A CMS Energy Company

William A. Schoenlein
Manager,
Hydro and Renewable Generation

December 2, 2015

Kimberly D. Bose, Secretary
Nathaniel J. Davis, Sr., Deputy Secretary
Federal Energy Regulatory Commission
888 First Street, NE
Washington, D.C. 20426

FERC PROJECT NO. 2680-108
LUDINGTON PUMPED STORAGE PROJECT
RE: INITIAL STUDY REPORT

Dear Ms. Bose:

This letter serves as Consumers Energy Company and DTE Electric Company (collectively, "Licensees") Initial Study Report ("ISR") for the Ludington Pumped Storage Project, FERC Project No. 2680 ("Project"). Pursuant to the provisions of 18 CFR § 5.15(c)(1), this report summarizes the status of the six studies that are being conducted in support of relicensing the Project. Summaries or interim reports for each study are provided in the attachments to this letter.

The Project is located on the east shore of Lake Michigan in Mason and Ottawa Counties, Michigan. The Project's powerhouse and impoundment are located in Pere Marquette and Summit Townships (Mason County). A small satellite recreation area is located in Port Sheldon (Ottawa County), 70 miles south of the powerhouse and impoundment. The Project currently has six generating units with an authorized installed capacity of 1,657.5 MW.[1] FERC issued the Project's license on July 30, 1969 for an effective period of July 1, 1969 to June 30, 2019.

The Licensees are using FERC's Integrated Licensing Process ("ILP"). In accordance with the ILP the Licensees filed the Pre-Application Document ("PAD") and Notice of Intent ("NOI") to seek a new license for the Project on January 21, 2014. The PAD provides a complete description of the Project, including its structures, operations, and potentially affected resources.

Following the filing of the PAD, FERC prepared and filed Scoping Document 1 ("SD1") on March 20, 2014. FERC also held two agency and public scoping meetings on April 17, 2014.

[1] By an Order Amending License dated May 7, 2012, 139 FERC ¶ 62,101, FERC approved Licensees' request to upgrade and overhaul all six pump-turbine/motor generating units at the Project. This upgrade will increase the authorized installed capacity of the Project from 1,657.5 MW to 1,785 MW.

On July 7, 2014 the Proposed Study Plan ("PSP") was filed. The PSP contained the Licensees' Proposed Studies, responses to stakeholder Study Requests and a schedule for conducting the site tour and Study Plan Meeting. The site tour was conducted on July 30, 2014 and the Study Plan Meeting was held on July 31, 2014. The Revised Study Plan ("RSP") document was filed with FERC on October 31, 2014. The RSP was approved with the Study Plan Determination issued by the Commission on December 1, 2014. The following six study plans were approved by the Commission:

1. Fish and Aquatic Resources
2. Wildlife Resources
3. Botanical Resources
4. Recreation Resources
5. Historical Resources Survey
6. Archeological Resources Survey

The Licensees have study work in progress consistent with the RSP. Completion of the Fisheries and Aquatic Resources and the Recreation Resources studies is scheduled to occur during 2016. Field work has been completed for the Wildlife Resources, Botanical Resources, Historical Resources Survey and Archaeological Resources Survey. Study reports are to be completed and filed based on the FERC approved study plan schedule. Final reports will be filed with the Commission following review and comment resolution.

The Licensees do not propose to conduct any additional studies. First year study results have not identified any new resource issues. The FERC approved study plans have been and continue to be successfully implemented to assess potential Project effects on resources.

Pursuant to 18 CFR § 5.15(c)(2) a meeting to discuss the initial study results with Relicensing Participants has been scheduled for Tuesday, December 8, 2015, in Pentwater, Michigan. The Licensees filed a letter on October 22, 2015 providing the date, time, location and an agenda for the meeting.

Please contact David McIntosh of my staff at (231) 779-5506 if you have any questions.

Respectfully,

/s/ William A Schoenlein
William A Schoenlein

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ATTACHMENT 1
Fisheries and Aquatic Resources Study

Summary

Phase 1 Report

OVERVIEW OF ENTRAINMENT ABATEMENT AND ENGINEERING ALTERNATIVES FOR ENTRAINMENT REDUCTION
November 24, 2015

Phase 2 Report

EVALUATION OF ENTRAINMENT ABATEMENT TECHNOLOGIES
November 25, 2015

2015 Work Summary – Fisheries and Aquatic Resources:

In March 2015 Consumers contracted with Alden Research Laboratory to conduct the Fisheries and Aquatic Resources Study. On April 14, 2015 an initial meeting was held with Alden and representatives from the organizations that comprise the Great Lakes Fisheries Trust (GLFT) and the Scientific Advisory Team (SAT) to discuss the Fish and Aquatics Resource Study and schedule. These GLFT and SAT members (termed the Relicensing Consultation Group) were requested to provide consultation and review for the Study outside of their normal GLFT and SAT duties. A panel of experts (comprised of a fisheries biologist, a hydro engineer and a fish protection engineer) was also created to provide expertise during the conduct of the study and provide expert opinions with regard to study results.

During 2015 Alden completed the first two of the three phases of the study; Phase 1 included the identification of entrainment abatement and engineering alternatives and the identification of target species and applicable life stages, Phase 2 provides an evaluation of the entrainment abatement alternatives. Alden also began Phase 3, the evaluation of engineering alternatives.

