transportation tank was also allowed to equilibrate with the temperature of water at the point of release before releasing the eels.

8.3.4 Applicability for Holding and Transporting Eels from Iroquois Dam

Except for those handled in the trap-and transport-study conducted by Stanley and Pope (2008), all eels held in the facilities reviewed here were destined for market. For this reason, holding facilities were designed to maintain eels in good physical condition, but the effect of holding on eels' behavior and physiology (e.g., sexual maturation, see Section 8.7) was not considered or evaluated. The findings of Stanley and Pope (2008) suggest that handling and transportation of the magnitude experienced by eels in that study did not adversely affect their maturation and migratory behavior. Given that those findings are preliminary, ensuring minimal holding times for eels to be released downstream, or at least limiting the holding period to less than the time estimated for eels captured at Iroquois Dam to move below Beauharnois Generating Station naturally, seems reasonable to protect the eels. NYPA's telemetry studies (McGrath et al. 2005) indicated that migration between Moses-Saunders Power Dam and Beauharnois Dam approximately 85 km downstream took an average of 8.2 days at an average speed of 0.12 m/s. Based on that information, eels might require 18 to 20 days to move downstream from Iroquois Dam to below Beauharnois Dam, which would allow for a considerable holding period. A lengthy holding period may be necessary because the density of outmigrating eels in the upper St. Lawrence River currently is considered to be very low (see Section 9.6); consequently, accumulating a sufficient number of eels to transport them economically might take time.

Holding eels in tanks would appear to be relatively straightforward, given the information presented above; however, that method would require handling the eels twice: once from trap to tank, and another time from tank to transport vehicle. Having the tanks permanently mounted and maintained on the transport vehicles would require handling them only once, presuming that a discharge system for returning them to the river would eliminate the need for any kind of handling during release. Holding and transporting eels on a barge would involve handling the eels only once, presuming that the discharge capability on the barge would allow eels to be released directly to the river. Barges would be considerably more expensive to construct and maintain than tanks. In addition, mooring a barge would require constructing a dock facility along the shoreline, which could be more expensive than preparing an area near the shoreline for tanks and supporting equipment (e.g., pumps, aerators).

In a conceptual design for an eel collection, holding, and transportation system at Iroquois Dam, Kleinschmidt (2006) assumed that captured eels would be sorted and placed into a transport vehicle or holding tanks for later transport. Kleinschmidt's design assumes that trucks would be the initial transport system and that a barge could be used later, when rates of capture increase. The conceptual system includes transport trucks capable of holding approximately 19,000 liters (or kg) of water each. The trucks would be equipped with aerators, circulators, and monitoring equipment as necessary. Kleinschmidt's design assumes that a transport density of 227 g in 3.79 l would be acceptable, based on transport densities used for salmon smolts in the Pacific Northwest and recommended densities for adult salmon (Bell 1984). Based on this estimate, each truck could transport 1,134 kg of eel. The average weight of an eel was assumed to range from 1.5 to 2 kg (actual weights vary from approximately 1.3 kg in the estuary to 2.1 kg for mature eels in Lake St. Lawrence; McGrath et al. 2003b). Based on these estimates, between 570 and 760 eels could be transported per truck. Maximum capacity to transport eels based on two truck loads per day over the 105-day migration season would be approximately 160,000 eels; however, this model may be unrealistic because the number of migrating eels would not be distributed evenly throughout the migration period. This truck-transport system assumes an 8-hour day to load a truck, transport and release eels downstream of Beauharnois, return to Iroquois, and prepare the truck for the next trip. If the number of eels exceeds the capacity of two transport trucks, more trucks could be added. The logistics of transferring eels to the trucks (e.g., working space, handling ability, and time) was considered to be a potentially limiting factor. If eel numbers increase to the point of exceeding the capacity of a truck system, Kleinschmidt considered a barge system with on-board holding facilities similar to the systems used to transport salmonid smolts on the Columbia and Snake rivers (Section 8.4.1) to be the most appropriate method

Kleinschmidt (2006) indicated that although transport by barge could be more efficient for handling large numbers of eels, holding times could be longer, which would increase stress and the potential for adversely affecting eels' behavior and maturation. On the positive side, using barges to transport eels downstream would allow for continual exchange of barge water with surrounding waters, providing eels with a natural progression of olfactory cues while moving downstream. Eels experience olfactory cues while migrating upstream during their early life stages that may play an important role in their later outmigration. Westin (1990, 1998) showed that hatchery-raised, anosmic (i.e., unable to smell) eels migrate slowly and navigate poorly, suggesting some role of olfaction in migration. Capturing and transporting eels some distance downstream without providing contact with the waters through which they would pass naturally might result in disorientation. Such phenomena are believed to occur with anadromous salmon, but no such effect has been demonstrated with catadromous eels.

Kleinschmidt estimated capital costs (converted to 2007 U.S. dollars) for the two transport options: truck - $282,667 ($565,333 for two trucks), or barge - $2.0 million. Operating costs to transport eels were estimated at $156,472 per year.

Information from several of the reviewed sources suggests that a ratio of 1 to 1 for weight of water to weight of eels is appropriate for holding and transporting eels. Using that relationship and assuming that the 19,000 kg of truck contents would be half water and half eels by weight, a considerably larger number of eels (4,524 to 7,307) than is considered in Kleinschmidt's conceptual design could be transported in the trucks it describes. Given the small number of eels expected to be migrating past Iroquois Dam in the near future, a major logistical decision would be whether to transport eels daily, regardless of the number captured, or to initiate transport only when some minimum number of eels is available. The potential effect of holding on eels' sexual maturation is discussed in Section 8.7.

8.4 POTENTIALLY RELEVANT TRAP-AND-TRANSPORT PROGRAMS FOR OTHER SPECIES

Several large-scale programs for aiding fish migrations are operating in other river systems. These programs are potentially relevant to a trap-and-transport program for out-migrating eels in the St. Lawrence River because they are similar in scale and were implemented to achieve objectives similar to NYPA's desire to reduce mortality of downstream migrating fish due to turbine passage at hydroelectric plants. Many features of these programs, as well as the problems encountered in implementing them, could inform decisions required to develop a similar program for silver eels on the St. Lawrence River, even though some aspects of these programs are not directly applicable.

8.4.1 Snake and Columbia Rivers

The Juvenile Fish Transportation Program (JFTP) is a major mitigation program operated by the Army Corps of Engineers. The program began operation in 1981 (Ward et al. 1997) and is designed to protect juvenile salmonids from the effects of passage through Federal hydropower projects (dams) and reservoirs on the lower Snake River and middle and lower Columbia River. Juvenile Pacific salmon (genus *Oncorhynchus*, including sea-run steelhead, *O. mykiss*) that are migrating downstream are collected from bypass systems at Lower Granite, Little Goose, and Lower Monumental dams on the Snake River, and McNary Dam on the Columbia River (Figure 8-20). Transported fish are released below Bonneville Dam, the most downstream dam on the Columbia River.

Transportation is intended to protect the juvenile migrants from conditions including the direct and cumulative mortality associated with turbine passage, predation that occurs at dams and in reservoirs, damage incurred from passage through spillways, and gas super saturation caused by spill at dams (DOE 1995). The JFTP also counteracts the inevitable delays in migration caused by the low-flow reservoir waters between dams as well as the sometimes substantial delays in dam forebays and inside dam structures.

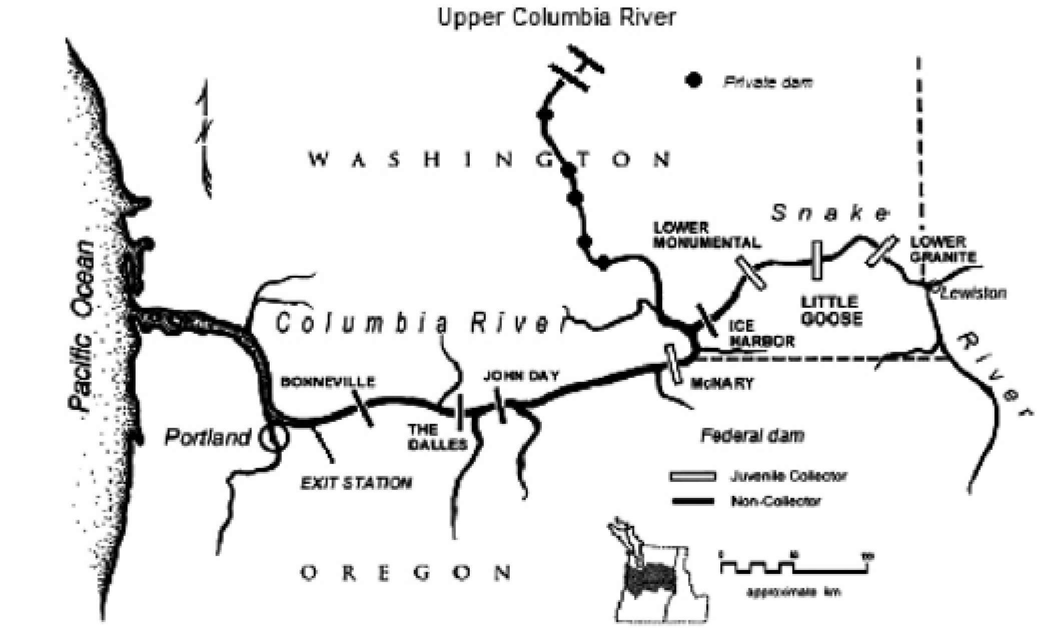

Figure 8-20. Schematic drawing showing the main waterways in the Columbia-Snake River Basin. Note the four dams, marked by white bars, at which some proportion of the downstream-migrating salmonids that are screened into the juvenile bypass systems can be collected for transportation downstream by barges or trucks. (Source: Wertheimer and Evans 2005).

8.4.1.1 Collecting Juvenile Fish

The number of juvenile fish collected each year is a function of how many fish are produced above the collector dams, the guidance efficiency of fish screens in the turbine intakes, and the quantity, proportion, and timing of spill at each dam (DOE 1995). In years when in-system survival is deemed likely to be especially poor, such as the drought year of 2001, a relatively greater proportion of the entire downstream run may be consigned to transportation than in other years.

Collection Facilities. As juvenile salmonids, which typically prefer to swim near the surface, approach powerhouses, they dive or are drawn down and enter turbine intakes through trash racks with gaps of 15 cm. As they pass near the ceiling of the turbine intake, the fish encounter traveling screens (see Gessel et al. 1991 for a review) that divert them upward into vertical gate-well slots that lead into a collection channel, tunnel, or flume (Figure 8-21). Collected fish are conveyed from the dam to a collection facility adjacent to the downstream side of the dam. At the collection facilities, most of the water is removed at a separator where adult fish and debris are bypassed back to the river. Juvenile fish swim downward between bars in the separator and exit through orifices and into distribution flumes that route them into holding tanks (raceways), sample tanks, or directly into barges or trucks. Fish are held at collection facilities for less than 48 hours after being captured.

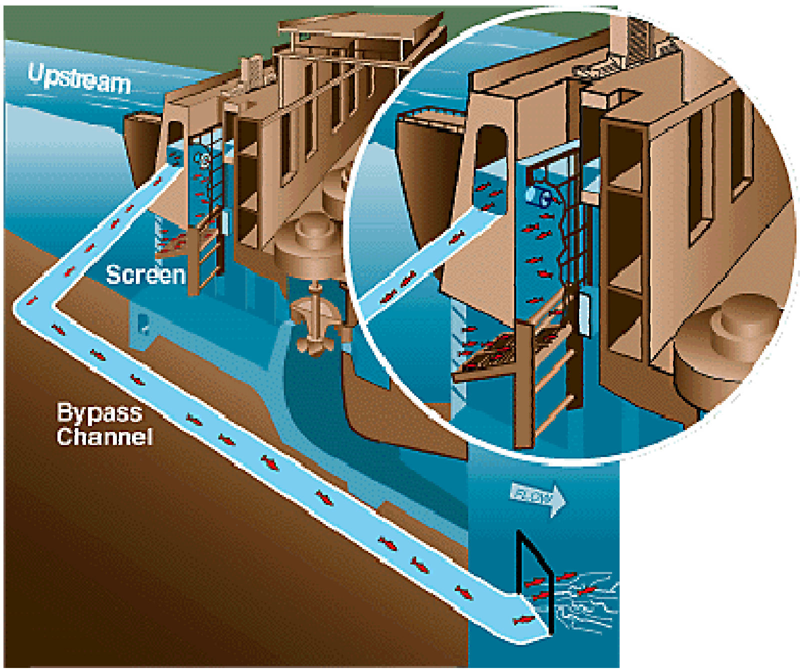

Figure 8-21. Schematic drawing showing the mechanism for collecting migrating juvenile salmonids downstream of a dam in the lower Columbia-Snake Basin. (Source: https://www.nwp.usace.army.mil/home.asp)

Bypass Water Supply. River water enters the juvenile fish collection systems through orifices from the bulkhead slots within the turbine intakes of each dam. A 30.5-cm orifice typically passes water at 0.3 to 0.4 m^3/s at the rate of up to 7.6 m/s (DOE 1995). The cumulative total flow in the collection channel ranges from about 6.8 m^3/s at Lower Granite Dam to more than 19.8 m^3/s at McNary Dam. Flow of approximately 1.7 m^3/s is required to run the distribution system, holding tanks, and raceways at each facility.

Size Separation. At McNary, Little Goose, and Lower Monumental dams, smaller fish are diverted to raceways, sample tanks, or into barges by flumes separate from those that divert larger fish. When loaded on trucks or barges, the fish are kept separated by size in order to reduce stress and predation on the smaller smolts (DOE 1995).

Raceways. At Lower Granite and Little Goose dams, raceways (rectangular channels used to hold juvenile salmonids) are typically 1.2 m wide, 1.5 m deep, and 24.4 m long. At all dams, fish are distributed among the raceways to limit loading in individual raceways to below the overloading criterion (DOE 1995). The criterion of 50 g/l is met only when facilities are filled to capacity. When capacity is exceeded, excess fish are bypassed back to the river. During most of the passage season, fish are held and transported at lower densities.

Biological Sampling. Sample rates vary across projects and throughout the season. Between 92% and 97% of the collected fish are routed to raceways or directly into barges without ever being sampled or handled (DOE 1995). During the later part of the migration season when numbers of collected fish are low, 100% may be routed into the laboratory for processing. As a result, anywhere from 10% to 87% of the fall chinook salmon (*O. tshawytscha*) are sampled at different dams. Automatic sampling systems divert approximately 3% to 8% of the collected chinook and sockeye salmon (*O. nerka*) into sample tanks.

8.4.1.2 Loading Fish

Fish collected in raceways are crowded to the exit pipe by lowering the water level in the raceway. The fish are moved through an exit pipe and water is flushed through the pipe to ensure that all fish are loaded into the truck or barge. Pipes to trucks or barges are typically 25.4 cm to 30.5 cm in diameter. The loading system typically is a combination of aluminum flumes and pipes. All loading to trucks and barges is by gravity flow, and pipes and flumes are constructed according to review criteria for the design of fish facilities. Maule et al. (1988) reported that based on physiological assays and performance in challenge trials, the loading portion was the most stressful part of the operation.

8.4.1.3 Transporting Fish

Juvenile salmonids are transported from the collector dams to release areas below Bonneville Dam. When numbers are low, fish are trucked and released from the shore below Bonneville Dam. When the numbers are high, most fish are transported by barge. At the beginning and end of the spring barging season, a barge leaves Lower Granite Dam every other day. Summer barging lasts through mid-August, then fish trucked from McNary Dam are barged to the middle of the river for release, typically through the end of December (DOE 1995).

Barges. Six barges are available for transporting juvenile fish (Figure 8-22). All barges are constructed of painted steel with compartments varying from 1.2 m deep around the perimeter to 1.8 m deep at the release hole. Two of the six barges are small, Army surplus vessels acquired in 1978. These barges have three tanks constructed in line from bow to stern. The tanks are separated by partitions, and each tank slopes toward a central release hole. The holes serve a dual function; pumped water flows through screens and is discharged through the release holes into the river during loading and transport. For release, the screen mechanism and a stopper are lifted vertically to allow water and fish to exit from each tank through a 43.2-cm hole. These barges are equipped with 3 pumps capable of providing 17,400 liters per minute of inflow. Water is pumped upward against a baffle and allowed to fall back into the holding tanks to aerate or degasify the water. Each small barge can hold about 322,000 liters of water, but loading capacity is rated on 2.3 kg fish/liter/minute inflow. As a result, these barges are capable of transporting up to 10,433 kg of fish or, assuming an average of 20 fish/kg, approximately 230,000 fish that are each about 17.8cm long (DOE 1995).

Figure 8-22. Barge for juvenile fish transportation program. Note the hull lying low in the water and flow-through water being discharged down the side (Source: https://www.nwp .usace.army.mil/home.asp)

The two medium barges were constructed in 1981 and 1982. They have four compartments, two forward and two aft on either side of the centerline. These barges can hold up to 378,000 liters of water. Like the small barges, the medium ones have three pumps, but these are capable of providing 37,000 liters per minute of inflow. At 5 2.3 kg fish/liter/minute inflow, they can haul up to 22,680 kg of fish. Each tank slopes toward a stopper near the centerline through which fish are released. The screened, water-overflow system is separate from the fish-release system. Water is pumped through packed columns to provide aeration and degasification (DOE 1995).

The two largest barges were built in 1989 and are similar to the medium ones but have two additional compartments. They can hold 567,000 liters of water, and the pumps provide 47,304 liters per minute of inflow. These barges can hold up to 34,000 kg of fish at 2.3 kg fish/liter/minute inflow. The medium and large barges are equipped so that inflow can be shut off, and water within the barge can be recirculated in the event of a chemical spill or poor water quality along the transport route (DOE 1995).

Each barge is equipped with at least one backup pump system. When fully loaded, three pumps of four on the large barges, or two pumps of three on the medium and small barges, are required. If a pump fails, the backup pump is started. When a barge is less than fully loaded, only one or two pumps are necessary to maintain oxygen levels. Each barge has an oxygen-sensing system that monitors gas levels continuously when the barge is filled with water. When fish are loaded on board, the barge rider typically monitors fish condition, temperature, and oxygen levels for the first hour or two after leaving the collector dam. As the trip progresses, monitoring occurs every other hour, then every four hours until release. Each barge is equipped with gas-stripping equipment in case water is being spilled at dams along the transport route (DOE 1995).

Trucks. Early and late in the season, when fish numbers at Lower Granite Dam are less than 20,000 per day, 13,000-liter fish trucks are used to transport the juvenile salmonids (DOE 1995). Seven fish trucks are used: two at Lower Granite Dam, one at Little Goose Dam, one at Lower Monumental Dam, two at McNary Dam, and one spare. The trailers have painted steel or stainless steel tanks divided into three compartments. The floors of the tanks slope toward a central unloading trough, which slopes to the rear of the truck where the exit is equipped with a pneumatic, knife-valve for unloading. All tanks are equipped with air stones, agitators, and a recirculating pump. Liquid oxygen and compressed air are used to maintain oxygen levels. Refrigeration units are included in the recirculation systems to maintain water temperature. The tanks are surrounded by insulation, and the trucks are covered with metal plate. When fish numbers are very low at dams on the Snake River during the late summer and fall, three, 570-liter mini-tankers are used to transport fish. These smaller trucks have insulated fiberglass tanks equipped with agitators, oxygen supplies, and refrigeration units. The tanks can be divided into two compartments if necessary.

Time inTransit. The time in transit via barge from Lower Granite Dam to the release point below Bonneville Dam (472 km) is about 36 hours; from Little Goose Dam (410 km), transit time is about 30 hours; from Lower Monumental Dam (365 km) about 24 hours; and from McNary Dam (235 km) about 15 hours (DOE 1995). Time in transit via truck is 6 to 10 hours from Lower Granite Dam, 6 to 8 hours from Little Goose Dam, 5 to 7 hours from Lower Monumental Dam, and 4 to 5 hours from McNary Dam. Holding time in transport vehicles is limited to 48 hours. No fish are to be held more than 96 hours from time of collection to time of release downstream of Bonneville Dam.

8.4.1.4 Releasing Fish

From the beginning of the transport season until mid-April, fish are trucked from Lower Granite and McNary dams to Bradford Island (downstream of the north end of Bonneville First Powerhouse), where they are released through a pipe into the river. From mid-April through mid-June (spring barging season), fish are barged from the collector dams to random release sites downstream of Bonneville Dam. From mid-June until the end of the season, fish are transported from the Snake River dams in large trucks or mini-tankers. Large and small trucks are transported by barge to the middle of the river downstream of Bonneville Dam so that fish can be released away from concentrations of predators along the shore.

8.4.1.5 Mortality

The potential for injury or mortality during collection and transportation begins as fish pass through the trash racks. When the trash racks are clean, the potential for descaling is small. As biofouling organisms and debris collect on the racks, the rates of injury and mortality can increase. Similarly, rates of injury and mortality are likely to increase if vertical barrier screens or orifices become blocked with debris.

Technicians remove dead fish from the collection from time they enter the turbine intakes until they are loaded onto barges or trucks. Total collection mortality ranged from 0.1 to 0.7% at Lower Granite Dam from 1981 through 1995. During the same period at Little Goose Dam, total collection mortality ranged from 0.4% to 2.1%. Overall mortality at Lower Monumental Dam was estimated at less than 0.5% in 1993. Mortality at McNary Dam has ranged from 0.4% to 3.9%. Mortality rates at collection facilities vary annually, probably as a result of variable outflow conditions and water temperatures. In the trucks and barges, seasonal mortality typically is less than 1% (DOE 1995).

Estimates of mortality during collection and transportation are based on recovery of dead or moribund fish. Juvenile salmonids that are diseased or injured when they come into the system are collected and transported as live fish. Fish that are stressed or injured during collection and transportation also are counted as live fish unless they die and are removed during the process. Mortality rates reported for collection and transport, consequently, exceed rates actually caused during the process but can underestimate mortality caused by the process that occurs after the fish are released.

Personnel from state agencies and the Smolt Monitoring Program monitor descaling and other injures daily at the collection facilities. When rates of descaling or mortality increase, biologists check facilities upstream in the collection system to find the cause. Orifices and screens are inspected and cleaned or repaired, if necessary. If the problem continues, the trash racks are cleaned. If the problem persists, biologists may dip fish from gatewells to determine whether fish are entering the system with greater than normal descaling rates (DOE 1995).

8.4.1.6 Problems with the Trap-and-Transport Program

Although the cost of the transportation program in the Columbia and Snake rivers is less than the cost of foregone electric power generation if spills were to be used to move fish downstream without passing through turbines, the extent to which transporting fish past the dam actually reduces the rate of mortality among smolts during the seaward migration and increases the number of fish that return as adults is unclear. Fish collection in the Columbia-Snake Basin goes back at least to the early 1970s (Park and Farr 1972), and the federal transportation program conducted by the USACE has been in operation since 1981 (Ward et al.1997). Giorgi et al. (2002) and Ferguson et al. (2004) provided recent analyses of past successes and failures and prognoses for the future. In the past quarter-century, capturing and transporting smolts has not solved the problem of getting juvenile salmonids to sea in the developed Columbia-Snake River Basin. Although barging has a permanent place in the array of strategies that managers can use in this system, it should not be considered a sustainable solution in the context of salmon recovery in the Snake and Columbia rivers (Williams et al. 2005). Trapping and hauling can create or exacerbate some problems. According to Williams et al. (2005):

> *Transportation is not a panacea for negative effects of dams on fish stocks. When comparing annual indices of transported, wild, yearling Snake River spring-summer Chinook salmon (Oncorhynchus tshawytscha) and hatchery fall Chinook salmon versus in-river fish, in many cases transportation appeared to confer little benefit or harm. However, under certain times of the year and under low-flow conditions (particularly in 2001), transportation appeared to increase return rates of some segments of the yearling migrant populations. Further, the benefits of transportation decreased at transportation sites closer to Bonneville Dam. Thus future operations should focus on optimizing adult return rates, independent of the transportation process currently in operation. Strategies such as "spread the risk" and promotion of diversity suggest we should allow more fish to migrate in the river whenever it appears migration might lead to reasonable return rates compared to the alternatives. At times transportation may provide the best alternative. We note that transportation apparently has not provided any benefit to Snake River sockeye salmon.*

Stress. Maule et al. (1988) measured the physiological effects of, and recovery from, the stressors involved in handling, barging, trucking, and releasing juvenile chinook salmon in terms of concentrations of stress hormones and plasma glucose, white blood cell count, and response to several physical challenges. They found that stress responses were substantial and long-lasting, especially those associated with being loaded into barges and trucks.

Timing. The trap-and-transport operation in the Columbia and Snake rivers is especially complex because the animals arriving at a dam with fish-collection facilities during any one day are all handled in the same manner, although they are usually of several species and at many different stages of "smoltification" (i.e., the physiological processes that change freshwater salmonid parr into marine animals). Williams et al. (2005) suggested that although the transport system speeds fish past slack-water reservoirs and dam forebays, it could be delivering many of them to the estuary too soon to match their physiological ontogeny with the appropriate ecological environment.

Disease. Bacterial Kidney Disease (BKD) may be spread due to the density of fish in holding and transportation facilities (Raymond 1988).

8.4.1.7 Costs

Costs associated with the construction of the smolt collection facilities on the Columbia and Snake rivers ranged from $10 to $20 million per facility (Table 8-3). The costs to operate and maintain the facilities was about $500,000 for each project in 2007, and monitoring and sampling costs for that year ranged from $80,000 to $98,000 per facility. Construction costs for transport barges ranged from $500,000 to $1,700,000 depending upon capacity and when they were built or retrofitted (Table 8-4). The cost to lease tow boats varied with time in operation and was as high as about $713,000 in 2007 (Table 8-5). The capital cost for transport trailers was $179,000 each, and four semi-tractor trucks rented in 2007 cost a total of about $66,000 (Table 8-6).

Table 8-3. Facility construction costs and 2007 operation/maintenance (O&M) and monitoring/sampling costs for USACE's smolt transportation program on the Columbia and Snake rivers.*

	Construction		2007 O & M		2007 Monitoring & Sampling
Facility	Cost (Millions)	Year Built	Cost (Dollars)	Operational Period	Cost (Dollars)
Lower Granite	Not Available	1975	$514,414	28 Mar to 31 Oct	$94,180
Little Goose	$10	1989	$492,805	1 Apr to 31 Oct	$97,615
Lower Monumental	$15	1992	$499,544	1 Apr to 30 Sep	$80,578
McNary	$20	1994	$498,000	1 Apr to 31 Oct	$89,518

* Information provided by USACE, Walla Walla District, in response to a Freedom of Information Act request

Table 8-4. Transport barge construction costs for USACE's smolt transportation program on the Columbia and Snake rivers.*

Barge #	Construction Costs	Year Built/Retrofitted	Capacity (lb)	Capacity (kg)
**2127	$500,000	1977	23,000	10,433
**2817	$500,000	1977	23,000	10,433
4382	$910,000	1980	50,000	22,680
4394	$910,000	1981	50,000	22,680
8105	$1,340,000	1989	75,000	34,019
8106	$1,340,000	1989	75,000	34,019
8107	$1,700,000	1998	75,00	34,019
8108	$1,700,000	1998	75,000	34,019

* Information provided by USACE, Walla Walla District, in response to a Freedom of Information Act request.
** Converted WWII/Korea/Viet Nam era potable water barge.

Table 8-5. Towboat lease costs in 2007 for the USACE's smolt transportation program on the Columbia and Snake rivers.*

	2007	
Towboat #	Costs	Hours Operated
1	$712,968	2,922
2	$638,715	2,607
3	$147,000	600
4	$128,870	526
5	$37,720	184

Table 8-6. Transport equipment costs for the U.S. Army Corps of Engineers' smolt transportation program on the Columbia and Snake rivers.*

Transport Equipment	Rental or Purchase Cost	Capacity (gal)	Capacity (Liter)	Comments
4 Truck	$65,767	n/a	n/a	2007 semi-tractor rentals
Trailers 1-5	unknown	3,500	13,245	built in 1970s or 1980s
Trailer 6	$179,000	3,500	13,245	bought in 1993
Trailer 7	$179,000	3,500	13,245	bought in 1993
Trailer 8	$179,000	3,500	13,245	bought in 1993
Trailer 9	$179,000	3,500	13,245	bought in 1993
3 1-ton pickups	unknown	300	1,135	used when fish numbers are low

* Information provided by USACE, Walla Walla District, in response to a Freedom of Information Act request

8.4.1.8 Relevance for St. Lawrence River

The trap-and-transport program for juvenile salmonids in the Columbia and Snake rivers has been successful in collecting, holding, transporting and releasing large numbers of downstream migrating fish in an attempt to avert the harmful effects of passing through hydropower dams; however, only some elements of the program appear to be relevant to collecting and transporting outmigrating eels in the St. Lawrence River. Salmon smolts exhibit a near-surface distribution during their downstream migration (Ploskey et al. 1998); therefore, they are subject to guidance by the submerged traveling screens and subsequent collection in the bypass channels at collector dams. In contrast, eels instead exhibit no discernible vertical distribution pattern during their downstream migration in the St. Lawrence River (NYPA 2007); consequently, a collection system that captures fish near the surface has little relevance for collecting eels on the St. Lawrence River. If eels in the St. Lawrence River could be collected effectively through other means, the transportation elements of the program used in the Columbia and Snake rivers might be applicable for conveying eels safely downstream of the hydropower projects. The development of methods for trucking and barging salmon smolts in the Columbia and Snake rivers has resulted in transportation mortality of less than 1% (DOE 1995). Following similar protocols for transporting eels might minimize mortality rates during transportation.

8.4.2 Lower and Upper Baker River Projects

A new, large-scale trap-and-transport system for salmonids (particularly juvenile sockeye) is currently being deployed on the Baker River in Washington State (Figure 8-23). Downstream migrating fish are collected using a barrier-net guidance system, a floating attraction/collection barge (gulper), and facilities for trap and sampling fish. Puget Sound Energy (PSE), Inc., operates these systems at its hydroelectric projects on the Lower Baker River and Upper Baker River.

Lower Baker Dam is located 1.9 km upstream of where the Baker River flows into the Skagit River. The average daily inflow at the Lower Baker Project from 1981 through 2002 was 74.9 m^3/s (PSE 2005a). Minimum and maximum daily flows for that period were 7.9 m^3/s and

1,087 m^3/s, respectively. Downstream migrating salmonids are captured at the Lower Baker project by guiding them with barrier nets into the gulper and then into the trap/sampling facility. Fish are sampled for biological information, transferred into a tank trailer, and trucked to the mouth of the Baker River where they are released. Depending upon handling protocols for the species, some fish may be returned to the Skagit River or taken as hatchery broodstock.

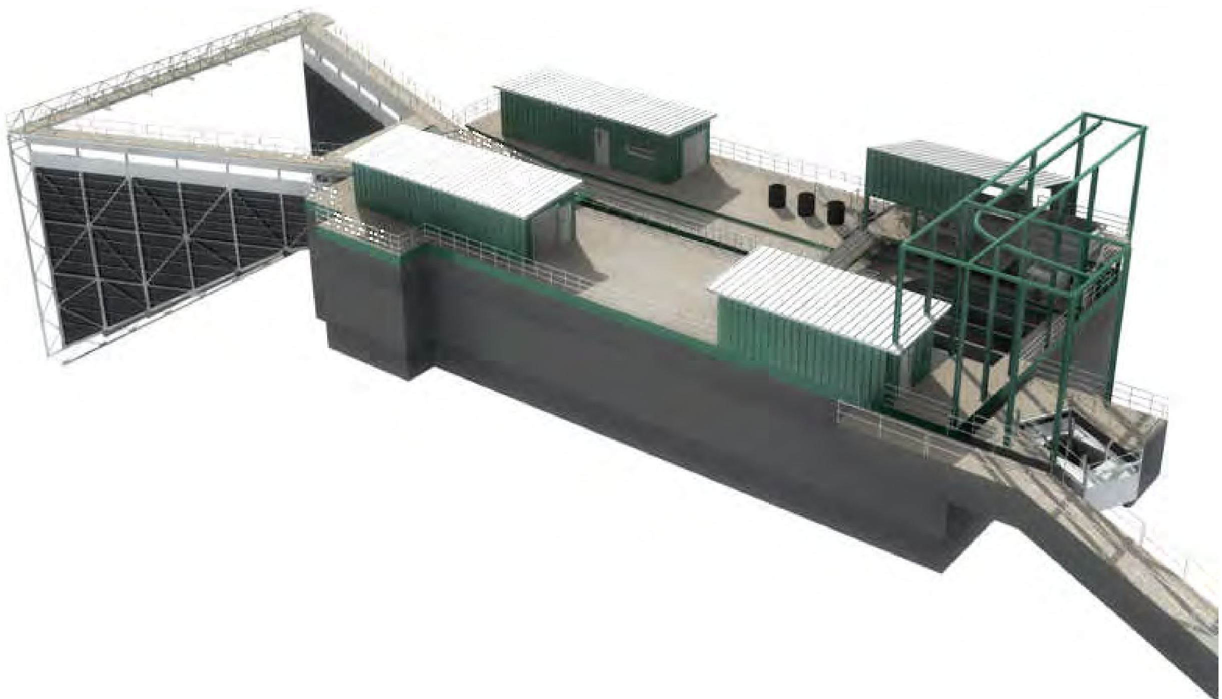

Figure 8-23. Conceptual illustration of the gulper system being installed at Puget Sound Energy's Lower Baker Dam in Washington State (image courtesy of PSE). The net transition structure is shown at left connecting to the gulper. The gulper houses a fish trap with holding and sorting raceways. After sampling, fish are moved into the white holding tank (shown on the right and attached to the walkway by cable) which is moved to shore for transportation down stream.

The barrier net has a mesh size of 6.4 mm and extends the full width of the river about 183 m upstream of the dam. Net sections extend from the reservoir surface to approximately the contour of the reservoir bottom and range in length from 15.2 to 76.2 m. The surface collection facilities attract fish with a flow created by two pumps that each draw 76,000 liters per minute. Fish are guided over a weir into a flume, which connects to a pipeline that discharges into a trap. At the trap, a screen diverts arriving fish into holding bins where they are counted and sampled. The fish are placed into 757-liter hoppers, which are transported by mini-barge to shore. A crane is used to lift the hopper onto a truck for transportation to the release locations.

Upper Baker Dam is located at 13.1 km upstream of Lower Baker Dam. Average flow at the Upper Baker Project from 1981 through 2002 was 57.7 m^3/s (PSE 2005a). Minimum and maximum daily flows for that period were 4.9 and 767.1 m^3/s, respectively. Downstream migrating salmonids are captured by guiding them with barrier nets into the gulper and then passing them into the trap/sampling facility. Fish are sampled for biological information, transferred into a tank trailer, and trucked to the mouth of the Baker River at the Skagit River to be released.

The guide net has a mesh size of 6.4 mm and spans the entire forebay. The net extends from the reservoir surface to approximately the contour of the reservoir bottom and has a maximum length of 86.9 m. The guide net connects to the surface collector, which is located about 40 m upstream of the dam. The collection facilities attract fish with flow created by two pumps that each draws 129,000 liters per minute. The fish are guided over a weir into a flume that directs them into a pipe connecting to the fish trap. At the trap, fish are held in four raceway channels where they are counted and sampled. The fish are placed in hoppers, raised by crane to the top of the dam, released into a 1,500 liter fish tank trailer, and transported downstream to the release locations.

8.4.2.1 Facility Improvements

Despite the estimated 60% capture efficiency of PSE's existing collection facilities (N. Verretto, PSE, pers. comm.), increased understanding of the biology of juvenile sockeye and their response to various hydrological conditions prompted PSE, federal agencies, and tribes to advocate for improved collection facilities on the Baker River. Facility enhancements currently underway are predicted to provide 95% capture efficiency for juvenile sockeye (PSE 2004). The major components of the improvement project include the floating surface collector (gulper), net transition structure, and the guide nets. The following sections describe the components of the improvement project based on personal communication with Nick Verretto, Sr. Natural Resource Scientist, PSE.

Floating Surface Collector or Gulper. The gulper is a conventional V-screen contained within a floating channel in which submersible pumps are used to induce flow. The floating channel is designed to allow complete dewatering of the channel and pump plenum during the seasons when salmon are not migrating. The screens are designed to meet NMFS' criteria for safe fish passage. The gulper is to be installed in phases. The initial installation will have a capacity of 14.2 m^3/s and an approach velocity of 12.2 cm/s but will be designed to accept a screen-expansion module to accommodate increased flow capacity to a maximum of 28.3 m^3/s (which equals approximately 20% of the generation capacity of Upper Baker Dam). The design also will accept two additional expansion modules to accommodate modifications of the fish channel to reduce acceleration and ramp slope. The pump/screen expansion will be implemented only if the 14.2-m^3/s capacity fails to achieve 95% capture efficiency or to satisfy other considerations. The gulper is designed to accommodate a net transition structure (NTS) at its upstream end. The gulper also will house a fish trap with four holding/sorting raceways, a sampling/handling station, and fish-transfer capabilities. Similar facilities are to be installed in the forebays of both reservoirs.

Net Transition Structure (NTS). The net transition structure is constructed of steel trusses lined with 100-mil HDPE; it attaches to the upstream end of the FSC and the downstream end of the guide net (Figure 8-24). The NTS is 24.4 m long; its upstream opening is 22.9 m wide and 15.2 m deep, and its downstream opening is 7.6 m wide by 4.9 m deep. Its purpose is to improve attraction and collection effectiveness by modifying initial approach conditions and providing a gradual physical and hydraulic transition from the vertical guide net to the defined channel of the primary screen bay of the FSC.

Figure 8-24. Photograph of Puget Sound Energy's net transition structure prior to deployment on the Baker River in Washington State.

Guide Net. The guide net is attached to the upstream end of the NTS and extends upstream into the forebay to create a non-hardened, vertical, V-screen to guide fish to the FSC (Figure 8-25). The net extends from the surface to the bottom of the reservoir and from north to south shores to create a fish barrier. The layout of the net was designed to limit searching and milling behaviors and to maximize sweeping flow toward the entrances to the NTS and FSC. It incorporates an inflatable float line, controls that allow the net to be submerged to limit loads during spill conditions and for boat passage, and an intermediate float line to prevent impingement on the floor of the reservoir.

Mooring System. The gulper will be moored in the forebay, 45.7 m upstream of the intake. Fish captured, held, and sampled in the gulper will be transported in tanks to the dam via a floating cableway. The position of the gulper has to be fixed within 0.9 horizontal m in any direction because of its detached layout and the tolerances of the cableway and walkway. Given the 15.2-m range of fluctuation of the pool, the mooring system for the gulper becomes very complex. It will consist of 13 separate lines and anchor points, some self-adjusting via counter-weights and some that must be adjusted manually using winches.

Figure 8-25. Aerial photograph showing the old collection structure and guide nets spanning the forebay of Upper Baker Dam, Washington State. The old guide net is closer to the dam (it is in the process of being removed), and the new net is farther from the dam and extends farther upstream than the old net. The structure along the bottom of the photograph is a log boom.

Transportation Facilities. The facilities for transporting fish will consist of the fish-trap hopper, monorail crane, transport tanks and jib crane at Upper Baker, fish transport tank trucks and trailers, and watering stations. Once the fish have been sampled and moved to the dam via the cableway, they will be lifted onto trucks or trailers and transported to stress-relief ponds for later release.