The Relicensing Consultation Group received the Phase 1 draft results on June 30 for review. A meeting was held on July 30 with the Relicensing Consultation Group to discuss the results and address any comments or questions. A final Phase 1 report was prepared on November 24. The draft Phase 2 results were provided to the Relicensing Consultation Group for comment on October 13. A meeting was held on November 13 to discuss the results and address any comments or questions. A final Phase 2 report was prepared on November 25, 2015.

Details of the Phase 1 and Phase 2 results are contained in the attached copies of the reports.

Work on the Phase 3 engineering alternatives evaluation will continue thru the end of 2015, a draft report is scheduled to be provided to the Relicensing Consultation Group in March 2016. A meeting is scheduled with the Relicensing Consultation Group to discuss the report in July 2016 with a final report scheduled to be available in November 2016.

There were no variances to the FERC approved Fisheries and Aquatic Resources Study Plan.

Ludington Pumped Storage Project
Fish and Aquatic Resources Study

PHASE 1 REPORT

OVERVIEW OF ENTRAINMENT ABATEMENT AND ENGINEERING ALTERNATIVES FOR ENTRAINMENT REDUCTION

Prepared for

Consumers Energy Company

Prepared by

ALDEN Research Laboratory, Inc.

November 24, 2015

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Acronyms and Abbreviations

Acronym / Abbreviation	Definition
AECOM	Architecture, Engineering, Consulting, Operations, and Maintenance Company
AFB	Aquatic filter barrier
ASA	ASA Analysis and Communication, Inc.
BTA	Best Technology Available
CEATI	Centre for Energy Advancement through Technological Innovation
CEC	Consumers Energy Company
CH2MHILL	CH2M HILL Companies Ltd
CWIS	Cooling Water Intake Structure
DNR	Department of Natural Resources
DTE	DTE Energy (Formally Detroit Edison Energy)
EEI	Edison Electric Institute
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESEERCO	Empire State Electric Energy Research Corporation
FERC	Federal Energy Regulatory Commission
FFS	Filtrex Filter System
ft	Feet
FVES	Flow velocity enhancement system
GLFC	Great Lakes Fishery Commission
GLFT	Great Lakes Fishery Trust
gpm	gallons per minute
HDR	Henningson, Durham and Richardson, Inc.
Hz	Hertz
ISI	Intake Screens Incorporated
Khz	Kilohertz
LLC	Limited liability Company
LLP	Limited liability partnership
LMS	Lawler, Matusky & Skelly Engineers LLP
LPSP	Ludington Pumped Storage Project
LTD	Limited company
MIS	Modular inclined screen
m	Meter
mm	Millimeter
MDAG	Michigan Department of Attorney General
NGO	Non-Government Organization
NMFS	National Marine Fisheries Service

Acronym / Abbreviation	**Definition**
NOAA	National Oceanic and Atmospheric Administration
NYPA	New York Power Authority
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PSEG	Public Service Energy Group
PSG&E	Public Service Gas and Electric
R2	R2 Consulting, LLC
RFI	Request for information
SAT	Scientific Advisory Team to the Great Lakes Fisheries Trust
sec	Second
SENES	SENES Consultants
SWEC	Stone and Webster Engineering Corporation
USACOE	United States Army Corps Of Engineers
USBR	United States Bureau of Reclamation
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WIP	Water Intake Protection

1 Introduction

Ludington Pumped Storage Project's (LPSP) current Federal Energy Regulatory Commission (FERC) license (P-2680-108) expires on June 30, 2019. Re-licensing was initiated on January 21, 2014 when a Pre-Application Document and Notice of Intent were submitted to FERC. Initial agency consultation was held on May 21, 2014 and the agencies collectively filed a study request to "comprehensively identify and evaluate the feasibility and effectiveness of all available measures, including additional technologies and Project design and operational changes, to eliminate or reduce to the greatest possible extent, fish entrainment and mortality caused by operation of the Project."[1]

A study plan that includes a Fish and Aquatic Resources Study was approved by FERC on December 1, 2014. The goal of the Fish and Aquatic Resources Study is to identify and assess existing entrainment abatement technologies and engineering alternatives that may have potential for application at LPSP, in addition to or in place of the seasonal fish barrier net, in an effort to further reduce fish entrainment mortality. To meet this goal, the study was divided into the following primary components:

- Phase 1: Identification of Entrainment Abatement and Engineering Alternatives
- Phase 2: Feasibility Assessment of Entrainment Abatement Technologies
- Phase 3: Feasibility Assessment of Engineering Alternatives

A goal of the Phase 1 report was to identify potential data sources and technologies for the Phase 2 and 3 reports (fish entrainment abatement and engineering alternatives evaluations). Information was obtained through a literature search including Alden Research Laboratory Inc.'s (Alden's) extensive library on fish protection technologies, and by soliciting information from pertinent organizations and individuals who are known to have experience with fish protection technology design, testing, and/or installation. Phase 1 is limited to the identification and general description of potential entrainment abatement and engineering alternatives. Phase 1 provides a comprehensive list for stakeholder review to ensure a thorough study without missing an important protective measure for consideration. Phase 1 is not an evaluation of the applicability of these technologies to LPSP.

A second goal of the Phase 1 report was to develop a comprehensive list of fish species and life stages that occur in the vicinity of the LPSP. Data available from state and federal resource agencies, tribal entities, entrainment studies conducted at LPSP prior to the seasonal barrier net installation, and data collected during annual barrier net monitoring was used to develop this list.

The data and information obtained from both the identification of potential technologies and species will be used to complete the Phase 2 and 3 feasibility assessments. The Phase 2 study will include a matrix of fisheries information, to allow for a qualitative evaluation of entrainment

[1] Joint Comments and Study Request by Michigan Department of Natural Resources, Michigan Attorney General, United States Fish and Wildlife Service, Grand Traverse Band of Ottawa and Chippewa Indians, Little Traverse Bay Bands of Odawa Indians, National Wildlife Federation, and Michigan United Conservation Clubs on Licensees' Pre-Application Document and Federal Energy Regulatory Commission's Scoping Document 1 of 8 (May 21, 2014).

potential on a seasonal basis. This biological information along with site-specific engineering information will then be used to screen the list of entrainment abatement technologies to identify technologies potentially suitable for LPSP. Conceptual designs and order-of-magnitude costs of the potential entrainment abatement technologies will be included in the Phase 2 report.

In Phase 3, an engineering alternatives evaluation will be completed by reviewing the existing design and operation of the project as it relates to the entrainment of fish. The evaluation will focus on potential options for altering the design and operation of the project to reduce the entrainment of fish. Alternatives evaluated will be based on the engineering alternatives identified in the Phase 1 report. A comparison of entrainment abatement methodologies and engineering alternatives to identify whether any alternatives may be effective and where a combination of alternative methodologies may complement each other will also be completed.

The Phase 2 and 3 feasibility assessments will include:

- Applicability to the project;
- Engineering feasibility and practicality;
- Biological effectiveness for species and life stages present;
- Order of magnitude capital costs;
- Conceptual drawings;
- Operation and maintenance costs; and
- Potential impacts to project operations and reliability.

These design alternatives will be summarized in a matrix that will identify the strengths and weaknesses of each concept including the seasonal barrier net.

In addition, a biological evaluation will be completed on the engineering alternatives. This evaluation will include sufficient detail in terms of narrative, conceptual drawings and proven effectiveness at other locations for the licensees to make a decision regarding potential implementation at the project.

2 Station Description

The LPSP is located on approximately 1,000 acres along the Lake Michigan shoreline, four miles south of the city of Ludington, MI. The plant operates by pumping water from Lake Michigan during periods of low electric demand and cost to an upper reservoir where it is stored as potential energy. When both demand for electricity and the value of energy is high, the water is released and flows through one to six pump-turbine runners to generate electricity.

The LPSP was built over a period of four years between 1969 and 1973 and is jointly-owned by Consumers Energy Company (CEC) and DTE Energy (formally Detroit Edison). The project is operated by CEC and includes an 842-acre reservoir with a storage capacity of up to 27 billion gallons of water and a generating capacity of 1,872 megawatts. Each of the six penstocks leading to the pump-turbine runners is about 1,300 foot (ft) long and the diameter varies from 28.5 ft to 24 ft. The Upper Reservoir operates between water level elevations of 942 ft and 875 ft[2] for generation and pumping operations.

The Lower Reservoir (Lake Michigan) project facilities consist of the powerhouse, a concrete apron, and a tailrace formed by two combination sheet pile/rock jetties and a breakwater rock structure. Flow enters into the tailrace from Lake Michigan for pumping and exits from the tailrace into Lake Michigan during generation. A seasonal barrier net that is approximately 12,850 ft long is installed on a seasonal basis in the Lower Reservoir to prevent fish entrainment into the powerhouse pump-turbine runners.

The 516 ft wide powerhouse contains six reversible pump-turbine/motor-generator units (units). The individual units draw water from the tailrace and Lake Michigan via draft tubes which are part of the powerhouse. The top elevation of the powerhouse is 600.0 ft with the draft tube invert elevation at 522.13 ft. The draft tubes have two 30.5 ft by 22.2 ft rectangular openings where the powerhouse meets the concrete apron. The draft tubes transition to a 21.7 ft circular opening over 84.5 ft while turning 90 degrees vertically leading to the pump-turbine runners. The concrete apron extends horizontally approximately 73 ft from the powerhouse where it then slopes from elevation 522.13 ft to 551.67 ft over approximately 120 ft.

The tailrace is approximately 1,100 ft wide and 2,715 ft long, extending from the powerhouse to the center of the breakwater. The breakwater is approximately 1,700 ft long by 20 ft wide at its crest, which is at elevation 590.0 ft. There are two combination sheet pile/rock jetties that extend approximately 1,600 ft west from the powerhouse with a top elevation of approximately 590 ft to create the northern and southern tailrace channel banks. See Figure 2-1.