8.4.2.2 Costs of Downstream Fish Passage Improvements

The annual cost for PSE's new collection, holding, and transportation facilities is the levelized annual amount equivalent to the 2006 value of the planning, design, implementation, construction, operation, and maintenance costs over the 30-yr period of analysis. The numbers were derived directly from the economics used for the Settlement Agreement. Capital costs exceed $40,000,000 (Table 8-7).

Table 8-7. Costs of PSE's downstream fish passage implementation plan at dams on the Upper Baker and Lower Baker rivers (2006 U.S. dollars) (Source: PSE 2005b)

Capitol Cost	Levelized O&M Costs	Total Levelized Annual Cost	Levelized O&M Costs	Total Levelized Annual Cost
$41,926,400	$585,900	3,488,600	$741,100	$4,412,700

8.4.2.3 Maintenance Issues

Debris loading of the guide nets has not been problematic at the Baker River projects because the prevailing winds blow floating debris towards the opposite end of the reservoir, away from the nets (C. Ebel, USACE, Seattle District, pers. comm.). As a result, very little effort has been necessary to clean and maintain the guide nets.

8.4.2.4 Relevance for St. Lawrence River

The gulper traps on the Baker River were designed to capture outmigrating juvenile salmonids. Unlike the smolt-collection facilities on the Snake and Columbia rivers, which skim fish in the upper water column, the gulpers, in combination with the guide nets, sample the entire water column. This feature is critical for collecting outmigrating eels in the St. Lawrence because of their distribution throughout all depths (NYPA 2007). To be effective, any facility for collecting eels must incorporate some means of diverting eels from the entire water column to a collection facility.

Guide nets that stretch from the surface to the bottom of the reservoir associated with the gulper would be infeasible for use on the St. Lawrence River. Debris in the St. Lawrence would fill the guide nets quickly and frequently, most likely causing them to collapse unless they were cleaned and maintained continuously. Maintaining such nets in the St. Lawrence probably would be impossible because of the large loads of debris from submerged aquatic vegetation in the river and average water velocities in excess of 1m/s.

8.5 TRAP-AND-TRANSPORT PROGRAMS FOR SILVER EELS

Capturing outmigrating eels and transporting them downstream of hydroelectric facilities has been considered as a means of reducing the mortality caused by passing through turbines in many locations. Our search identified three active trap-and-transport programs, although none as large as the salmon transport programs described in Section 8.3. A recent study by Stanley and Pope (2008) that investigated methods for a trap-and-transport program on the St. Lawrence River is discussed in Section 8.7.3.

8.5.1 RWE Power AG's Eel Protection Program

RWE Power AG (RWE) owns hydroelectric power stations at each of the 10 dams on the Moselle River in Rhineland Palatinate, Germany. Each power station has a discharge rate of approximately 400 m^3/s. In some instances, outmigrating eels can pass the dams and hydroelectric facilities via fish passage facilities or other migration channels (e.g., weirs, locks) depending on the level of discharge, however, some eels pass through the turbines at each facility. In 1995, the Federal State of Rhineland Palatinate (the fisheries authority on the Moselle River) and RWE reached an agreement entitled the "Moselle Eel Protection Initiative" in which RWE committed to collaborate with scientific institutes to investigate ways to minimize the damage incurred by eels at the power stations and enhance eel stocks in the Moselle River in an economically feasible manner (S. Teggers-Junge, RWE Power AG, pers. comm.).

RWE finances the Eel Protection Initiative in the amount of 215,000 Euros ($332,000, 2007 U.S. dollars) annually. Half of the money is given to the Federal State of Rhineland Palatinate as compensation for fishing-related measures such as replenishing fish stocks, and the other half is spent on measures to protect eels. In total, 1.3 million Euros ($2 million 2007 U.S. dollars) have been spent through this initiative since its inception in 1995 (S. Teggers-Junge, RWE Power AG, pers. comm.). Almost two-thirds of the money has been used to hire 11 professional fishing operators to trap migrating eels upstream of the power stations and transport them to Linz on the Rhine River, where the eels can continue their migration into the delta of the Rhine without having to pass hydroelectric power stations.

The trap-and-transport program for eels in the Moselle River has operated since 1997. The fishermen employed by RWE catch eels using fyke nets set in the head races (i.e., waterways feeding water into the turbines), then transport their catches downstream into the Rhine River. Details of method of transport were not provided, except for anecdotal information suggesting that eels were loaded into containers in pick-up trucks. No specific criteria dictate when the fishermen should set their nets; they generally rely on moon phase and discharge (i.e., storms) to determine when to fish for eels. The weight of eels captured and transported annually has ranged from 1,500 kg to 6,000 kg (10,000-15,000 eels, depending on size of the eels) and generally has increased over time (Table 8-8). An average of 4,800 kg of eels was caught and transported annually over the last five years (S. Teggers-Junge, RWE Power AG, pers. comm.).

Table 8-8. Weight of eels captured in the Moselle River and transported to the Rhine River, Germany, annually since 1997.

Year	Weight (kg)	Year	Weight (kg)
1997	1,500	2000	4,600
1998	1,932	2001	6,000
1999	3,418	2002	4,735
2006	4,990		

We contacted RWE to solicit the opinions of participating researchers regarding whether trapping and transportation affects the migratory behavior of eels after they are released. RWE referred us to Mr. Lothar Jörgensen and Mr. Ansgar Hehenkamp of the Fishery Administration, which is responsible for cooperation with the fishermen. We attempted to contact each of them on two occasions. Mr. Hehenkamp provided a brochure on the trap-and-transport program but did not respond to any of our specific questions.

We solicited comments on RWE's trap-and-transport program from Uli Dumont of Floecksmuhle Consultants in Germany and from Beate Adam and Ullrich Schwevers at the Institute for Applied Ecology in Germany. We learned from Dr. Adam that the Institute for Applied Ecology is linked to RWE's trap-and-transport program through the Institute's early warning system for eel migration, known as MIGROMAT.© The Institute runs MIGROMAT© in one tributary of the upper course of the Moselle River to predict the timing of the downstream migratory movements of eels. On two occasions last season, the fishery administration responded to a MIGROMAT© prediction and caught 80% of its yearly total catch of eels. MIGROMAT© predicted downstream movements at 25 other times during which fishermen did not attempt to catch the eels. Dr. Adam estimated that the Moselle River system has a yearly output of at least 150,000 kg of eels. A comparable river (the Meuse) has an output of about 200,000 to 250,000 silver eels weighing about 200,000 kg. The 5,500 kg of eels caught and transported via RWE's program in the Moselle River, therefore, is a relatively small portion of migrating eels in the Rhine River system. According to Dr. Adam, the Institute has concluded that catching, keeping, and transporting eels could cause mortality of more than 50% and that RWE's trap-and-transport program probably results in only a marginal reduction in the mortality due to passage through all the hydroelectric facilities.

8.5.2 Manapouri Hydroelectric Power Complex, South Island, New Zealand

In New Zealand, fyke netting is being used as part of a trap-and-transport operation to protect large, highly fecund, migrating female eels from passing through turbines at a hydro-electric dam in the vicinity of Lakes Manapouri and Te Anau (Boubée 2007). These lakes are in the Waiau River system and, together with their tributaries, are home to the largest unexploited population of longfin eels in New Zealand. Initially, fyke nets of various dimensions were set around the edges of the lakes, and all eels weighing more than 4 kg were transferred to the

Waiau River downstream of the Mararoa Control Structure. Smaller eels were released at the point of capture. No attempt was made to identify and separate eels exhibiting silver eel characteristics or to determine the size-structure of the population of captured eels until 2002, when a portion of the catch was examined (Spooner-Kenyon 2002).

More robust procedures for trapping and sorting eels were introduced beginning in 2005. Up to 15, 1-m diameter fyke nets with leaders of 20 m or more are deployed around the shore of Lake Manapouri from 18 February to 30 May. The nets usually are baited with frozen pilchard and retrieved at intervals of one or two days. Silver eels are identified based on body coloration and eye size (Jellyman and Todd 1982) and separated from the catch. The weight of feeders (i.e., sexually immature, non-migrant adults) is estimated, and those eels are returned to the lake. Most silver eels are retained for tagging, but some untagged eels are released downstream of the Mararoa Control Structure at the end of each season.

Fyke nets are set during rain storms because rainfall of greater than 40 mm appears to trigger migration (Figure 8-26). Setting the net is reported to be a very labor intensive process. This fishing method works well only in the absence of macrophytes and debris. Catch efficiency varied between 2000 and 2007 (Table 8-9). Fishery authorities in New Zealand estimated that 13 fyke nets operated by one fisher in the lakes could save 300 to700 male and female eels from turbine mortality each year. Current netting procedures enable about 200 to 400 silver eels per year to be transferred downstream of the Mararoa Control Structure so they can safely continue their migration to the sea (E. Brunton, Te Anau, New Zealand, pers. comm.). That is a small fraction of the total number of silver eels in the Waiau River system. Hobbs (1947) estimated the annual migration of longfins at Lake Ellesmere (South Island coastal lake with a surface area of 181 km^2, and a catchment area of 2,039 km^2) to be nearly 4,000 individuals.

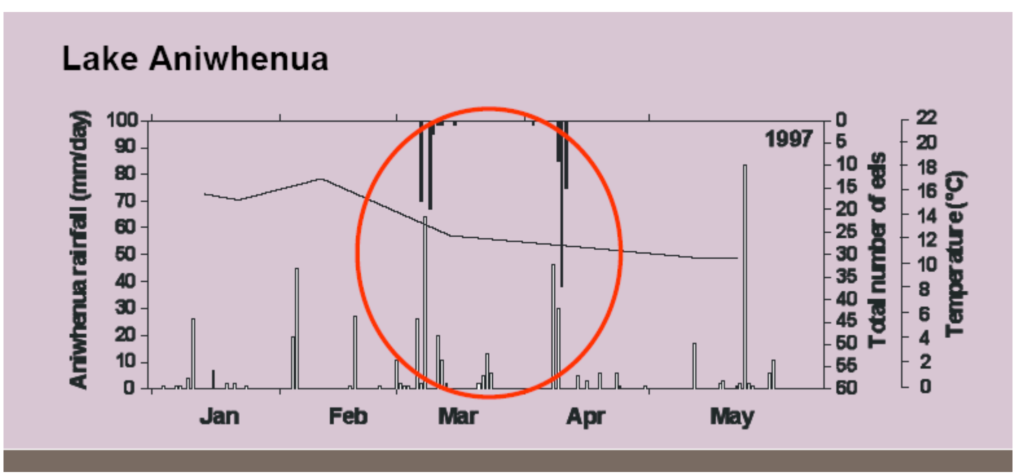

Figure 8-26. Number of outmigrating eels versus annual rainfall and temperature in Lake Aniwhenua, New Zealand (Source: Boubée 2007).

Table 8-9. Annual catches in fyke nets in Manapouri Lake and Te Anau Lake, New Zealand (Source: Boubée 2007).

Year	Catch (kg)	No. Transferred	No. Migrants
2000	-	137	-
2001	9800	527	-
2002	12,000	721 (3390 kg)	5%
2003	14,200	707 (3220 kg)	-
2004	603	74	42
2005	4,860	40 (+130 tagged)	170
2006	1,765	180 (+143 tagged)	323
2007	3,776	550 (+112 tagged)	682

8.5.3 Electricity Supply Board, Ireland

The Electricity Supply Board (ESB) is conducting a major eel research program in conjunction with Dr. T.K. McCarthy of the National University of Ireland, Galway. This program recently was expanded to cover all of the catchments affected by ESB's hydroelectric projects (i.e., Shannon, Erne, Lee, Liffey, Clady/Crolly). Silver eels are captured during their annual migration (September - January) in large coghill nets set at Killaloe Eel Weir above Ardnacrusha Station (Figure 8-27). The magnitude of daily catch is related to river discharge (Figure 8-28). Some of the eels collected there are used for non-commercial, mark-recapture studies and other research. Decreasing trends in catches at this weir (Figure 8-29) reflect declining stock size and regional shifts in fishing effort over time. A portion of the catch is released several kilometers downstream of the weir, downstream of several hydroelectric facilities, and participating fishermen keep the rest. The total weight of released eels varies with the magnitude of the catch. The eels are trucked in large transportation tanks.

Figure 8-27. Coghill nets being fished at the Killaloe eel weir in Ireland. (Source: ESB 2004).

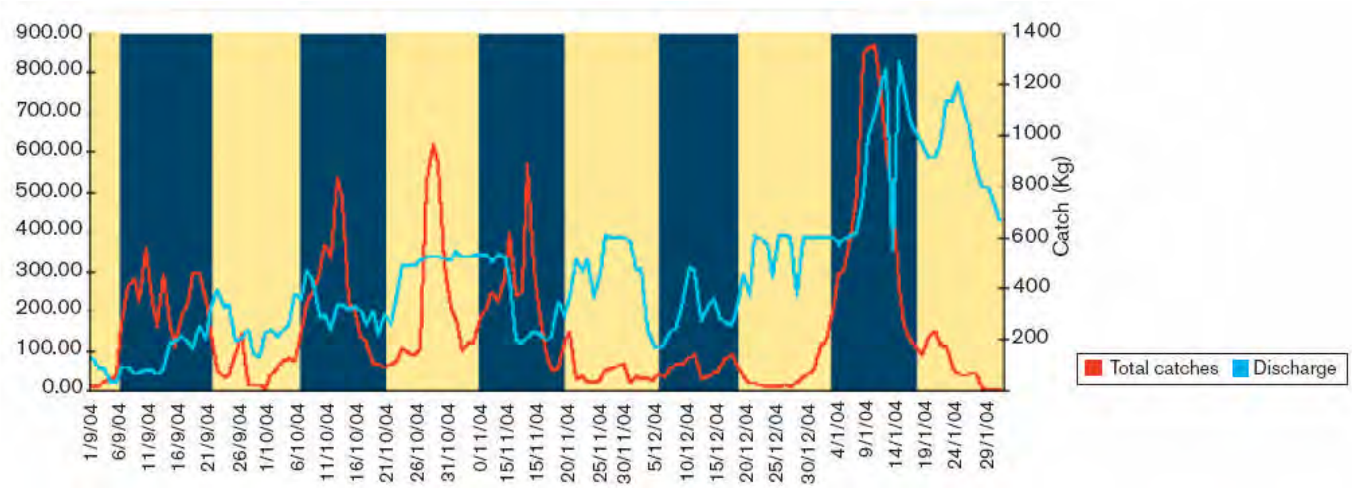

Figure 8-28. Seasonal catches of silver eels and river discharge at the Killaloe eel weir on the Shannon River in Ireland during 2004; note that the last six dates should be 1/05 (Source: ESB 2004)

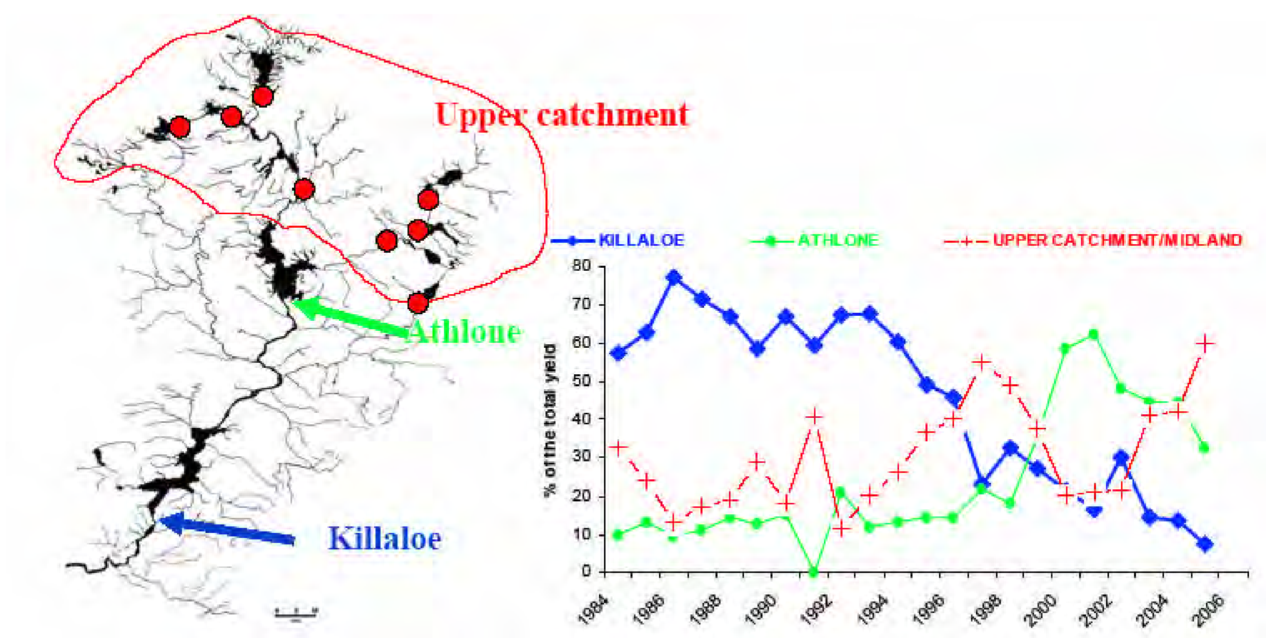

Figure 8-29. Long-term variation in the percentage of the total annual yield of silver eels from the Shannon River caught at the Killaloe weir (blue) and in the Athlone and upper catchment between 1984 and 2006 (Source:ESB 2004)

8.6 REGULATIONS PERTAINING TO INTERNATIONAL TRANSPORTATION OF FISH

The trap-and-transport program for outmigrating eels being considered for the St. Lawrence River would involve collecting eels at Iroquois Dam and transporting them for release downstream of the Beauharnois Generating Station in Canada. If eels were to be captured in a trap on the Canadian end of the dam, they would have to be transported to holding facilities on NYPA's property in the United States. Regardless of the location of capture, eels would have to be transported across an international border to be released below Beauharnois, and that process would have to comply with all applicable regulations.

Attorneys at the U.S. Department of Agriculture indicated that the Animal and Plant Health Inspection Service regulates only fish imported for use in aquaculture operations; therefore, no regulations or laws within the Department of Agriculture would pertain to transporting eels captured in Canada into the United States (B. Ollila, FOIA Officer, General Law Division, USDA, pers. comm.). The U.S. Department of the Interior requires all wildlife imported into or exported from the United States to be declared to the U.S. Fish & Wildlife Service and cleared by U.S. Customs and Border Protection prior to release or consignment for export. Transporting American eels across the border with Canada would require submitting Declaration Form 3-177 (http://www.fws.gov/le /pdffiled/3-177-1.pdf). In addition, the designated port should be contacted to arrange an appointment and to inquire if any additional permits or paperwork are required (see http://www .fws.gov/le/ImpExp/Canadian _Border_Ports.htm to identify designated port).

NYPA would have to seek an import license from the National Aquatic Animal Health division of the Canadian Food Inspection Agency in order to transport eels into Canada. The responsibility to comply with import/export regulations could be avoided if eels were trapped only at gates located on the U.S. side of Iroquois Dam and released in U.S. waters downstream of Moses-Saunders Power Dam.

8.7 POTENTIAL EFFECTS OF TRANSPORTATION AND HOLDING ON MATURATION OF EELS

NYPA's request-for-proposals required a review of available information concerning whether the process of capturing, holding, and transporting migrating fish might adversely affect their health, physiology, or behavior. Such potential effects are a major source of concern because they could preclude a trap-and-transport program like the one being considered at Iroquois Dam from affording the desired level of protection of outmigrating eels in the St. Lawrence River. In the case of outmigrating American eels, the specific question is whether handling prevents eels from successfully completing the reproductive part of their life cycle. This section reviews the cues that indicate maturation (i.e. "silvering") of American eels in fresh water and the potential effects, if any, of holding and transportation on that process. Specific questions considered during the search for literature and information on this topic concerned whether the disruption of “natural” downstream migration could delay or suspend the maturation process by eliminating or altering important internal or external cues that control it:

- What internal and external cues influence the maturation of American eels?
- Does disrupting the “natural” course of downstream migration delay or suspend the maturation process by eliminating internal or external cues?
- What techniques are used to prevent or minimize the disruption of the maturation process in other migratory fishes that are trapped and transported around obstacles?

8.7.1 Cues to Maturation

Eels enter freshwater systems as elvers and grow to sexual maturity over 8 to 30 years as yellow eels. Their transformation from the yellow phase (sedentary/feeding) to the silver phase (migratory/non-feeding) occurs during the spawning migration, but the processes that trigger this metamorphosis have not been studied thoroughly. Often, outmigrating eels are captured in different stages of silvering. Also, eels captured in the upper portions of large river systems often are less advanced in the silvering process than those captured closer to coastal waters (Cottrill et al. 2001; McGrath et al. 2003a; Durif et al. 2005), which suggests that silvering progresses with time and downstream movement. Hoar (1988) reported smoltification of salmonids to be a similarly progressive phenomenon.

Recent studies (van den Thillart et al. 2005; Durif et al. 2005) have described silvering in five stages for females and two stages for males. The stages for females correspond to a growth/yellow phase (I and II), a pre-migrant/pre-silver phase (III), and the migratory/silver phase (IV and V). Males were classified as either yellow or silver, and their silver phase corresponds to stages IV and V in females. Females transitioned from stage III to IV in the late summer (July and August), and females at stage IV-V and silver males first appeared in September. Similarly, van Ginneken et al. (2007a) recently found that only yellow eels were captured in fyke nets from April to July, and only silver eels were captured in fyke nets from September to November. August appeared to be a transition month during which researchers collected yellow, silver, and “half-silver”eels.

The length and age of silver eels migrating from their freshwater nursery areas vary greatly (Acou et al. 2003; Vøllestad 1992), which suggests that the process of silvering not only is associated with size or age but also is affected by external environmental factors. Silvering is a gradual process that van den Thillart et al. (2005) suggested is initiated by a peak of growth hormones at the end of spring. Pankhurst (1984) proposed that the metamorphic changes associated with silvering are related to the onset of migration and gonadal development. Additionally, sex steroids may play a significant role in silvering. Aroua et al. (2005) reported that female yellow eels treated with a sex steroid (testosterone, T) expressed a significant increase in ocular index (OI) and a significant decrease in digestive tract-somatic index (DSI), which has been observed under natural conditions. In addition, the authors found that treating female silver eels concurrently with sex steroids (testosterone, T and estradiol, E2) and cortisol amplified their silvering coloration. Likewise, Cottrill et al. (2001) reported that plasma levels of sex steroids were significantly greater in silver eels than in resident yellow eels. Van Ginneken et al. (2007b) found that the transformation of wild-caught eels from the yellow stage to the silver stage occurred in association with increased hormonal levels of testosterone (T) and estradiol (E2), but not with thyroid hormones (TH) and growth hormones (GH). Furthermore, van Ginneken et al. (2007a) suggested that cortisol might be a factor in the mobilization of energy reserves because they found a seasonal pattern in plasma levels of cortisol, which corresponds with a previous observation in chinook salmon (*Oncorhynchus tsawytscha;* Congleton et al. 1984). Finally, Dufour and Rousseau (2007) proposed that metabolic factors such as insulin, growth factors and hormones, leptin, and ghrelin might be involved in the silvering/maturation process.

Like smolting in salmon (Kiiskinen et al. 2002), silvering in eels is suggested to begin after periods of favorable growth (Vøllestad and Jonsson 1988; Vøllestad 1992), or when concentrations of muscle fat reach a peak (Larsson et al. 1990). Svedäng and Wickström (1997) found, however, that silvering and the spawning migration also begin when concentrations of muscle fat are low, but the authors felt that such individuals would be unlikely to have sufficient fat reserves to complete the spawning migration. In a maturation study in which eels were artificially stimulated to transform, Durif et al. (2006) found that individuals that were the most advanced in the silvering process and had the highest condition factor showed the highest level of gonadal maturation. She also found that gonad development was most advanced among eels that measured more than 700 mm long.

Water temperatures regulate the activity levels of fishes and probably influence physiological and morphological changes. Schulz et al. (2006) found that water temperatures influence the transformation of salmonids from parr into smolts. Additionally, Vøllestad et al. (1986) and van den Thillart et al. (2005) suggested that silvering in freshwater eels is linked to cool water temperatures during late summer. Photoperiod may play a role in silvering; it is known to control the smoltification of salmonids (Wedemeyer et al. 1980). Low water temperatures, however, have been found to limit the ability of photoperiod to advance the smoltification process (McCormick et al. 2000).

Active swimming may stimulate sexual maturation in eels. Van Ginneken et al. (2007c) found that yellow, farm-raised eels subjected to a 5,500-km swim trial that simulated their migration to the Sargasso Sea showed increased levels of 11-ketotestosterone, pituitary luteinizing hormone (LH), and estradiol in plasma; however, the increases were not significant compared with a control group held for the same period. In addition, oocyte diameter was found to be significantly greater in the treatment group. No significant increases in morphometric and reproductive parameters were observed. Similarly, van den Thillart et al. (2005) also conducted 5,500-km swim trials and found that three-year-old, farm-raised yellow eels expressed changes in reproductive hormones that lead to early maturation and that the diameter of the eyes of five-year-old, farm-raised yellow eels increased after swimming exercises. In addition, wild yellow eels older than 13 years showed significant changes after a week of swimming, including increased eye diameter, gonadal mass, and oocyte diameter. Their digestive tracts degenerated as well, but that may have been related to starvation. The authors reported that silvering was positively correlated with age.

8.7.2 Stress Associated with Collection

As described earlier, few trap-and transport-programs are conducted for outmigrating eels, and none of the active programs monitor the physiological condition of transported eels. The potential stress experienced by eels in such programs can only be inferred from studies of stress exhibited by other transported species or from laboratory studies of eels in other circumstances.

Maule et al. (1988) found the most stressful aspects of a trap-and-transport program for juvenile chinook salmon to be diverting the fish from the gatewells to the raceways and loading them onto a barge or truck. They found the transportation procedure to be stressful overall, but the initial stress induced during loading did not appear to increase during transportation. The authors reported, however, that stress responses were considerable and cumulative during the entire trap-and-transfer process. In addition, the authors found increases in cortisol levels and decreases in numbers of white blood cells, osmoregulatory ability, and swimming endurance. Congleton et al. (1984) also noted increased cortisol levels among chinook salmon during trapping and transportation, especially when fish were being diverted from the gatewells and being loaded onto trucks and barges. Soivia and Virtanen (1982) found that the physiological status of stocked Atlantic salmon (*Salmo salar*) smolts was somewhat unbalanced five days after transport from a hatchery. They reported decreases in blood hematocrit concentration, hemoglobin concentration, plasma glucose concentration, liver glycogen content, muscle lipid content, muscle water content, plasma chloride, and magnesium concentration. They also observed an increase in mean cellular hemoglobin content. Ban (2001) determined that handling stress could disturb the osmoregulatory ability of sockeye salmon (*Oncorhynchus nerka*) smolts in seawater. Bugert et al. (1997) found that chinook salmon that were transported to an estuary as smolts had higher straying rates as adults than smolts released from a hatchery and allowed to migrate downstream naturally. The inference from these results is that the stress of handling may have interfered with physiological processes that contribute to the homing ability of the fish when they reach adulthood. Chapman et al. (1997) suggested that transportation impaired the homing of some transported chinook and sockeye salmon because they exhibited slower upstream migration as adults. Williams et al. (2005) suggested that barging and trucking may deliver smolts to the estuary before their smoltification process is complete, possibly leaving them unable to osmoregulate in seawater conditions. Juvenile winter flounder (*Pseudopleuronectes americanus*) transported from a hatchery exhibited a stress response at all stocking densities; however, only fish transported at densities 600 times the density of the substrate surface area in the hatchery failed to recover to baseline cortisol levels within 48 hours (Sulikowski et al. 2006). Overall, handling and transportation appear to increase stress levels among fish and may leave them physiologically unstable for some period following release.

Several states in New England and the Mid-Atlantic use trap-and-transport programs in their efforts to restore clupeids. Maine stocks pre-spawned adult American shad in the Androscoggin and Kennebec rivers. In addition, New Hampshire has been stocking adult American shad (*Alosa sapidissima)* into various coastal rivers since the 1980s. Massachusetts transfers American shad to several rivers, and Rhode Island has transported pre-spawned adult American shad to a river system (ASMFC 1999). Furthermore, Connecticut is actively involved with transferring pre-spawned adult American shad and alewives (*Alosa pseudoharengus)* to many river systems (B. Eltz, pers. comm.). Other states that trap and transport alosines include New York, New Jersey, Maryland, and Virginia (ASMFC 1999). One of the most extensive trap-and -transport programs ever implemented was on the Susquehanna River in Maryland. Maryland's shad restoration program began in 1969 (ASMFC 1999). Adult shad were trapped below Conowingo Dam and released upstream in spawning areas beginning in 1972. The trap-and-transport program ceased when fish passage facilities were completed at all four dams on the lower Susquehanna River in 2000.

Although the physiological responses of outmigrating eels to a trap-and-transport program have not been documented, their responses to other forms of handling have been studied under other circumstances. Table 8-10 summarizes the effects of capturing and holding eels (collectively known as handling effects) observed during telemetry studies and other kinds of studies of yellow and silver eels. The responses were quite variable, but the most noticeable effects of handling were observed during telemetry studies and in an early-warning detection system[35] in which mortality was significant (B. Adam, pers. comm.). Handling effects appear to increase with increasing holding time. Only one researcher represented in Table 8-10 investigated the effects of handling and transportation on physiology (i.e., Oliveira 1996). Eels in that study showed significantly elevated levels of cortisol, an indicator of physiological stress, over the short-term. Eels held for several days tend to become sedentary upon release and, in some cases, to forgo seaward migration until the following year, which can be interpreted as a response to stress. Van Ginneken et al. (2007a) found that the stress associated with capturing eels in fyke nets, holding them in storage tanks, and sampling them caused plasma cortisol levels to rise.

8.7.3 Potential Effect of Holding and Transportation on the Maturation Process

Currently, only three programs are operating in which silver eels are trapped and transported downstream past hydroelectric facilities. These programs require extensive handling, and stresses or injuries resulting from capture and holding could prevent some eels from maturing fully and completing their spawning migration. Ontario Power Generation initiated a research program to investigate the feasibility of trapping and transportation as means of mitigating turbine mortality among outmigrating eels at the Saunders Generating Station (Stanley and Pope 2008). In 2008, OPG contracted with fishermen to capture large yellow eels

[35] This is a system in which the activity of eels maintained in an enclosure is monitored. A high level of activity of the enclosed eels is considered to be indicative of potential migratory activity among eels in the field, triggering fishing operations or hydroproject shutdowns. No specific details of the conditions of enclosure were provided.

Table 8-10. Summary of handling effects associated with telemetry studies and other studies of yellow and silver American eels

Author	Phase*	Hold Time	Noticeable effects of handling
Acou 2006	Y & S	1 hour	None reported
B. Adam, Institut für angewandte Ökologie (Pers. comm.)	S	8 months	Up to 50% mortality
S. Amaral, Alden Labs (Pers. comm.)	S	A minimum of 24 hours before use in lab tests	None reported
Brown 2005	S	Less than 48 hours	Minimal upstream movement
Carr & Whoriskey (submitted to Fisheries Management and Ecology)	S	16-18 hours	Some eels remained stationary for hours before continuing migration
Caron et al. 2003		1-14 days	None reported
Dominion 2007	Y	1-2 days	Low recapture rates
Dutil et al. 1988	Y	Less than 24 hours	Possibly reduced movement upon release
Eltz 2006	S	Less than 24 hours	Some initial loss of movement
EPRI 2007	S	30-36 hours	Some delays observed
Goodwin & Angermeier 2003; Goodwin 1999	Y	2 hours	None reported
Haro and Castro-Santos 2000	S	Less than 24 hours	Some initial loss of movement
Jellyman and Tsukamoto 2002	S	1-2 hours	Extensive post-tagging movement; little immediate movement; loss of initial diel movement
Jellyman and Sykes 2003	Y	1-2 hours	Extensive post-tagging movement; little immediate movement; loss of initial diel movement
McGrath et al. 2003b	S	Less than 12 hours	Some eels remained stationary for days before continuing migration
Normandeau Associates, Inc. 2007	S	0.7 - 8.5 days	Post release monitoring did not indicate aberrant behaviors
Morrison & Secor 2003	Y	15-60 minutes	None reported
Morrison et al. 2003	Y	15-60 minutes	None reported
Morrison and Secor 2004	Y	15-60 minutes	None reported
Oliveira 1996	Y & S	20 minutes to several days	Sulking and 5-10% of silver eels wait until the following autumn to continue migration; electroshocked-anesthetized and then freeze branded yellow eels appear to produce annuli-like ring formations on the otoliths; raised cortisol levels significantly elevated over the short-term
S. Parker, National Institute of Water and Atmospheric Research (pers. comm.)	S	30 minutes	Lack of movement
M. Pedersen, Danish Fisheries Research -DFU (pers. comm.)	S	One day to a week	None reported, but did report that if you hold eels too long they swim upstream, cease migration, and wait until the following autumn to complete migration

* Y = yellow, S = silver

upstream of Moses-Saunders Power Dam. Those eels were expected to mature and migrate in the immediate future. A total of 1,177 eels were captured, held for up to one week, fitted with PIT tags, and released below the Beauharnois hydroelectric project. To monitor the long-term survival, condition, maturation and migration of the transported yellow eels, 14,737 silver eels captured in the commercial eel fishery in the St. Lawrence River estuary that fall were scanned for PIT tags. One-hundred-sixty-six of the scanned eels were PIT tagged; 48 had been tagged during the 2008 trap-and-transport effort with yellow eels, and the remaining 118 during various studies conducted by NYPA and Hydro Quebec at Moses-Saunders Power Dam and Beauharnois Dam between 1998 and 2001. The PIT-tagged eels all had been captured, handled and transported during the studies for which they were tagged, yet all exhibited silvering and morphometric indices comparable to those of untagged silver eels that had not been handled. These preliminary data support the conclusion that capture and transportation does not affect the maturation or migratory behavior of outmigrating eels in the St. Lawrence River. This program will be continued during 2009.

The Stanley and Pope (2008) study is the only one conducted to date that addresses the question of whether trapping, handling, and transportation affect maturation and behavior of outmigrating eels. The subject eels were captured, tagged, and released during their yellow phase and recaptured as silvered, outmigrating eels in the St. Lawrence River estuary. Although such handling does not appear to have adversely affected the maturation and migration of those eels up to that point in their migration, any affects on their further development or behavior after leaving the estuary cannot be determined. A definitive study of potential delayed effects of handling may be impossible to conduct because of the nature of the eels' life cycle (i.e., spawning in the Sargasso Sea)

Only a very limited amount of research has investigated the question of whether or not the process of silvering is reversible in eels, perhaps as a response to handling. A modest number of studies, however, have investigated the reversibility of smoltification in salmon, and those studies may provide some useful insight regarding the potential effects of handling on the maturation process in eels. McCormick et al. (1999) found that the smoltification process in Atlantic salmon (*Salmo salar)* smolts could be reversed in warm water, and Shrimpton et al. (2000) reported that Atlantic salmon are able to smolt twice. In addition, Handleand et al. (2004) and McCormick et al. (1998) suggested that Atlantic salmon smolts have a small physiological smolt "window" in which they are able to make the transition from fresh water to salt water.

The maturation process of American eels may be similarly plastic and might be temporarily arrested or reversed when conditions for downstream migration are not optimal, or when energy reserves are insufficient (Svedäng and Wickström 1997; Durif et al. 2003). Durif et al. (2006) suggested that only outmigrating eels in the most advanced stage of silvering would complete the migration to the Sargasso Sea after encountering obstacles to migration and those individuals at less advanced stages of maturation would cease their migration and revert to the yellow phase. Stocked and landlocked eels in Nordic countries have been reported be able to revert to the yellow phase when they are prevented from initiating their migration (Svedäng and Wickström 1997). Also, van den Thillart et al. (2005) suggested that stage IV female eels captured in the spring of the year were most likely migrants from the previous fall that did not complete migration and were regressing to the growth phase. Additionally, the authors estimated that European eels can cover approximately 380 km downstream each year, suggesting that eels in large river systems may require multiple years to emigrate. Silver eels held in captivity are unable to mature fully (Dufour et al. 1988; van Ginneken and Maes 2005) and lose their silver characteristics (van den Thillart et al. 2005). Fontaine et al. (1982) reported that eels that reached ovulation and spermiation in an artificial maturation study were capable of feeding again and that their stomachs regenerated. The results of these diverse studies suggest that silvering is reversible and, by extension, that capturing, holding, and transporting freshwater eels could alter the maturation process, if conditions become unfavorable for completing the seaward migration.

8.7.4 Techniques that Might Prevent Disruption of the Maturation Process in Other Species

Although little literature was found regarding techniques that might prevent the disruption of the maturation process of eels during a trap-and-transport program, some methods that could reduce stress and injury were documented. Congleton et al. (1984) reported that using dilute seawater (5 to 10 $^{o}/_{oo}$) in transportation vessels would reduce mortality caused by osmoregulatory or ionoregulatory disturbances in chinook salmon smolts. Using salt as a stress reducer during transportation by barge is not a viable option because the water is generally pumped in continuously from the river and in such a system salt would have to be continuously injected into the water flow. Sulikowski et al. (2006) recommend transporting juvenile winter flounder to the release site and holding them in acclimation cages for a minimum of 48 hours before releasing them to reduce transport stress. Soivia and Virtanen (1982) recommended limiting handling of fish, using low densities, adding salt to the transport water, and allowing recovery time at the stocking site to minimize stress when transferring Atlantic salmon smolts. In addition, Rottman et al. (1991) recommend keeping the handling time of broodstock fish to a minimum, using knitted fine-mesh dip nets, minimizing the number of times the fish are lifted from the water, and working as quickly as possible when transferring fish. They also suggested reducing crowding during transportation so that fish have complete freedom of movement, eliminating sharp corners in tanks, and keeping water well oxygenated. Likewise, Bocek (2008) recommends transporting brood fish in well-oxygenated water. Rottmann et al. (1991) suggested transporting fish during the coldest part of the day or night during periods of hot weather. In addition, Bocek (2008) suggests that fish should not be dumped from any height into the water.

8.7.5 Conclusions

Our review of the available literature suggests that the potential for holding and transportation of outmigrating eels to affect their maturation process exists. Eels appear to rely on a variety of internal and external cues that could be disrupted by being captured, handled, and moved to a downstream location at an inopportune stage in the process. In addition, handling appears to cause stress in eels, as illustrated by the abnormal behavior summarized in Table 8-10.

Some anecdotal information suggests that the silvering process in eels is reversible. Both Vøllestad et al. (1994) and Durif et al. (2003) supported the notion that an outmigrating eel can revert to the yellow phase if it has missed a favorable "environmental window." Additionally, silver eels held in captivity are unable to complete the maturation process. These observations suggest that minimizing the amount of handling and the duration of holding and transportation would be advisable in any trap-and-transport program for eels to reduce the risk of incurring adverse effects.

The major unresolved question is whether the rates of mortality or failure to complete the spawning migration that could result from the cumulative effects of handling, holding, and transporting outmigrating eels are greater than the rate of mortality that results from passing through turbines at the two hydroelectric facilities on the St. Lawrence River. The initial findings of the study conducted by Stanley and Pope (2008) suggest that capturing, holding, and transporting large yellow eels assumed to be nearing maturation did not affect their maturation and behavior, at least to the point at which they entered the estuary; however, effects on their condition and behavior that might emerge later during their migration to the Sargasso Sea cannot be determined.

8.7.6 Summary of Findings

NYPA's request for proposals posed questions regarding each of the topics to be considered and required responses to be drawn from review findings. The following questions pertain to the potential effects of handling outmigrating eels:

- **What are the internal/external cues to silvering/maturation?**

A multitude of internal and external cues appear to be involved in stimulating the maturation process in freshwater eels. Recent evidence suggests that sex steroids (testosterone, T and estradiol, E2) play an important role in the maturation process. Other factors that stimulate maturation may include periods of favorable growth and condition factor. Along with internal cues, eels may rely on environmental factors to stimulate metamorphosis, much like juvenile salmonids. Cool water temperatures during late summer along with decreasing daylight hours are probably key environmental cues. Eels are known to migrate during freshets, and recent studies show that swimming induces maturation; therefore, rain-induced peak flows may be an important cue in the silvering process. Eels in the St. Lawrence River exhibit an extended migration generally throughout the summer, without strong lulls and pulses linked to peak flows in small tributaries. Outmigrating eels in the St. Lawrence River, therefore, are more likely to rely on internal cues to initiate and continue their maturation process and downstream migration.

- **Will disruption of "natural" downstream migration delay or suspend the silvering maturation process by eliminating internal/external cues?**

It is possible that the disruption of downstream migration might delay or suspend maturation by eliminating important cues. The best support of this notion comes from the fact that silver eels held in captivity never fully mature. In addition, silvering eels in Nordic countries that were not allowed to initiate migration reverted to the yellow phase. Silver eels captured and held for long periods (e.g. up to several days) tend to lie sedentary for a period of time after release and in some cases wait until the following year to migrate downstream.

On the other hand, many studies show that silver eels that have been captured, held, radio-tagged, and released continue seaward migration. The one study that directly addresses this issue by Stanley and Pope (2008) support the view that the maturation and behavior of outmigrating eels may not be affected by capture, holding and transport. Although, some telemetry studies do show an initial lack of movement after release, these behaviors may be attributed to experimental methods (e.g. capture technique, surgery technique, how eels were held) rather than an effect of holding and transport.

- **What techniques used in trap-and-transport programs for other species might prevent the disruption of the maturation process?**

Several techniques documented in the literature could reduce stress and the probability of disrupting the maturation process during transport:

- Use dilute saltwater in truck tanks and on barges to reduce stresses associated with transportation.
- Avoid overcrowding during transportation to allow free movement throughout the vessel.
- Limit handling.
- Use fine-mesh dip nets or soft canvas hammocks when transporting fish.
- Minimize the number of times fish are lifted out of the water.
- Keep the water well oxygenated.
- Eliminate or cover sharp corners and edges in the transportation vessel.
- Transport fish during the coolest part of the day or night.
- Release fish as near to the surface of the water as possible or under water.

9.0 METHODS FOR MONITORING THE MOVEMENTS OF OUTMIGRATING EELS

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Sections 3.0 through 7.0 review technologies that might be useful for guiding outmigrating eels in the St. Lawrence River to a capture location in the vicinity of Iroquois Dam. Section 8.0 reviews technologies that have potential for use in capturing, holding, and transporting eels. Those sections identify needs for further research, many of which can be addressed only through telemetry studies or other means of monitoring the movements of outmigrating eels. This section reviews state-of-the art technologies that could be used to monitor the movements of eels and assesses their potential for use in the vicinity of Iroquois Dam. The primary objectives of this effort were to

- document existing telemetry technologies and tagging techniques that can be used to determine the behavior of outmigrating eels, with particular reference to work that has been conducted over the past 10 years;
- identify and evaluate other technologies that could be used to determine the behavior of outmigrating eels, such as hydroacoustics, dual-frequency identification sonar (DIDSON), and others;
- assess the relevance and applicability of the technologies reviewed for studies of outmigrating eels at Iroquois Dam;
- evaluate the potential effect of the tagging procedure or the presence of the tag itself on the behavior of outmigrating eels; and
- determine the best method for capturing outmigrating eels for use in such studies.

Section 9.1 provides brief descriptions of the two major telemetry technologies (radio and acoustic), including information on their primary applications. Section 9.2 provides detailed descriptions of several telemetry studies of migrating eels, including the NYPA-funded research conducted between 1998 and 2002 that was described in Section 1.3, followed by the results of a survey of vendors of telemetry equipment to define the characteristics and capabilities of their products. Such information is required to determine if a vendor's product is suitable for use at Iroquois Dam. Section 9.3 reviews technologies other than telemetry that could be useful for documenting eel behavior at Iroquois Dam, including active sonar and sonar imaging. Descriptions of studies in which each of these technologies have been used with eels are followed by, as was done for telemetry, results of a survey of vendors documenting the capabilities of their respective products. Survey results list the advantages and limitations of the various technologies and discuss the viability of the technologies for assessing eel behavior at Iroquois Dam. The final portions of this section address two other major issues regarding telemetry studies of eels: (1) the potential effects of handling on the behavior of eels being tracked by telemetry, and (2) the most effective means of capturing outmigrating eels to serve as subjects for telemetry studies.

9.1 BIOTELEMETRY TECHNOLOGIES

Biotelemetry refers to the remote measurement of the physiology, behavior, or both of free-ranging animals in their natural environments. Telemetry equipment and techniques have been used to monitor the behavior of fish for several decades, since the pioneering work of Trefethen (1956) and Johnson (1960). As technology has advanced, telemetry equipment (i.e., transmitters/transponders, receivers, and data loggers) has enabled researchers to monitor the movements of fish in real time, through three dimensions and in many demanding environments. In general, two kinds of telemetry are relevant for this review: (1) radio-telemetry, and (2) acoustic telemetry. In biotelemetry studies, if the tracking device attached to a fish emits a signal, it is known as a transmitter. If the device returns a signal in response to one sent to it, it is called a transponder. Transponders either have their own power sources (active transponders), or an interrogating system induces a current in them (passive transponders; Winter 1996).

9.1.1 Radio Telemetry

Radio tags operate within the very high frequency (VHF) range from 27 megahertz (MHz) to 300 MHz. The components of a radio telemetry system include transmitters, antennas, and receivers. Radio transmitters emit radio signals from wire antennas through water and into the atmosphere, and transmissions are received with tuned antennas. VHF frequencies can penetrate through fresh water very well and have been used extensively to monitor the behavior of freshwater fishes. Radio tags have many advantages over acoustic tags in appropriate applications because they are less affected by physical obstacles, turbidity, turbulence, and thermal stratification (Thorsteinsson 2002). Radio telemetry does, however, have some significant limitations. Radio signals are attenuated with increasing depth of the water in relation to the source of the signal and by the presence of dissolved salts (measured by conductivity or salinity). The precision of radio tracking is poor when using fixed stations or manual tracking is employed as a means of determining the location of fish. Primary vendors of radio telemetry gear include Advanced Telemetry Systems, Inc., Lotek, Inc., and Sonotronics.

Despite its limitations, radio telemetry has proven to be a very successful tool for monitoring fish migration as it relates to passage at hydroelectric facilities and other water-control structures. Radio telemetry has been used extensively in the Pacific Northwest to assess migration behavior and passage of both juvenile (Stevenson et al. 1997; Hensleigh et al. 1998) and adult salmonids (Bjornn et al. 2002; Boggs et al. 2004) at hydropower projects on the Snake and Columbia rivers. French investigators successfully used radio telemetry to identify significant obstacles to the passage of Atlantic salmon and passage efficiency in the Gave de Pau River (Chanseau et al. 1999; Larinier et al. 2005). Other investigators have used radio telemetry to evaluate the effectiveness of fish guidance structures at hydropower dams in the Pacific Northwest (Adams et al. 2001; Plumb et al. 2002; Ogden et al. 2005).

Satellite Telemetry. Satellite telemetry is a subset of radio telemetry in which the receiving system is a satellite instead of a ground-station antenna. One satellite telemetry system uses two Arcos-TIROS satellites in polar orbits around the earth. Transmitters that communicate with those satellites are called platform transmitter terminals (PTTs). All PTTs use the same frequency (401.65 MHz), but individual PTTs are identified by unique codes in their signals. A PTT transmits messages every 90 seconds, and a satellite passes over a position for about 10 to 12 minutes each day (Winter 1996).

Satellite telemetry generally is used in combination with pop-up tag technology to monitor the movements of highly migratory fishes, such as swordfish (Sedberry and Loefer 2001) or blue marlin (Graves et al. 2002). The utility of this technology for monitoring the fine-scale movements of fish is limited because satellite signals cannot be used to geolocate underwater and because of general constraints associated with the large size of the tags. Recent advances in battery technology have produced smaller tags that have the strength to transmit data to the Argos system (Jellyman and Tsukamoto 2002**;** Jellyman and Tsukamoto 2005). The tags used by Jellyman and Tsukamoto (2002) were 18 cm long and weighed 65 grams; however, tag size was less limiting in their study because they worked with large, long-finned eels that ranged from 136 cm to 152 cm in total length (TL). The smallest archival pop-up tag made by Microwave Telemetry, manufacturer of the tags used by Jellyman and Tsukamoto, is 120 mm long, 32 mm in diameter, and weighs 40 g (http://microwavetelemetry.com/Fish_PTTs/xTag_specs.php).

Passive Integrated Transponders. A passive integrated transponder (PIT) tag is an integrated circuit attached to a copper-wire antenna coil encapsulated in glass. Each uniquely coded tag can be as small as 2.1 mm in diameter by 12 mm long. Tags operate at one of three frequencies: 125, 134.2, and 400 kHz. The tag typically is injected subcutaneously using a 12-gauge hypodermic needle and remains in place throughout the life of the fish. PIT tags rely upon an external power supply for detection; a PIT-tag detector energizes a tag as a fish travels through or over it. The energized tag emits its code back to the interrogation equipment, which processes the code through a computer interface. The distance from which a tag can be read (i.e., the read range) depends on many factors, including operation frequency, antenna power, tag orientation, and interference from other devices. Low frequency tags are detected in milliseconds at close range from a few inches to about a foot (0.33 meter) in distance; using a 12 mm super tag (the PIT tag most commonly used) and a stationary 1.2 m by 6.1 m flat plate antenna, the maximum distance to read the tag would be 0.8 m (S. Gary, Biomark, Inc., pers. comm., and http://www.biomark.com/rfid.htm). Fish generally are guided to pass near antennae (e.g., in a fishway) to facilitate detection. The largest in-stream, pass-through PIT tag antenna built to date measures 7.6 m by 1.2 m; the largest, high-velocity flume antenna is 1.4 m by 1.5 m (A. Hopkins, Biomark, Inc., pers. comm.).

PIT tag technology was developed to monitor the movement and behavior of anadromous salmonids in the Columbia and Snake river basins and has been used there continuously since 1987 (PSMFC 2004). PIT tags have been used in a variety of other applications with anadromous fish including to estimate migration and survival rates for chinook salmon (Hockersmith et al. 2003), to estimate delayed mortality of turbine-passed juvenile Pacific salmon (Ferguson et al. 2006), and to estimate the relative vulnerability of juvenile salmonids to avian predation (Ryan et al. 2003). PIT tags also have been used in other regions of the United States such as in work conducted by Castro-Santos et al. (1996) in which American shad and blueback herring were monitored in fishways.

NEDAP TRAIL. A technology developed recently by a firm in the Netherlands, NEDAP, is known as the Telemetric Remote Active Identification Loop (TRAIL). This method is based on inductive coupling between an antenna loop and a ferrite-rod antenna within a transponder (Breukelaar et al. 1998; Vriese et al. 2006). Variable transmission frequencies can be used, but 33.25 kHz is typical. The connection between the transponder (tag) and an antenna loop placed on the river bottom is a loosely coupled transformer that emits no radio signals, which eliminates interference with radio users. The NEDAP TRAIL system consists of implantable transponders and detection stations. Each detection station includes an antenna loop consisting of three parallel cables (typical distance of 10 m) crossing the bottom of a river or canal, an antenna connection box, a receiver, and a transmitter. The antenna loop is tuned in the antenna connection box. Every four seconds the transmitter generates an interrogating signal that triggers any transponder passing over the antenna loop. The transponder responds by transmitting its unique signal. The receiver demodulates the signal, and a microprocessor unit connected via a telephone modem decodes and records the signal. The transponder transmits its signal over two periods of eight seconds, separated by eight seconds of silence. The unique code is transmitted 32 times during each eight-second transmission period. After the entire transmission period (24 seconds), the transponder is mute for two minutes to prevent the batteries from running down if a tagged fish stops above the antenna. The implantable transponder consists of a biocompatible glass tube that is 15 mm in diameter and 65 mm long. Inside the transponder is a 25-mm-long, ferrite rod; a custom-made, integrated electronic circuit; and a 12-mm-diameter by 10-mm-long battery with a lifetime of at least one year. The transponder weighs about 10 g in water.

Field tests have shown that the NEDAP TRAIL functions well with a maximum antenna length of 550 m, water depth of 15 m, and maximum passing speed of 5 to 6 m/s. Effects of boat motor noise are negligible. Maximum tolerable conductivity of river water has not been tested, but calculations have shown that conductivity of up to 6,000 µS/cm[36] does not affect transmission when the distance between the antenna and the transponder is less than 15 m (Breukelaar et al. 1998).

[36] µS = micro siemens, a measure of electric conductance that is equivalent to amperes/volt.

9.1.2 Acoustic Telemetry

Acoustic (or ultrasonic) telemetry is the preferred method where radio telemetry methods are not practical, such as in deep water and marine environments. Acoustic telemetry systems are manufactured by Vemco; Lotek, Inc.; Sonotronics; and Hydroacoustic Technology Inc. (HTI). USACE-Northwest Division and Battelle Laboratories are in the process of developing a new product known as the juvenile salmon acoustic telemetry system (JSATS).

Typical frequencies for acoustic tags range from 20 to 300 kHz. Acoustic tag transmissions are detected with hydrophones deployed in the study area of interest (either manually positioned by boat for continuous tracking or fixed). Depth positions of acoustically tagged fish are obtained either by using pressure-sensor tags or based on geometric calculations determined from a hydrophone array. In cases where tags have temperature-sensing capability, depth can be inferred from the recorded fish temperatures and the temperature-depth profiles of the water body; this same approach can also be done using temperature-sensing radio tags. The use of hydrophone arrays represents an advance over conventional radio telemetry, but the utility of hydrophones can be limited by interference from outside noise, and acoustic telemetry may be inoperative in certain noisy environments. The accuracy of determinations of position with acoustic tags, although superior to what can be accomplished with radio telemetry, is restricted by errors incurred as a result of hydrophones not being stationary and other uncontrollable environmental factors (Ehrenberg and Steig 2003).

Despite these limitations, acoustic telemetry systems have increased researchers' ability to determine the precise positions of individual fish in the water column. Acoustic tags and hydrophone arrays have been used successfully to monitor all mobile stages of salmonids in the Pacific Northwest (Steig and Timko 2000; Timko 2001; Johnson et al. 2004) and to evaluate fish-guidance structures at hydropower projects on the Columbia and Snake rivers (Faber et al. 2001; Cash et al. 2002).

9.2 USES OF BIOTELEMETRY IN STUDIES OF EEL MIGRATION

9.2.1 Radio Telemetry Studies

Haro et al. (2000) used radio tags (Lotek CFRT-3B at 149.76 MHz, 14.5 x 43 mm, 10.9 g, and CFRT-3CM tags 149.76 MHz, 10.6 x 36 mm, 5.9 g) in a study to assess the movements of eels and routes of passage at the Cabot Station hydroelectric facility on the Connecticut River in 1996 and 1997. Transmitters were attached externally just anterior to the origin of the dorsal fins of 11 eels and through the base of the dorsal fins of 5 eels in 1996. In 1997, 14 eels were tagged using smaller transmitters attached just anterior to their dorsal fins. Lotek SRX-400 data loggers and dipole antennas were used to detect tagged eels. Results indicated that several of the tagged eels showed considerable activity, moving into and out of the canal and forebay prior to passing through turbines. River flows during the study ranged from 75 to 440m^3/s, and water velocities averaged about 0.5 m/s in the forebay.

Bypass structures (bottom and surface) for outmigrating eels in the Nive River in France recently were evaluated using radio telemetry techniques (Gosset et al. 2005). The study was conducted at the Halsou hydroelectric power plant, at a dam that is 172 m long and 2.5 m high. Maximum water velocity was 1.6 m/s in the headrace and about 0.5 m/s in front of the trash racks. Over a period of 3 years (1999-2001), 74 eels were surgically implanted with ATS tags (Model 10/28; 48 to 49 MHz, 11 x 45 mm, 8 g) Tags were placed in the eels' abdominal cavities and had mortality switches (i.e., tags automatically switched off when the eel stopped moving, and the fish was presumed dead). Movement of tagged eels was monitored with ATS 2000B and Lotek SRX_400 data loggers and various antennas. Results indicated that a fish bypass located near a trash rack with 3-cm bar spacing and a discharge of 2% to 5% of the turbine discharge could be partially efficient for passing eels (efficiency ranged from 56% to 65%).

Gosset et al. (2005) reported that tagged eels preferred to pass through the bottom bypass; three to four times as many eels transited through the bottom bypass than through the surface one. Close to half of the radio-tagged eels returned up the headrace after their release, and most eventually migrated downstream over the dam during environmental windows corresponding to increased flow and turbidity, and increased conductivity. The time between release and migration activity depended only on these specific environmental conditions. No patterns in mean frequency and duration of approaches characterized overall behavior (time spent in the forebay varied from 30 seconds to more than 22 days). In general, eel behavior comprised alternating phases of exploration of the forebay area and rest in areas where velocity gradients were very low. A trash rack in front of the turbine intake appeared to repulse eels, and the effect increased with increasing turbine discharge.

Although lampreys are not related to *Anguilla* eels, they have a body form and swimming pattern similar to eels and methods used in lamprey studies are relevant to those that may be applicable to eels. Radio telemetry was used to identify the factors that might delay upstream migration of Pacific lampreys traversing the Columbia and Snake rivers (Moser et al. 2002). Between 1997 and 2001 migrating Pacific lamprey were captured and tagged with radio transmitters that weighed between 4.5 and 7.7 g in air (3.7 and 2.9 g in water). After the tagging procedure, each lamprey was allowed to recover for two hours before being released downstream of Bonneville Dam. Movements of radio-tagged lampreys were monitored by a network of 170 fixed receivers located on each dam, at the dam tailraces, and at the mouths of major tributaries. The receivers recorded unique transmitter codes. The date and time of reception at each antenna site were downloaded electronically, and the data were screened to eliminate false positive signals. Underwater antennae positioned outside the fishway entrances detected approaching lampreys, and antennae positioned immediately inside the entrances indicated successful entries. Entrance efficiency (the number of lampreys that successfully entered a fishway divided by the number that approached that fishway) was compared for different kinds of entrances (main entrances versus orifice entrances) and entrance locations (powerhouse versus spillway). Lampreys used orifice entrances less frequently than main entrances, and their rate of successful passage was generally low (< 50%) at all entrances to fishways at Bonneville Dam (the most downstream dam in the system). Lampreys' activity at the entrances was greatest at night. The number of lampreys that exited at the top of the fishway was determined for each dam.

Satellite Telemetry Studies. Two recent studies using archival "pop-up" tags to document the migration movements of eels (*Anguilla dieffenbachia*) were conducted in New Zealand (Jellyman and Tsukamoto 2002; Jellyman and Tsukamoto 2005). Those studies represent the first attempts to use satellite technology to document the movements of eels. The first study was conducted in May of 2000, during which four large migrating eels were captured in the southwest corner of Lake Ellesmere, South Island, New Zealand. Individual eels were fitted with pop-up tags using an internal bridle that was secured to both sides of the eel and emerged through the dorsal midline of the fish. PTT-100 tags manufactured by Microwave Telemetry were attached to the top portion of the bridle. Each tag was 18 cm long with a 16-cm aerial, and weighed 65 g. Once the tagging procedure was complete, the eels were transported to the Pacific Ocean and released. Each tag collected hourly data on water temperature, light levels, and the angle of the tag to the vertical. Light variables were used to estimate latitude and longitude of the eel's position at particular times (accuracy of ± 132 km) of the tag. Archival tags eventually break away from the eel and ascend to the surface, where data are then uploaded to the satellite. The straight-line distances between points of release and final tag data upload location for the four tagged eels ranged from 368 to 1000 km. Data from each tag were recovered successfully. The estimated migration pathways showed that the eels moved substantial distances along inshore areas before moving offshore and eastward. Average swimming speed of all eels ranged from 15.1 km per day to 31.3 km per day, but evidence of diel vertical movement within the water column was limited.

The second study by Jellyman and Tsukamoto (2005) followed a similar design including methods of capturing, tagging, and locating eels except that the monofilament used on the tags was heavier, and the tags were built by a different manufacturer. Each tag in this study weighed 75 g and was 175 mm long. A total of 10 eels were tagged and released in this study. Not all data were recovered successfully. Only 3 of the 10 tags had usable data. The recovered data indicated that eels used the top of the water column while migrating and frequently descended to depths between 100 m and 200 m. In addition, the data also showed that eels may head to the tropics during spawning migrations.

Transponder Studies. Several investigators have used PIT tags to obtain information about the behavior and biology eels in recent years, in some cases to gain ancillary information to supplement data obtained using other primary technologies. Strickland (2002) used PIT tags to estimate growth rates and abundance in a study of American eels in tributaries of the James River, and Eltz (2006) used PIT technology along with radio telemetry to characterize passage routes at Rainbow Dam on the Farmington River in Connecticut. Brown L.S. (2003) used PIT tags along with acoustic telemetry to assess movement of eels at a small hydropower project on the Connecticut River. In New Zealand, Boubée (2003) used PIT-tagged eels exclusively to assess bypass effectiveness and the influence of flooding on weir passage at a hydropower project.

Bruijs et al. (2003) used PIT tags to monitor activity levels in European eels to attempt to predict migration timing in the Meuse River in the Netherlands. PIT-tagged eels were kept in tanks divided into five articulated compartments (known as the MIGROMAT© system). A system of four, frame-antennas around the openings in the walls registered "displacements" of eels between the compartments within each tank. Displacements occurred when an eel passed two antennas within a period of two minutes. Eels contained in the MIGROMAT© tanks exhibited significant pre-migratory restlessness just before dawn on the night before eels in the river started to migrate. The same researchers used other radio telemetry methods simultaneously to monitor migration in the river.

During the same study, Bruijs et al. (2003) used NEDAP TRAIL to document the paths of 150 tagged silver eels as they migrated throughout the Dutch portion of the Meuse River. Results indicated that river discharge was more important than lunar phase in determining the timing of the eels' migration. Activity among the eels was greater during the nighttime and remained proportionally less during daylight hours. Diurnal patterns of movement were stronger (peaks were higher during nighttime hours) at detection stations in front of the intakes of the hydropower dam than at in-river detection stations, indicating the eels' reluctance to pass the hydropower project. Many of the tracked eels performed a stepwise downstream migration in which periods of frequent movement alternated with inactive periods.

In a similar study, Vriese et al. (2006) used NEDAP TRAIL to document the timing of migration, routes, and abundance of outmigrating silver eels throughout the Rhine River during 2005. A total of 157 silver eels were implanted with transponder tags that measured 15 mm in diameter and 65 mm long. Eighty-four of the 157 tagged eels were detected. This study demonstrated that NEDAP TRAIL was useful for detecting eels as they passed over or near the systems' detection stations, although not at high efficiency. Contrary to most investigations in which eels are reported to move extensively during nighttime hours, Vriese et al. (2006) reported 49% of the eels detected passing did so during daylight hours. Eel migration in the Rhine River was most intense on dates with a new moon and during periods of greater relative discharge. Eels' swimming speed varied from 0.5 km/h to 6.2 km/h (at a speed of 6.2 km/h and an average river-flow velocity of 1 m/s, the eels actively migrated downstream at a velocity of 0.72 m/s). General migration characteristics included frequent downstream movement alternating with periods of inactivity.

9.2.2 Acoustic Telemetry Studies

9.2.2.1 NYPA's Studies on the St. Lawrence River

Eel studies funded by NYPA as one element of pre-licensing studies at the FDR project were described in Section 1.3, together with study objectives. Here we present the findings of those studies.

1998 Investigations. Studies conducted in 1998 (McGrath et al. 2003a) examining techniques for monitoring eels at Moses-Saunders Power Dam provided the following findings:

1. High conductivity (> 280 microhos /cm^3) in the St. Lawrence River precluded the effective use of radio telemetry techniques at depths greater than7 m.

2. Standard, off-the-shelf acoustic telemetry equipment operating in the range of 60 kHz to 80 kHz provided a reception range of approximately 1 km in areas away from the dam; however high levels of background noise in the forebay precluded the use of this equipment near the dam.
3. The behavior of tagged eels minimized the effectiveness of manual tracking because tagged eels commonly retreated to the cover of submerged aquatic vegetation and other substrate that blocked reception of hydrosonic signals.
4. Specialized, depth-sensitive hydrosonic transmitters provided a feasible means of collecting data on the depths that eels occupied with accuracy to within less than one meter.
5. Surgical implantation of a transmitter into the coelomic cavity proved to be the best means of fitting specimens with transmitters when compared with external attachment and gastric insertion.

***1999 Investigations*.** Studies conducted in 1999 (McGrath et al. 2003a) focused on determining the feasibility of developing a telemetry system that could function near Moses-Saunders Power Dam despite the significant background noise that precluded the use of standard equipment. Analysis of the sound spectrum in the vicinity of the dam revealed no distinct band of quiet frequencies, but background noise substantially decreased as frequency increased. Regardless of location, the intensity of background noise at frequencies between 60 kHz and 80 kHz was greater than the noise measured between 150 kHz and 200 kHz. The intensity of background noise at all frequencies decreased with increasing distance upstream from the dam. Based on the results of the sound spectrum analysis and other preliminary signal-propagation tests, the researchers concluded that frequencies of 150 kHz or 200 kHz would provide the best opportunity for developing equipment that could function effectively near the dam.

Two kinds of prototype transmitters that operated at both 150 kHz and 200 kHz were developed, simple pingers and coded transmitters. The primary receiving unit was a Vemco VR60 manual receiver (coupled to an omni-directional hydrophone) modified to operate at those frequencies and to reject low-frequency noise. Sixteen trials were conducted to compare the performances of the two frequencies under similar conditions, resulting in four major findings:

1. The reception range at 200 kHz was greater in the area close to the dam than the range at 150 kHz because lower noise levels at 200 kHz permitted the use of higher gain settings on the receiver. Reception range at 200 kHz was approximately 230 m near the dam and 400 m in upstream areas.
2. The best reception for receivers located on the dam was obtained when receivers were attached to the face of the large concrete piers that separate the intake bays of each turbine.
3. The optimal depth for receiver deployment based on percent signal detection and signal strength was 4 m, regardless of location.

4. Using a conical, 45º reflector increased reception range at 200 kHz by about one-third in the area of high background noise near the dam.

Comparison tests indicated that a 200-kHz system would perform better than one operating at 150 kHz. That result led to refining the prototype equipment at 200 kHz; redesigning the configuration and housing of the receiver; developing a depth-sensitive, coded transmitter suitable for implantation in large adult eels; and designing directional hydrophones to increase reception range beyond the range expected for an omni-directional hydrophone. The custom receivers (VR25), transmitters, and directional hydrophones were tested in the forebay of the dam. Performance was evaluated in nine experimental trials by placing receivers at different locations, using various deployment techniques, using different kinds of hydrophones, and placing transmitters at a variety of depths. In all trials, directional hydrophones performed better than omni-directional hydrophones with respect to distance, rate, and consistency of detection.

Three trials were conducted in which three receivers were moored adjacent to each other along a transect 300 m upstream of the dam, and a transmitter was drifted past them. The transmitter was deployed at three depths: 1 m below the surface, mid-depth, and 1 m above the bottom. The drift trials produced two important findings:

1. Electronic detection rate was similar at each receiver in each trial, indicating significant overlap in the reception area.
2. The rate of electronic detections and relative signal strength recorded at individual receivers during each of the trials indicated that reception range was similar regardless of depth.

Based on the results of the prototype equipment tests, a full-scale prototype system was constructed and tested by releasing 10 eels (ranging from 915 mm to 1,095 mm TL) that had been surgically implanted with depth-sensitive transmitters to determine the feasibility of tracking the movements of outmigrating eels in the forebay of the dam. The prototype system consisted of an array of 10, VR25 receivers with directional hydrophones mounted on nose piers and 9 horizontally oriented receivers with directional hydrophones deployed on moorings 300 m upstream of the dam. Test eels were collected from a commercial weir fishery located 300 km downstream and were thought to be migratory. The prototype array successfully monitored the movement of nine test specimens. The reception area for the full-scale array of 19 fixed receivers extended 800 m upstream of the dam and covered the full, 1-km-wide face of the dam. Movements of all eels that entered the reception area were monitored continuously by two or more receivers operating simultaneously. The travel route of tagged eels through the reception area could be determined in three dimensions based on the relative strength of the signal and depth data recorded by the receivers.

2000 Investigations. The 2000 telemetry study involved tagging outmigrating eels with depth-sensitive acoustic transmitters (NYPA 2007). Their movements were tracked from Long Sault Island (about 6 km upstream of the dam) to Moses-Saunders Power Dam using 38 receivers. Twenty-five receivers were deployed within 400 m of the dam (10 receivers on the dam, and 15 were moored in the forebay). Additional receivers (7) were deployed in a line across the river, 2.5 km upstream of the dam, two on each side of Sheek Island and three just below Long Sault Island. System components were the same as those developed for testing in 1999. Receivers were powered by batteries with a lifespan of 25 to 30 days. Transmitters (19 x 75 mm, 15 g in water) were surgically implanted into the coelomic cavity, as in 1999.

A total of 152 eels were captured (mid-water trawl), tagged, and released 20 km upstream of the dam. Sixty-two eels were detected in the Sheek Island array, the array off Barnhart Island, the forebay array, and the array deployed at the dam (indicating that 62 eels passed the dam). Sixty-six eels did not pass the dam but were detected by manual tracking, and an additional 24 eels did not pass through the dam and were never located by manual tracking. Thirty-five of the 62 eels detected at the Sheek Island array passed to the south of the island. Observations at the array off Barnhart Island indicated that the eels redistributed themselves in transit: 24 eels passed near the middle of the river; 21 eels passed through the north portion of the array, and 17 passed through the south portion of the array. Observations at the array in the forebay indicated that the eels redistributed again after passing the previous array: 33 were detected in the south portion, followed by 17 in the north portion and 12 in the middle. The final estimated position of the eels immediately prior to passing through the dam indicated a nearly uniform distribution across the north (20), middle (23), and south (19) sections of the array and showed no distinct pattern associated with depth.

Based on the speed at which the tagged eels traveled, they appeared to be swimming downstream actively rather than simply being carried along with the current. Eels moved through the upstream array off Barnhart Island at rates ranging from about 0.6 m/s to 1.1 m/s, which is substantially faster than the current velocities in that area (0.2 - 0.4 m/s). In a portion of the forebay array, eels were estimated to move downstream at rates ranging from 0.4 m/s to 0.9 m/s; whereas, flow velocities in that region were measured at about 0.3 m/s.

All eels exhibited undulating vertical movements near the upstream arrays. One individual was observed to dive 7 times in 34 minutes. Some dives covered more than 15 m of depth. In general, 34% of detections of actively migrating eels upstream of the dam occurred within 3 m of the surface of the river, 52% within 5 m of the surface, and 25% at depths greater than 10 m.

According to records of the hourly movement of tagged eels, most activity near the dam (75% of detections) occurred during nighttime hours. Eels generally approached the dam directly and then passed relatively quickly regardless of whether they traveled north or south of Sheek Island. Thirty-five percent of eels detected within 50 m of the dam passed it in less than 2 minutes, and 92% passed in less than 21 minutes. Eels' swimming paths indicated that they could cross in front of the intakes without being entrained. Most of the vertical and lateral movement observed occurred within 100 m of the dam in regions where flow velocities were about 0.5 m/s.

2001 Investigations. NYPA continued the development of optimized telemetry gear and deployment techniques in 2001 with an emphasis on refining receivers and transmitters for fine-scale positioning of tagged fish in the forebay of Moses-Saunders Power Dam (NYPA 2007). These investigations demonstrated that triple-moored receivers moved the least but were more difficult to deploy, maintain, and recover than double- or single-moored configurations. The work resulted in the development of a new battery pack that increased the life span of all electronic components of the telemetry system to three months, and a transmitter that can sample depth every 10 seconds and switch from fast to slow transmission when an eel's behavior shifts from migrating to resting.

2002 Investigations. As noted in Section 1.3, the focus of NYPA's studies in 2002 shifted to Iroquois Dam, which was determined to be a more suitable location for diverting and capturing of outmigrating eels (NYPA 2007). Studies of the improved transmitter indicated that the behavioral switch worked well both in the laboratory and in the field and that the transmitter lasted for a total of 98.5 days (46.5 days in fast mode and 52 days in slow mode), or approximately 3 times the life of the original transmitter (NYPA 2003). Range testing at Iroquois Dam indicated reception over a range of 550 m from the dam, or approximately 2.5 times the range at Moses-Saunders Power Dam. The increase in detectable range was the result of lower background noise levels at Iroquois Dam. A system for accurately locating fish in three dimensions was developed by precisely synchronizing multiple receivers in time. The accuracy of the newly developed positioning algorithm was tested by deploying four buoy-mounted receivers in the forebay and three receivers on the face of Iroquois Dam. Results indicated that the new transmitters, GPS time-synchronization system, and newly developed positioning algorithm allowed for determining the position of a tagged eel within a general range of accuracy of 1 m to 10 m depending upon the actual location of the tag relative to the receivers (positioning was most accurate when the tag was inside the receiver array), and the geometry of the receivers recording the signal.

9.2.2.2 Other Acoustic Telemetry Studies

During the radio telemetry study at the Cabot Station hydroelectric facility on the Connecticut River performed by Haro et al. (2000; Section 9.2.1) the researchers also tagged eels with external, acoustic depth-sensor transmitters (Vemco V16-P-3H, 50-69 kHz, 16 x 74 mm, 14 g). Three fish were tagged in 1996 and five in 1997; tagged fish were detected using a Vemco VR-60 acoustic receiver. Eels were detected most frequently at depths between 6.6 m and 10 m (the forebay of Cabot Station is 10 m deep). Data from acoustically tagged eels indicated that eels in the forebay made regular excursions to the surface.

Brown (2005; Brown et al. 2007) also used acoustic telemetry to document the behavior of silver eels as they encountered the forebay at Cabot Station during the fall of 2002 and 2003. The study area was approximately 75 m wide by 100 m long by 10 m deep. Cabot Station is equipped with 6 turbines and has a generating capacity of 51 MW/hr. Canal flows during the study reached a maximum of 607 m^3/s and a minimum of 28 m^3/s. Twenty silver eels were tagged with HTI Model 795F Tags, which measure 8 mm in diameter by 18 mm long and weigh 2.2 g in air and 1.1 g in water. Eels were released upstream of the power station, and movements and pre-passage behavior were monitored using the HTI Model 290 Acoustic Tag Tracking

System. The system operated at 307 kHz and consisted of a receiver, 8 omni-directional hydrophones deployed in a set pattern in the forebay, acoustic cables, and a personal computer. Tests of the accuracy of the spatial resolution of the system indicated that the standard error of three-dimensional tag positions within the array was ± 0.26 m in the X and Y lateral coordinates and increased outside of the array up to ± 0.43 m. The standard error for the Z (depth) position was higher than those determined for the X and Y positions and varied within the array. Standard error estimates ranged from ± 0.26 m to ± 0.93 m near the bottom and ± 0.26 m to ± 0.78 m near the surface. The most accurate three-dimensional position (i.e., lowest error) was recorded near the edge of the array. The shallow forebay (10 m) compromised the spatial resolution of the system in the Z dimension. Eels occupied a variety of depths within the forebay, but they spent the most time near the bottom. The depth at which eels entered the forebay did not differ with flow conditions (i.e., low < 255 m^3/s; high > 255 m^3/s). Attempts to pass through the dam occurred primarily between dusk and six hours after dusk. Slightly more than half the tagged eels swam upstream after encountering the trash racks, and most tagged eels exhibited searching behaviors near the trash racks, including rapid changes in vertical position.

The movements of ultrasonically tagged, European silver eels were documented in the Mosel River, Germany, during autumn of 1999 to determine if downstream migration is related to abiotic parameters, to determine if migration occurs at a particular time of day, and to monitor the behavior of tagged eels as they approached a hydropower plant (Behrmann-Godel and Eckmann 2003). The study area consisted of the Mosel River and two major tributaries, the Saar and the Sauer. Approximate widths of the Mosel, Saar, and Sauer rivers in the study areas were 200 m, 100 m, and 60 m, respectively (http://www.gefahrenatlas-mosel.de/#). Both the Mosel River and the Saar River have been converted almost completely into canals for navigation, but the Sauer River is not navigable. Fourteen hydropower plants are situated on the Mosel River, and each plant is equipped with four Kaplan turbines. The average discharge of the Mosel River is 330 m^3/s. Nine eels were tagged with Sonotronic CHP-87- s/PRG94 HP, 65-mm-long, 18-mm-diameter, ultrasonic tags weighing 8 g in air. Eight of the nine eels survived tagging, and seven were documented migrating down the river. Tags operated at 70 kHz preliminary because measurements of noise in the Mosel River were determined to be low at that frequency; tags were detected within a range of 300 m to1,000 m. Tagged eels were tracked manually using a Sonotronic Narrow Band USR-96 receiver and DH-2 directional hydrophone. Timing of turbine passage and upriver movements after swimming in the vicinity of the hydropower plant for some time were recorded for five of the tagged fish. Migration timing was linked to increased water discharge in most of the tagged eels.

In the fall of 2004, Hydro-Quebec conducted a study in the intake canal of the Les Cèdres Generating Station to document the behavior of silver eels in relation to a light barrier being tested as a tool for guiding adult eels in the St. Lawrence River (Desrochers and Fleury 2005). A total of 210 silver eels were tagged and released upstream of a light array. The eels were purchased from a commercial fisherman who captured them near the south bank of the St. Lawrence River in Quebec. Eels were tagged internally with HTI Model 795F Acoustic Tags (8 mm in diameter x 18 mm long; 2.2 g in air and 1.1 g in water). The behavior of tagged eels was documented using the HTI Model 290 Acoustic Tag Tracking System, which consisted of a receiver and seven omni-directional hydrophones operating at 307 kHz. Hydrophones were located near the light array and detected the fine-scale movements of eels as they approached the array. The dimensions of the study area were 400 m by 225 m by 2 m (depth). During 30 days of observations, 136 (64.8%) of the tagged eels were detected with the hydrophones and 40 passages were recorded in the light zone. Results indicated partial avoidance (33.3%) at light intensities greater than 100 lux.