[2] All Water Surface Elevations are referenced to Local Project Datum (Mean Sea Level)

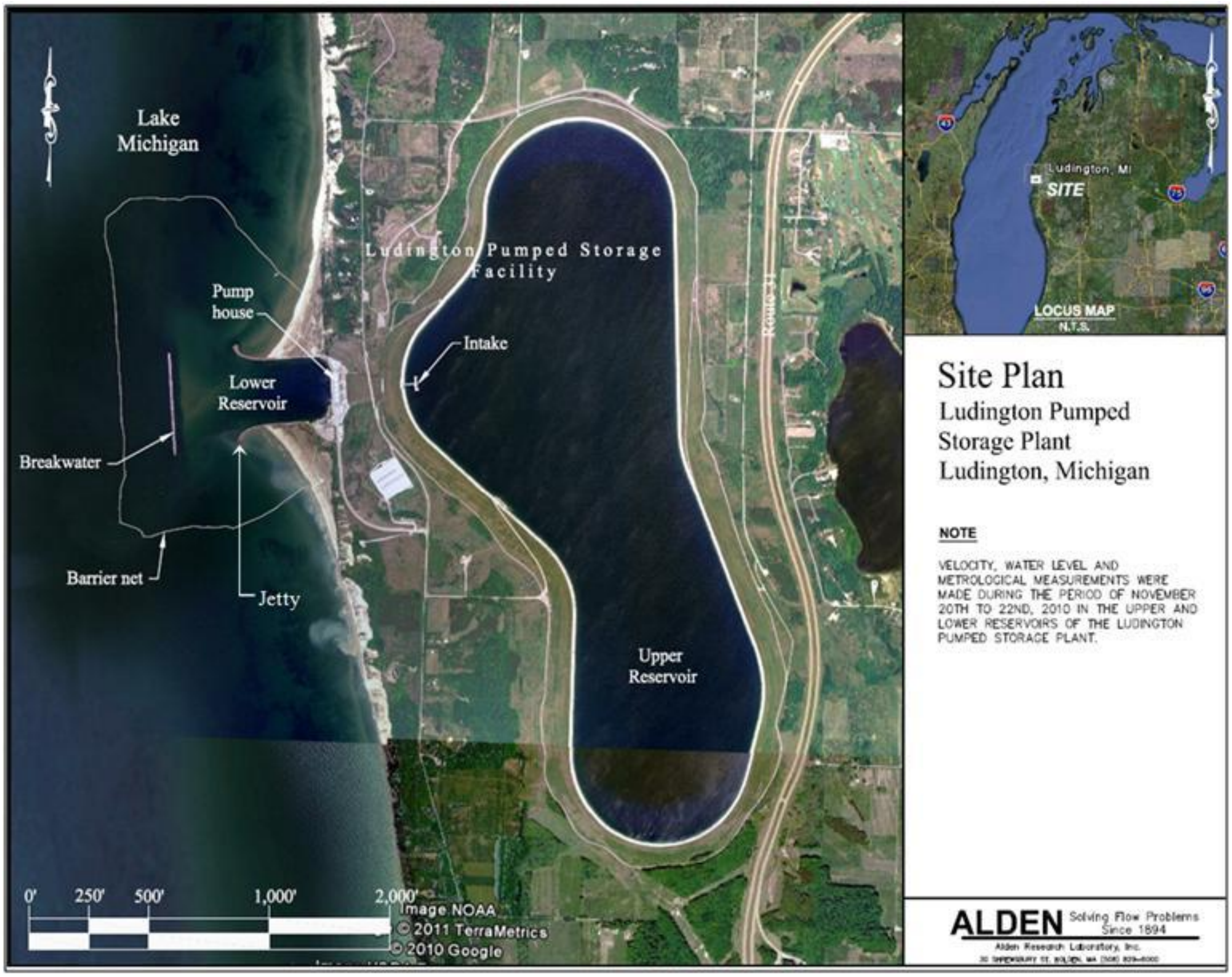

Figure 2-1: Ludington Pumped Storage Project Site Plan

3 Information Solicitation

As part of the effort to compile a comprehensive list of all available entrainment abatement technologies and engineering alternatives (existing and in development), Alden conducted a literature search and solicited information from pertinent organizations and individuals who are known to have experience with fish protection technology design, testing, and/or installation. A solicitation was also made to the Great Lakes Fishery Trust's (GLFT) Scientific Advisory Team (SAT) member organizations and other relevant individuals and organizations for biological information on the fish species and life stages that occur in the vicinity of the project. The GLFT and SAT were formed as part of a FERC-approved settlement agreement between CEC and government, non-government, and tribal organizations with the intent of ensuring appropriate fish mortality mitigation continues to be implemented at the LPSP. The following organizations are represented on the SAT:

- Consumers Energy;
- Michigan Department of Natural Resources;
- Chippewa-Ottawa Resource Authority;
- Grand Traverse Band of Ottawa and Chippewa Indians;
- National Wildlife Federation;
- DTE Energy;
- U.S. Fish and Wildlife Service;
- Michigan State University;
- Michigan United Conservation Clubs;
- Little River Band of Ottawa Indians; and
- Little Traverse Bay Bands of Odawa Indians.

For the request for information on fish protection technologies, the solicitees included:

- Universities;
- Private consultants;
- Private manufacturers;
- Government agencies;
- Tribal parties;
- Hydroelectric facility owner and operators;
- Steam electric facility owner and operators;
- Turbine manufacturers; and
- Industry organizations.

A request for information (RFI) email was distributed on May 1, 2015.

There are numerous publications, reports, and conference papers describing technologies used to minimize potential impacts to organisms at large industrial water withdrawals. Much of this information has been developed to address entrainment and impingement of aquatic organisms at once-through cooling water intakes at steam electric power generation facilities. The hydroelectric power and desalination industries have also evaluated fish protection technologies for minimizing entrainment. A comprehensive literature review was conducted using Alden's in-house library of over 7,000 fish protection references and online journal abstracts. Internet literature searches were also conducted.

3.1 Solicitation of Fish Protection Technology Information

A summary of the solicitation process and the responses to the fish protection technology RFI is provided in Table 3-1. The information gathered as part of the solicitation will be used for determining the feasibility of different fish protection technologies evaluated during Phase 2 and 3 screening of entrainment abatement and engineering alternative options, respectively. The formal information solicitation process officially concluded on July 10, 2015.

Table 3-1 Information Survey Log

Type	Organization	Number of Contacts	Sent	Response	Information Provided
Consultants	HDR	1	X	X	
	Kleinschmidt	3	X	X	X
	Turnpenny Horsfield Associates	2	X	X	X
	R2	2	X	X	
	Normandeau	2	X		
	Fishway Consulting Services	2	X	X	
	Arcadis	1	X	X	X
	Golder	1	X		
	Mead & Hunt	1	X		
	Barr	1	X	X	
	AECOM	1	X	X	
Government	PNNL	2	X		
	ORNL	1	X	X	
	USGS Conte Center	1	X	X	
	USFWS	3	X	X	
	NMFS	3	X	X	X
	USACOE Walla Walla District	1	X		
	DNR	4	X	X	X
	GLFC	2	X	X	X
	Swiss Institute of Aquatic Science and Technology	1	X	X	
Non-profit	EPRI	2	X	X	
	CEATI	1	X		
Utility	Electicite de France	1	X		
	Brookfield	1	X		
	Duke	1	X		
	Southern Company	1	X	X	X
	Exelon	1	X		
	Puget Sound Energy	1	X		
	FirstLight	1	X	X	X
Vendor	Smith-Root	1	X	X	X
	Hydrolox	1	X		
	Natural Solutions LLC	1	X	X	X
	Bilfinger	1	X		

Type	Organization	Number of Contacts	Sent	Response	Information Provided
Vendor	ISI	1	X	X	
	ProFish	1	X	X	
	Neptun	1	X		
	Fish Guidance Systems (Turnpenny Horsefield Associates)	1	X	X	X
	Ovivo	1	X	X	X
	Beaudrey	1	X		
	Evoqua	1	X	X	X
	Atlas	1	X		
Academia	University of Saskatchewan	1	X		
	University of Michigan	2	X	X	X
SAT Organizations	Consumers Energy	1	X[1]	X	X
	Michigan Department of Natural Resources	1	X[1]	X	X
	Chippewa-Ottawa Resource Authority	1	X[1]		
	Grand Traverse Band of Ottawa and Chippewa Indians	1	X[1]		
	National Wildlife Federation	1	X[1]		
	DTE Energy	1	X[1]		
	U.S. Fish and Wildlife Service	1	X[1]		
	Michigan State University	1	X[1]		
	Michigan United Conservation Clubs	1	X[1]		
	Little River Band of Ottawa Indians	1	X[1]		
	Little Traverse Bay Bands of Odawa Indians	1	X[1]		

1. The SAT has had several meetings in 2015 at which verbal requests were made for pertinent information.

Alden received technical responses from several solicitees. A brief summary of the information provided in their responses is provided below.

United States Geological Survey (USGS) Conte Center – They have not been involved with studies of any technologies comparable to what is of interest at the LPSP.

Evoqua – Provided an informational brochure on their 316(b) Best technology available (BTA) modified Ristroph fish handling traveling water screens

Natural Solutions LLC – Supplied documentation summarizing the design and testing of the Flow Velocity Enhancement System (FVES). This information was used to characterize FVES in this report.

Smith Root – Provided information on their electrical barrier that may be relevant to LPSP.

Turnpenny Horsfield Associates – Provided several studies documenting the testing and use of non-physical (behavioral barriers) and physical barriers in Europe and across the globe.

National Marine Fisheries Service – Provided a table of downstream fish passage technologies at hydroelectric projects.

FirstLight – Provided description of fish guidance technologies at the Northfield Mountain Pumped Storage Project.

3.2 Solicitation of Biological Data

Understanding the biological characteristics of affected species and life stages and how they contribute to entrainment risk and respond to technology performance will be an important component of the feasibility assessment of fish protection technologies for possible application at Ludington. The barrier net monitoring program includes extensive biological data gathered during sampling efforts conducted in the vicinity of the project over the past 25 years (1989-2014). Data from this sampling program include species, life stage, fish size, and spatial and temporal information. A large-scale sampling program was also conducted in the 1970's after the project came online. This program included extensive sampling near the powerhouse in Lake Michigan and in the upper reservoir. There are limitations associated with both of these datasets with respect to the current composition and abundance of species in the project vicinity and the spatial and temporal aspects of species and life stage presence. Consequently, the acquisition of additional information from other organizations that have conducted fish sampling near the LPSP will be important to the successful completion of the feasibility assessments of fish protection technologies.

To identify and acquire relevant biological information from other organizations, Alden and CEC issued a solicitation for biological data to state and federal agencies, tribal entities, and NGOs associated with fish sampling activities on Lake Michigan (the distribution list included all SAT member organizations). The following responses and information were received:

- Dave Clapp (MDNR): Provided extensive database with Lake Michigan fish sampling data collected from 1965-2014.