Aoyama et al. (2002) monitored the movements of yellow and silver eels at the mouth of the Fukui River and in the adjacent waters of the Tachibina Bay, Japan, from August through November of 1999. In this study 16-mm by 62-mm, pressure-detecting, ultrasonic telemetry tags manufactured by Vemco/Canada were attached externally to four yellow eels and three silver eels. Tagged eels were released 300 m from the mouth of the Fukui River and tracked immediately using a depth-decoding, ultrasonic Vemco receiver and hydrophone. All four yellow eels released in August moved immediately into the river and upstream, making several stops at "refuge" locations, until they could not be detected. Each refuge appeared to be a relatively small area adjacent to a series of concrete blocks along the shore. All tagged yellow eels used the areas repeatedly. Tagged yellow eels spent most of their time in the refuges during daytime and moved predominantly at night. In contrast, a silver eel released in November demonstrated rapid movement towards the sea without stopping after release.

In 2004, Brown et al. (In Prep.) used three-dimensional acoustic telemetry to track longfin eels and shortfin eels as they approached, encountered, and passed Arapuni Hydro Power Station on the Waikato River in New Zealand. The study area encompassed the width of the dam (94 m) to 100 m upstream into the forebay and to a depth of 9 m. Approach velocity at the turbine intakes varied between 0.9 and 1.7 m/s; flow volume through the study area was not reported. Eels were collected by commercial fishermen in the Waikato watershed. HTI Model 795X Acoustic Tags (15.7 mm in diameter x 47.5 long; 18 g in air and 13 g in water) were surgically implanted into 21 eels (15 shortfin and 6 longfin). Tags were operated at 307 kHz and a ping rate of 2.9 seconds to 3.1 seconds. Five hydrophones were deployed throughout the forebay (three at 1 m below the surface and two at 1 m from the bottom). HTI Model 290 Acoustic Tag Tracking System was used to record tag data. Longfin eels also were tracked using VEMCO model V16-6H-R256 69 K transmitters (16-mm in diameter x 90 mm long: 36 g in air), VEMCO acoustic telemetry data loggers, and VR1 receivers. Thirteen of the 21 tagged eels (7 shortfin and 6 longfin) were detected. Migration occurred primarily at night, and most tagged eels entered the forebay in mid-channel. Longfin eels were initially reluctant to pass through trash screens and into the turbines and spent long periods of time searching the entire forebay before eventually passing. Shortfin eels either passed into the turbines immediately when they first encountered the trash screens or exhibited search behaviors similar to those of the longfin eels. The data set was limited due to power failures and equipment malfunctions that resulted in the loss of 16 days' records. Results from the VEMCO tags were not reported.

A recent study by Bradford et al. (2007) involved the use of Vemco equipment (depth-coded V9P-6L-R64K tags and submerged VR2 receivers) to assess the behavior of silver eels and the influence of environmental parameters on eel migration near Passamaquoddy Bay in New Brunswick, Canada. The tags were 9 mm in diameter by 38 mm long and weighed about 3 g in water. Twenty eels were tagged and released during the dark of the moon, 10 during low and 10 during high tide. Tagged eels departed the bay at night and during ebb or high water/ebb tidal periods. Eels were inactive 40% of the time, and most activity occurred during the night. Most eels were detected at depths of less than 40 m while in the bay.

9.2.3 Survey of Telemetry Vendors

All known vendors of telemetry technologies for fisheries were surveyed to obtain information concerning the capabilities of their equipment (Table 9-1). The surveys were conducted by emailing questionnaires (Appendix D) and following up with additional email and phone calls. The questionnaires were designed to elicit information regarding prior use of their technologies for evaluating the behavior of eels as well as the potential for using their equipment in the St. Lawrence River at Iroquois Dam. Four of the 11 vendors solicited with the questionnaire responded: Hydroacoustic Technology, Inc., Lotek Wireless, Inc., NEDAP, and Vemco. None of the other vendors responded to further inquiries. Table 9-2 summarizes results of the survey and highlights relevant features of the telemetry systems manufactured by the vendors who responded, including system frequencies, transmitter characteristics, system requirements and capabilities, data-reduction methods, and approximate estimates of the cost to use the system to sample eels in the vicinity of Iroquois Dam. Appendix E provides vendors' complete responses to Part 2 of the questionnaire (i.e., capabilities for documenting fine-scale movements of eels near Iroquois Dam).

Table 9-1. Vendors of telemetry technology solicited for information in a survey of capabilities

Vendor Name	Technology	Responded
Advanced Telemetry Systems, Inc.	Radio	No
Andreas Wagener Telemetrieanlagen	Radio	No
AVM Instrument company, Ltd.	Radio	No
CIs America	Satellite	No
Grant Systems Engineering, Inc.	Radio	No
Hydroacoustic Technology, Inc.	Acoustic	Yes
Lotek Wireless, Inc.	Radio / Acoustic / Satellite	Yes
NEDAP	Radio	Yes
Sonotronics	Radio / Acoustic	No
Vemco	Acoustic	Yes
Wildlife Track, Inc.	Radio	Wildlife Specific

Table 9-2. Features and specifications of selected telemetry systems.*

	Hydroacoustic Technology, Inc.	Lotek Wireless, Inc.	NEDAP	Vemco
Transmitter Size and Weight	Model 795G Tag-11 mm diam. x 25 mm length, wt: 3.1 g in water, Model 795X Tag-15.7 mm diam. x 47.5 mm length, wt: 18 g in air, 13 g in water	Tag with depth sensor: 11 mm diam x 48 mm length, wt: 8.5 g in air	15 mm diam x 62.5 mm length, wt: 26.55 g in air, 10.16 g in fresh water and saline water at 4ºC	200 kHz Model – 18 mm diam x 75 mm length, wt: 40 grams in air, 20 grams in water
Transmitter Characteristics	Battery life for Model 795G Tag approx. 45-65 day; for Model 795X approx. 6 months; transmission interval field programmable from 25 pings/sec to 1 ping every 16 sec	MA-TP11-25 transmitter will last up to 104 days with a 5-second transmission interval	Battery life – 12 months under normal environmental conditions; up to 36 months in other dimensions available; transmits only when stimulated by the interrogation signal from the antenna	Battery life – up to 98 days, varies due to behavioral switch; 8 millisecond pulse width; transmission rate – varies due to behavioral switch; power – 158 dB re 1 uP @ 1m
System Frequencies	307 kHz	147 to 168 MHz for combined acoustic/radio transmitters; receivers operate at 200 kHz	33.25 kHz	69, 180, and 200 kHz
Methods of Transmitter Attachment	Surgical	Surgical	Surgical	Surgical
Deployment Techniques and Requirements	Along face of dam hydrophones are typically mounted in brackets and aimed facing upstream, alternating surface and deep hydrophones; in the forebay arrays of tensioned buoys cabled to anchors are deployed with tension lines to minimize hydrophone movement during changes in flow conditions; to avoid damaged cable during high debris loads, suggests anchoring cables along the bottom.	Impossible to determine without more information about the bottom substrate; clients have used molded cement anchors and pipes driven into the bottom; all depends upon the nature of wind, wave, boat traffic, etc. in the area during the deployment.	Interrogation units are typically placed in locked cabinets along the riverside.	Hydropones on the dam are typically mounted in brackets and deployed off nose piers; forebay deployments usually include mounting from mooring buoys
Power Requirements	120 VAC power is required for the receiver and computer stations at all times and use of a backup power supply with surge protection recommended to minimize risk of lost data.	Receivers and hydrophones are autonomous, batteries last about 90 days	230 to 240 VAC for interrogator units; power consumption is about 25 VA which could allow for battery/inverter in combination with solar panel and/or wind charger	Power requirements for receivers is unnecessary as receivers are autonomous with a battery life > 1 yr
Electronic and Communication Requirements	One PC (i.e., Pentium class, 1 GHz w/Windows 2000, 256 MB RAM, 4 GB HD) per receiver, Model 290 Tag Receivers permit use of satellite communication to maintain system synchronization and to facilitate quality control and data transfer; satellite connections permit automatic data uploads.	Receivers are autonomous, no additional power required	GSM/GPRS data model for communication is included in the interrogation unit	None required if all receivers are VR2Ws
3-D Tracking Capabilities	Yes	Yes	No	No

Table 9-2. (Continued)

	Hydroacoustic Technology, Inc.	Lotek Wireless, Inc.	NEDAP	Vemco
Accuracy of Tag Positioning	Sub-meter accuracy in all dimensions; error in 3-D positioning can be modeled using HTI modeling software; additional quality control testing can be conducted on site by dragging a test tag throughout the array and overlapping known GPS positions with the 3-D position estimates	To be determined during testing after deployment	No Reponse	At least ± 5 m for time synchronized receivers
Range of Detection	Up to 1 km per hydro-phone in acoustically quiet sites; for 3-D track-ing, usually do not exceed 100 to 150 m between hydrophones; for 3-D tracking a minimum of 4 hydrophones must detect the tag within the array	200 to 600 m	River widths up to 500 m, to 20 m depth	Several hundred meters should be achievable at the Iroquois Dam site but actual range of detection will not be known until on site testing is conducted
Data Reduction and Analysis Methods	Typically a combination of auto and manual data reduction steps using HTI's Mark Tags; 3-D position estimation will require use of HTI's Acoustic Tag software; 3-D position estimates can be run automatically once the data has been selected with the appro-priate system parameters; database requirements would depend on the volume of data acquired but would likely include MS Access	Acoustic positioning system is supplied with BioMAP software (centralized database for managing raw data); exports data in standard formats to third party software (ESRI, Matlab, Excel)	No Response	Current products are supported by Vemco User Environment software which allows the user to quickly create a database of all selections from all receivers within a sys-tem and to export the data to commercial database, plotting or animation programs; Baird software associates produced animation package for NYPA studies
Effects of Fouling of Gear by SAV and other Debris	Occasional maintenance may be required to remove floating debris from surface oriented hydrophones upstream of the dam; cables and hydrophones are some-times damaged and replacement during the study period	No Response	No Response	No Response
Cost Estimate for Equipment Needed to Sample at Iroquois Dam	$475,000	Up to $230,000	Depends upon the number of stations needed (each interrogation unit costs about $44,000, trans-ponders cost about $250)	About $250,000

*Information obtained in response to a questionnaire (Appendix D) and subsequent discussions with vendors. See Appendix E for vendors' complete responses to Part 2 of the questionnaire.

9.3 OTHER TECHNOLOGIES FOR MONITORING THE MOVEMENTS OF EELS

9.3.1 Standard Active Sonar

In general, active sonar (hydroacoustics) involves the transmission of an acoustic signal and detection of reflections of the signal from objects in the surrounding water (MacLennan and Simmonds 1992). The primary components of a sonar system are a transducer, which converts electrical energy into acoustic pulses transmitted in a directional beam, and an echo sounder, which produces the burst of electrical energy at a particular frequency. Some of the energy of the transmitted pulses encounters a target and is reflected back to the transducer (i.e., an echo). The transducer converts the echo to an electrical signal. The echo sounder receives the signal, amplifies it, and displays it or records it on an echogram.

Since Kimura's (1929) initial work on acoustic detection of fish in cultivation ponds, sonar has been used extensively for surveying fishery resources in rivers (Eggers 1994; Burwen and Fleischman 1998), reservoirs and lakes (Degan and Wilson 1995; Knudsen and Seagrov 2002) and deep-water marine systems (Foote and Traynor 1988; Lima and Castello 1995). Hydroacoustic sampling is widely used at hydropower projects the Pacific Northwest to estimate juvenile salmon passage (Ploskey et al. 2001, 2005) and to evaluate the effectiveness of guidance structures (Moursund et al. 2005; Dawson et al. 2005) and behavioral barriers (Ploskey et al. 2000; Johnson P.N. et al. 2005). Principal manufacturers of hydroacoustic gear are Biosonics, Inc., HTI, and Simrad.

9.3.2 Sonar Imaging

Sonar imaging systems operate at high frequencies and emit multiple beams that allow for the collection of near-video-quality, streaming imagery in two spatial dimensions. Presently, there are three sonar imaging systems on the market, the most prominent of which is dual-frequency identification sonar (DIDSON). DIDSON was developed by the University of Washington Applied Physics Laboratory for the U.S. Space and Naval Warfare Systems Center as a defense technology for surveilling harbors and detecting underwater mines (Belcher et al. 2001; Belcher et al. 2002). The standard DIDSON unit has two operational frequency modes. The high-frequency mode operates at 1.8 MHz and uses an array of 96 beams, each extending 0.3^{o} horizontally and 12^{o} vertically; the low-frequency mode operates at 1.1 MHz and uses an array of 48 beams, each extending 0.6^{o} horizontally and 12^{o} vertically. The overall sampling volume using both modes covers an area of 29^{o}. DIDSON images are constructed in sequence and consist of 8 sets of 12 beams (high-frequency mode) or 4 sets of 12 beams (low-frequency mode) fired simultaneously. The manufacturer, SoundMetrics Inc., also produces a long-range model that operates at 750 kHz and 1.1 MHz and is capable of sampling to a range of 60 m (the range of the standard unit is about 24 m.). DIDSON has recently become available for fisheries investigations and has been used primarily to assess the behavior of salmon at hydropower dams (Moursund et al. 2003; Ploskey et al. 2005) and enumeration of upstream migrating adult salmon in river systems (Maxwell and Gove 2004; Holmes et al. 2006; Cronkite et al. 2006; Johnson

P.N. et al. 2006). DIDSON systems also have been used to evaluate the effectiveness of fish-guidance structures (Ploskey et al. 2005; Johnson G.E et al. 2006).

Other sonar imaging systems on the market include those made by BlueView Technologies and Imagenex. BlueView sonar imaging units have a 45^o field of view and operate at 450 kHz to maximum range of about 137 m and at 900 kHz to a maximum range of about 54 m. Specifications for the Imagenex sonar systems include an operating frequency of 260 kHz and a field of view spanning 120^o horizontally and 20^o vertically. These systems typically are used for search and recovery, diver support, ship-hull inspection and as an aid for real-time navigation (http://www.blueviewtech.com/?page=news; http://www.imagenex.com/html /delta_t_imaging.html). No applications involving fisheries investigations have been documented.

9.3.3 Uses of Other Technologies for Monitoring the Movements of Eels

9.3.3.1 Standard Active Sonar

Few studies to date have involved the use of hydroacoustics to monitor migrating eels in riverine systems. A pilot study by Haro et al. (1999) evaluated whether echoes from adult eels can be distinguished from those from other common acoustic targets in the laboratory and in the field. The study was limited to evaluating the characteristics of echoes from eels, spatial and temporal patterns of eels' movements, and eels' swimming behavior in a riverine environment. Acoustic echoes from American eels were characterized, and mathematical acoustic models were developed for American eel and two species of Australian freshwater eel, short finned eel (*A. australis*) and long finned eel (*A. dieffenbachia*). The study (1) identified target strength and echo characteristics of adult eels in various orientations to the transducer; (2) evaluated a fixed-aspect, hydroacoustic system for detecting in-field movements of eels; (3) derived a mathematical model (Kirchoff-ray mode - KRM) to estimate backscatter as a function of eel length, aspect, and acoustic frequency; and (4) provided recommendations for applied use of hydroacoustic monitoring for evaluating the behavior of eels.

Experiments to estimate target strength were conducted at the Conte Anadromous Fish Research Center (CAFRC) in Turner Falls, Massachusetts, during July and August of 1998. The passage of outmigrating eels was monitored in the forebay of Cabot Station Hydroelectric Facility on the Connecticut River. A Biosonics DT6000 digital echosounder with a 420-kHz, split-beam transducer (6^o x 12^o beam width) was used to estimate the target strength of eels in a pond and to sample for eel passage in the forebay. The transducer was mounted next to a concrete wall of the forebay, 1 m below the water surface, and the hydroacoustic beam sampled to a maximum range of 45 m across the forebay in an area where eels had been observed at the surface. Flow in the Connecticut River ranged from 75 m^3/s to 250 m^3/s during the study. An underwater, closed-circuit video camera was used to verify the relative abundance of eels in a bypass weir in the forebay at Cabot Station during the hydroacoustic monitoring period. Target strengths varied by as much as 20 dB within sets of dorsal and lateral measurements. Target strength also varied as a function of angle of the acoustic axis. The greatest target-detection rate in the forebay occurred between 1800 and 2000 hours. No trends were apparent with respect to range across the forebay or depth strata. Nightly video counts at the bypass weir were low (< 1 eel/hr). Daily run timing for eels in the bypass was somewhat similar to acoustically tracked fish larger than 70 cm but more closely resembled the distribution of fish larger than 100 cm. Diel movements of acoustically tracked eels and eels observed in the bypass also showed some similarity, but the relationships between them were small and were not statistically significant.

Haro et al. (1999) concluded that hydroacoustics can be used as a qualitative tool to identify spatial and temporal patterns in the behavior of large eels (> 70 cm) in the forebays of hydroelectric facilities. Distinguishing eels from other fishes was problematic, but the difficulty is likely to be site-specific. Confounding factors in a hydroacoustic survey include water turbulence, turbidity, and the presence of drifting debris. Peak downstream movements of eels generally occur when these conditions are at the worst for acoustic monitoring (i.e., high flows).

Kleinschmidt and Aquacoustics (2006) used hydroacoustics to monitor the behavior of eels on the Kennebec River in Maine. The objectives of that pilot study were to (1) verify empirically that a hydroacoustic system could detect eels; (2) experiment with transducer locations and arrays to determine a suitable sampling scenario; (3) develop specifications and recommendations for deploying an interim hydroacoustic monitoring system; (4) develop methods to recognize the echograms and acoustic image patterns of outmigrating eels and non-target species; and (5) develop recommendations for operating turbines and waste gates when eels are migrating downstream. Two sonar technologies were evaluated: split-beam active sonar and DIDSON. Both were installed in the Anson Canal on the Kennebec River and tested during the pilot study (DIDSON results are summarized in Section 9.3.3.2). An initial test consisted of allowing tethered, live yellow and silver eels and tethered, live specimens of other, non-target species to drift through the acoustic fields to determine the distance from the transducer at which eels could be detected and distinguished from the other species. The split-beam system enabled researchers to distinguish eels from other species out to the maximum sampled range (i.e., 27 m). The characteristics of the split-beam trace that were used to identify signals from an eel were more subtle and sometimes more ambiguous than the identifying features of DIDSON images. The identifying characteristics of split-beam traces of eel echoes included a sawtooth pattern and variable echo width.

Natural eel migration was monitored from 19 September through 4 October in the Kennebec River with two split-beam systems (Biosonics DTX 6000 and Simrad EK 60) and one DIDSON. Flows throughout this period ranged from 86 m^3/s to 199 m^3/s. The Biosonics system used either a 6º circular transducer or a 4º by 8º, elliptical transducer operating at 201 kHz; the Simrad system used a 7º circular, 120-kHz transducer. The three acoustic systems sampled simultaneously and covered partially overlapping sample areas. The bottom-mounted, split-beam system detected more than 200 eels. A surface-mounted, split-beam system appeared to have missed a substantial number of eels, most likely as a result of poor echo traces and complications associated with debris and surface noise. Generally, split-beam sampling indicated that eels showed no pronounced preference for a particular position in the water column. Most passed downstream during the first two hours after sunset and the last hour prior to sunrise.

Most downstream movement occurred during just a few nights. Authors concluded that the bottom-mounted, split-beam system allowed for consistent identification of eels.

9.3.3.2 Sonar Imaging

Few examples of uses of sonar imaging to monitor the behavior of eels are available because the technology is relatively new (Belcher et al. 2001; Belcher et al. 2002). The only large-scale investigation in which sonar imaging was used to monitor eel behavior occurred on Maine's Kennebec River in 2005 (Kleinschmidt and Aquacoustics 2006). DIDSON images enabled researchers to detect and identify large eels (> 900 mm) to a maximum range of approximately 20 m. Sub-adult eels (< 700 mm) were detected and identified to a maximum range of 15 m. The two most important features of DIDSON images that distinguished eels from other objects were unique shape and serpentine swimming motion. DIDSON images showed more than 200 eels, which agreed well with data from a bottom-mounted, split-beam, active sonar system tested at the same time and place (Section 9.3.3.1). The researchers concluded that DIDSON enabled consistent identification of eels. Both systems provided a sufficient sample for determining general run-timing and diurnal patterns in the migration of silver eels. The main difference between the two systems was the kind of features used to distinguish the signals of eels from those of other species. The clear identifying features of the DIDSON images (i.e., shape and swimming motion) made it the better candidate for use in developing an automated system for monitoring eels, especially when differentiating eels from debris is a concern, as it is in the Anson intake canal.

Degan et al. (2007) used the DIDSON data from the eel study in the Kennebec River. The work is part of a continuing effort to develop an automated hydroacoustic monitoring system for detecting outmigrating adult eels. The objective of the effort is to develop a classification algorithm that can identify eels accurately enough to reject more than 99% of debris and other targets, which outnumbered eels by a ratio of about 100:1 in the Kennebec River. The key steps were identifying characteristics of the DIDSON-imaged eels that quantified the size, shape, and motion of the detected targets and finding processing techniques that enhanced eel-specific features. The characteristics were then used in a pattern-recognition program that calculated each target's probability of membership in two categories: eels and non-eels. Development of the algorithm is preliminary, and success is uncertain.

A series of tests to examine the feasibility of using DIDSON as a fisheries monitoring tool were conducted recently in the UK (Hateley et al. 2006). In one pilot study, DIDSON was used to assess the rate of escape of silver eels from a trap at Welford Mill on the Leven River, North Yorkshire, UK, during 2004. The researchers did not report the physical characteristics of the study site or the dimensions of the trap. Eels' behavior was classified into four categories: (1) moving into the trap, (2) moving out of the trap (i.e., escaping), (3) milling, and (4) unknown (i.e., moving towards or away from trap but not observed to enter or leave it). Thirteen eels were removed from the trap after two full nights of sampling. DIDSON records for the same period corresponded closely: 26 eels entered the trap, and 12 exited the trap, leaving a net count of 14 eels (24 other movements were recorded). The length-frequency distribution of trapped fish and the distribution of DIDSON measurements were similar; however, DIDSON reported fish in the larger classes that did not appear in the trap. This discrepancy probably was the result of the tendency of DIDSON to overestimate fish lengths. The pilot study indicated very good potential for using DIDSON to monitor eels. The authors noted, however, that careful site selection is important to avoid problems with weeds and to ensure that the beam covers the entire water column. Weeds and debris seriously affected the automatic counting features (echogram counter) of the DIDSON software. Image-mode review was very effective for identifying eels and enumerating their movements but was time consuming. Overall, DIDSON provided excellent insight into the behavior of eels near the trap, including avoidance and escape, which suggests that DIDSON could be used to improve the efficiency of traps.

The Nature Conservancy's Delaware River Basin Program recently sponsored a demonstration of DIDSON for imaging outmigrating American eels in the Neversink River (M. Grooms, Ocean Marine Industries, pers. comm.). A tripod-mounted DIDSON system obtained several hours' of data, and numerous images of eels swimming through the DIDSON's field of view were acquired between 2030 and 2330 on 12 September 2007. During the demonstration, the wetted width of the river was about 30 m; flow was approximately 4 m^3/s; and current velocity was approximately 0.3 m/s (M. DeLucia, Nature Conservancy, pers. comm.).

Most recently, Mueller et al (2008) explored the extent to which computer-driven analysis of DIDSON data could be used for automatic detection of downstream-migrating adult American eels in a hydroelectric project intake canal. The images were collected by a dual-frequency identification sonar with sufficient resolution to show the distinct shape and swimming motion of eels, and thus to allow confident visual identification. The goal was to find a set of image processing, tracking, and pattern recognition techniques that would reproduce the results of the visual classification. Of the three classification methods tested, neural network analysis had the lowest misclassification rate for eels (7% of the eels being misclassified as debris) and the second-lowest misclassification rate for debris (5% of the debris being misclassified as eels). Discriminant function analysis misclassified 12% of the eels as debris and 4% of the debris as eels. They concluded that, depending on the application, different degrees of automation may be achieved, ranging from a relatively high degree of human supervision in the classification of all potential targets to a fully automated process that requires only periodic quality control and adjustments of the classification model.

9.3.4 Survey of Vendors of Other Technologies

All known vendors of fisheries acoustic gear (Table 9-3) were surveyed regarding the capabilities of their equipment by emailing questionnaires (Appendix D) and following up with additional email and phone calls. The questionnaires were designed to elicit information regarding prior use of their technologies for evaluating the behavior of eels as well as the potential for using their equipment in the St. Lawrence River at Iroquois Dam. Four of the 12 vendors solicited with the questionnaire responded: Biosonics, Inc., (hydroacoustic gear), HTI (hydroacoustic and acoustic telemetry gear), Scientific Fishery Systems, Inc., (hydroacoustic gear), and Sound Metrics Corp. (imaging sonar). None of the other vendors responded to further inquiries.

Table 9-3. Vendors of hydroacoustic technology solicited for information in a survey of capabilities

Vendor Name	Technology	Responded
Biosonics, Inc.	Active Sonar	Yes
Blue View Technologies	Imaging Sonar	No
Furuno	Active Sonar	No
Hydroacoustic Technology, Inc.	Active Sonar	Yes
Imagenex Technology Corp.	Active Sonar/Imaging Sonar	No
Kaijo Sonic Corp.	Active Sonar	No
Precision Acoustic Systems	Active Sonar	No
Reson Underwater Acoustic Systems	Active Sonar	No
Scientific Fishery Systems, Inc.	Active Sonar	Yes
Simrad	Active Sonar	No
Sonar Data	Acoustic Data Software	No
Sound Metric Corps	Imaging Sonar	Yes

Table 9-4 summarizes results of the survey and highlights relevant features of the sonar systems manufactured by the vendors who responded, including system frequencies, transmitter characteristics, system requirements and capabilities, data-reduction methods, and approximate estimates of the cost to use the system to sample eels in the vicinity of Iroquois Dam. HTI responded to the survey but indicated that its system would not be an appropriate method for sampling eels at Iroquois Dam; consequently, HTI's information is not included in Table 9-4. Appendix E provides vendors' complete responses to Part 2 of the questionnaire (i.e., capabilities for documenting fine-scale movements of eels near Iroquois Dam).

9.4 RELEVANCE AND APPLICABILITY AT IROQUOIS DAM

The preceding sections provide overviews of the kinds of technologies that may be useful for tracking or monitoring eels in natural environments. Table 9-5 summarizes the attributes of each of those technologies, identifies their respective advantages and limitations, and presents conclusions regarding their potential for use at Iroquois Dam.

Table 9-4. Features and specifications of selected active sonar and sonar imaging systems.*

	Biosonics	**Scientific Fishery Systems, Inc.**	**Sound Metrics Corp.**
Technology	Narrow band split-beam sonar	Combined narrow band split-beam and wide band single beam sonar	Imaging Sonar
Operating Frequencies	200 and 420 kHz	135 to 200 kHz	Standard Unit: 1.1 and 1.8 MHz Long-Range Unit: 750 kHz and 1.1 MHz
Deployment Techniques and Requirements	Tripod bottom mount is anticipated with dimensions and weight based on substrate and current velocity, transducer cables would run along the reservoir bottom.	Typically use aluminum mounts at the bottom or attached to structure; frequently use rotators attached to transducers that allow for manual adjustment of pitch and yaw	Typically DIDSON is deployed off of pole mounts, tripods, H mounts, frequently a Pan and Tilt rotator is used to remotely change aiming directions
Power Requirements	Each echo sounder draws 30 W. data collection PC draws about 50 W, use of Ethernet components and external hard drives would add to total (assume 500 W)	120 VAC power to dry end; TCP/IP connection form dry end to master PC	Consumes 30 W with voltage range of 14-32 V DC; two wires are needed for power and four wires are needed for the Ethernet connection
Electronic and Communication Requirements	Systems operate on AC or DC power to be supplied at each echo sounder location; ideally each station would be internet accessible for remote control, quality controls and download of data	Each sonar has its own onboard computer with local hard drive; each sonar is a node on a TCP/IP network	DIDSON uses 100/10 Base T Ethernet to communicate to a host laptop; third party options for transmission of the Ethernet over 4,000 ft of a single twisted pair or miles of a fiber optic line; RF communication is also possible
3-D Tracking Capabilities	Yes – the Active Fish Tracking System, composed of a split-beam transducer mounted on a dual-axis computer controlled rotator, allows for tracking; the transducer sends the target coordinates to the motors, which then rotate the transducer to keep the target near the acoustic axis	Yes – through the use of split-beam sonar with automated tracking algorithms; tracking from one beam to the next (along an array of beams) can be achieved by integrating into a single homogenous system	No
Spatial Resolution	X and Y angular resolution is better than 0.5º, Z spatial resolution is 1.7 cm	Angular resolution of 0.1 degrees in up-down and left-right for split-beam pulses; broadband pulses provide 2.5 cm range resolution	Varies as a function of operating parameters: Cross-range resolution = (range/2)/number of beams used; down-range resolution = window_length/512

Table 9-4. (Continued)

	Biosonics	Scientific Fishery Systems, Inc.	Sound Metrics Corp.
Anticipated Reception Range per Unit Deployed	50 to 100 m in range, with a 6 degree circular transducer the spread is a 1:10 ratio (at 50 m the beam is about 5 m across)	Up to 15 0m in horizontal range using a 3 degree beam in water 10-12 m depth (covers 0.036% of sample space)	Standard Unit: 20 m / 333 m^3 Long-Range Unit: 60 m / 9,000m^3
Data Reduction and Analysis Methods	Biosonics or Echoview tracking software	Echoview for processing analysis	Computer assisted discrimination algorithms have been developed for eel classification of DIDSON images; Echoview can now be used to read in DIDSON data
Effects on Ability to Sample Eels by Floating or Submerged Debris, or other Fish Species	Acoustic size and unique swimming behavior of eels both help to provide classifiers for separating eel targets from debris and fish	Inclusion of interleaving broadband and narrowband would allow for some discrimination between eels and other targets	Based on already developed algorithms, eels can be identified within a population of their fish and debris with 95% accuracy
Cost Estimate for Equipment Needed to Sample at Iroquois Dam	$250,000	$1,000,000	$90,000 per unit (DIDSON, mount, rotator); $7,560,000 (84 units) to cover length of sample area

*Information obtained in response to a questionnaire (Appendix D) and subsequent discussions with vendors. See Appendix E for vendors' complete responses to Part 2 of the questionnaire.

Table 9-5. Tracking and monitoring technology attributes and their relevance to application at the Iroquois Dam

Technology	Advantages	Limitations	Potential for use at Iroquois Dam
Radio telemetry - Satellite	Can collect both physiological data (e.g., heart rate) and physical data (e.g., water temperature, dive depth)	Accuracy of positional information is usually within 1 km Sample size usually is small because of the cost of tags Signals received only when tagged animals are near the surface; system cannot geolocate under water Only 10 locations can be calculated per day	Typically used in combination with pop-up archival tags to monitor highly migratory animals in large rivers and marine systems. **Not feasible for monitoring eels at Iroquois Dam** because spatial resolution is too coarse to function effectively in areas the size of the forebays of hydropower dams.
Radio telemetry – NEDAP TRAIL	Signal transmission is only minimally affected by physical obstacles, turbidity, turbulence, and thermal stratification Ability to detect transmitters from the air is advantageous for studying highly migratory species through large river systems Can detect and transmit both physical (temperature, depth) and physiological data	Works poorly in deep and highly conductive environments Sample size usually is small because of the cost of tags Fish handling and surgical implantation of tags may bias behavior Poor spatial resolution Cannot estimate three-dimensional positioning	Successfully documented movement of eels (Bruijs et al. 2003; Vriese et al. 2006) Is useful when objective is only to detect individuals as they move past areas of interest. **Not feasible for monitoring eels at Iroquois Dam** because: conductivity is high in the St. Lawrence River at Iroquois Dam spatial resolution is too poor to determine fine-scale position of eels at Iroquois Dam
Radio telemetry - PIT	Transponder should last through the lifetime of a tagged eel Can detect tagged fish in freshwater and marine environments Billions of unique codes are available for PIT tags Low cost per tag; bulk supply chains established for Northwest applications	Requires pass-through antennas that are limited spatially to 7.6 m x 1.2 m in low flow and 1.4 m x 1.5 m in high flow Saline water attenuates the electromagnetic field produced by the antennas; small (1.5 m x 0.6 m), shielded antennas required in estuarine locations	Frequently used to collect ancillary data on eel movement in studies using other primary tools (radio and acoustic telemetry) **Not feasible for monitoring eels at Iroquois Dam** because of the relatively small size of detectors and small read range (inches to feet) compared to the scale of the study area and areas through which eels may pass. Possible secondary use to identify eels tagged at tributary streams in the Great Lakes during collection and transport.
Acoustic telemetry	Works well in deep and highly conductive environments, including estuaries Equipment already customized for use with eels in the St. Lawrence River Allows for three-dimensional positioning No external antenna on transmitters; implantation of the transmitter is less invasive, and absence of external tag eliminates drag Detection capability is not adversely affected by depth Greater detection range underwater than radio telemetry Can detect and transmit both physical (temperature, depth) and physiological data	Turbidity and turbulence can negatively effect signal transmission Other background noise can influence signal transmission and reception Fish handling and surgical implantation may bias behavior Receiving gear frequently fouled by SAV; increased maintenance costs Position accuracy is affected by errors resulting from moving hydrophones and other uncontrollable environmental factors Detection capability and/or efficiency reduced in high velocity areas Aerial mobile tracking is not applicable	**Demonstrated effectiveness for assessing eel behavior in the St. Lawrence River**. (McGrath 2003a; NYPA 2007; Bradford et al. 2007) Recent studies employing HTI's system to monitor three-dimensional movements and behavior of silver eels as they approached power-station intakes on the Connecticut River (Brown L.S. 2003) suggest that this technology **may be viable for use at Iroquois Dam.**

Table 9-5. (Continued)

Technology	Advantages	Limitations	Potential for use at Iroquois Dam
Standard active sonar (Split-beam hydroacoustics)	Sampling is unobtrusive; no need to capture, handle, or tag eels Allows for detection of large numbers of targets over long periods (i.e., yields a large sample size) Monitoring can be automated; allows for minimizing labor costs Available software for data processing and analysis can be used to automate those tasks Effective in estuarine applications	Echoes generally not characterized by species; other methods may be needed to verify detected species. Documented saw-tooth trace patterns of eels may preclude the need for alternative methods. Entrained air, water turbulence, and the presence of drifting debris may confound the ability to monitor fish Sample volumes associated with fixed-aspect hydroacoustic transducer beams are small relative to the study area at Iroquois Dam Cannot sample fish immediately along structures because echoes from the structure mask the targets May count the same fish multiple times; cannot distinguish between one-time movements of many fish and repeated movements of a single fish Processing and analysis of hydroacoustic data is complicated	**Demonstrated viability for characterizing spatial and temporal behavioral patterns of large eels** in the forebays of hydropower projects (Haro et al. 1999). **Sawtooth trace patterns and variable echo widths allow for consistent identification of eels** over a range of 27.m (Kleinschmidt and Aquacoustics 2006) Demonstrated use of hydroacoustic systems for evaluating fish guidance and diversion structures in the Pacific Northwest coupled with the results of successful investigations with eels indicate that this method **may be viable for use in some context at Iroquois Dam**; however, the limited volume of the entire river cross-section that would be insonified using a single unit would require that many units be deployed to provide completed coverage of the large river cross-section at Iroquois Dam, an effort likely to be economically infeasible. If outmigrating eels were diverted to a smaller portion of the total river cross-section through use of some type of barrier, hydroacoustic systems could be used as a means of quantifying downstream migrants and documenting their movement patters within the field of the equipment. The best use of hydroacoustic sampling may be as a secondary tool for assessing localized distribution and behavior of eels in select areas upstream of Iroquois Dam. Hydroacoustic counts of eels in distinct areas during on / off tests of a guidance device could supplement the overall evaluation of its performance. An automated fish tracking system could record the behavior of eels as they approach a guidance device. Such information would help to define how closely eels approach the device before they react to it and if the reaction point changes with variable flow or other factors.

Table 9-5. (Continued)

Technology	Advantages	Limitations	Potential for use at Iroquois Dam
Sonar imaging (DIDSON)	Sampling is unobtrusive; no need to capture, handle, or tag eels Allows for detection of large numbers of targets over long periods (i.e., yields a large sample size) Monitoring can be automated; allows for minimizing labor costs DIDSON imaging is near-video quality so eels can be identified readily Sampling can take place along structures and in tight corners; not limited by physical boundaries within the water	Turbulence may confound the ability to monitor fish Sample volume is very small relative to the study area at Iroquois Dam Range is limited to about 24 m with standard unit, 60 m with long-range unit May count the same fish multiple times; cannot distinguish between one-time movements of many fish and repeated movements of a single fish if targets are all similar in size High cost for a single unit Data collection is volume intensive for electronic storage (typically 1.7 GB/hr) DIDSON data processing software is under development	**Eels can be imaged and readily identified** (Kleinschmidt and Aquacoustics 2006; Hateley et al. 2006) DIDSON as been used successfully to evaluate guidance structures in other regions; therefore, it **could be a viable tool for assessing eel guidance in areas upstream of Iroquois Dam**. Small sample volume and the expense of DIDSON per unit probably preclude the use of an array of units to form a sampling curtain like those suggested by the hydroacoustic vendors. The most likely utility of DIDSON at Iroquois Dam would be as a secondary means of assessing the performance of a diversion structure. The most important asset of DIDSON for such use is its ability to sample with high resolution at the structure itself. DIDSON would allow fine-scale behavioral monitoring of eels as they approach and encounter the structure. No other sampling methods can provide that kind of information. The imaging capabilities of DIDSON might be useful for optimizing operational configurations of a guidance structure.

9.5 COLLECTION OF TEST SPECIMENS FOR TELEMETRY STUDIES

Section 8 and Appendix C describe a wide range of technologies that have been used to capture eels in many different environments and for a variety of purposes, most commonly for commercial harvest. This section describes the best candidate methods for collecting test specimens that might be used in a large-scale telemetry study in the vicinity of Iroquois Dam. Acoustic telemetry appears to be a viable technology for such a study (Table 9-5). Many of the same gears described in Section 8 are considered to be potentially useful for capture of telemetry subjects, but they would be applied differently than is discussed in that section. NYPA's RFP suggested that a total of 300 downstream migrating eels would be required for a large-scale telemetry study. A study involving that number of test specimens would be very likely to yield a well-defined characterization of the movements of eels within a study area. This section addresses the following specific questions:

- What is the most effective method for collecting outmigrating eels in Lake St. Lawrence for use in a large-scale telemetry study?
- Should any collection methods be ruled out and why?
- Is there a preferred location in the Lake Ontario/Upper St. Lawrence River at which to collect outmigrating eels?
- What effort would be required to collect the necessary number of eels?

- What would such a collection effort be likely to cost??
- Could eels from other river systems be used in a telemetry study on the St. Lawrence River?

This section reviews methods used around the world to capture eels as documented in the literature or in communications with eel researchers and describes the methods that NYPA used and evaluated in its studies in the St. Lawrence River.