- Julie Hinderer, National Wildlife Federation (NWF): Provided a Michigan DNR report summarizing nearshore fisheries data collected from sampling locations throughout the Great Lakes, including in Lake Michigan. One aspect of this study was to assess fish community spatial and temporal trends. Ms. Hinderer also indicated a multi-agency sampling program was being conducted on Lake Michigan this summer and would include a transect near Ludington. Data from this sampling effort will be available later this year.

- Charles Madenjian (USGS): Has mean biomass densities for prey fish species developed from data collected at transect near Ludington from 2010-2014. These data are from sampling tows conducted at the depths of 18, 27, 37, 46, 55, 64, 73, 91, and 110 m.

- David Jude, PhD (University of Michigan): Provided seining data collected from several sampling locations in southeast Lake Michigan during three years (2005, 2013, and 2014).

- Charles Coutant: Provided a schematic diagram of the life cycle of the alewife (*Alosa pseudoharengus)* in relation to the Palisades plant on Lake Michigan.

- Scott DeBoe (CEC): Provided data from field studies conducted at the J.H. Campbell Power Plant on Lake Michigan.

Additional literature searches were conducted for Lake Michigan sampling data and follow-up phone calls were made to individuals who received the information requests but did not respond. As with the technological RFI, the formal biological information solicitation process officially concluded on July 10, 2015.

4 Entrainment Abatement Technologies and Engineering Alternatives

This section provides a list and brief descriptions of entrainment abatement technologies and engineering alternatives that were identified during Phase 1 efforts. The applicability of these technologies at LPSP will be evaluated in the Phase 2 and 3 studies. A review of the biological effectiveness and engineering considerations of these systems and devices is presented in detail in two recent Electric Power Research Institute (EPRI) reports; one for cooling water intake structures (EPRI 2007a) and the other for hydroelectric facilities (EPRI 2002). Both of these technology reviews are publically available on EPRI's website. Information from these reports was used to assist in the identification of potentially relevant technologies and to develop brief summaries of each one.

Fish protection technologies were categorized by mode of protection (behavioral deterrence/guidance, physical barrier/diversion, collection, or a combination of modes) and assigned as an entrainment abatement technology or engineering alternative based on the following definitions:

> *Entrainment Abatement Technologies*: Technologies that do not require substantial project structural changes to the intake project structures. These options can include behavioral barrier (e.g. electric fields, strobe light, or low frequency sound) or other non-structural (relative to the project) components such as the barrier net.
>
> *Engineering Alternatives*: Technologies that require more substantive civil/structural changes to the project/project structure. This can include options that require modifications to existing structures or a whole new structure (e.g. porous dike).

The classifications of technologies identified during Phase 1 efforts are presented in Table 4-1. These technologies represent options that have been used or considered for reducing entrainment at large water withdrawals. A screening of these options with regard to their application at LPSP will be conducted for entrainment abatement options in the Phase 2 feasibility assessment and engineering alternatives will be evaluated during the Phase 3 assessment.

Table 4-1 Fish Protection Technologies Considered for Application at Ludington

Mode of Protection	Technology	Near Shore	Off Shore
ENTRAINMENT ABATEMENT TECHNOLOGIES			
Behavioral deterrence/guidance	Sound (infrasonic, sonic, ultrasonic, impulsive/high impact)	X	
	Light (strobe, continuous)	X	
	Chemicals	X	
	Air bubble curtain, (including CO_2)	X	
	Water jet curtain	X	
	Hanging chains	X	
	Visual keys	X	
	Multi-technology behavioral system	X	X
	Modified flow systems (current inducers, FVESTM)	X	
	Hybrid behavioral barriers	X	X
Physical barrier/guidance	Barrier net	X	
	Aquatic filter barrier	X	
Physical barrier/guidance and Behavioral deterrence/guidance	Multi-technology physical/behavioral deterrent system	X	X
ENGINEERING ALTERNATIVES			
Physical barrier	Fixed screens	X	
	Narrow-spaced bar racks	X	
	Infiltration intakes	X	X
	Porous dike	X	
	Filtrex filter system	X	
	Perforated pipe screens	X	X
	Cylindrical wedgewire screens	X	X
	Closed loop pump storage system	X	
Physical diversion	Angled louvers and bar racks	X	
	Angled screens (fixed or traveling)	X	
	Angled rotary drum screens	X	
	Inclined-plane screens	X	
	Eicher screen	X	
	Modular inclined screen (MIS)	X	
	Submerged traveling screens	X	
Behavioral deterrence/guidance	Offshore intake		X
	Velocity Cap		X
	Veneer Intake	X	X
Mechanized physical barrier w/collection	Modified (Ristroph) traveling screens	X	
	Bilfinger Multi-Disc™ Screening System	X	
	HydroloxTM Screens	X	
	Beaudrey Water Intake Protection (WIP) Screen	X	
Mechanized physical barrier	Standard traveling water screens	X	

4.1 Behavioral Deterrents

Behavioral deterrents are designed to elicit avoidance responses from target species in order to prevent entrainment or guide fish to a bypass. In addition to deterrence, some behavioral stimuli (mainly light) have been investigated as means to attract fish away from intakes and into safe areas or bypasses. Some behavioral systems have been investigated in conjunction with other fish protection technologies to increase effectiveness. Brief descriptions of the various behavioral technologies that will be considered for application at large water withdrawals are provided below.