9.5.1 Capture Methods for Telemetry Studies

One basis for selecting an optimal method for capturing eels for telemetry studies is to review methods of capture used in other studies. Table 9-6 summarizes capture methods used in documented telemetry studies of the movements of eels. Several general approaches are evident in the literature. In many cases, eels were captured at locations where downstream movements already were restricted (e.g., at a dam) and where eels could be captured by placing nets in some kind of limited bypass outflow (e.g., Durif et al. 2003). The two most common methods of capture were fyke nets and weirs. Both of those methods can be used readily in flows of moderate velocities and are efficient for capturing fish that are actively moving downstream with the flow. In most studies in which eels were collected with these two gears, the eels were captured in relatively small bodies of water, most commonly streams and rivers much smaller than the St. Lawrence River (e.g., Barbin et al. 1998). Even in waters of appropriate size, both gears have several limitations. When flow is very rapid, which is generally when eel migration is at its peak, fyke nets generally must be removed from the water or modified to fish only a portion of the stream channel because of the limitations of systems for anchoring the nets. In addition, heavy loads of leaf debris, also concurrent with high flows and peak eel migration in the fall, often preclude sampling with fyke nets and weirs in smaller rivers and streams (B. Eltz, pers. comm.).

Some information was obtained regarding methods of capturing silver eels from large bodies of water, which would be more comparable to the St. Lawrence River; however, in most of those cases the purpose of capture was not specifically for telemetry studies. Boubée et al. (2008) used fyke nets to capture longfin eels in a large lake/river system in New Zealand to assess the efficacy of the method for use in a trap-and-transport program to move migrating eels past a hydroelectric facility. Lake Manapouri, where the nets were set, is approximately 10 km wide at its widest point and approximately 40 km long; average annual flow through the system is 520 m^3/s. As many as 15, 1-m-diameter fyke nets with 20-m leaders were deployed around the shoreline of Lake Manapouri during the period of silver eel migration, generally from February through May each year. Catches were stable at about three eels every two days throughout the netting period, except in one instance in which 50 silver eels were captured after a major rainfall. Based on tag/recapture information, the authors concluded that the fyke nets were between 9% and 20 % efficient for capturing silver eels.

Table 9-6. Summary of methods used to capture eels for telemetry studies

Author	Location	Method
Aoyama et al. 2002	Fukui River and Tachibana Bay, Tokushima Prefecture, Japan Tone River, Chiba Prefecture, Japan	Eel pots at the mouth of the river Commercial weir
Baras & Jeandrain 1998	River Meuse, Netherlands	Bypass facility
Baras et al. 1998	Awirs Stream, Southern Belgium	DC electrofishing
Barbin et al. 1998	Souadabscook Stream, Penobscot River, Maine, U.S.A.	Weir
Barbin 1998	Penobscot Bay, Maine, U.S.A.	Taken from a common capture site – no further information given
Boubée and Williams 2006	A small hydroelectric plant on the Mokau River, New Zealand	Bypass facility; Large, double-wing fyke net attached to log boom in front of the intake
Boubée et al. 2008 (just submitted to Hydrobiologia)	Te Anau Lake, Manapouri og Lake, and Waiau River, New Zealand	Fyke nets
Breteler et al. 2007	Rhine River, Cologne, Germany Moselle River, Germany	Fyke nets
Brown 2005	Connecticut River, Massachusetts, U.S.A.	Hadley Station downstream bypass sampler; Commercial fishermen using weirs on the Sebasticook River, Maine (when Hadley Station sampler was shut down)
Bruijs et al., 2003	River Meuse, Netherlands	Fyke nets, Anchored stownets, Electrofishing
Cottrill et al. 2006	Quebec City, Canada	Eels captured at eel weirs were purchased from commercial fisherman
Desrochers & Fleury 2005	St. Lawrence River Estuary, Canada	Eels captured at eel weirs were purchased from commercial fisherman
Durif et al. 2003	EDF Hydroelectric Power Station, Halsou, France	Trap at outlet of spillway
Dutil et al. 1988	Calumet River, France	Fyke nets
Eltz 2006	Rainbow Dam, Farmington River, Windsor, Connecticut, U.S.A.	Double-wing fyke net (21-m-long wings and 4-mm. cod-end mesh) fished in tributaries of the Farmington River during rain or periods of high flow; Unbaited, single-wing fyke nets placed along the shore of the Rainbow Reservoir; Rainbow Dam bypass sampler; Hadley Station bypass sampler
EPRI 2007	Hadley & Turners Falls, Connecticut River, Massachusetts, U.S.A	Hadley Station bypass sampler, Cabot Station bypass sampler
Gosset et al. 2005	Halsou Hydroelectric Plant, Nive River, France	Bypass facility at hydroelectric plant
Haro and Castro-Santos 1997	Cabot Station, Connecticut River, Massachusetts, U.S.A	Cabot Station bypass sampler
Haro and Castro-Santos 1995	Cabot Station, Connecticut River, U.S.A.	Cabot Station bypass sampler
Helfman et al. 1983	Friday Cap Creek, Georgia, U.S.A.	Baited eel traps

Table 9-6. (Continued)

Author	Location	Method
Jellyman et al.1996	Lake Ellesmere, South Island, New Zealand	Commercial eel fishers (gear not known)
Jellyman & Tsukamoto 2002	Lake Ellesmere, South Island, New Zealand	Fyke nets
Jellyman and Sykes 2003	South Branch and Cust River, New Zealand	Electrofishing
Lamothe et al. 2000	Hammond Pond, Maine, U.S.A.	Wire-mesh traps baited with earthworms
McCleave & Arnold 1999	Rivers Orwell & Stour Rivers & Estuaries Yorshire, United Kingdom	Baited traps Seines and trawls Draining pond
McGrath et al. 2003b	St. Lawrence River, Quebec City Quebec	Commercial eel fishery, Stownets, Hoop nets, Electrofishing
Pederson (unpublished data)	Not available	Fyke netting Commercial eel trap
Strickland 2002	South Fork Piney River, South Fork Tye River, and Shoe Creek, Virginia, U.S.A.	Electrofishing
Thibault et al. 2006	St. Jean River, Quebec, Canada	Wheel trap and counting semi-barrier, Hoop nets
Watene et al. 2003	Lake Rotorangi, New Zealand	Fyke nets by commercial fishermen
Westin & Nyman 1979	Island of Askö, Stockholm, Sweden	Commercial eel fishery; gear not known
Westin 1998	Lake Fardume, Sweden	Trap at lake outlet
Winter et al. 2006	River Meuse at Oh6 en Laak, Netherlands	Fyke nets, by a commercial fisherman
Winter et al. 2005	MIGROMAT© tank, River Meuse, Netherlands	Fyke nets

Commercial fisheries on the Baltic Sea employ large nets set from the shore at headlands and are reported to take several tons of silver eels per net during peak migration periods (J. Boubée, pers. comm., 2007). No information about the dimensions and specifications of this kind of fishing gear was available. On the lower portion of the estuarine Potomac River in Maryland, harvest of eels as a by-catch in pound nets peaked in November each year over a 20-year period, albeit at very low levels (A.C. Carpenter, Potomac River Fisheries Commission, pers. comm. 2007). This fall catch is assumed to be composed of migratory silver eels. Pound netters sometimes target eels by fishing smaller mesh in "swash" nets (i.e., nets that run from the shore to several hundred feet off shore). Such nets are considered to be "boys' training nets," which accounts for PRFC having exempted them from the 1.5-inch minimum mesh size requirement for pound nets set within 1,000 feet of the shore. Many of the estuarine commercial fisheries for silver eels throughout the world employ fyke nets with wings or leads or somewhat similar net weirs, including the fall fisheries in the tidal portion of the St. Lawrence River (Section 8). Such commercial fisheries served as the source of silver eels used in many telemetry studies (Table 9-6).

No obvious relationship was apparent between the gear used to capture eels for telemetry studies and the behavior of tagged eels after they were released (Section 9.6); as a result, no conclusions can be drawn regarding whether a particular method of capture does or does not affect subsequent behavior. The relationship between method of capture and subsequent behavior is also complicated by the fact that many factors involved with, and subsequent to, capture could affect the physical condition and behavior of captured eels (e.g., frequency of checking nets, holding conditions, holding times, procedures for implanting tags). The relevance of capture methods used in the reviewed studies to methods that might be used in the St. Lawrence River is also marginal. In most cases, silver eels were captured during typical episodic fall migrations, when eels generally move in large numbers. This contrasts markedly with the more continuous summer migration of relatively small numbers of eels in the upper St. Lawrence River (McGrath et al. 2003a).

9.5.2 NYPA's Studies of Methods for Capturing Eels

As one of the first steps in designing and implementing telemetry studies of eel migration in the St. Lawrence River, NYPA evaluated the potential efficacy of nearly all the capture methods employed in other telemetry work with eels. As was described in Section 1.3, NYPA's 1998 studies evaluated the efficacy of electrofishing, eel pots, and hoopnetting as eel capture methods in the St. Lawrence River. Work was conducted throughout the entire reach of Lake St. Lawrence, upstream of Moses-Saunders Power Dam. The study area was broken down into eight sampling strata, and all three capture methods were tested in each stratum. Electrofishing resulted in the largest catch-per-unit-effort and the greatest total number of eels; eel pots produced the smallest catches. Most of the eels captured using all three methods were non-migratory yellow eels, which were of no value for the intended telemetry work. Electrofishing and hoop netting produced substantial numbers of eels and appeared to merit further investigation (McGrath et al. 2003b).

In 1999, NYPA explored the use of a large, mid-water trawl to capture migrating eels in the St. Lawrence. NYPA selected the large trawl for testing because researchers believed outmigrating eels to be moving downstream in the main part of the river channel in the mid to upper portions of the water column where they were inaccessible to the gears studied earlier (McGrath et al. 2003c). NYPA used a 90-m x 7.0-m x 33.5-m, modified French midwater trawl. Tows were made in two different configurations, one using a single vessel, and a second using two vessels. Sampling was conducted at night during the period when maximum eel migration was anticipated to occur in the St. Lawrence River. A total of 254 tows were made from June 26th to August 6th, and 34 American eels were captured. Trawling captured mature, migratory eels in good physical condition. One sampling location produced a catch rate sufficient to be feasible for collecting enough eels for a large telemetry study (0.353 eels/10-minute tow); however, several factors suggested that trawling would not be the optimal method for capturing eels for telemetry studies. Eels collected in trawls probably experienced considerable stress because the net had to be towed at high velocities (approximately 2 m/s), and eels were pressed against the net for some time. The requirement for large deep areas in which to maneuver the towing vessel and prevent the net from snagging limited where trawling could be performed.

Also, the intermittent nature of sampling (i.e., periods of trawling interspersed with time to deploy and retrieve the net) limited the soak time of the net and, thus, reduced the cost-effectiveness of the method. These limitations led NYPA to investigate alternative sampling methods that could produce similar catch rates.

Work continued in 2001, with further study of electrofishing and hoop nets, and the addition of anchored stownets. Advantages of the stownets included more continuous sampling and greater efficiency than trawling, the ability to check the cod end while the main body continued to fish, and slower sampling velocities (approximately 0.6 m/s) that reduced stress. Stownets required a robust system of anchors and buoys and a large vessel from which to deploy and tend them. Although stownets tended to get clogged with floating debris, primarily vegetation, researchers learned how to alleviate that problem by modifying the placement of the net. Two initial deployment locations were selected in areas of high flow because literature suggested that outmigrating eels tend to move in the portions of the river in which velocities are greatest. In one deployment (South Sheek Island), the net was deployed with wings extending from each side of the net. Electrofishing was conducted at night in a variety of habitats but was concentrated in "shallow" areas along the channel. Hoop nets were the same as those tested in 1999. Sampling locations were at depths of 5.8 m to 12.2 m and at velocities of 0.2 to 0.5 m/sec near the main channel. Table 9-7 summarizes the results of the 2001 program.

Table 9-7. Results of NYPA's 2001 study of methods of capturing eels (Source: NYPA 2001b)

	Electrofishing	**Hoop Netting**	**Stownetting (overall)**	**Stownetting with Wings (South Sheek only)**
Sample Days	13	14	16	4
Hours of Effort	73.5	3,336	212	67
Standard Effort	5.6	240	16	16
Total Eels Collected	22	12	29	13
Migratory Eels	13	3	29	13
Migrants/Standard Effort	1.01	0.22	2.19	3.1

Electrofishing and stownetting yielded the greatest numbers of migratory eels and the largest catches per standard unit of effort. Although the stownet with wings had a high catch per unit effort, the wings collected substantial debris and required extensive tending. Catch efficiency of a gear is an important consideration when capturing eels that will be the subjects of telemetry studies; nevertheless, other factors can be equally or even more important. Captured eels must be in good health to avoid bias in the telemetry study, and electrofishing has been documented to injure captured fish (Reynolds and Holliman 2004; Holliman and Reynolds 2002; Reynolds and Kolz 1995). NYPA examined eels captured using all three of the methods it studied (i.e., electrofishing, hoop netting, stownetting) for damage: 52% (11 of 21) of the mature eels taken by electrofishing had some kind of vertebral injury; whereas, only 10% of eels caught in hoop nets (1 of 10) and 20% (2 of 10) of those caught in stownets were injured. Bruijs et al. (2003), however, found electrofishing to be the preferred method for collecting undamaged eels during their work in the Meuse River, Netherlands. Those researchers emptied their fyke nets and anchored stownets only every 3 days; consequently, many of the captured eels were damaged or stressed due to substantial degradation of their slime layer. Bruijs et al. (2003) reported that eels captured by electrofishing appeared to be undamaged and were more likely to survive after being tagged than eels captured in the net gear. Unlike NYPA, Bruijs et al. (2003) did not report having X-rayed captured eels; therefore, their specimens could have incurred undetected internal injuries that did not affect their behavior immediately. Based on the low efficiency of hoop nets for capturing migratory eels and the documented potential of electro-shocking to injure eels, NYPA concluded that stownets are the optimal gear for collecting eels in the St. Lawrence River for use in telemetry studies.

NYPA also used stownets in its 2002 proof-of-concept study of a light barrier for diverting eels at Iroquois Dam because of their demonstrated effectiveness in the 2001 gear comparison studies. Three nets were arranged across the river upstream of the dam and downstream of the experimental light barrier. The nets were of the same design as those used in the 2001 gear studies. Together, the 3 nets captured 159 eels during the study period (i.e., 536 hours over 28 nights).

9.5.3 Relevance of Findings for Conducting Telemetry Studies in the St. Lawrence River at Iroquois Dam

Silver eels used in most of the documented telemetry studies were collected either in small streams and rivers using standard sampling gear (e.g., fyke nets) or at pre-existing optimal sampling locations (e.g., bypasses at dams), or were purchased from commercial fishermen, who typically used weirs or fyke nets. Many of the sampling methods used for those studies (e.g., weirs extending across an entire stream, fyke nets with wings across entire streams, nets positioned to capture all organisms coming through a bypass) cannot be employed in the St. Lawrence River because of the size and depth of the river. NYPA evaluated the same kinds of gear used in the documented studies (i.e., electrofishing, hoop nets, pots) and found them to be inappropriate or ineffective for use in the St. Lawrence River. Although other studies used multiple gears to capture eels for telemetry (e.g., fyke nets and anchored stownets; Bruijs 2007), no program other than NYPA's evaluated a variety of sampling gears for their effectiveness at capturing eels and their relative effects on the condition of the captured eels.

One approach used in several of the telemetry studies summarized in Table 9-5 was to collect outmigrating eels from upstream tributaries. Several small tributaries drain into Lake Ontario and into the St. Lawrence River upstream of Moses-Saunders Power Dam might afford easier opportunities to capture eels than the main stem of the river; however, virtually no eels have been found during recent surveys of small tributaries in New York (R. Klindt and S. Lapan, NYDEC, pers. comm.), which precludes this approach. In addition, eel migration through the St. Lawrence appears to be distributed throughout the entire summer, unlike the episodic migrations typical of the smaller rivers and streams that are the most common source of eels used in telemetry studies; consequently, even if eels were present in tributaries, the timing of their movement into the main stem to begin their downstream migration and their stage of transformation would be uncertain.

Based primarily on the results of NYPA's work, both mid-water trawling and anchored stownets appear to be effective means of capturing outmigrating eels in the St. Lawrence River for use in telemetry studies. One advantage of mid-water trawling over anchored stownets is the ability to sample in multiple locations easily. The relatively narrow configuration of the St. Lawrence River in the vicinity of Iroquois Dam may concentrate eels, which could result in higher catch rates than those NYPA attained in its tests of mid-water trawling in Lake St. Lawrence; however, the shallow water and jagged bottom topography in the vicinity of Iroquois Dam probably precludes extensive use of midwater trawling there and at many other locations. In addition, the high towing speed required for that method creates greater potential for injuring captured eels than would be the case with anchored stownets. Anchored stownets fish continuously while they are deployed and capture eels at a slower water velocity. Given the advantages of the stownets described earlier, they appear to be the most effective gear for use in collecting eels for telemetry studies in the St. Lawrence River.

9.5.3.1 Potential Capture Locations in the Upper St. Lawrence River

The largest numbers of eels captured during NYPA's 1999 mid-water trawl study were taken at two locations along the north side of Sheek Island (Figure 9-1). One of those was subsequently a site for testing an anchored stownet because it is an area of high velocity that is likely to be a major route for outmigrating eels and has depths appropriate for using stownets. The stownets that NYPA used in its gear-comparison studies had a net-opening-height of 6 m. Appropriate depth for deployment was considered to be within the range of 7 m to 12 m. Deploying the stownets in deeper waters would result in sampling a decreasing proportion of the water column and potentially missing a greater proportion of the eels passing downstream. Figure 9-1 illustrates locations that are within the preferred depth range in a river reach extending from 8 km upstream of Iroquois Dam to downstream of Moses-Saunders Power Dam. NYPA's telemetry studies illustrated that most eels move downstream in the main channel, where velocities are likely to be the greatest; therefore, the locations at which depths are appropriate for stownetting (i.e., within the main river channel just upstream of Iroquois Dam) probably would be optimal locations for capturing silver eels. Site-specific characteristics would determine the feasibility of deploying stownets at any given location, including substrate characteristics (i.e., for anchoring or mooring nets) and accessibility for boats (i.e. for deploying and monitoring nets).

9.5.3.2 Sampling Effort Required to Collect Sufficient Eels for Study

A relatively large number of eels must be tracked to obtain enough data to characterize patterns of eel movement rigorously in a telemetry study. In NYPA's 2000 telemetry study, only 41% (62 of 152) of tagged eels passed Moses-Saunders Power Dam. Assuming a 40% rate

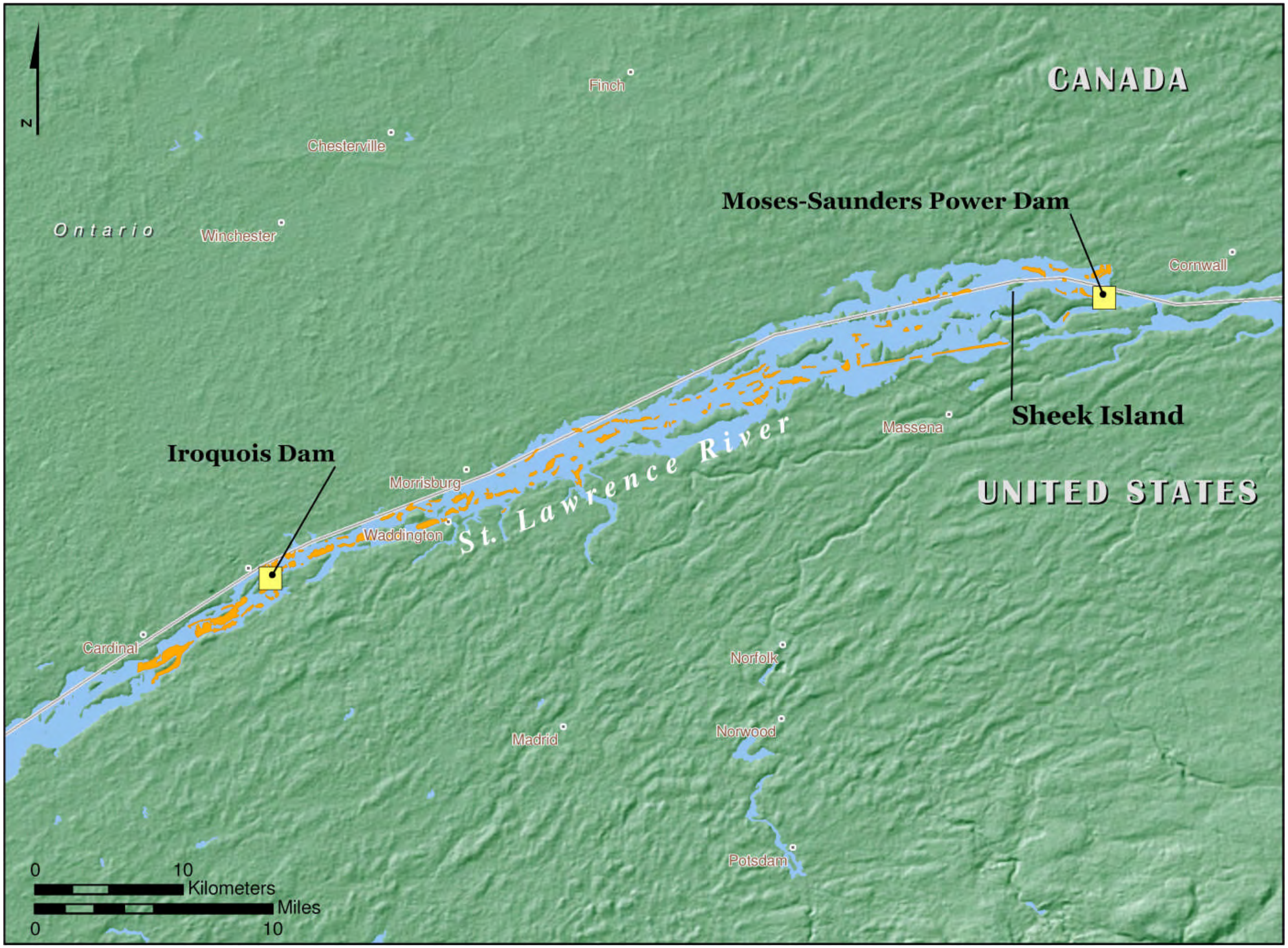

Figure 9-1. Orange areas indicate locations within the upper St. Lawrence River with depths between 7 m and 12 m that are suitable for deploying stownets with a mouth opening of 6 m. Yellow boxes indicate the locations of Iroquois Dam and Moses-Saunders Power Dam.

of tracking success, 300 tagged migratory eels would be expected to yield 120 records, which is likely to be sufficient to characterize representative movement patterns near the dam. Table 9-8 summarizes the catch-per-unit effort (CPUE) obtained in NYPA's gear studies in the St. Lawrence River. Cost information was available for trawls and stownets only. If the future density of migratory eels in the St. Lawrence River is assumed to be the same as densities observed during NYPA's studies (1999-2002), the CPUE data from NYPA's studies provide a reasonable basis for a first-order estimate of the sampling effort required to obtain 300 eels. The hours sampled during each of the studies and the CPUE based on hours sampled illustrate the relative catch efficiency of the four different programs (Table 9-8); however, the number of sampling nights would be a more meaningful unit of effort for estimating the cost of a collection program. In the light barrier study, 3 stownets were deployed for a total of 28 sampling nights and captured 159 eels (5.7 eels/sampling night). Based on this catch-per-night ratio, fishing 3 nets for approximately 53 nights would yield a catch of 300 migratory eels at Iroquois Dam. Given that the migration period in the St. Lawrence is roughly from July through September (about 90 days; McGrath et al. 2003b), three nets would have to be deployed continuously during approximately 60% of the migration period.

Table 9-8. NYPA's effort and cost to collect eels from 1999 through 2002 (data provided by S. Ault, Kleinschmidt Associates)

	1999 Experimental Trawling	**2000 Intensive Trawling**	**2001 Stownetting**	**2002 Stownetting (Light Study)**
Number of eels	32	155	52	159
Hours sampled	42.3	342	212	536
CPUE	1.24	0.45	0.25	0.30
% of river discharge Sampled	1.86	1.12	0.54	2.13
Number of sampling nights	Not available	73	Not available	28
Cost of program	$193,000	$165,000	$140,000	$295,000

The assumption that eel density in the future will be the same as it was during the studies summarized in Table 9-7 clearly is not valid. NYPA's tailrace monitoring program at Moses-Saunders Power Dam showed that the abundance of downstream migrating eels in 2007 was half the abundance observed in similar studies conducted during 2001 and 2002 (NYPA 2007). The expected future abundance of downstream migrating eels can be estimated roughly using findings from several other studies, albeit with substantial uncertainty. All eels upstream of Moses-Saunders Power Dam have had to pass over the dam via eel ladders. The number of eels moving through the eel ladders each year is monitored. The age distribution of eels that move over the dam also has been monitored in some years by sampling the upstream migrants. Eels that pass over the dam remain in the St. Lawrence River or Lake Ontario until they reach sexual maturity and migrate downstream. If the average age at sexual maturity and the average age at which eels passed over the dam are known, we can predict how many years after moving over the dam a group of eels may begin migrating downstream. Thus, it is possible to estimate the relative abundance of downstream migrants in any given year in the future based on the relative abundance of eels passing through the eel ladders in some prior years.

Table 9-9 presents the numbers and average size of eels that passed upstream over Moses-Saunders Power Dam from 1974 to 2007. Those data illustrate that the number of eels that moved upstream from the late 1990s through the early 2000s was on the order of 1% or 2% of the maximum numbers that passed annually during the early 1980s. The age of eels ascending the ladder through the 1980s was on the order of 6 years but increased markedly and remained high through the 1990s; large, older eels were dominant until about 2005, when the size, and presumably the age, of upstream migrants began a substantial decline (OMNR 2007). Casselman (2008) evaluated the age composition of eels ascending the R. H. Saunders eel ladder from 2003 to 2007 (Figure 9-2). Upstream migrating eels ranged in age from 3 to 19 years over this recent 5-year period; the broadest age distributions and the highest modal ages (10 and 9 years, respectively) occurred in the 2003 and 2004 samples. Note that the mean sizes of upstream migrants in 2003 and 2004 (Table 9-9) were similar to the mean size (and probably age) of upstream migrants from the mid-1990s and substantially greater than the size and age of the eels that moved upstream during the early 1980s.

Although the age of eels leaving Lake Ontario and Lake Champlain has been documented to be about 13 years (Hurley 1972; Facey and LaBar 1981), eels captured in the upper St. Lawrence River most recently were shown to be about 21 years old (G. Verreault, pers. com., November 2007). Stanley and Pope (2008) indicated that outmigrating eels from the St. Lawrence River are approximately 15 to 25 years old. No explanation for this change in age-at-outmigration over several decades has been suggested yet, but it appears appropriate to use the most recent information to represent the age-at-outmigration in the near future (i.e., assume average 21 years old).

Assuming that outmigrating eels captured in NYPA's studies in 2000 were 21 years old, based on Verreault's data, they would have been spawned in the 1979 year-class. If those eels averaged 6 years of age when they passed upstream over Moses-Saunders Power Dam, they would have passed in 1985. Taking into account that the eels ascending the ladder in any year exhibit a range of ages and that the ages of eels outmigrating also exhibit a range, the average numbers of eels passing over the ladder over several years (i.e., 1984, 1985, and 1986) may be representative of the abundance of eels that migrated downstream in 2000. The average number of eels that moved upstream during those 3 years was 604,290 (Table 9-9). If we assume that studies will be done in 2010 and that outmigrating eels captured in those studies will be 21 years old, those eels would have been spawned in the 1989 year-class. If they ascended the ladder at age 6, they would have passed upstream over the dam in 1995. Casselman's (2008) estimate of the age of more recent upstream migrants (i.e., 10 years) would appear to be more appropriate to apply to the 1988 year-class, such that they would have passed upstream over the dam in 1999. The average numbers of eels that passed upstream from 1998 through 2004 was 2,958 (Table 9-9), which is less than 1% of the average number that passed upstream from 1984 through 1986. This figure is consistent with the change in eel densities documented in NYPA's tailrace monitoring program. These ratios suggest that the CPUE of sampling programs conducted in 2010 and later would be less than 1% of the CPUE during NYPA's studies around the year 2000. The effort required to collect 300 eels at this lower CPUE, therefore, would be more than 100 times the effort calculated using the estimates of CPUE presented in Table 9-7.

Table 9-9. Total count and mean length of juvenile eels ascending ladders at Moses-Saunders Power Dam from 1974 to 2007 (Source: Verreault et al. 2008)

Year	Saunders ladder		Moses ladder		Moses-Saunders
	Total Count (n)	Mean Length (mm)	Total Count (n)	Mean Length (mm)	Total Count (n)
2007	2,860	386.6	11,344	400.9	14,204
2006	8,960	383.7	8,184	382.8	17,144
2005	14,891	413.6			14,891
2004	11,325	456.0			11,325
2003	2,876	479.3			2,876
2002	2,663	469.2			2,663
2001	944	454.7			944
2000	2,895	457.1			2,895
1999	1,860	457.9			1,860
1998	3,432	471.6			3,432
1997	6,117	470.9			6,117
1996					
1995	35,076				35,076
1994	163,518	492.8			163,518
1993	8,289	414.3			8,289
1992	11,534				11,534
1991	40,241	433.6			40,241
1990	121,907	429.8			121,907
1989	258,622	458.2			258,622
1988	213,187	404.0			213,187
1987	465,364	409.8			465,364
1986	23,070	406.1			23,070
1985	935,320	404.3			935,320
1984	647,480	382.4			647,480
1983	1,313,570	367.0			1,313,570
1982	1,013,848	374.6			1,013,848
1981	748,724	362.7			748,724
1980	253,758	373.5			253,758
1979	869,135				869,135
1978	794,600	318.9			794,600
1977	966,800	367.8			966,800
1976	659,478	347.9			659,478
1975	936,128	347.0			936,128
1974	130,000				130,000

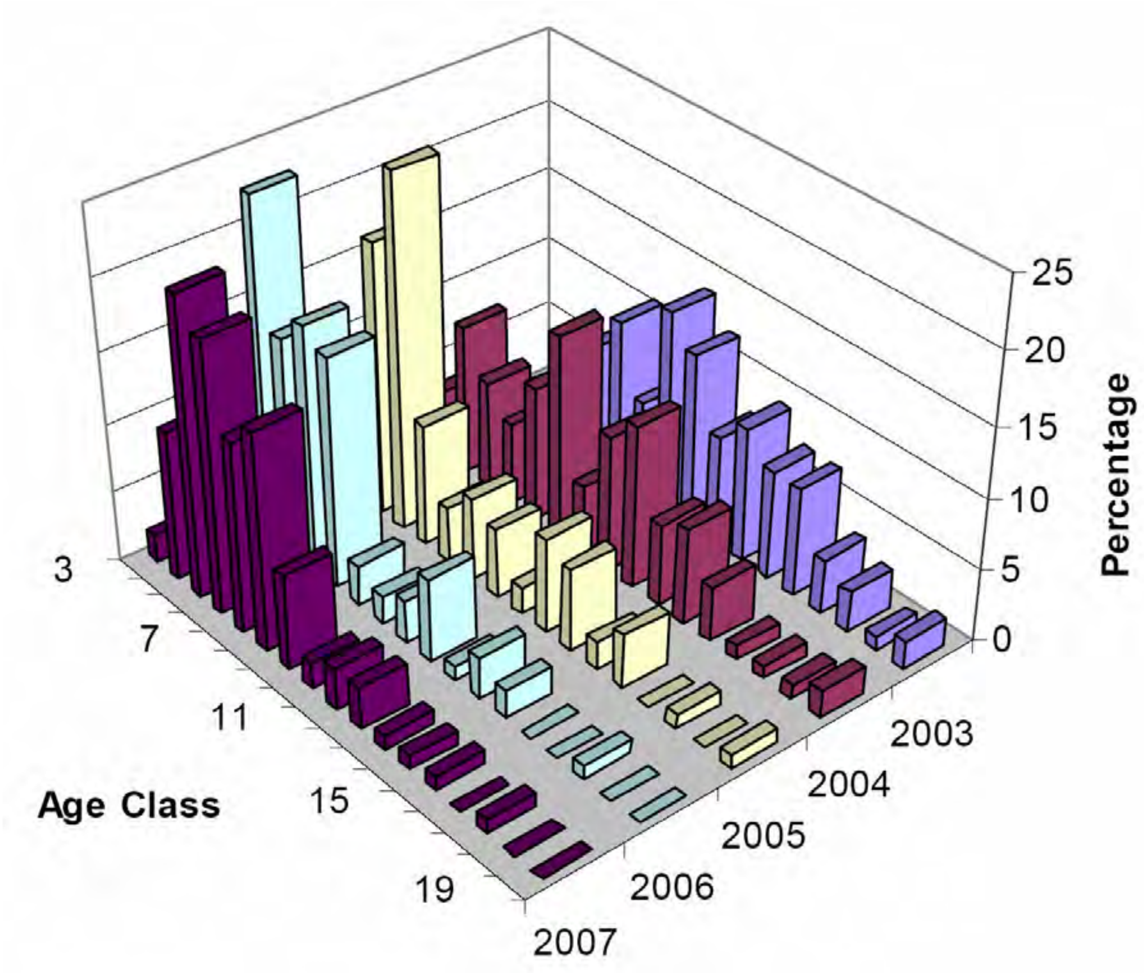

Figure 9-2. Age class distribution observed in eels ascending the Saunders eel ladder (Source: Casselman 2008)

The only means of increasing sampling effort would be to increase the number of nets deployed, to increase the frequency of collection, or both. Considering first an increase in the number of nets deployed, NYPA estimated that its three stownets (during the light diversion study) sampled about 2% of the discharge of the river, presumably over the course of any single sampling night (K. McGrath, NYPA, pers. comm. 2007). Increasing the number of nets deployed to collect eels from the entire discharge of the river (which is not possible), would only increase effort by a factor of 50, not the factor of 100 that would appear necessary. Considering an increase in the frequency of sampling, we estimated earlier that if eels were as abundant at Iroquois Dam now as they were in 2000, sampling with three stow nets would have to continue for approximately 53 days (i.e., 60% of the entire migration period) to yield a catch of 300 migratory eels). Given that the abundance of outmigrating eels over the next four to five years is expected to be less than 1% of the abundance during NYPA's 2000 studies, extending sampling to 100% of the migration period would not approach doubling the sampling effort. Clearly, capturing 300 eels from the St. Lawrence River at Iroquois Dam will be impossible at any realistic level of effort.

9.5.3.3 Estimated Cost to Collect 300 Eels

Table 9-8 shows the costs for four of NYPA's eel sampling programs. Several factors that influenced those costs would not pertain to future efforts and must be accounted for in estimating the potential cost of a future program (S. Ault, Kleinschmidt Associates, pers. comm.) For example, the intensive trawling effort in 2000 was relatively inexpensive because of the ready availability of the boat required for that work. When demand for boat services increased elsewhere (i.e., Lake Erie basin), boat service could not be acquired for the same cost. The 2002 stownetting effort was more expensive because stownetting requires more labor than trawling. The trawling vessel had a crew of three, but the tender for stownetting required a crew of four to six. Implementing a large-scale stownetting operation probably would require a crew of similar size, resulting in similar costs for each night of sampling.

The dominant factor in estimating the cost of future efforts is the expected number of nights of sampling because the total cost of sampling is determined primarily by the costs for the boat and personnel, which are incurred on a daily basis. Information about the number of nights that NYPA sampled during its gear studies was available only for the 2000 and 2002 efforts. Dividing the number of eels caught by the number of nights of intensive trawling provides a CPUE of 2.12 eels per night. Dividing the total cost of the trawling program by the number of nights sampled provides a cost of $2,260 per night. If we assumed that eel density in the future would be the same as in 2000, 143 nights of sampling would be required to capture 300 eels. Given that the duration of eel migration in the St. Lawrence River is only about 90 days, the only way to achieve that level of sampling would be to employ two or more vessels. If the cost per night of trawling were the same as in 2000, the total cost to capture 300 eels using the midwater trawl would be about $321,000. Given that the costs incurred in 2000 are believed to have been below market rate at that time, that eels are expected to be significantly less abundant in the St. Lawrence River in the future, and expected increases in fuel costs and inflation, the total cost of a trawling program to collect 300 eels conducted during late 2000s would be substantially greater.

CPUE for the 2002 stownet study was 5.68 eels per night, at a cost of $10,536 per night. Assuming that eel density in the future is the same as in 2002, 53 nights of sampling using three nets (as in the 2002 study) would be required to capture 300 eels. If the cost per night of sampling were the same as in 2002, the total cost to capture 300 eels would be $558,408. Again, given increasing fuel costs and inflation and the fact that eels are expected to be significantly less abundant in the St. Lawrence River in the future, the future cost of a stownetting effort to capture 300 eels would be substantially greater. Estimates of the future cost of trawling and stownetting both assume that boats of appropriate size and capability would be available at rates similar to those paid during the earlier studies. Neither of these requirements is likely to be met, which decreases the feasibility of implementing a collection program of the scope described here. If the abundance of eels in the future is only 1 percent of the abundance during the past NYPA studies, collection programs would likely be logistically impossible, and, if possible, costs would be orders of magnitude greater than the estimates presented.

9.5.3.4 Using Silver Eels from other River Systems in Telemetry Studies in the St. Lawrence River

The logistical challenges and expense of attempting to capture a sufficient number of outmigrating eels in the St. Lawrence River for use in large-scale telemetry studies are formidable. Using eels captured from other places where easier, less expensive methods can be effective for collecting eels (Table 9-5) is an appealing prospect; however, using eels from other river systems to try to examine the behavior of eels in the St. Lawrence River could be misleading. NYPA used 10 silver eels purchased from commercial fishermen operating in the St. Lawrence estuary as subjects in its 1999 telemetry study. McGrath et al. (2003c) noted significant uncertainty about whether the behavior of those eels accurately represented the behavior of eels that would be moving naturally through waters upstream of Moses-Saunders Power Dam. The 10 fish from the estuary, which is 300 km downstream of the study area, were more sexually mature than eels that normally would be present in the study area. Those eels had moved into a euryhaline environment and probably had experienced some associated physiological changes prior to being captured by the commercial fisherman. Also, those eels had been subjected to capture, holding and transportation, all of which may affect behavior (Section 9.6).

Most eels used in other telemetry studies were captured in small rivers and streams during typical fall episodic migrations. Those episodic migrations result in large catches of eels within short periods, which make achieving the appropriate sample size for a study relatively easy. In the St. Lawrence River, such episodic fall migrations occur only in the lower, estuarine portion of the river (Verreault et al. 2003). Eels participating in those migrations already have moved through the upstream reaches of the river, including Lake St. Lawrence, during the summer, generally sometime between July and September (McGrath et al. 2003a). The behavior of the fall migrants probably differs from the behavior of “pre-staging” eels moving downstream during the summer. In order to eliminate the potential bias of any such behavioral differences from a telemetry study, eels from another river system collected for use in the vicinity of Iroquois Dam would have to be captured at the same stage of development and within the same mode of migratory behavior as eels that would be moving naturally through the subject portion of the St. Lawrence River. That may be impossible for several reasons. In general, behavior at a given time probably would be similar only in systems that are located at similar distances from the spawning grounds. This review of studies in the United States revealed no studies other than those in the St. Lawrence River in which outmigrating eels were captured during the summer and used in telemetry studies; consequently, no potential source of eels in the appropriate stage of development could be readily identified.

The specific objectives of future telemetry studies in the vicinity of Iroquois Dam have not been defined clearly and might determine the significance of behavior differences between study subjects collected from another river system and outmigrating eels in the St. Lawrence River in the vicinity of Iroquois Dam. Obtaining site-specific information about the behavior of eels as they approach and pass Iroquois Dam could contribute to designing the most efficient and cost-effective diversion or guidance technology for use there. The findings of NYPA's extensive telemetry work suggest that eels are likely to use the entire width and depth of the river as they move past Iroquois Dam; however, observations of any particular preferences during passage might contribute to optimizing the design of a diversion structure. If eels taken from another system and at a different stage of development respond to environmental cues in the same manner as eels that would be moving past Iroquois Dam naturally, useful information could be obtained from a large-scale telemetry study using eels that are much more readily available and less costly to obtain than native eels. A controlled study using both native eels and eels from another river system would be required to determine if the assumption of similar behavior is valid. The same logistical challenges would pertain to collecting eels from the St. Lawrence River for such a behavior-comparison study as described for collecting native eels for a telemetry study; whether sufficient eels could be captured with a feasible level of effort to produce reliable study findings cannot be determined.

9.6 EFFECTS OF HANDLING ON BEHAVIOR OF TAGGED EELS IN TELEMETRY STUDIES

The potential effect of collection, handling, anesthesia, surgery, recovery, and release on the behavior of subjects typically is a concern in all animal telemetry studies. In fishes, telemetry techniques usually involve one or more steps that are physiologically or neurologically stressful, require some degree of invasive surgery, and create the presence of a solid foreign body outside the fish's body or within the coelomic cavity. The possibility of infection, intrusion of water into the body cavity through wounds, and the size of the tag in relation to the mass of the fish also are sources of concern.

Radio-tagged eels used in behavioral studies may not express "true" behaviors because of the effects of handling and tagging. Eels collected from nets, bypass samplers, or electrofishing (e.g., Reynolds and Holliman 2004) occasionally exhibit abnormal behaviors or injuries resulting from the stress of capture (e.g., lethargy, "spinning" about the body axis, hindered swimming ability, apparent broken vertebrae, contusions), and the viability of these individuals for use in telemetry studies is questionable. Neilsen (1988) indicated that eels may be particularly sensitive to certain kinds of marking techniques (e.g., external marks and attached tags). No "standard" surgical technique for implanting transmitters has been developed, so anesthetics and techniques vary widely. Baras and Jeandrain (1998) tested several techniques in the laboratory, and many eel researchers seem to have accepted a modified version of their preferred technique as the technique of choice, as illustrated by frequent citations of their paper in recent publications. Cotrill et al. (2006) noted that neither the presence of telemetry transmitters nor the method of attachment affected the swimming capacity of silver American eels; however, only tags implanted into the peritoneal cavity exhibited good long-term retention. Canadian researchers who studied the effects of surgery and implantation of telemetry tags on the survival, growth and swimming performance of small eels recommended that tags should not exceed a total-body-weight ratio (TBWR) of 2% because tags of that size or smaller do not appear to influence eels' swimming capacity or growth (I. Thibault, Laval University, Quebec, unpublished data). The cryptic behavior of eels often belies any complications of handling or surgery; therefore, determining the viability of tagged eels just before release is often difficult.

Data from some studies suggest that the behavior of tagged eels may not be representative of normal downstream migratory behavior. Some tagged eels cease migratory movements after release or exhibit unexpected behaviors (e.g., swimming upstream) or "learned" behaviors (e.g., if a fish is released into a river reach from which it was previously captured). The following sections summarize relevant observations.

9.6.1 NYPA's Telemetry Studies

NYPA's studies of the feasibility of using telemetry to track the movements of eels at Moses-Saunders Power Dam (NYPA 2007) initially employed a variety of kinds of gears and tags but ultimately focused on high-frequency acoustic technology with three-dimensional positioning capability. These studies necessitated development of a relatively large, custom acoustic tag (ca. 20 mm in diameter by 75 mm long) for trials in 1999 and a slightly smaller internally implanted tag (17 mm in diameter by 75 mm long) for subsequent trials. Although these tags seem relatively large, in most cases they were within the recommended 2% TBWR (I. Thibault, Laval University, Quebec, unpublished data). Initial post-release behaviors of tagged eels were variable. During 2000, only about half of the released eels (62 of 152) passed through the dam, and many eels remained stationary, moved upriver, or were lost. Eels that moved downstream did so in a directed fashion, and some individuals moved faster than the average river water velocity, suggesting active, directed swimming, at variable depths. Based on observations of free-swimming eels at an experimental light array near the study site, swimming at multiple depths (often close to the surface) is a normal behavior of unhandled migrating eels in this system.

Eels that reached the dam displayed hesitation and searching behaviors noted in similar studies of the downstream passage of eels (Brown 2005; Durif et al. 2003), suggesting active searching and response to local hydraulic conditions. Several migrating eels were detected at points downstream of Moses-Saunders Power Dam. The wide range of metamorphic states of the outmigrating eels collected in the studies contributed to some concern that the degree of metamorphosis could have influenced migratory motivation and behaviors, but the relationship between degree of silvering and behavior did not appear to be statistically significant.

9.6.2 Laboratory Studies

Few, if any, studies have assessed the effects of handling or attaching/implanting tags on the downstream migratory behavior of eels with adequate controls (i.e., unhandled, untagged eels). A few studies, however, have investigated the effects of tagging on post-surgery behaviors in captive eels.

Haro and Castro-Santos (1995) noted that in a study of eels held in tanks, eels with surgically implanted tags in their peritoneal cavities were sluggish and less responsive than externally tagged or untagged control eels for several days after tagging. Nevertheless, most of the tagged eels embarked on extensive downstream migratory movements within several days of release.

In a study comparing the activity of eels marked with small PIT tags (TROVAN, ca, 2 mm in diameter, 12 mm long) or large, dummy tags (NEDAP TRAIL, 14 mm diameter, 63 mm long) and held in a chamber designed to monitor locomotor activity, Winter et al. (2005) found that individual activity among eels with the large tag was 38% less than activity among the small-tag control group, indicating at least some effect of implanting larger transponders. There was no difference between groups in the timing of seasonal or diurnal activity. Unfortunately, the authors did not include a sham-implanted group, so the differences in activity cannot be attributed specifically to either the surgery/wound or to the presence of the implanted tag.

Breteler et al. (2007) marked eels with dye for a mark-recapture study to estimate population that was conducted simultaneously with a telemetry study, but the authors did not report comparative data on migration behaviors between dye-marked-only and dye-marked and tagged eels. One reason for the failure to report comparative data may have been that the number of recaptures of dye-marked eels (and delay in reporting of captures) was too small for valid statistical comparisons.

9.6.3 Field Studies

Several telemetry studies of migrating eels have been conducted recently, mostly with respect to passage at hydroelectric dams. These studies usually assume tagging to be relatively benign; consequently, they typically do not include controls to account for the potential effects of tagging (e.g., assessment of movements of unmarked eels). Table 9-10 summarizes techniques and general behavioral results of the more comprehensive telemetry studies described in the next three sections. The table also includes data on capture method, size of eels, relative size of tags (as a percent of the subject’s body weight) and general post-tagging behaviors. While the studies do not address the effects of handling on behavior, comparisons among the behaviors observed can contribute to inferences regarding the potential magnitude of handling effects on behavior.

9.6.3.1 Outmigrating European eels

Durif et al. (2003) surgically implanted silver eels captured in a bypass trap with radio transmitters and released then into a power canal and forebay. Ten of 15 eels initially swam 2 km or 3 km upstream after being released. Most eels remained still for four to five days either

Table 9-10. Summary of conditions and results of several field studies involving downstream migration/passage of eels, relative to effects on migratory behavior.

Study	Species	Eel Size Range (mm TL)	Eel Weight Range (g)*†	Capture Method	Pre-tagging Holding Time	Anesthetic	Attach-ment Method	Tag Type	Tag size (dia. x length in mm, weight in g)	Percent of Body Weight of Tag (Range)	Post Tagging Holding Time Before Release	Release Location	Initial Delay	Upstream Move-ment	Eventual Downstream Movement
Durif et al. 2003	*A. anguilla*	570-930	*372-1650**	bypass	not given	clove oil	internal	ATS 10/28; 10/35	11x45, 8; 12x56, 11	0.5-3.0	<24 h	upstream of bypass	0-28 d	66%	100% (15/15)
Gosset et al. 2005	*A. anguilla*	not given	*355-1694*	bypass, electrofishing	not given	clove oil	internal	ATS 10/28	11x45, 8	0.5-2.3	hours after tagging	upstream of bypass	0-65 d	38-50%	33-59%
Winter et al. 2006	*A. anguilla*	640-930	*588-2086*	commercial fyke net	several days	2-phenoxy-ethanol	internal	NEDAP-TRAIL	14x63, 26.5	1.3-4.5	immediate	capture location	not given	low	80% (121/150)
Breteler et al. 2007	*A. anguilla*	640-730	*530-791**	commercial fyke net	not given	benzocaine	internal	NEDAP-TRAIL	15x65, 26.5	3.4-5.0	"after recovery"	downstream of capture location	not given	low	50-75%
Haro and Castro-Santos 2000	*A. rostrata*	710-910	*644-1484*	bypass	< 48 h	MS-222	external	Vemco V16	16x74, 14	0.9-2.2	<24 h	upstream of bypass	0-13 d	low	52% (13/25)
Brown 2005 (2002 study year)	*A. rostrata*	590-870	*365-1283*	bypass, commercial fyke net (Maine eels)	<24h to 1 week	clove oil	internal	HTI 795F, Lotek MCFT-3GM	8x18, 2.1; 8.2x19, 1.8	0.2-0.6	<48 h	upstream of bypass	not given	low	44%
Brown 2005 (2003 study year)	*A. rostrata*	627-1005	*444-2047*	bypass	< 24h	clove oil	internal	HTI 795F, Lotek MCFT-3D	8x18, 2.1; 8.2x19, 1.8	0.1-0.5	<48 h	upstream of bypass	not given	low	46%
Eltz 2006	*A. rostrata*	535-849	*266-1700*	bypass, small fyke net	< 24h	clove oil	internal	Lotek NTC-4-2L	8.3x18.3, 2.1	0.1-0.8	<24 h	upstream of bypass	0-30 d	low	97% (29/30)
EPRI 2007	*A. rostrata*	535-910	*350-1800*	bypass	< 24h	MS-222	internal	Lotek MCFT-3G	8.2x18.9, 1.75; 8.2x19, 1.8	0.1-5.0	30-36 h	upstream of bypass	2-22 d	low	100% (24/24; data subset)
McGrath et al. 2003	*A. rostrata*	915-1095	*1650-3100*	eel weir	not given	clove oil	internal	Vemco custom	19x74, 33	1.1-2.0	<24 h	2 km upstream of dam	not given	low	90% (9/10)
Watene et al. 2003	*A. dieffenbachii, A. reinhardtii*	870-1248	*2000-6380*	commercial fyke net	<24 h	MS-222	internal	Vemco V16	16x108, 39	0.6-2.0	<24 h	1 km upstream of dam	1 d to >1 year	low	(25/31)
Boubée (pers. comm.)	*A. dieffenbachii & A. australis*	830-1700	*1380-11820*	fyke net	<12 h	clove oil	internal	Vemco V16, HTI 795F	16x108, 39; 8 x 18, 2.1	<2.6	immediate	3.8 km upstream of intake	1 -46d	100%	100% (17/17)

***†** TBWR of tags was calculated based on eel weights given in the publication or calculated from reported total lengths using length-weight relationship formulae for large female European (* = Sinha and Jones 1967) or American († = Barbin and McCleave 1997) eels.

immediately after being tagged or after initially swimming a short distance upstream. All 15 eels eventually swam downstream and passed the dam. Most eels passed the dam during periods of high flow that correlated with natural runs of eels captured in downstream bypasses. Most tagged eels displayed searching behavior in the forebay around the trashracks and bottom bypass before passing downstream.

Gosset et al. 2005 conducted a similar study in which most tagged eels (collected in a bypass and by electrofishing) moved 2 km to 3 km upstream out of the forebay after release and were sedentary for up to 65 days before continuing migration. Only 36 of 74 tagged eels passed the dam. Most eels passed during periods of high flow during which turbidity increased and conductivity decreased. Untagged eels were observed to be migrating at the same time as tagged eels.

Winter et al. (2006) surgically implanted 150 silver eels (collected in commercial fyke nets and held in aerated basins for several days) with NEDAP TRAIL transponders; eels were released at the catch site. Most of the tagged eels (121) migrated downstream, but only 37% reached the North Sea. Downstream migration occurred primarily during periods of high flow during October and November 2003 and again from January to February 2003, but 26 eels were detected migrating downstream between March 2003 and November 2005. Thirteen tagged eels (8.7%) never were detected downstream of the release site.

Breteler et al. (2007) tagged 150 silver and 157 “intermediate” European eels with NEDAP TRAIL transponders in each year of a two-year study on the Meuse River, Netherlands. By the end of the study period (mid-January) 55% of eels tagged in 2004 and 53% of eels tagged in 2005 were detected downstream; another 7% of the 2004 group was detected by January 2006. Only 23% and 15% of the eels released in 2004 and 2005, respectively, were classified as escapes to the sea. Most downstream migration of tagged eels during both years took place during the months of October and November, primarily during periods of high flow. The authors attributed the small percentage of overall detections to fishing pressure and mortality resulting from passage through hydroelectric facilities.

9.6.3.2 Outmigrating American eels

Haro and Castro-Santos (2000) externally tagged 25 silver eels captured in a bypass sampler at Cabot Station on the Connecticut River in Turners Falls, Massachusetts. Eight subjects received both radio tags and acoustic tags. Thirteen of the 25 eels released upstream of the hydroelectric project were captured downstream of the dam. Those that did not pass remained relatively stationary, and many probably shed their tags. One eel remained stationary for 13 days before continuing its migration and passing the dam. Most eels that passed made frequent excursions in the forebay before passing. Eels typically moved within a few hours after sunset.

At the same site, Brown (2005) internally tagged 20 silver eels in 2002 and 30 silver eels in 2003 with combinations of radio, acoustic, and PIT tags. Thirteen of those tagged in 2002 were collected from a watershed in Maine. Holding times varied. Eels from the Connecticut River were captured, tagged, and released within 48 hours; eels from Maine were tagged one week after capture and released 48 hours after tagging. The author noted some minor upstream movement of a few eels, but 44% (2002) and 46% (2003) of tagged eels moved 1.5 km downstream from the release site to the Cabot Station powerhouse within 24 hours but did not pass the powerhouse. Most activity and passages occurred within six hours after sunset and during periods of high flow. There were no discernable differences in behavior (time to downstream movement, passage rate) between eels carrying different tags or from different rivers of origin.

Eltz (2006) studied passage at Rainbow Dam on the Farmington River, Connecticut. He surgically implanted 30 silver eels captured in fyke nets and at two downstream bypasses (one at the dam and another at Holyoke Dam, which is in a different basin) with radio-tags. Most eels were tagged and released within 48 hours. Twenty-nine of the 30 eels passed the dam within one month, predominately during periods of high flow. Movements of tagged eels were correlated with the activity of PIT-tagged eels held in an activity monitor and with numbers of eels that passed a counting window at the same site. Most eels remained sedentary after release and waited until periods of high flow to continue migration. Most activity and passages occurred within a few hours after sunset. In addition, eels made frequent excursions at the hydroelectric plant and multiple attempts to pass it before doing so successfully. There was no apparent difference between migratory behaviors of eels based on method or location of collection.

The behavior of 24 radio- and floy-tagged silver eels at a louver array was observed during a 30-day period at Holyoke Dam, Massachusetts (EPRI 2007). Eels were collected from the bypass sampler at the site. All tagged eels resumed migration after release, but nearly half (42%) exhibited a delay in movement. During the 6 hours immediately following release, 40% of radio-tagged eels and 70% of floy-tagged eels were detected at the bypass sampler. Seventy percent of radio-tagged eels were recorded at the bypass over the next five days. All movement and downstream passage occurred during the evening hours; and most eels passed during periods of high flow.

9.6.3.3 Outmigrating Eels in New Zealand

Studies of eels in New Zealand (which generally are 50% to 75% longer than American and European eels) typically involve larger transmitters with longer battery life, which facilitates observations of eels that do not move downstream immediately within a migratory season. Wantene et al. (2003) internally tagged 17 shortfin (*A. reinhardtii*) and longfin (*A. dieffenbachii*) eels at a hydroelectric project. Ten tagged eels moved downstream over 14 months. Many of the eels that did not pass in the first season remained in the impoundment until the next year, then moved downstream and passed the dam during the normal migratory season. Causes of the delay are unknown, but the authors noted that eels that remained in the impoundment for more than a year ultimately made their downstream movements during seasonal events (e.g., rain/flow events) that normally stimulated peaks in downstream eel runs.

Boubée and Williams (2006) implanted 31 female, silver shortfin and longfin eels with coded acoustic transmitters. The eels were captured in fyke nets in a large impoundment. Downstream movements were not immediate, but 25 eels passed the dam within several months. Other tagged eels remained in the impoundment for at least an additional year. Periods of increased downstream migratory activity occurred at night and were associated with increases in water level in the lake.

9.6.4 Studies of Yellow Eels

Several telemetry studies with yellow eels deserve mention even though they did not assess downstream migration directly because behavioral or physical responses to implanted tags among yellow eels may be indicative of responses of silver eels. Baras et al. (1998) studied the activity of seven yellow European eels captured by electrofishing and tagged with surgically implanted radio transponders. Tagged eels were sedentary during the daytime, and activity increased greatly during the early evening. Three eels expressed periods of low activity during the first two weeks; the authors related this behavior to low water temperatures rather than tagging because two of these eels were fully healed when captured three weeks later. Eels that were captured and sacrificed three weeks after tagging showed no internal signs of damage from radio-tagging and were fully healed. Parker and McCleave (1997) noted strong homing behavior in tagged yellow eels in the Penobscot River estuary, suggesting that the degree of silvering may strongly influence migratory behavior; specifically, less metamorphically advanced fish may retain homing behaviors or otherwise be less influenced by migratory triggers.

Barbin (1998) showed that eels rendered anosmic (without olfactory sense) by plugging the nares lose homing capability as well as the ability to respond to tidal stimuli during their downstream migratory movements. Techniques that debilitate the sensory systems of eels (e.g. anesthesia, particularly MS-222), therefore, could be a source of concern in telemetry studies. Conventional tagging techniques indicate that this debilitation may be only temporary (e.g., hours to a few days).

9.6.5 Conclusions and Recommendations

This review of past telemetry studies of eels indicates that the potential for collection, handling, and surgery to alter the behavior of eels is real and requires careful attention when designing a study. Eels require special care during telemetry studies, especially with respect to selection of tag morphology, anguilliform swimming, greater thickness of skin, response to anesthetics, and other characteristics (Jepsen et al. 2002, Moser et al. 2007). Eels are very responsive to environmental conditions during downstream migration, and the stresses of collection, holding, and surgery appear to influence their migratory motivation. Eels that are highly metamorphosed and collected during migration commonly cease migration after tagging and release and do not resume migration for at least several days (or in the case of New Zealand species, until the next season). Once activity resumes, however, migratory behavior appears similar to that of untagged fish in most cases (e.g., the tagged eels move past dams during high flows, as do untagged eels), suggesting that a period of recovery is important. An unresolved issue concerns whether eels can recover effectively while being held or should be released immediately so that they can respond to natural stimuli. The latter option may be a better choice, especially if the number of available fish and the migratory window are relatively small. Upstream movements of a portion of released fish are to be expected, but generally those individuals ultimately express downstream migratory behavior.

The selection of sites of capture and release requires consideration. Typically, tagged eels for telemetry studies are released several kilometers upstream of the study area (e.g., dam, hydro project) to allow fish to express natural behaviors and distributions in the river channel by the time they arrive at the site, but not so far upstream that fish have to travel for long periods to arrive at the site. Eels captured downstream of the release site (e.g., in a bypass sampler) might avoid a route over which they had traveled before they were collected. No evidence of such "learned" behavior is documented in the reviewed studies; nevertheless, the possibility of such an effect should be considered in data analyses. A capture site upstream of and relatively near the study area is preferable to avoid such a bias.

Some of the reviewed studies suggest a measurable effect of tagging on downstream migratory behavior, at least in terms of migratory rate. One might expect similar effects on route choice and response to hydraulics in proximity to the site of interest; however, these potential effects do not appear to be pronounced. The "immediate post-tagging effects" appear to be relatively short-lived. Eels appear to recover their migratory motivation and normal downstream migration rates within several days of surgery. The presence of the tag may impair swimming ability to a minor degree. Study designs should take these effects into consideration by choosing release sites farther upstream and tagging/releasing fish as early in the season as possible.

More data are needed about the migration of eels through the St. Lawrence system as a whole. Eels emigrating from the St. Lawrence River cover many hundreds of kilometers, at a wide range of metamorphic stages, over a long period (several months), starting unusually early (July). Traditional migratory cues for eels (e.g., peaks flows caused by rain storms) and concomitant peaks in run timing are minimal in the upper St. Lawrence River. Several European studies have indicated that small but significant percentages of silver eels do not emigrate from larger rivers in Europe within one season (van Ginniken and Maes 2005). Although no similar direct evidence has been documented from the St. Lawrence River system, the possibility that eels may take more than one migratory season to travel from Lake Ontario to the sea has ramifications for designing telemetry studies and interpreting their results.

Other authors' suggestions for study designs and techniques drawn from personal experience and the study reviews are listed below; note that suggestions for collection of eels are given in Collection-Handling-Transport section (Section 8):

Handling and Holding

- Eels should be tagged as soon as possible after collection, usually within 24 hours.

- Eels should be observed for 24 hours prior to tagging to note any effects of injuries; any fish exhibiting abnormal behaviors should not be tagged.
- Fish with outward signs of injury or disease should not be used for telemetry studies.
- Eels should be handled as briefly as possible using soft, small-mesh nets.
- Eels should not be removed from water any longer than is necessary.
- Eels should be provided spacious facilities during holding and transportation, preferably with flow from the body of water from which they were collected (e.g., streamside), or to which they will be introduced.
- Holding facilities should have a natural photoperiod and adequate shelter (e.g., hiding places).

Anesthesia and Surgery

- MS-222 and clove oil typically are used as anesthetics; clove oil is somewhat preferred. The United States Food and Drug Administration has not approved clove oil for use as a fish anesthetic but is currently reviewing the issue. Ice should not be used, either alone, or in concert with an anesthetic, because freezing can induce metabolic acidosis. Electronarcosis is unproven with eels, but initial trials indicate that it is difficult to perform efficiently and may cause undue stress.
- Eels should be anesthetized only deeply enough to allow for rapid recovery.
- Eels should be provided with flowing water (anesthetic solution) over the gills during surgery; the rest of body should be kept moist and cool, preferably at ambient water temperature.
- Telemetry tags less than or equal to 2% TBWR should be used whenever possible; larger tags may be acceptable if they can be shown to have minimal effects. Some consideration also needs to be given to volume and length-width ratio of tags for anguilliform fishes (Moser et al. 2007; no standards for these metrics exist for fish). Sterile technique and analgesia should be used during and after implantation. Antennas and other tag components exiting the body cavity are acceptable, but perforations through the body wall should be kept as small as possible.

Recovery

- Eels should be held for recovery for a minimum amount of time. Holding fish for a maximum of 24 hours after surgery is a common practice to (1) assure that fish are not expressing any behavioral indications of post-surgical trauma, (2) verify that tags are performing acceptably, and (3) determine if eels can still respond to environmental conditions experienced immediately before capture.

- The same conditions used for initial holding should be used for recovery.

Release

- Eels should be handled carefully to avoid trauma and damage to the surgical wound or transmitter.

- Eels should be transported as quickly as possible, with a minimum of stress and noise.

- Eels can be released from shore if the release site is far enough upstream of the site of interest; otherwise, fish can be released in mid-channel.

- Eels can be released at any time of day; typically fish released during the day will stay in the vicinity of the release site and remain mostly sedentary until darkness, but eels may initiate downstream movements soon after sunset.

- Some upstream movement of individuals can be expected, but it should be minimal (e.g., less than 25% of released fish). Fish that exhibit extended upstream movement or very long sedentary periods are suspect with respect to exhibiting natural behaviors of silver eels, unless environmental conditions are unusual (e.g., low flow, high temperatures).

- Fish should not be released in the vicinity of fishing gear, hydraulically challenging environments (e.g., high flows, waterfalls), or where natural predators are abundant. Although larger eels may not be at immediate risk of predation in freshwater, they may be at risk from larger predators once they enter the marine environment (e.g., marine mammals, sharks)

9.7 OVERVIEW

NYPA's request for proposals posed questions regarding each of the technologies and specified that responses should be drawn from the review of findings. The following questions were posed regarding using eels in telemetry studies.

- **What is the optimal method for attaching a transmitter to eels?**

Most recent studies have converged on abdominal implantation of telemetry tags as the method of choice because of maximum tag retention, minimal tagging mortality, and minimal effects on long-term behavior and locomotor ability (assuming tag size is within recommended limits). Very small tags (e.g., PIT tags 12 mm long or smaller) attached subdermally or in the dorsal sinus may be acceptable; subdermal attachment of larger tags (e.g., radio tags) is not recommended. External attachment of transmitters currently is used only when absolutely necessary (e.g., larger satellite tags); in general, tags that are too large to be implanted internally should not be attached externally.

- **What types of physical and behavioral effects result from use of transmitters in studies of downstream migrating eels?**

Generally, researchers appear to be using smaller internal tags and to prefer "antennaless" tags such as acoustic and PIT tags for long-term studies to allow surgical wounds to heal completely and eliminate a route by which water could enter the body cavity. Some concern about tag rejection has been suggested (e.g., through the gut or body wall; J. Boubée, pers. comm.), but tag rejection in eels has not been studied definitively.

Tag size is of some concern because of the relatively narrow geometry of an eel's body cavity and the ability of eels to bend their bodies to more extreme degrees than most fishes. The recommendation not to exceed 2% TBWR seems to be a conservative and generally acceptable guideline. TBWR greater than 2% may be allowable because several studies indicate that eels will still exhibit strong downstream migratory behavior when fitted with tags greater than 2% TBWR. It is important to note that TBWR is a mass-based metric and that no studies have defined criteria for acceptable dimensions of tags, which may be equally important for narrow-bodied and flexible eels. Given average dimensions of current telemetry tags (cylindrical with length three times the diameter and density 1.25 times that of water), a tag of 2% TBWR for a typical 800-mm-TL eel (1 kg) would weigh 20 g and measure about 20 mm in diameter and 75 mm long. A tag of this size probably would approach the maximum volume that most researchers used in recent studies. In general, the procedures described by Baras and Jeandrain (1998) have very low infection and rejection rates, at least over the short-term, and are an acceptable standard method for tagging with or without external antennas. Some modifications of the procedure (e.g., omission of the attachment of a clipped fin to the wound, alternative anesthetics) may be acceptable.

Eels fitted with external tags may spend considerable amounts of time attempting to remove the tag by gripping it or the sutures with their mouths or by rolling, sometimes successfully[37]. Such activity invites loss or damage of the tag, opening of the suture wounds, and infection. Extension of dipole (whip) antennas outside the body cavity is acceptable for short-term studies, (e.g., < 6 months) but may induce infection or other complications over a longer period.

- **What is the efficacy of telemetry technologies as a means to document down-stream migration behavior in eels, particularly in response to encountering some type of downstream guidance device?**

At present, telemetry appears to be the best available technology for assessing migratory behaviors, movement patterns, and passage routes of fishes in downstream passage studies, at the scales likely to be encountered in the St. Lawrence River. Concerns about effects of telemetry on behaviors may be difficult to alleviate completely. Standard hydroacoustics or acoustic cameras have the potential to yield behavioral data, but only at a much reduced scale and without

[37] Personal observations of A. Haro during studies conducted at the S.O. Conte Anadromous Fish Research Laboratory.

the ability to identify individuals. Hydroacoustics and acoustic cameras may, however, be useful in supplementing telemetry data by supplying fine-scale movements or reactions to hydraulic conditions (e.g., accelerating flows at bypass entrances).

- **To what extent would studies conducted in flumes or tanks be of value is assessing the extent to which eel behavior may be affected by tagging?**

Flume and tank studies may be helpful for indentifying gross effects of tagging on eel behaviors in a relative sense (i.e., compared to untagged eels held and monitored under similar conditions). Flumes offer the added component of enabling researchers to monitor the response of fish to flow (i.e., measurement of downstream and upstream movement and activity), especially if the flume is in an annular or "endless" configuration. The behaviors of unhandled fish in the wild are expressed over much larger spatial scales than even the largest flume facilities currently available can mimic, and eels respond to physical and environmental variables in the field that generally either are not present or are highly artificial in tanks or flumes. Also, studies using tanks and captive fish often are plagued by side effects such as initial escape behaviors (which may mask migratory behaviors) and disease caused by crowding. Nonetheless, tank/flume studies could be instructive for addressing very general questions about the influence of the presence and size of tags on gross activity or general behavior if experiments are designed carefully with adequate controls.

Carefully designed mark-recapture field experiments similar to those of Breteler et al. (2007) would be preferable to flume or tank experiments for improving confidence in the assumption that tagging is "benign" relative to effects on behavior. Breteler and colleagues assumed that tagged eels that are behaviorally uninfluenced by the presence of a tag would emigrate at the same rates and via the same routes as untagged fish. Such experiments could be repeated in the St. Lawrence River, but smaller studies on shorter or smaller watersheds also could be performed to confirm the minimal effect of attaching transmitters. Control (untagged) fish would have to be collected and marked; therefore, separating the effects of collection and handling from the effects of the tag itself would still be difficult because both the treatment group and the control group would have to be collected and handled. Parallel monitoring of run peaks/timing at sites of the collection and recapture would offer an additional control to compare the migratory rates of wild, unhandled fish to those of tagged and marked fish.

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APPENDIX A

TABLE OF EEL CONTACTS

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Anthony Acou	ERT 52 Biodiversité Fonctionnelle et Gestion des Territoires Campus de Beaulieu, Bat. 25 1er étage, 35042 Rennes cedex, France Phone: +33 2 23 23 51 60 fax: + 33 2 23 23 51 38 anthony.acou@univ-rennes1.fr	Researcher					X	
Steve Amaral	Alden Research Laboratory, Inc. Worchester, MA Phone: 508-829-6000 x415 Fax: 508-829-5939 amaral@aldenlab.com	Researcher		X	X	X	X	X
Paul Angermeier	USGS and Virginia Tech PH : 540-231-4501 biota@vt.edu	Researcher					X	
Martin Castonguay	Institut Maurice-Lamontagne Peches et Oceans CP 1000 Mont-Joli Quebec G5H 3Z4 Canada Phone : +1 418 775 0582 Fax : +1 418 775 0740 CastonguayM@dfo-mpo.gc.ca	Researcher	X				X	X
Jonathon Carr	Atlantic Salmon Federation Canada Phone: 506-529-1385 Fax: 506-529-4985 JCarr@asf.ca	Researcher					X	X
Denis Desrochers	MILIEU INC. Phone:450-444-6880 Fax: 450-444-6894 denis.desrochers@milieuinc.com	Researcher	X				X	X

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Jean-Denis Dutil	Pêches et Océans Canada Fisheries and Oceans Canada 850 route de la Mer, C. P. 1000 Mont-Joli Quebec, Canada G5H 3Z4 Phone: +1 418 775 0582 Fax: 418 775-0546 DutilJD@dfo-mpo.gc.ca	Researcher				X	X	X
Kari Fenske	University of Maryland, Chesapeake Biological Lab Phone: 410-326-7225 fenske@cbl.umces.edu	Researcher					X	
Brian Eltz	Beltz72@cox.net	Researcher	X		X		X	
Bob Graham	Dominion Energy Phone: 804 271-5377 Fax: 804 271-2977 Bob.Graham@dom.com	Researcher					X	X
Alex Haro	USGS S.O. Conte Anadromous Fish Research Laboratory 1 Migratory Way Turners Falls, MA Phone: 413-863-3806 alex_haro@usgs.gov	Researcher	X	X	X	X	X	X
Ken Oliveira	University of Massachusetts, Dartmouth Department of Biology 285 Old Westport Road N. Dartmouth MA 02747-2300 Phone: 508-999-8227 Fax: 508-999-8196 koliveira@umassd.edu	Researcher					X	X

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Steve Parker	National Institute of Water and Atmospheric Research (NIWA) Phone: +64 4 386 0867 Fax: +64 4 386 0574 steve.parker@hmsc.orst.edu & s.parker@niwa.co.nz	Researcher					X	X
Michael Pedersen	Danish Fisheries Research -DFU Afd. for Ferskvandsfiskeri Veilsovej 39 8600 Silkeborg Denmark Phone: +45 33 96 31 00 Fax: +45 33 96 31 50 MIP@DFU.MIN.DK ; mip@difres.dk	Researcher					X	X
Caroline Durif	Institute of Marine Research-Austevoll N-5392 Storebø, Norway Tel (central): +47 55 23 85 00 Tel (direct): + 47 56 18 22 50 caroline.durif@imr.no	Researcher	X					X
Asbjørn Vøllestad	Asbjorn.vollestad@bio.uio.no	Researcher	X					X
Robert Mason	3029 Cordley Hall, Department of Zoology, Oregon State University, Corvallis, Oregon 97331 Phone: 541-737-4107 masonr@science.oregonstate.edu	Researcher	X					
Rob McGregor	rob.macgregor@ontario.ca	Researcher	X (Eel balls)					
John Rohrbeck	PH: 613.476.3777	Fisherman	X (Eel balls)					
Mar Huertas	Centre of Marine Sciences University of Algarve Campus de Gambelas 80005-139 Faro, Portugal Phone: +351 289 800 900 mhuertas@ualg.pt	Researcher	X					
Floyd Campfield	PH: 845-252-3287	Fisherman	X (Eel balls)					

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Dave Whitten	PH: 207.938.4159	Fisherman	X (Eel balls)					
John Casselman	Queen's University, Department of Biology, Biosciences Complex, 116 Barrie Street, Kingston, Ontario K7L 3N6 PH: 613.533.6000 X 75371 e-mail: casselmj@biology.queensu.ca	Researcher	X (Eel balls)		X		X	
Don Hamilton	National Park Service Upper Delaware Scenic and Recreational River 274 River Road Beach Lake, PA 18405-9737 PH: 570.729.7842 don_hamilton@nps.gov	Researcher	X (Eel balls)					
Damien Sonny	Chemin des Pêcheurs 114, 5100 Namur - Belgium Phone : +32 81 40 32 D.Sonny@profish-technology.be	Researcher		X				
Keith Whiteford	Maryland Dept. of Natural Resources, Stevensville Field Station PH: 410-643-6801 x 124 kwhiteford@dnr.state.md.us	Manager					X	X
Mitch Feigenbaum	South Shore Trading Company Nova Scotia PH: 215-859-0428	Dealer					X	
Lewis Gillingham	Virginia Marine Resource Commission PH: 757-247-2243 Lewis.Gillingham@mrc.virginia.gov	Manager					X	
Guy Dionne	19 rang Haute-Ville, Saint-Denis-de-Kamouraska, G0L 2R0, Canada PH: 418 498 3338	Fisherman					X	

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Joseph Paquet	2705 chemin Royal, Saint-Pierre Ile-d'Orléans, G0A 4E0, Canada PH: 418 828 2670	Fisherman					X	
G.-H. Lizotte	145-C Chemin de la Pointe, Rivière-Ouelle, G0L 2C0, Canada PH: 418 856 1388	Fisherman					X	
Bruno Ouellet	38 Avenue Morel, Kamouraska, G0L 1M0, Canada PH: 418 492 1872	Fisherman					X	
André Gagné	1309 route 137, La Présentation, J0H 1B0, Canada PH: 450 796 3259	Fisherman					X	
Claude Guy	1489 route 132 Est, La Pocatière, G0R 1Z0 Canada PH: 418 856 3743	Fisherman					X	
A.C. Carpenter	222 Taylor Street P.O. Box 9 Colonial Beach, VA 22443 PH: (804) 224-7148 or (800) 266-3904 ac.prfc@verizon.net	Manager					X	
Julian Partridge	Reader in Zoology School of Biological Sciences University of Bristol Woodland Road Bristol BS8 1UG UK Tel: +44 (0)117 928 7591 J.C.Partridge@bristol.ac.uk	Researcher				X		
Thomas Kieran McCarthy	tk.mccarthy@nuigalway.ie	Researcher	X (Eel Balls)	X		X		X
Alastair Mathers	alastair.mathers@ontario.ca	Researcher						X

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Denis Doherty	ESB Fisheries Conservation ESB Salmon Hatchery, Knather Road, Ballyshannon, Co Donegal. Direct line +353 (71) 9851712 denis.doherty@esb.ie	Researcher				X	X	
Patrick Gilbride	Director for Fisheries Conservation Electricity Supply Board, Ireland pat.gilbride@esb.ie	Manager					X	
Susanne Teggers-Junge	RWE Power Aktiengesellschaft Regenerative Erzeugung (PNS) Abt. Technik (PNS-T) Huyssenallee 2, 45128 Essen +49(0)201/12-21385 susanne.teggers-junge@rwe.com	Researcher					X	
Russell Poole	Marine Institute, Furnace, Newport, Co. Mayo, Ireland. Tel: 00-353-98-42300. russell.poole@marine.ie	Researcher					X	X
Hakan Wickstrom	Swedish Board of Fisheries Institute of Freshwater Research SE-178 93 DROTTNINGHOLM Sweden phone: +46-(0)86990607 hakan.wickstrom@fiskeriverket.se	Researcher					X	X
Lothar Jörgensen	SGD Nord (Struktur- und Genehmigungsdirektion Nord) Stresemannstraße 3-5 D-56068 Koblenz lothar.joergensen@sgdnord.rlp.de	Fishery Admin-istrator					X	
Eamon Cusack	Shannon Regional Fisheries Board Ashbourne Business Park Dock Road Limerick TEL 061 300238 ECusack@shrfb.com	Researcher					X	

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Jerry Braley	207.664.8065	Fisherman					X	
Michael Flanagan	Board member of the Shannon Fisheries Board mfln.ennis@eircom.net	Fisherman					X	
Dr Alan M. Walker	Salmon & Freshwater Fisheries Cefas Pakefield Road Lowestoft Suffolk NR33 0HT tel: +44 (0)1502 524351 alan.walker@cefas.co.uk	Researcher					X	
Doug Dixon	ddixon@epri.com		X	X	X	X	X	X
Chris Tomichek	Chris Tomichek Senior Fisheries Biologist Kleinschmidt Associates 35 Pratt St. Essex, CT 06426 (860) 767-5069 Chris.Tomichek@KleinschmidtUSA.com							X
Andrew Dollof	USFS Southern Research Station & Dept. Fisheries and Wildlife, Virginia Tech 540 231-4864 adoll@vt.edu	Researcher						X
Ansgar Hehenkamp	SGD Nord (Struktur- und Genehmigungsdirektion Nord) Stresemannstraße 3-5 D-56068 Koblenz ansgar.hehenkamp@gmx.net	Fishery Admin-istrator					X	
Robert Mueller	robert.mueller@pnl.gov	Researcher		X				
Les at "Tidewater Express"	PH: 410.632.4011, extension 201	Trucker					X	
Christian Goehl	PH: + 49 – (0)89 –99 222 442 christian.goehl@rmd-consult.de	Researcher					X	

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Dr. Beate Adam	Institut für angewandte Ökologie Neustädter Weg 25 D-36320 Kirtorf-Wahlen Tel.: +49 (0) 6692 - 6044 Fax: +49 (0) 6692 - 6045 schwevers@vobis.net	Researcher			X	X	X	
Uli Dumont	Floecksmuehle Consultants 52066 Aachen, Germany Bachstr. 62-64 PH: +49 241 94986-0 u.dumont@floecksmuehle.com	Researcher			X		X	
Ulrich Schwevers	Institut für angewandte Ökologie Neustädter Weg 25 D-36320 Kirtorf-Wahlen Tel.: +49 (0) 6692 - 6044 Fax: +49 (0) 6692 - 6045 schwevers@vobis.net	Researcher			X	X	X	
John Phillips	Department of Biological Sciences Virginia Tech Derring Hall Blacksburg, VA 24061 PH: (540) 231-1481 jphillip@vt.edu	Researcher	X					
Paula Cullen	pauline.cullen@nuigalway.ie	Researcher				X		

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Andre Breukelaar	RWS-RIZA Institute for Inland Water Management and Waste Water Treatment Directorate Water Quality Management and Information (WI) Dept. Ecology (WIE) Zuiderwagenplein 2 P.O. Box 17 8200 AA Lelystad tel 0031 320 297624 andre.breukelaar@rws.nl	Researcher						X
Willem Dekker	Netherlands Institute for Fisheries Research RIVO PO Box 68 1970 AB Ijmuiden Netherlands willem@rivo.wag-ur.nl	Researcher					X	
Gerard Manshanden	Visserijbedrijf G.A.M. Manshanden Hazewaal 1 1671 LA Medemblik, the Netherlands Telephone 0031 227 543609 Mobile 0031 6 51564469 Fax 0031 227 543609 gam.manshanden@quicknet.nl	Fisherman				X	X	
Olav Sand	University of Oslo Department of Molecular Biosciences PO Box 1041 Blindern, N-0316 Oslo, Norway PH: +47 22854637 Olav.sand@imbv.uio.no	Researcher		X				
Don Jellyman	National Institute of Water and Atmospheric Research (NIWA) Phone: 64-3-348887 d.jellyman@niwa.co.nz	Researcher	X				X	X

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Joe Dembeck	Maine Department of Inland Fisheries and Wildlife PH: 207-941-4719 Fax: 207-941-4450 Joe.Dembeck@maine.gov		X (eel Balls)			X	X	X
Curt Gelin	Curt.Gelin@kemira.com	Fisherman					X	
Guy Verreault	Ministère des Ressources Naturelles et de la Faune, Direction de l'aménagement de la faune du Bas Saint-Laurent, 506, rue Lafontaine Rivière-du-Loup, Qc G5R 3C4 Canada tel: +418.862.8649 # 226 guy.verreault@mrnf.gouv.qc.ca	Researcher					X	
Leah Brown	HTI lbrown@HTISONAR.COM	Vendor						X
Lawrence R. Egan	Director, Marketing & Sales Group Lotek Wireless, Inc. 115 Pony Drive Newmarket, Ontario Canada L3Y 7B5 PH: 905-836-6680 ext. 285 Fax. 905-836-6455 Email: legan@lotek.com	Vendor						X
Brian Knights	University of Westminster/NRA Applied Ecology Research Group 115 New Cavendish Street London W1M 8JS PH: +44 171 911 5000 Fax: +44 171 911 5087 PandBKnights@aol.com	Researcher					X	X
Don Degan	djdegan@aquacoustics.com	Researcher						X

Name	Contact Information	Contact Type	Attractants/ Repellants	Infrasound	Physical Barriers	Light	Capture/Hold/ Transport	Telemetry
Jim Dawson	jdawson@biosonicsinc.com	Researcher						X
Anna-Maria Mueller	Aquacoustics, Inc. PO Box 1473 29824 Birdie Haven Court Sterling, AK 99672-1473 PH: (907) 260-6341 ping@aquacoustics.com	Researcher						X
Jon Hateley	jon.hateley@environment-agency.gov.uk	Researcher						X
Marc Schmidt	schmidt@lfv-westfalen.de	Researcher						X
Mike Potthoff	michael.pothoff@ncmail.net	Researcher						X
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APPENDIX B

WHAT DO FISH HEAR?