4.1.1 Sound (infrasound, acoustic, ultrasound)

Sound has been evaluated as a fish deterrent for application at water intakes for over 40 years (see EPRI 2007a for reviews of relevant studies). Three types of sound systems have been extensively evaluated: (1) infrasonic (< 50 Hertz (Hz)); (2) sonic (50 Hz to 10 kHz); and (3) ultrasonic (> 10 kHz). The most successful applications of sound have involved the use of ultrasonic signals (> 100 kHz) as a means to repel Alosinae species (Clupeidae family, including alewife, blueback herring, and American shad) (Nestler et al. 1992; Ross et al. 1993, 1996; Schilt and Ploskey 1997). The strong response of Alosines has been attributed to specialized hearing abilities that are only found in this sub-family of fish and which are thought to have developed for predator avoidance (i.e., echo-locating marine mammals). There is no evidence that any species other than those in Clupeid sub-family Alosinae can hear frequencies above about 4 to 5 kHz. Consequently, sonic sound signals (typically between 50 and 1,000 Hz) have been evaluated as a deterrent to anadromous salmonids and estuarine and riverine fishes (EPRI 1998; Goetz et al. 2001; Maes et al. 2004; PSEG 2005).

In the near field, fish response to sound is more related to particle motion than acoustic pressure (Kalmijn 1988). Particle motion is the primary component of sound in the near field and is what fish most likely sense (and respond to) when exposed to infrasonic signals (i.e., frequencies less than about 50 Hz). In the first practical application of an infrasonic device, Knudsen et al. (1992, 1994) demonstrated that a piston-type particle motion generator operating at 10 Hz was effective in repelling Atlantic salmon smolts in a tank and in a small diversion channel. In addition to the mixed results of biological studies, the limited small effective range of infrasound (10 ft to 30 ft) may be an issue at some intakes where velocities may be too high for fish to respond before escaping the intake flow. Studies investigating the effectiveness of sound deterrents indicate that the response to sound is very species specific (EPRI 2007a). Sound, like other behavioral barriers, would not reduce the entrainment of non-motile organisms.

4.1.2 Strobe Lights

The use of strobe light as a means to repel fish from water intakes has been evaluated during numerous studies over the last 25 years (EPRI 2007a). Avoidance responses have been demonstrated by a variety of fishes during laboratory and field studies. Research efforts have shown that several salmonid species can be repelled with strobe light (Nemeth and Anderson 1992; Amaral et al. 2001; Johnson et al. 2001; Maiolie et al. 2001; Mueller et al. 2001).

Clupeid species (shads and herrings) have also exhibited avoidance of strobe lights in laboratory studies, as well as at hydroelectric projects (EPRI 1992a). Unlike some salmonids and clupeids, avoidance responses of freshwater fishes have been less evident (EPRI 1998). However, several studies have indicated that some riverine/lacustrine species may avoid strobe light (McCauley et al. 1996; Amaral et al. 2001; Ichthyological Associates 1997) and that passage into water intakes may be reduced by this technology (McCauley et al. 1996). Conversely, a recent study at the Plant Barry Steam Station on the Mobile River in Alabama did not detect any reductions in impingement during strobe light operation for a wide array of species, including blue and channel catfish, freshwater drum, and threadfin and gizzard shad (EPRI 2008a).

4.1.3 Continuous Light Sources

Continuous light sources (e.g., mercury, incandescent, vapor) have been considered primarily as a method to attract fish to bypasses. Response to mercury light has been shown to be species-specific; some fish are attracted, some repelled, and others have demonstrated no obvious response (EPRI 2007a). Underwater incandescent lights have been examined as fish attractants and deterrents, and underwater fluorescent and drop lights have been tested as fish deterrents. Overhead sodium lights have been assessed as attractants. Existing station lighting also has been used in attempts to enhance bypass efficiencies.

4.1.4 Chemicals

Certain chemicals have been shown to attract or repel a wide array of organisms. Chemicals such as copper, zinc, and chlorine that are used as biocides may repel fish at sub-lethal levels (Bell 1973), however, there is only limited research on their application as repellants. More recently, semiochemicals, the chemicals that organisms use to communicate with each other, have been used to repel or attract organisms. The most recognizable semiochemicals are pheromones. Recent studies have evaluated the use of different sea lamprey pheromones to attract adult sea lamprey to traps. These studies have shown that male sea lamprey mating pheromone and sea lamprey migratory pheromone can increase the trapping efficiency enhancing sea lamprey control (GLFC 2013). Several fish species of the superorder *Ostariophysi* are known to release semiochemicals when attacked to warn the rest of the school of the presence of predators (Kapoor 2004 et al.). The use of these chemicals has not been tested for use as a fish repellent.

4.1.5 Electric Barriers

Electric barriers and guidance systems have been evaluated with wide range of fish species and sizes (Palmisano and Burger 1988; Swink 1999; Savino et al. 2001; Holliman 2010, Sparks et al. 2010; Moy et al. 2011;). In the US, most electric barrier applications have been designed to prevent upstream movement of fish (e.g., blocking non-natives or keeping upstream migrants out of hydro tailraces). Electric deterrent systems have also been investigated as means to divert downstream migrants away from hydropower intakes and have been installed at cooling water intakes (primarily in Europe) to prevent entrainment. For downstream passage and water intake applications, effectiveness of electric barriers appears to be site-specific with water velocity being an important factor. Electric screens that use DC current have been used to prevent fish entrainment at relatively low flow intakes (e.g., irrigation canals) and to prevent upstream passage of invasive fish species (e.g., sea lamprey, and Asian carp) (Verrill and Berry 1995; Swink 1999; Sparks et al. 2010) . A schematic example of an electric barrier array installed at a water intake is shown on Figure 4-1.