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Hearing range and sensitivity

It is possible to ask fish "what they hear" by using behavioral methods to train fish to respond to the presence of a sound (e.g., Tavolga and Wodinsky 1963). More recently, investigators have also been using auditory evoked potentials (AEP), which are signals directly recorded from the brain, to measure hearing. Using these methods, it is possible to determine the frequencies and intensities of sounds that a fish can detect by changing the signal parameters (e.g., Kenyon et al. 1998; Popper et al. 2007). These studies provide a measure of hearing that is often called an audiogram (Fig. B1). The data points in the audiogram represent the lowest sound level that an animal is able to detect at a particular frequency. This level is often called the "threshold."[1]

Hearing thresholds have been determined for perhaps 100 species of the more than 29,000 living fish species. Figure B1 shows the hearing sensitivity of several species to illustrate the range and intensity of sound that different species can detect. By way of comparison, a young normal human can generally detect sounds from 20 Hz (hertz = cycles/second) to almost 20,000 Hz, which means that humans have a much wider hearing range than most fishes.

The goldfish (*Carassius auratus*), one of the most sensitive of all fish species,[2] can detect sounds from below 50 Hz to about 3,000 Hz (see Jacobs and Tavolga 1967; data in Fay 1988). In contrast, other species such as tuna and salmonids only hear to 300 Hz and their sensitivity (lowest sound they can hear or threshold) is much poorer than that of the goldfish. Fish that hear particularly well, such as the goldfish, are called "hearing specialists" because they have special structures, described below, that enhance their hearing capabilities by allowing them to effectively detect the pressure component of the sound field. Other fishes, such as the salmon, are often called "hearing generalists" because they have no special adaptation for hearing and primarily detect the particle motion component of the sound field. Although we have data for a small proportion of all of the extant fish species, it appears that most fish fall into the hearing generalist category, and this certainly includes most of the more common food fishes such as, haddock, trout, and salmon as well as eels.[3]

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[1] Although the threshold is an important concept and is used throughout the literature, it needs to be noted that a threshold is a statistical concept that is based on the lowest value of a signal that is detectable some percent of the time. Very often, for fish, hearing thresholds are the lowest levels at which a fish will detect a sound 50% of the time. In other words, whereas a fish will detect a particular signal 50% of the time, it will not detect the same signal 50% of the time. Variation in threshold is well known for all animals and for all senses. It often reflects momentary changes in the detecting structure, in the motivation of the animal, and innumerable other factors.

[2] The goldfish is the "white rat" of fish hearing research. It is the species for which we have the most data on hearing capabilities. However, it should be noted that hearing in the goldfish is not necessarily representative of species other than for members of its taxonomic group, the Otophysi.

[3] It is important to note that direct comparison of hearing data for different species is often problematic. Much of the older literature, as pointed out by Fay (1988), was reported as pressure thresholds. However, we now know that many species, and particularly hearing generalists, are likely to primarily detect the particle-motion component of a sound field. This means that data for such fish are likely incorrect because the investigators did not calibrate particle motion or necessarily present a substantial particle-motion field. See a fuller discussion of this issue in Popper et al. 2003.

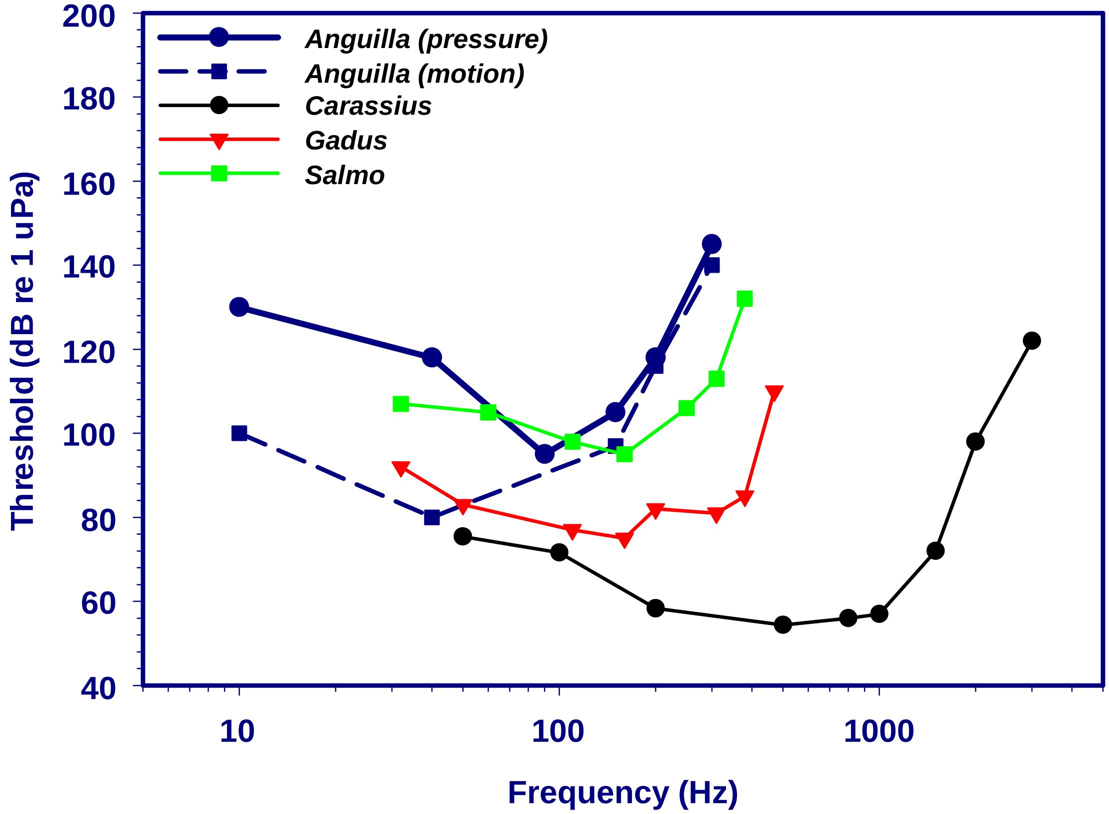


Figure B1: Hearing thresholds for select fish species

Note that the data for *Anguilla* represent a measure in the pressure mode (solid line) and motion mode (dashed line). See text for explanation (page B-11). It is important to note that although it appears that *Anguilla* is the only species to detect sounds below 30 Hz, it is likely that some or all of the other species tested at 10 Hz would show hearing capabilities as well. It should also be noted that two thresholds are shown for *Anguilla*. Indeed, as discussed in Section 5, salmon (*Salmo*), Atlantic cod (*Gadus*) and several other species have been shown to detect sounds to below 1 Hz. Goldfish (*Carassius*) is included in the graph to represent hearing range and lower threshold (sensitivity) for hearing specialists vs. the other species that are considered hearing generalists (see text).

Of all fishes, those with by far the widest hearing range are some of the herrings and shads (all members of the genus *Alosa*). These fishes can detect sounds from below 100 Hz to over 180 kHz, a range that is only reached by a few mammals such as some bats and dolphins (e.g., Mann et al. 2001). Although hearing in these fishes is not yet well understood, behavioral studies have shown that *Alosa* react very strongly to dolphinlike sounds, supporting the argument that they use ultrasound detection to avoid being eaten by dolphins. To date, no other species of fish have been shown to detect sounds above 7-8 kHz, although there are some data suggesting that Atlantic cod (*Gadus morhua*) may be able to detect 38-kHz signals (Astrup and Møhl 1993). However, these were very intense sounds and so the investigators suggested that the signals were not detected by the ear. Instead, they suggest that the signals were so intense that they were probably detected by other, very insensitive, non-auditory receptors in the skin.

Other fish are able to detect sounds well below the hearing range of humans. Although only a few species have been studied (Popper et al. 2003), it appears that infrasound signals as low as 20 Hz (or below) are detected in taxonomically diverse species including eels, salmonids, and perch. It is not clear yet if infrasound detection is more broadly found among different fish species and/or whether such detection is widely found.

Beyond detection

Although the earliest studies on fish showed that they can detect pure tones (single frequencies), there are few pure tones in any normal environmental or biologically relevant sound. Instead, most sounds are made up of a wide range of frequencies (e.g., human speech, bird song, fish sounds). Moreover, the most critical role of the auditory system in all sound-detecting animals is not just detection. Instead, a major role of the auditor system is to discriminate between sounds, detect signals in the presence of other (background) sounds, and determine the direction (and possibly the distance) of a sound source.

Although there have been few studies on discrimination of sounds by fish, all species studied appear to be able to discriminate sounds of different intensities and frequencies (Fay and Megela Simmons 1999; Popper et al. 2003). Intensity-discrimination studies in goldfish suggest that this hearing specialist can detect signals as close to one another as 3-10 dB in amplitude and suggest an ability to differentiate sounds that are as close 30 Hz or less[4] (see Fay 1988 for details). However, there is also evidence that hearing generalists are not quite as adept at discrimination as the specialist goldfish. It needs to be kept in mind, however, that there are data for very few species and that the methods used in each case were very different. Thus, even comparison of discrimination abilities between fish species must be done with considerable caution.

Similarly, studies of the detection of signals in the presence of noise must be done with caution due to the few species for which there are data (Fay and Megela Simmons 1999). The results of these studies show that fish hearing is affected by the presence of background noise that is in the same general frequency band as the biologically relevant signal. In other words, if a fish has a particular threshold for a pure tone in quiet and a background noise that contains energy in the same frequency range is introduced, this will decrease the detection of the biologically relevant signal. In effect, the threshold for the biologically relevant signal will become poorer.

The significance of this finding is that if background noise is increased, such as a result of human-generated (anthropogenic) sources, it may possibly make it harder for a fish to detect the biologically relevant sounds it needs to survive. Similarly, if there is a strong background noise near a dam or other human-made object, any sound being used to modify fish behavior has

[4] Note that both intensity and frequency-discrimination data vary by species, frequency, and the starting amplitude of the sound. Numbers given here are primarily to demonstrate that the discrimination capabilities of the auditory system in at least some fish species are comparable to those found in many terrestrial vertebrates, including some mammals.

to be louder to be detected by the fish and thus be potentially effective in eliciting a response from the fish than if the noise was not present.

Sound source localization

One of the most critical aspects of sound detection is the ability of an animal to determine the location of a sound source around it. Only by being able to perform sound source localization is it possible for an animal to know the location of a predator or prey or something of biological relevance in its environment. Sound source localization is very highly refined in humans and well understood. However, very little is known about the capabilities and mechanisms of localizations by fish (Popper et al. 2003; Fay 2006). It is likely that fish can perform localization, but we lack data for most species, primarily due to the very difficult acoustic problems that arise when trying to study sound localization in the water (Fay 2006). We do know, however, that the localization mechanism in fish is related to the orientation pattern of sensory hair cells in the inner ear which can directly determine the direction of a sound source (Popper et al. 2003).

How do fish detect sound?

The ear

Although fish have no external structures for hearing, such as the human pinna, they do have an inner ear that is similar in structure and function to the inner ear of terrestrial vertebrates (Fig. B2). Unlike terrestrial vertebrates, however, who require external structures to gather sound waves and change the impedance to match that of the fluid-filled inner ear, sound gets directly to the fish ear because the fish's body is the same density as the water. As a consequence, the fish ear and body move with the sound field. Although this might result in the fish not detecting the sound, the ear also contains very dense structures, the otoliths, that move at a different amplitude and phase from the rest of the body. This provides the mechanism by which fish hear.

The ear of a fish (Fig. B2) has three semicircular canals that are involved in determining the angular movements of the fish. The ear also has three otolith organs, the saccule, lagena, and utricle, that are involved in both determining the position of the fish relative to gravity and detecting sound. Each of the otolith organs contains an otolith (a dense calcareous structure) that lies in close proximity to a sensory epithelium.

Sensory cells of the ear and lateral line

The sensory epithelium (or macula) in fish contains mechanoreceptive sensory hair cells that are virtually the same as those found in the mechanoreceptive cells of the lateral and in the inner ear of terrestrial vertebrates. All parts of the ear have the same kind of cell to detect movement whether it be movement caused by sound or movement of the head relative to gravity.

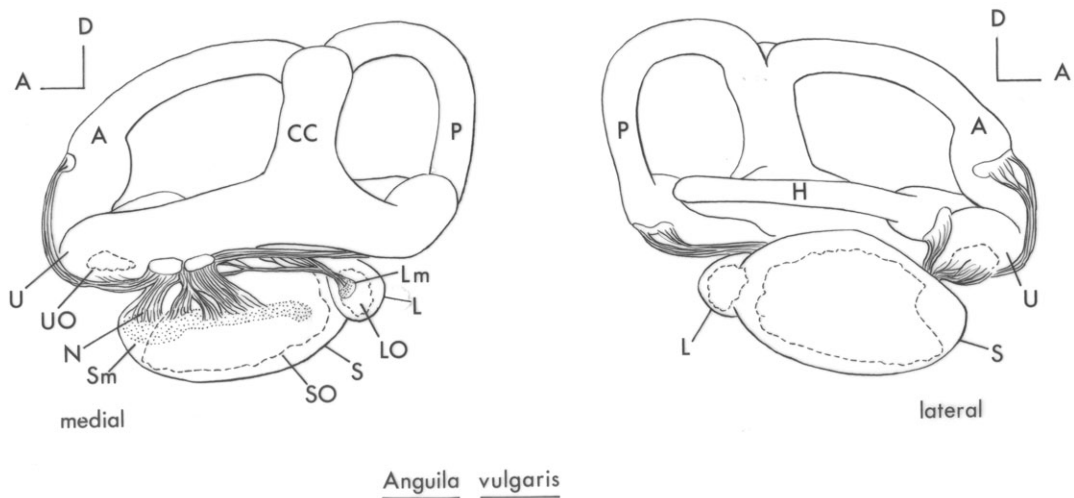


Figure B2. The ear of *Anguilla anguilla*
The ear of the European freshwater eel formerly known as *Anguilla vulgaris*[5] and referenced that way by Retzius (1881) from whom this figure is modified. A is anterior and D is dorsal. The left side shows a medial view of the right ear and the right side shows a lateral view of the same ear. Each ear has three semicircular canals, the anterior (A), horizontal (H), and posterior (P), and these come together in a common crus commune (CC). There are three otolithic organs, the lagena (L), saccule (S), and utricle (U). Each otolithic organ is innervated by a branch of the eighth cranial nerve (N). Lm, lagena sensory epithelium (macula); LO, lagenar otolith; Sm, saccular macula; SO, saccular otolith; UO, utricular otolith.

The sensory hair cells (Figs. B3 and B4) are not very different from other epithelial cells of the body except that on their apical (top) ends, they have a set of cilia (sometimes called "hairs," hence the name of the cell) that project into the space above the epithelium and contact the otolith. Each cell has many cilia. Generally, these are graded in size, with the longest being at one end of the ciliary bundle. The sensory hair cell responds to bending of the ciliary bundle by a change in its electrical potential. This, in turn, causes release of chemical signals (neurotransmitters) that excite neurons of the eighth cranial nerve that innervate the hair cells. These neurons then send signals to the brain to indicate detection of a signal.

Bending of the ciliary bundles results from the relative motion between the sensory epithelium (and the fish's body) and the overlying otolith (Figs. B5 and B6). There is evidence that suggests that the motion of the otolith relative to the body of the fish depends on the direction of the sound source. Because the sensory hair cells are responsive to bending in only certain directions, they can detect the direction of motion of the otolith and provide the fish with information about the direction, relative to the fish, of a sound source.

[5] The correct naming of this fish as *Anguilla anguilla* was found on www.fishbase.org.

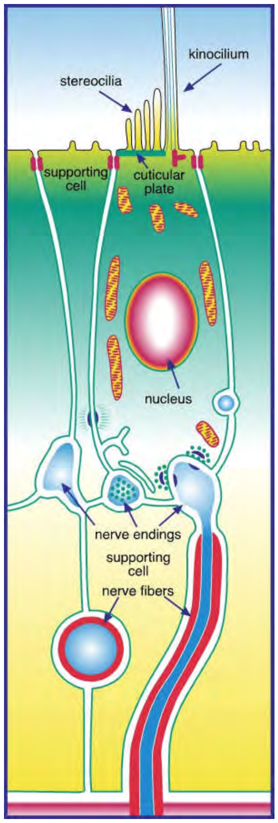


Figure B3: Schematic drawing of a sensory hair cell from a fish
The body of the cell contains structures typically found in other cells. The cell is innervated by the eighth cranial nerve. The apical (top) end of the cell, the region closest to the otolith, has a ciliary bundle consisting of a single kinocilium and many stereocilia. Bending of this bundle causes release of a neurotransmitter and stimulation of the nerve. (From Popper and Coombs 1980.)

The number of sensory cells in each of the otolithic end organs varies depending on the size of the end organ. Moreover, unlike most terrestrial animals, the number of sensory hair cells in the ear increases as the fish grows (Lombarte and Popper 1994). Although we have data for only a few species, data from the hake (a gadid) show that hair cells are added to the ear for at least nine years after the hatching of the fish (Lombarte and Popper 1994), with the number of cells reaching into the hundreds of thousands or more in larger animals. The same phenomenon is likely in most species because fishes continue to grow for much of their lives and the ear grows along with the rest of the body.

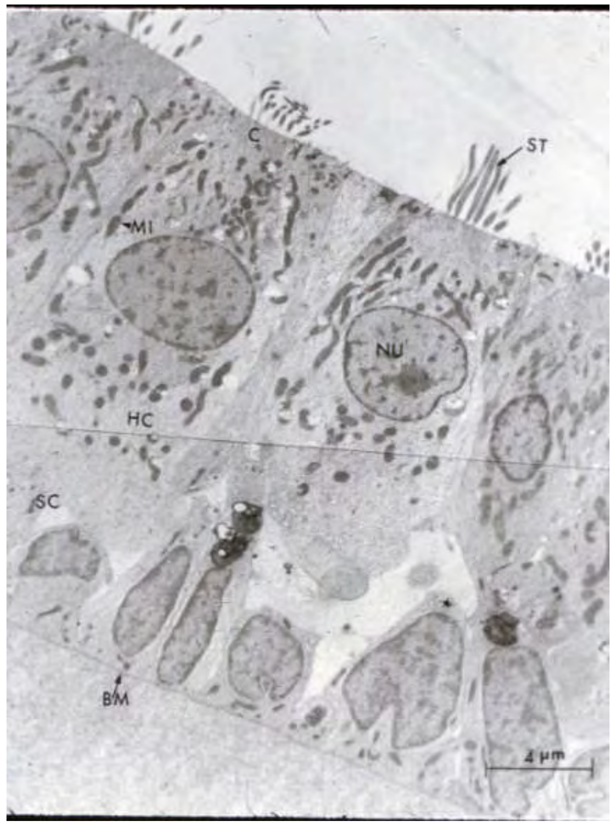


Figure B4: Transmission electron micrograph of the sensory hair cells of a moray eel, *Gynothorax* sp.
The basic structure of the ear in the moray eel is very similar to that in *Anguilla*, although no direct comparisons have been done. The stereocilia (st) are seen at the apical end of the sensory cells. The sensory cells and supporting cells (SC) that surround the sensory cells sit on the basement membrane (BM). The cells have a large number of mitochondria (MI). (From Popper 1979.)

Figure B5: Eel saccular otolith
Scanning electron micrograph of the medial side of the saccular otolith from the right ear of a moray eel (*Gynothorax* sp.). The groove is the location of the sensory epithelium (macula). Anterior (A) is to the left and dorsal (D) is to the top. (From Popper 1979.)

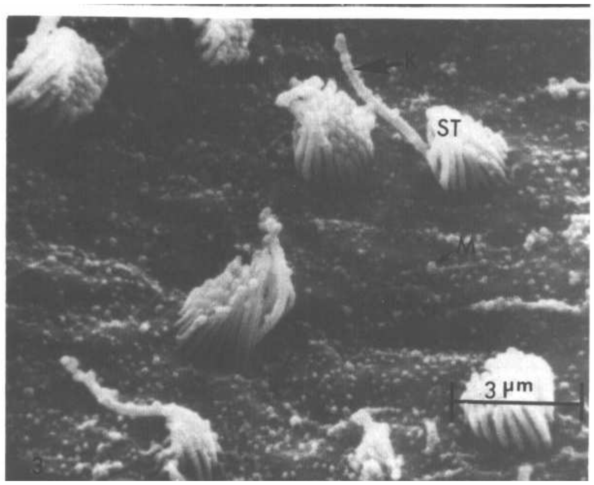


Figure B6: Eel sensory epithelium
Scanning electron micrograph of the surface of the sensory epithelium from a moray eel showing several ciliary bundles on nearby hair cells. The longest of the cilia, the kinocilium, on the lower bundles is located to the right of the cell, whereas those on the upper cells are oriented to the left. ST, stereocilia. This image represents the border between cells that are oriented in two different directions. In fish, the sensory epithelia are organized so that there are large numbers of sensory cells in each region that have similar orientations. See Figure B7. (From Popper 1979)

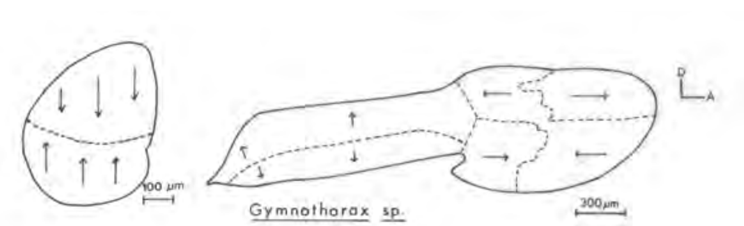


Figure B7: Eel hair cell orientation patterns
Schematic drawing of the hair cell orientation patterns from a moray eel. The saccule is on the right and the lagena is on the left. Anterior (A) is to the left and dorsal (D) is to the top. The arrows indicate the direction of the kinocilium on the sensory cells in each area of the epithelium, with the dashed lines indicating approximate borders between orientation groups. (From Popper 1979.)

Hair cell orientation patterns in the ear

The sensory epithelia in fish are organized into what is commonly known as "orientation groups." All of the ciliary bundles on the hair cells in a particular epithelial region are oriented in the same direction, resulting in an overall pattern on the epithelium (Figs. B6 and B7) that is somewhat similar in most fish. As shown in Figure B7 from a moray eel (Popper 1979), there are four hair cell orientation groups on the saccular epithelium and generally two on the lagena (and although not investigated in the moray eel, generally two in the utricular epithelium as well). The cells on the anterior end of the saccular epithelium are oriented anterior and posterior, whereas those on the posterior end are oriented dorsally and ventrally. Because these cells are physiologically polarized and respond best to signals along the axis that runs from their kinocilium posterior to the back of the cell, the cells at the anterior end of the epithelium presumably respond best to signals from front and back, whereas signals on the posterior part of the epithelium respond best to signals from up and down. It has been suggested that this information can be used to "compute" the location of a sound in the space around a fish (see Popper et al. 2003; Fay 2006).

How the ear works

It is widely believed that each otolith organ of the ears of all fishes function primitively as particle-motion detectors, potentially in both the near and far fields. For any species in which fluctuations of the swim bladder or other gas-filled cavities can stimulate the otolith organs by reradiated particle motion, the question to be answered is whether this second, indirect mechanism is actually used. In addition, the two mechanisms may operate simultaneously in the same or different otolith organs and the relative contribution of each mechanism may be frequency and level dependent.

Sound pressure thresholds and audiograms can be interpreted only for the pressure-specialized species and have little or no meaning for unspecialized species (Fig. B1). Nevertheless, it is often said that the sound pressure hearing specialists hear with greater sensitivity and over a wider frequency range than hearing nonspecialists. For most sound sources (vibrating bodies) and under many environmental conditions, specialists will be able to detect the sound at lower source levels of motion or energy, at greater distances, and at higher frequencies than nonspecialists. Specialists detect lower source levels and a given source at greater distances because of the auditory gain provided by the swim bladder, and they have a higher frequency range of hearing than nonspecialists because the underwater acoustic particle motions are smaller at the higher frequencies for a given sound pressure level.

Ancillary structures for hearing specializations

All species of fish detect sounds by detecting relative motion between the otoliths and the sensory hair cells. However, other fishes, and most notably the hearing specialists, also detect sounds using the air-filled swim bladder in the abdominal cavity (Fig. B8). The swim bladder is used for a variety of different functions in fish. It probably evolved as a mechanism to maintain buoyancy in the water column. In effect, fish can adjust the volume of gas in the swim bladder and make themselves neutrally buoyant at any depth in the water. In this way, they do not have to expend extra energy to maintain their vertical position.

The other two roles of the swim bladder are in sound production and hearing (e.g., Popper et al. 2003). In sound production, the air in the swim bladder is vibrated by the sound-producing structures, often muscles that are integral to the swim bladder wall, and serves as a radiator of the sound (see Zelick et al. 1999). The swim bladder, because it is filled with air, is also of a very different density than the rest of the fish body. Thus, in the presence of sound, the gas starts to vibrate. This is capable of reradiating sound to the ear and is potentially able to stimulate the inner ear by moving the otolith relative to the sensory epithelium. However, in hearing generalists, the swim bladder is quite far from the ear (Fig. B8) and any reradiated sound attenuates a great deal before it reaches the ear. Thus, these species probably do not detect these sounds very well. Hearing specialists always have some kind of acoustic coupling between the swim bladder and the inner ear to reduce attenuation and ensure that the signal from the swim bladder gets to the ear. In the goldfish and its relatives (e.g., catfish), there is a series of bones, the Weberian ossicles, that connect the swim bladder to the ear. When the walls of the swim bladder vibrate in a sound field, the ossicles move and carry the sound directly to the inner ear. Removal of the swim bladder in these fishes results in a drastic loss of hearing range and sensitivity.

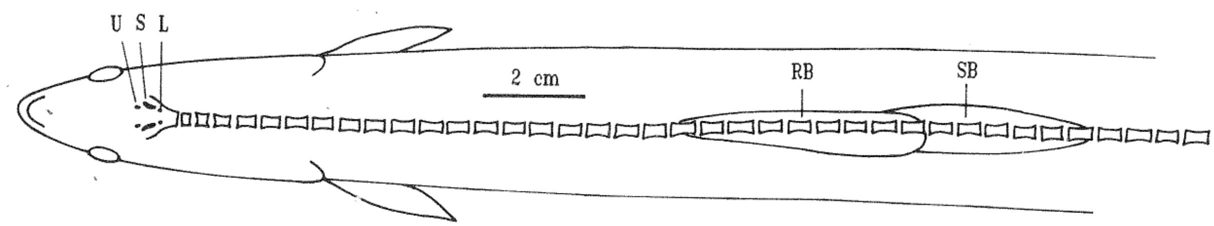


Figure B8: Swim bladder in European eel
Dorsal view of an *Anguilla* based on a radiograph of a live fish. The position of the swim bladder (RB and SB; the swim bladder is in two parts) is about 10-12 cm from the ear in a 50-cm fish. Anterior is to the left. U, utricle; S, saccule; L, lagena. (From Jerko et al. 1989.)

The other two roles of the swim bladder are in sound production and hearing (e.g., Popper et al. 2003). In sound production, the air in the swim bladder is vibrated by the sound-producing structures, often muscles that are integral to the swim bladder wall, and serves as a radiator of the sound (see Zelick et al. 1999). The swim bladder, because it is filled with air, is also of a very different density than the rest of the fish body. Thus, in the presence of sound, the gas starts to vibrate. This is capable of reradiating sound to the ear and is potentially able to stimulate the inner ear by moving the otolith relative to the sensory epithelium. However, in hearing generalists, the swim bladder is quite far from the ear (Fig. B8) and any reradiated sound attenuates a great deal before it reaches the ear. Thus, these species probably do not detect these sounds very well. Hearing specialists always have some kind of acoustic coupling between the swim bladder and the inner ear to reduce attenuation and ensure that the signal from the swim bladder gets to the ear. In the goldfish and its relatives (e.g., catfish), there is a series of bones, the Weberian ossicles, that connect the swim bladder to the ear. When the walls of the swim bladder vibrate in a sound field, the ossicles move and carry the sound directly to the inner ear. Removal of the swim bladder in these fishes results in a drastic loss of hearing range and sensitivity.

Besides species with Weberian ossicles, other fishes have evolved a number of different strategies to enhance hearing. For example, the swim bladder may have an anterior projection that actually contacts one of the otolith organs. In this way, the motion of the swim bladder wall directly couples to the inner ear of these species (see discussion in Popper et al. 2003).

The lateral line and mechanoreception

Structure and function of the lateral line

The lateral line consists of two groups of receptors located on the body surface. One group is in canals and are called canal organs, whereas other groups are located on the body surface and are called surface organs. The canal organs are primarily involved in the detection of low-frequency (e.g., below 100 Hz) hydrodynamic movements of other fish, whereas the surface receptors appear, at least in some species, to provide fish with information about general water motion and assist the fish in swimming with or against currents.

The lateral line receptors consist of the same sensory hair cells as found in the ear. However, the hair cells are organized into small groups called neuromasts, with perhaps up to 100 cells per group. The cilia from the neuromasts stick up into a gelatinous saillike structure called a cupula. Bending of the cupula caused by the movement of water particles results in bending of the cilia on the hair cell and the sending of signals to the neurons that take signals to the lateral line region of the brain. In essence, the lateral line hair cells are stimulated as a result of the net difference between the motion of the fish and the surrounding water particles.

The lateral line is involved with schooling behavior, where fish swim in a cohesive formation with many other fish. The lateral line tells the fish where the other fish are in the school and helps the fish maintain a constant distance from its nearest neighbor. The lateral line is also used to detect the presence of nearby moving objects such as food and to avoid obstacles, especially in fishes that cannot rely on light for such information, such as the cave fishes that live deep underground. Finally, the lateral line is an important determinant of current speed and direction, providing useful information to fishes that live in streams or where tidal flows dominate.

There is considerable variation in the exact pattern of the lateral line in different species. Some species have a single canal along the lateral trunk, whereas other species have multiple canals or even no canals along the trunk. Perhaps the most elaborate canal system, and the most variable, is on the head of fish. The lateral line segments on the head enable surface-feeding fish to detect and locate the source of surface waves produced by prey and may be important for making fine-scale adjustments in position in fish that form particularly tight schools.

Interactions between the ear and lateral line

It is generally thought that the ear and lateral line may be complementary systems. Both detect water motions, but whereas the ear can detect signals that come from great distances, the lateral line only detects signals that are very close to the fish. Significantly, the frequency range over which the two systems appear to work overlaps from about 50-150 Hz, although the ear can detect sounds to much higher frequencies and the lateral line can detect hydrodynamic signals to below 1 Hz.

APPENDIX C

CAPTURE, HOLDING, AND TRANSPORT METHODS THAT ARE LESS RELEVANT FOR THE ST. LAWRENCE RIVER IN THE VICINITY OF THE IROQUOIS DAM

Section 8 describes eel capture methods considered feasible for use at Iroquois Dam. Capture devices considered unsuitable that were identified in our literature review are described here.

C.1 St. Lawrence Box Trap

Design Characteristics

St. Lawrence box traps are a type of portable trap (Eales 1968) that were historically used in the eel fisheries of eastern Canada. Lacking leaders, these traps are made of several successive chambers each leading into the next through progressively smaller tunnel entrances (Eales 1968). A collecting box is located at the end of this succession. The chambers are composed of wire built around wooden supports and the collection box is also composed of wood. The traps are portable in that they are lifted out of the water to remove the catch and they can be brought back to shore for cleaning and re-deployed. These traps have been used in rivers in 1.2 to 4.9 m of water on variable bottoms composed of sand, mud, rock, or gravel.

Maintenance

Fishers report that these traps require 2-3 hrs per day to operate including time for emptying and maintenance (Eales 1968).

Cost

In 1968, this type of trap cost $40 ($252 in 2007 dollars) or more (Eales 1968).

Examples of Use and Efficiency

Historical catches were relatively small, bringing in <136 kg of eels per year (Eales 1968). It was possible for catches along the St. Lawrence to reach 500 eels (1.1-1.6 kg per eel) per day during the peak of the run which occurred early in the fall.

C.2 Swedish Box Trap

Design Characteristics

The Swedish box trap, another type of portable box trap, was historically used in the eel fisheries of Sweden (Figure C-1). These traps were composed of solid wood sides and a bottom and inner roof made from wooden boards that had been nailed together (Eales 1968). Laths (i.e., wooden strips) are nailed to the side edges to comprise the outer roof and high end. A series of laths was arranged to narrow the opening to the inner box. The overall trap was approximately 1 m in length. A horizontal opening at the low end measuring about 15 cm in height faces upstream and was the entry point for fish into the trap. A hinged side door provided access for fish removal and cleaning of the trap. Although reportedly successful in catching eels in Swedish rivers, few data are available on the efficiency of this fishing gear (Eales 1968).

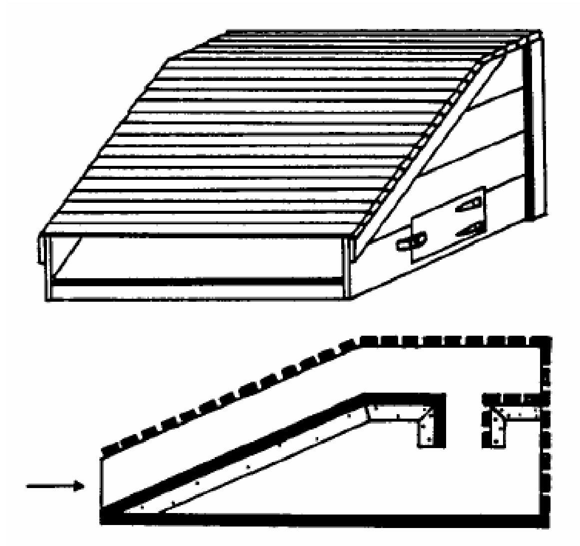


Figure C-1. Swedish Box Trap Design (after British Ministry of Agriculture, Fisheries and Food, 1959; taken from Eales 1968). Arrow indicates the direction of water and eel movement.

C.3 Trawl

Design Characteristics

A trawl net consists of a conical net attached to a moving vessel by wire warps (Figure C-2). Sweep nets form the sides of the cone and guide fish toward the cod end at the apex of the cone where fish are collected. Some designs include "otter" doors that stabilize the net and affect spread distance during towing.

Design Variation: Paired-vessel trawling

The trawl net may also be towed by two vessels traveling in tandem (Steinberg 1971; Figure C-3). The horizontal spread of the net is determined by the distance separating the two vessels. This makes otter boards unnecessary, thus reducing towing resistance. Two relatively small vessels can therefore tow large trawl nets. In German lakes, it is common to tow at speeds of 1-2 knots using a 20 hp engine. Bottom type does not matter although it is important that no obstacles occur in the path of the net. Important design consideration are net length, length of the middle legs of the net, net width, length of bridle, size of the front weights, thickness of the rope, rope weights, towing warp wire diameter, and relative speed and orientation of the vessels during fishing. One man per boat may be sufficient for operation. This type of fishing gear has been used in lakes and in rivers when the current is not strong and when there is little boat traffic.

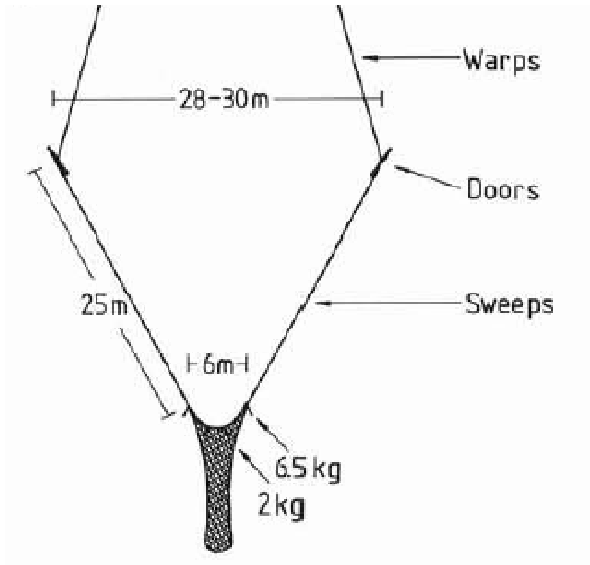


Figure C-2. Eel trawl design (taken from Riemann and Hoffmann 1991); dimensions of trawls may vary widely, depending on application and the size of the boat from which they are deployed.

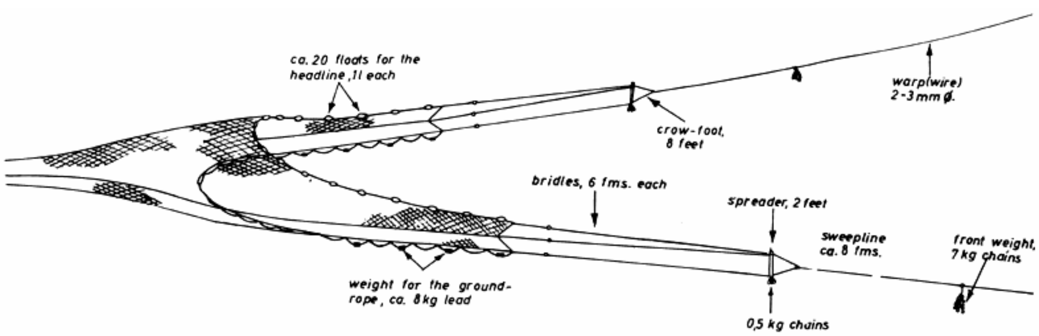


Figure C-3. Paired-vessel eel trawl design.

Examples of Use and Efficiency

Using trawl gears, the eel fishery in the Limfjord Sound (between the North Sea and the Kattegat) historically caught about 2,000 tons of eels per year; most trawling takes place during the summer. (Riemann and Hoffmann 1991). Nielsen (1985) estimated the fishing effort required for that level of catch was equivalent to trawling 3,000 m^2, or twice the area of the Limfjord Sound. Paired-trawl catches in North Germany historically yielded 300-500 eels per night (total weight 60-120 kg) (Steinberg 1971). As was described in Section 9.6.3 of this report, paired-trawls and single vessel trawls were both used to capture migrating silver eels in NYPA studies conducted in the St. Lawrence River.

C.4 Electrofishing

Electrofishing is a common technique used to collect freshwater fish. In this method, a direct current electrical pulse is discharged into the water which causes fish to move toward the positive electrode (Godfrey 1956). The electrical current renders fish momentarily stunned at which time they may be collected using a dip net. The electrical charge may be discharged either from a boat or while standing on the shore.

Examples of Use and Efficiency

Electrofishing is a very efficient method for catching eels. Godfrey (1956) reported that up to 83% of eels within the effective electrical field may be captured. Sharkey (1970) reported that a 350 V electroschocker that allowed pulse repetition frequency to be varied between 10 and 150 pulses per second yielded up to 16 lbs. of silver eels per hour. The efficiency of this method for catching silver eels has been explored in the vicinity of the Moses-Saunders Power Dam for research purposes, as was described in detail in Section 9.6.3 of this report. A comparison of electrofishing with fishing with nets found electrofishing to be a much more efficient method eels (Bahr 1957). However, environmental factors such as water conductivity, temperature, depth, and clarity can influence the efficiency of electrofishing, and injury to eels due to their electrification is of concern, as was discussed in Section 9.6.3.

Electrofishing has been reported to cause injury in American eel. Reynolds and Hoffman (2004) found that capture using a 30-Hz, pulsed, direct current caused greater internal injuries to adult American eel compared to trap-netting in the New York portion of the St. Lawrence River. Of eels caught by electroshocking, 60% had spinal damage compared to only 15% of those trap-netted. Hemorrhaging occurred in 30% of electroshocked eels but not at all for trap-netted eels. There was no difference in terms of length and weight between eels caught by trap-netting (956 mm and 1.894 g) and those caught by electrofishing (917 mm and 1.633 g). The authors recommend a lower frequency DC pulse (e.g. 15 Hz) but caution that this may result in lower capture rates.

C.5. Holding Methods

Fishing Gear and Holding Boxes

Eels may be left in submerged fishing gear or holding boxes until collection. Eales (1968) reports several eel holding mechanisms used around 1968 by commercial fishers such as hoop nets, wooden and wire boxes. For example, wooden boxes had dimensions of 3.7 m X 1.8 m X 1.2 m and 2.4 m X 0.9 m X 1.2 m and were constructed of planks that were 15.2 cm wide with 1.3 cm hardware cloth. A hatch on one side allowed access to catch and the box interior for cleaning. These holding boxes were portable and could be towed to a ship. In the U.K., Horne and Birnie (1970) reported that live boxes were used to store eels for up to two weeks. These boxes were rectangular cages made of 12 mm mesh and kept either in the river or in fresh running water. Box size was dependent upon the number of eels. For longer duration storage up to several months, shore based tanks were used. Both water temperature and aeration were controlled in these tanks.

C.6. Transport Methods

Air

For long distance travel, live eels may be packed in ice and shipped by air. Polyethylene bags perforated to allow air exchange and containing a chunk of ice may ship about 13.6 kg of eels each (Eales 1968). Mortality occurs with this method but percentage loss was not reported. Best results were obtained if eels were well-starved prior to shipping and if the eels were collected immediately upon arrival at their destination.

Historically, small quantities of live eels were shipped in tray boxes (Figure C-4) by fisheries in the U.K. (Horne and Birnie 1970). Tray boxes were constructed from wood and usually contained 4 lift-out trays of 50 mm depth. Crushed ice was kept in the top-most tray so that cold melt-water trickled down over the eels during the trip to maintain a cool temperature. There were 50 mm supports on the bottom of the box at either end inside. Overall, there were four layers of eels and one layer of ice per box. Trays were perforated by drain holes and frequently were divided at the midline resulting in a total of eight holding compartments each containing 5 kg of eels (about 40 kg per box). To prevent escape, the box lid was nailed into place and the entire box was steel-banded. Boxes of this type were used to transport eels throughout the UK and across Europe for journeys lasting up to 24 hrs with little or no mortality. Before use, the entire box was soaked in clean freshwater for several days. Trays made from expanded polystyrene were also used in Europe around 1970 (Horne and Birnie 1970). Drain holes perforating the bottom of the box in raised protrusions allowed a shallow pool of cool water to be maintained at the bottom of the box which aided in keeping the eels moist and cool. Each tray had an individual lid and multiple polystyrene boxes could be banded together and stacked in a wooden crate to prevent damage.

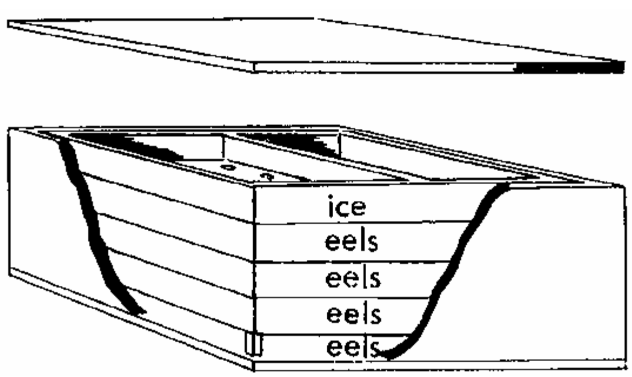


Figure C-4. Tray box.

APPENDIX D

TELEMETRY QUESTIONNAIRES

QUESTIONNAIRE SENT OUT TO THE LIST OF KNOWN VENDORS OF TELEMETRY TECHNOLOGIES

Telemetry Technologies Vendor Questionnaire

Intro

We are seeking information regarding the use of telemetric technologies for the sampling of eels and eel behavior. The information requested will contribute to the development of an eel white paper that defines the current knowledge base involving the use of hydroacoustic and telemetry technologies for assessing eels and eel behavior. The white paper will be used to guide New York Power Authority's (NYPA) future efforts to monitor and assess the behavior of eels in the vicinity of Iroquois Dam on the St. Lawrence River. Specifically, knowledge of the three-dimensional movements of eels is important to improve eel passage efforts at Iroquois Dam. However, the technology needed to monitor eel movements with fine-scale resolution at Iroquois Dam would require a reception zone of 0.6 km wide by 1 km long and 10-12 m deep and this technology may not currently exist. Therefore we are contacting researchers and equipment vendors to evaluate the status of current research using these technologies. We have contacted you seeking information regarding your product line and associated research activities.

Part 1.

Eel Studies

Has your equipment been used to investigate or document eel behavior in relation to a guidance or collection device for downstream migrating eels? If so, could you provide the citations for any manuscripts, reports, or data summaries produced from this work?

Has your equipment been used to investigate or document the behavior, specifically migratory or localized movements of any species with similar morphology as eels (e.g., lamprey)? If so, could you provide the citations for any manuscripts, reports, or data summaries produced from this work?

Has anyone conducted studies evaluating the effects of your tags or the tagging procedure on fish behavior? If so, could you provide the citations for any manuscripts, reports, or data summaries produced from this work?

If your equipment has not been used to document the behavior of eels or other surrogate species please move to the list of questions in Part 2 (below).

Study Goals and Study Design

What were the objectives of the study, and were the study objectives met?

Was telemetry sampling used as a primary or secondary investigative tool?

What was the study design in each eel application and what were the expected outcomes?

Methods

What were the components used in each application: (transmitter types and sizes, transmitter life, including information on battery size, ping or transmission rate, etc.)?

What was the primary means of transmitter attachment (internal or external)?

What were the transmitter power and reception in reference to channel depth, conductivity, habitat characteristics, water quality and potential sources of interference?

What were the design and deployment techniques of antenna and receivers used?

What type of tracking method was used (manual tracking or remotely sensed)?

What were the data reduction and analysis methods used (manual or auto-processed)?

What was the spatial resolution in the sample volume for each application (X, Y, and Z)?

Reliability and Cost

Were the components reliably functional throughout the study periods?

What were the costs associated with leasing/purchasing the gear in each application?

Can you provide names and contact information of other researchers who participated in these studies?

Part 2.

In the context of documenting fine-scale resolution movements of eels in the 0.6 km wide by 1 km long and 10-12 m deep area in front of Iroquois Dam:

In your opinion, could your gear be used for assessing eel behavior in studies involving eel guidance and deterrence?

What particular items from your product line might be applicable?

What is the anticipated reception range/area per unit deployed?

What would be the system configuration requirements needed to cover the study area?

What would be needed in terms of anchoring and attachment devices for the equipment?

What would be the power and hardwiring requirements?

What would be the electronic and communication requirements?

What is the anticipated proportion of the total study area that could be covered with the telemetry systems?

In potential future applications of your equipment for assessing eel movement:

What type of ground-truthing and/or other verification procedures would be required to determine the accuracy of the data?

What would be the data reduction and analysis methods used in such a study?

What are the estimated costs for equipment and deployment of hydroacoustic systems to monitor eel movement and behavior in relation to downstream guidance systems in a sample area approximately 0.6 km wide by 1 km long by 10-12 m deep?

What might be the constraints of using your equipment to document eel behavior in a scenario such as this?

How might these constraints be overcome (e.g. enhanced equipment or techniques) and what could be done to improve the technology in order to make it more viable for the monitoring and assessment of eels?

QUESTIONNAIRE SENT OUT TO THE LIST OF KNOWN VENDORS OF SONAR TECHNOLOGIES.

Hydroacoustic System Technologies Vendor Questionnaire

Intro

We are seeking information regarding the use of telemetric technologies for the sampling of eels and eel behavior. The information requested will contribute to the development of an eel white paper that defines the current knowledge base involving the use of hydroacoustic and telemetry technologies for assessing eels and eel behavior. The white paper will be used to guide New York Power Authority's (NYPA) future efforts to monitor and assess the behavior of eels in the vicinity of Iroquois Dam on the St. Lawrence River. Specifically, knowledge of the three-dimensional movements of eels is important to improve eel passage efforts at Iroquois Dam. However, the technology needed to monitor eel movements with fine-scale resolution at Iroquois Dam would require a reception zone of 0.6 km wide by 1 km long and 10-12 m deep and this technology may not currently exist. Therefore we are contacting researchers and equipment vendors to evaluate the status of current research using these technologies. We have contacted you seeking information regarding your product line and associated research activities.

Part 1.

Eel Studies

Has your equipment been used to investigate or document eel behavior in relation to a guidance or collection device for downstream migrating eels? If so, could you provide the citations for any manuscripts, reports, or data summaries produced from this work?

Has your equipment been used to investigate or document the behavior, specifically migratory or localized movements of any species with similar morphology as eels (e.g., lamprey)? If so, could you provide the citations for any manuscripts, reports, or data summaries produced from this work?

If your equipment has not been used to document the behavior of eels or other surrogate species please move to the list of questions in Part 2 (below).

Study Goals and Study Design

What were the objectives of the study, and were the study objectives met?

Was hydroacoustic sampling used as a primary or secondary investigative tool?

What was the study design in each eel application and what were the expected outcomes?

Methods

What were the components used in each application (frequency mode, transducer type and number used, signal parameters, multiplex)?

What was the spatial resolution in the sample volume for each application (X, Y, and Z)?

Was ground-truthing conducted to ensure that acoustic targets were indeed eels?

Did debris or other fish species confound the ability to sample eels?

What were the data reduction and analysis methods used (manual or auto-processed)?

Reliability and Cost

Were the components reliably functional throughout the study periods?

What were the costs associated with leasing/purchasing the gear in each application?

Can you provide names and contact information of other researchers who participated in these studies?

Part 2.

In the context of documenting fine-scale resolution movements of eels in the 0.6 km wide by 1 km long and 10-12 m deep area in front of Iroquois Dam:

In your opinion, could your gear be used for assessing eel behavior in studies involving eel guidance and deterrence?

What particular items from your product line might be applicable?

What is the anticipated reception range/area per unit deployed?

What would be the system configuration requirements needed to cover the study area?

What would be needed in terms of anchoring and attachment devices for the equipment?

What would be the power and hardwiring requirements?

What would be the electronic and communication requirements?

What is the anticipated proportion of the total study area that could be covered with the hydroacoustic systems?

In potential future applications of your equipment for assessing eel movement:

What type of ground-truthing and/or other verification procedures would be required to determine the accuracy of the data?

Would there be potential negative effects on the ability to sample eels associated with floating or submerged debris, or the presence of other fish species?

What would be the data reduction and analysis methods used in such a study?

What are the estimated costs for equipment and deployment of hydroacoustic systems to monitor eel movement and behavior in relation to downstream guidance systems in a sample area approximately 0.6 km wide by 1 km long by 10-12 m deep?

What might be the constraints of using your equipment to document eel behavior in a scenario such as this?

How might these constraints be overcome (e.g., enhanced equipment or techniques) and what could be done to improve the technology in order to make it more viable for the monitoring and assessment of eels?

APPENDIX E

RESPONSES TO PART 2 OF THE QUESTIONNAIRE SENT OUT TO TELEMETRY TECHNOLOGY VENDORS.

Questions are shown in italics. Respondents include Hydroacoustic Technology Inc. (HTI), Lotek Wireless (Lotek), NEDAP, and Vemco.

In the context of documenting fine-scale resolution movements of eels in the 0.6 km wide by 1 km long and 10-12 m deep area in front of Iroquois Dam:

In your opinion, could your gear be used for assessing eel behavior in studies involving eel guidance and deterrence?

All respondents answered affirmatively.

What particular items from your product line might be applicable?

HTI: HTI Model 290 Acoustic Tag Tracking System with Model 795F Acoustic Tags (8 mm diam, 18 mm length, wt: 2.2 g in air, 1.1 g in water); Model 795G Acoustic Tags (11 mm diam x 25 mm length, 3.1 g in air with approx. 45-65 day life); Model 795X Acoustic Tags (16 mm dia x 48 mm length, 13 g in air, 6 month life).

Lotek: MAP acoustic positioning system and MAP acoustic transmitters with pressure sensors (down to 11 mm diam, 48 mm length, wt: 8.5 g in air); the MA-TP11-25 transmitters are 11mm dia x 61 mm length, wt: 11 g (air) 5.5 g (water), provide 104 days life at a 5 second transmission interval; ALPS wireless positioning with submersible dataloggers (WHS 3050 or WHS 3150); other recommended transmitters include the MA-TP11-12 and MA-TP11-18.

NEDAP: the Trail ® interrogator (semi mobile detection unit), antenna junction box, and implantable Trail tags.

Vemco: VR2W (180 kHz) receiver and V16 180 kHz transmitters (release currently not scheduled); VR4 Global 69/180 receiver (initial customer evaluation of prototypes in late 2007; planned roll out in 2008) could be of interest for some locations if rapid access to detection data is desired.

What is the anticipated reception range/area per unit deployed?

HTI: the range of detection per hydrophone can be up to 1 km in acoustically quiet freshwater environments; for three-dimensional tracking at hydroelectric facilities (typically acoustically noisy sites) we usually do not exceed 100 to 150 m between hydrophones.

Lotek: typically 200 to 600 m.

NEDAP: the detection range of a station is determined by the width of the cable assembly, which normally consists of three heavy cables, 10 m distance to each other, resulting in a detection lane width of 30 m. The length of the detection lane is determined by the width of the river. It is recommended to separate the stations for at least 100 m in longitudinal direction.

Vemco: we understand that the proposed study location does not have hydroelectric generation so that the range of several hundred meters should be easily achievable (perhaps with less powerful transmitters than used in the Moses-Saunders eel telemetry studies). On-site testing is essential before one can be definitive on this.

What would be the system configuration requirements needed to cover the study area?

HTI: for three-dimensional tracking of monitoring eels at Iroquois Dam one would need approximately 50 HTI Model 590 hydrophones, a minimum of four HTI Model 290 Acoustic Tag Receivers, two SYNC hydrophones, four data collection computers, and assorted hydrophone cables. All systems will need to be synchronized by time, accomplished with handheld GPS units, satellite connections, etc.

Lotek: a 16 to 20 hydrophone system capable of three-dimensional positioning

NEDAP: depends on the required accuracy (refers to Bruijs et al. 2003 work where they used multiple detection stations covering the entire width of the River Meuse at numerous locations).

Vemco: probably similar to the Moses-Saunders project with 25 receivers in the immediate vicinity of the dam and another 13 upstream; may be of interest to place receivers downstream, and even far downstream to monitor arrival at key points. Because we anticipate significantly greater range at this location than at Moses-Saunders, fewer receivers could be used, but given the low cost of the receivers we would suggest using the larger number and using the fact that detections are logged by more receivers to improve accuracy.

What would be needed in terms of anchoring and attachment devices for the equipment?

HTI: along the face of the dam, hydrophones are typically mounted in brackets and aimed facing upstream, alternating surface and deep hydrophones. In the forebay of the dam, arrays of tensioned buoys cabled to anchors are deployed with tension lines to minimize hydrophone movement during changes in flow conditions. Anchored small floats have also been used in the past. To avoid damaged cable during high debris loads it is suggested to anchor the hydrophone cables along the bottom of the river.

Lotek: anchoring requirements would be determined during a pre-site inspection visit based upon flow, sea state, boat traffic, bottom substrate, etc.

NEDAP: The Trail interrogators are typically placed in locked cabinets along the riverside. The riverbed antennas are connected to a separate antenna junction box.

Vemco: similar to the Moses-Saunders project (hydrophones on the dam were mounted in brackets and deployed off nose piers; forebay deployments included mounting from mooring buoys).

What would be the power and hardwiring requirements?

HTI: power (120 VAC) is required for the receiver and computer stations at all times; a backup power supply along with surge protection is recommended to minimize the risk of lost data collection time. If data collection systems are to be operated during periods of extreme weather conditions (e.g., below freezing) a heat source will be required.

Lotek: MAP acoustic data logging receivers proposed for eel monitoring at Iroquois Dam are autonomous submersible units powered by battery packs.

NEDAP: The Trail interrogator is continuously operated and is powered from a main AC power source. As the power consumption is about 25 VA it could be fed from a battery using an inverter in combination with a solar panel and/or wind charger.

Vemco: no power requirements necessary as all receivers are autonomous with a battery life in excess of 1 year.

What would be the electronic and communication requirements?

HTI: electronic communication requirements include one PC (i.e., Pentium PC 1GHz with Windows 2000, 256 MB RAM, 4 GB HD) per receiver and method of time synchronization (GPS or satellite connection). Recent upgrades to Model 290 Acoustic Tag Receivers have permitted the use of satellite communication to maintain system synchronization, and to facilitate quality control and data collection transfer. Data collection transfer can be manual (i.e., USB key) or via remote log-in using a network or satellite connection. Satellite connections also permit automatic data uploads (hourly, daily, etc.).

Lotek: manual downloading of data would require a direct connection via the water tight connector; wireless data recovery involves the use of surface buoys and UHF or cellular telephone interface.

NEDAP: A GSM/GPRS data modem for communication is included in the Trail interrogator (note that the cell phone contract and SIM card is not included).

Vemco: none required if all receivers are VR2Ws.

What is the anticipated proportion of the total study area that could be covered with the telemetry systems?

HTI: the entire portion of the Iroquois Dam study area described could be covered with HTI Model 290 Acoustic Tag Tracking Systems. Depending on the study objectives, additional migration timing and survival data could be collected by deploying additional presence/absence arrays upstream and downstream of the dam.

Lotek: the entire study area

NEDAP: from the technical point of view we would be able to cover the total study area considering the technical features of the NEDAP Trail system.

Vemco: all of it plus monitoring at strategic as far as desired up and downstream.

In potential future applications of your equipment for assessing eel movement:

What type of ground-truthing and/or other verification procedures would be required to determine the accuracy of the data?

HTI: prior to deployment of a Model 290 Acoustic Tag Tracking System, the error in three-dimensional positioning would be modeled using HTI proprietary modeling software. Additional quality control testing would be conducted on site following the installation of gear by dragging a tag throughout the array and overlapping known GPS positions with the three-dimensional position estimates.

Lotek: the accuracy of position estimates produced by MAP acoustic positioning systems is verified through a series of commissioning experiments performed after system deployment and prior to release of tagged animals. During the first phase of commissioning, transmitters are moored at known locations (as determined by differential GPS) to assess the quality of the hydrophone survey, sound speed estimate, accuracy of position estimates (precision) and compared with pre-deployment performance predictions. The second phase of commissioning involves towing transmitters at various depths throughout the study area to determine overall coverage, system performance and geometric and numerical stability. Dilution of Precision (DOP) and other system generated data qualifiers measure the geometric and numerical stability of the position solutions.

NEDAP: no response given (vendor refers to previous studies conducted in the Netherlands, Belgium and Germany).

Vemco: current work on fine positioning involves a complete analysis of the performance of the positioning systems based on low cost VR2W receivers taking into account several factors including: the accuracy with which time can be synchronized; knowledge of receiver positions; relative position of receivers; and number of receivers detecting each transmission. With this in hand, little in the way of ground-truthing would be required other than a fairly straightforward on site test to verify that performance is as predicted. Based on work at Moses-Saunders, it is absolutely essential that any transmitter/receiver combination under consideration be range tested to ensure that system requirements are met.

What would be the data reduction and analysis methods used in such a study?

HTI: they would likely include a number of steps beginning with a combination of auto and manual data reduction steps using HTI's proprietary software MarkTags. three-dimensional position estimates would require use of HTI's proprietary software AcousticTag in conjunction with MS Access database software. three-dimensional position estimates can be run automatically once the data has been selected with the appropriate system parameters. Database requirements would depend on the volume of data collected, but will likely include the use of MS Access, and potentially HTI's larger database written in SQL server language.

Lotek: the MAP acoustic positioning system is supplied with BioMAP software, centralized database management tool for managing (collating, organizing) raw metadata with qualifiers. BioMAP is a Microsoft SQL based software that provides basic data query and graphics capability that permits the user to model and predict performance in the pre-deployment stage, efficiently manage very large (multi-gigabyte) data sets and export raw data in standard formats for further data reduction and analysis using third party software (e.g., ESRI, Matlab, Excel).

NEDAP: no response given (vendor refers to previous studies conducted in the Netherlands, Belgium and Germany).

Vemco: current products are supported by Vemco User Environment software which allows the user to quickly create a database of all selections from all receivers within a system and to export the data to commercial database, plotting or animation programs; Baird software associates produced animation package for NYPA studies.

What are the estimated costs for equipment and deployment of hydroacoustic systems to monitor eel movement and behavior in relation to downstream guidance systems in a sample area approximately 0.6 km wide by 1 km long by 10-12 m deep?

HTI: for the three-dimensional tracking system for the Iroquois Dam coverage described above, the 4 Model 290 Acoustic Tag Receivers, 50 HTI Model 590 hydrophones, 2 SYNC hydrophones, 4 data collection computers, and the required hydrophone cables costs would be approximately $475,000. Model 795 Acoustic Tags in quantities of 100-499 cost $275 each; Model 795X Acoustic Tags in quantities of 100-499 cost $305 each.

Lotek: the receiving equipment and software costs associated with two possible scenarios (eight node system with manual download and 16 node system with wireless download) would range in price from $71,200 to $230,000 depending on the number of nodes and download configurations. Application field support for the pre-site testing, deployment (including hydrophone survey), system commissioning and field staff training would amount to approximately $25,000 to $40,000 based on a fairly simple mooring arrangement. MAP acoustic transmitters suitable for implantation in eel (11 mm dia or less) range in price from $320 to $370 for ID only and $611 to $630 for ID plus depth. Prices associated with 16 mm dia transmitters are less costly but presumed not suitable for eel based on previous experience. Replacement batteries for the hydrophones to operate a total of 90 days would cost $4,000 to $5,000.

NEDAP: no response given (vendor refers to previous studies conducted in the Netherlands, Belgium and Germany).

Vemco: 25 to 50 receivers at $1,200 to $3,000 plus whatever number of transmitters is regarded as sufficient at $300 ($500 for pressure sensing tags) for a total up to about $250,000.

What might be the constraints of using your equipment to document eel behavior in a scenario such as this?

HTI: potential constraint to using this equipment would involve debris load. Anchoring the hydrophone cables to the bottom of the river would minimize most debris-related constraints. Given the relative shallow depth of the study area there is a potential constraint on the resolution of the depth (Z) position. In order to track in three-dimensional, the signal from the tag must be received at a minimum of four fixed hydrophones that are not located in a single plane. Typically this results in two hydrophones being deployed near the surface and two near the bottom, within each 4-hydrophone cell.

Lotek: constraints associated with acoustic positioning involve tag size vs. longevity, temporal/spatial resolution vs. tag size, tag longevity, hydrophone density and costs, and system security vs. data access. Practical acoustic positioning systems trade off resolution with costs. Because acoustic telemetry involves the propagation of mechanical energy in water (essentially relatively low frequency pressure waves), as opposed to radio telemetry involving very high frequency electromagnetic energy transfer, the potential for destructive interference is many times greater with acoustics over radio, and therefore the probability of complete and accurate ID plus depth data transmission and detection at a single hydrophone is considerably less than 100%.

NEDAP: no response given (vendor refers to previous studies conducted in the Netherlands, Belgium and Germany).

Vemco: potential constraints include the accuracy with which time can be synchronized, relative positioning of receivers and the number of receivers detecting each transmission.

How might these constraints be overcome (e.g. enhanced equipment or techniques) and what could be done to improve the technology in order to make it more viable for the monitoring and assessment of eels?

HTI: the ideal hydrophone deployment would be such that they define a cube. To the extent that the distance between hydrophones in one axis (e.g. depth) is less than in the other axes (e.g. horizontal N/S and E/W), the resolution in that dimension may be degraded to less than sub-meter. This is usually not a problem as long as the shorter dimension is not < 20% of the other dimensions.

Lotek: no response given

NEDAP: no response given (vendor refers to previous studies conducted in the Netherlands, Belgium and Germany).

Vemco: the proposed solution involves adapting existing technology to this type of application to provide fairly accurate positioning with low cost autonomous receivers which can be deployed almost anywhere. This is a clear trade-off to cabled solutions whish have the potential to provide more accurate positions but suffer the disadvantages of large cable costs and restrictions on the physical extent of the system.

ELECTRIC POWER RESEARCH INSTITUTE

APPENDIX D

ENGINEERING DRAWINGS OF IROQUOIS DAM

CONFIDENTIALITY

A. The following information is confidential information. The Bidder should only use the Confidential Information for the purpose of providing a proposal in response to the RFP entitled "*Assessment of Technologies to Study Downstream Migrating American Eel Approach and Behavior at Iroquois Dam, the Beauharnois Power Canal and the Beauharnois Generating Station*."

B. In order to preserve the confidentiality of the Confidential Information, the Bidder shall:

i) protect and preserve the confidential and proprietary nature of all Confidential Information and use the same care and discretion to avoid disclosure of Confidential Information as the Bidder uses with respect to its own confidential information;

ii) hold the Confidential Information in the strictest confidence and not disclose any Confidential Information to any persons other than the Bidder's employees or representatives of the Bidder who need to know the Confidential Information for the purposes described in the RFP;

iii) not use or make any records or copies of, or permit anyone else to use or make any copies of, the Confidential Information, except as may be required for the purposes of the Bidder's proposal;

iv) notify EPRI immediately of any loss or misplacement of Confidential Information, in whatever form.

C. In the event the Bidder is required by subpoena, court order or other similar process to disclose Confidential Information, it shall (unless prohibited from doing so by law or by court order) provide EPRI with immediate written notice and documentation thereof, so that EPRI may seek a protective order or other appropriate remedy.

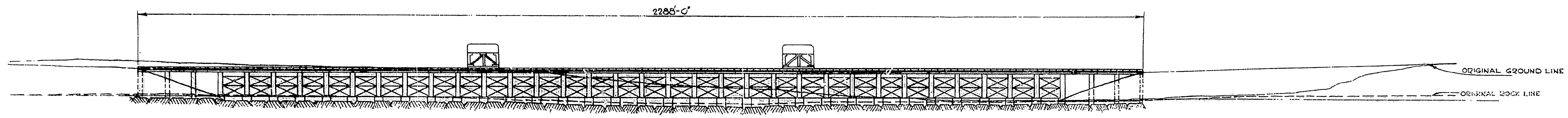
D. In no event, however, shall the Bidder disclose Confidential Information at any time which is deemed confidential by operation of law, rule, regulation or other governmental order.

E. For the avoidance of doubt, Confidential Information shall remain at all times the exclusive property of the New York Power Authority and Ontario Power Generation.

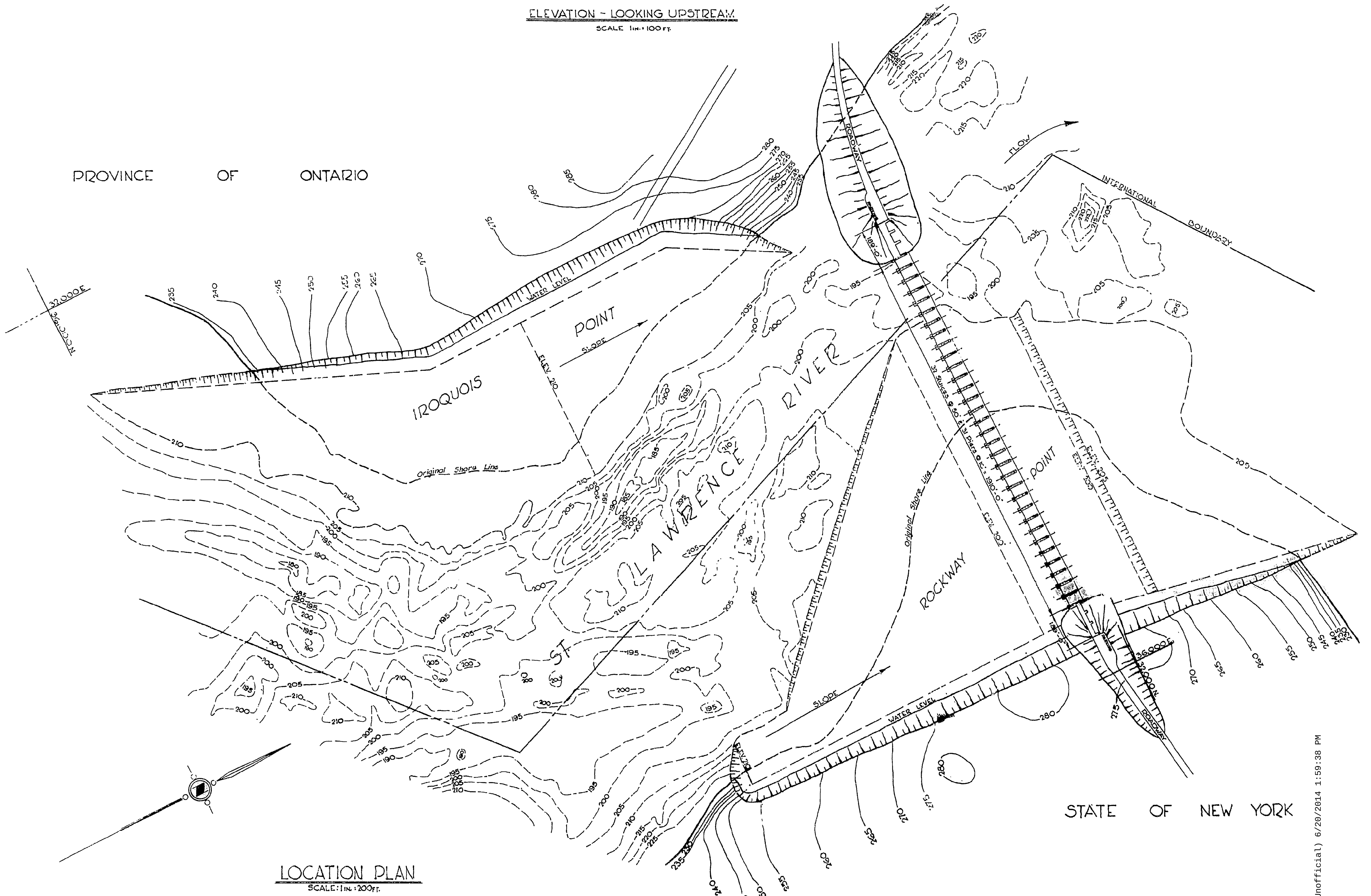
F. The Bidder shall not make any public announcements relating to this RFP without the prior written approval of EPRI.

G. The obligations of the Bidder under this Agreement shall remain in effect as long as the Bidder is in possession of Confidential Information and this Agreement shall survive termination or expiry of the Bidder's proposal.


FLOW
32 - 50FT. SLUICES & 31 - 10FT. PIERS = 1910'-0"
Bulkhead Section
Ramp
Roadway Crown EL. 260.0
Axis of Dam N32030
Apron EL.195.0
EL. 200.0
Detail A
East Abutment
U. S. A.
CANADA
West Abutment
PLAN
Scale: 1 Inch = 80 Feet
260.0 Guard rail
Gate raised
302.0
281.0
202.0
ELEVATION
Scale: 1 Inch = 80 Feet
DETAIL A (Plan at El. 255.44)
Typ Pier Plan Scale: 1 Inch = 20 Feet
Crane
H.W.L.
T.W.L.
Apron located between Piers 5 and 15 only
SECTION A
Scale: 1 Inch = 20 Feet
SECTION B
Scale: 1 Inch = 20 Feet
SECTION C
SECTION D
EAST ABUTMENT
Scale: 1 Inch = 20 Feet
SECTION E
SECTION F
WEST ABUTMENT
Scale: 1 Inch = 20 Feet
El. Varies
El. 207.0 To
El. 260.0
ST LAWRENCE RIVER
IROQUOIS CONTROL DAM
GENERAL ARRANGEMENT
AND SECTIONS
Ontario Hydro
design & construction branch
civil design
date JAN. 15, 1987
scale AS SHOWN
dwg no 160-0-2260
rev 00
00 JAN 15-87 ISSUED TO ACCOMPANY DESIGN REVIEW REPORT



ELEVATION - LOOKING UPSTREAM
SCALE 1in.=100ft.



LOCATION PLAN
SCALE: 1in.=200ft.

NOTE:
This drawing is for approval of the new location and general arrangement of the dam only, and is to accompany the memorandum to the Joint Board of Engineers, Dated Aug. 3 - 54

NOTE:
All Co-ordinates, Azimuths and distances are based on plane Co-ordinate grid and referenced to the Meridian through I.B.M. 11, whose Co-ordinate Values are 97,203.54 N, 165,278.04 E.

042109

REFERENCE DRAWINGS
Contours ------160-e-781

ST. LAWRENCE POWER PROJECT

IROQUOIS DAM
GENERAL ARRANGEMENT

THE HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
GENERATION DEPARTMENT

DRAWN	RECOMMENDED	SCALE: AS SHOWN
CHECKED		DATE: JULY 30, 1954
APPROVED H.E.P.C.		NA9-301-e-001

THE HYDRO ELECTRIC POWER COMMISSION OF ONTARIO
GEN. MGR. AND CHIEF ENG. — ASST. GEN. MGR. ENG.

THE POWER AUTHORITY OF THE STATE OF NEW YORK
CHIEF ENGINEER — GENERAL MANAGER

THE ST. LAWRENCE RIVER JOINT BOARD OF ENGINEERS
CHAIRMAN

IROQUOIS
N
PROVINCE OF ONTARIO
CANAL
FLOW
LOCK 25
NAVIGATION
INTERNATIONAL BOUNDARY
EL. 205
EL. 200
Bulkhead Section
Axis of Dam
Original shore line
Slope down
EL 210
EXCAVATION TO BE DONE BY OTHERS
IROQUOIS POINT
ROCKWAY POINT
ROCKWAY SHYE DIKE
GALOPS
ST. LAWRENCE RIVER
CANADA
U.S.A.
NEW YORK STATE
SECONDARY HIGHWAY N.Y. 37A
34,000 N
28,000 N
NOTES
All co-ordinates, azimuths and distances are based on plane co-ordinate grid and referenced to the meridian through I.B.M.11 whose co-ordinate values are 97,203.54 N; 155,278.04 E.
Elevations are based on U.S.L.S. datum 1935.
REFERENCE DRAWINGS
This plan is a tracing, combining data shown on Plans 160-d-315, 305-c-001, and St. Lawrence Seaway Authority Plans 3132 & 3750.
042017
ST. LAWRENCE POWER PROJECT
IROQUOIS DAM
GENERAL PLAN
THE HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO
GENERATION DEPARTMENT
JAN. 26, 1955
1 inch = 400
NA9-301-6-002

Document Content(s)