One manufacturer (Bilfinger) produces a unique electric fish protection system called the Electric Immobilization System that uses a short electric pulse to immobilize fish in front of modified traveling screens (Bilfinger 2015). This prevents fish from exhausting themselves before being collected by the screen. Once impinged on the screens the immobilized fish are quickly transferred by a fish lifting bucket into a fish return sluice discharging into the source waterbody.

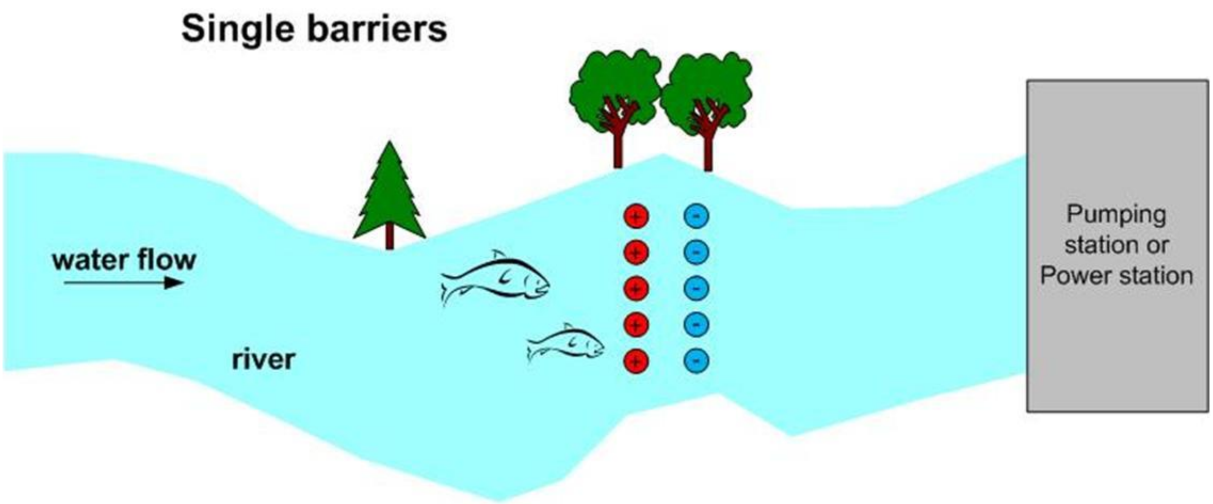

Figure 4-1 Arrangement of the NEPTUN Electric Fish Barrier at an Intake (Courtesy of PROCOM Systems)

4.1.6 Air Bubble Curtains

Air bubble curtains, operate by creating a wall of bubbles across an intake opening. An example of an air bubble curtain evaluated in a laboratory setting is provided in Figure 4-2. Air bubble curtains have been evaluated at a number of sites with a variety of species. Although air curtains have typically been shown to be ineffective (EPRI 2007a), they have been used in combination with other behavioral technologies, such as light and/or sound, to produce a more effective hybrid system. In addition to standard air injection, the use of CO_2 has also been investigated as a fish deterrent, including during recent studies targeting Asian carp (Dennis 2014) and sea lamprey (Suski et al. 2015).

Figure 4-2 Air Bubble Curtain (Courtesy of Alden)

4.1.7 Water Jet Curtains

Water jet curtains have been tested in both the field and the laboratory (Bates and Vanderwalker 1964, Stone & Webster 1976, ESEERCO 1981). Previous testing has examined the ability of water jets to exclude fish or guide them to a bypass. Chinook salmon were effectively guided using water jets (Bates and Vanderwalker 1964) and smelt and alewife were excluded from an intake (Stone & Webster 1976).

A new water jet concept, the Flow Velocity Enhancement System (FVES) developed by Natural Solutions LLC, is a Venturi pump, or “eductor”, and a pump that delivers high-pressure motive water to the Venturi (Figure 4-3). A small volume of water at high pressure is injected through narrow nozzles into a larger-diameter, underwater pipe, resulting in acceleration of larger volumes of water at lower velocity and pressure through the larger pipe. The eductor produces a plume of water consisting of a series of turbulent boils. The FVES may act as a behavioral barrier by guiding downstream migrating riverine fish that have evolved to follow turbulent river currents. The FVES has been tested at several facilities to determine its ability to guide downstream migrating fish (Coutant et al. 2013). The FVES has been tested for its ability to guide juvenile Chinook salmon on the Cowlitz River in Washington State and in the Netherlands to determine its ability to guide migrating silver eels to a trap.

Figure 4-3 The Flow Velocity Enhancement System (FVES) (Coutant et al. 2013)

4.1.8 Hanging Chains

Hanging chains for use as a behavioral barrier for fish deterrence and guidance has been tested extensively in the lab (Stone and Webster 1976, ESEERCO 1981 Patrick and Vascotto 1981). Under laboratory conditions these studies have shown the ability to divert several species, but this success has not carried over to field evaluations as demonstrated in the interim use of hanging chains at the Lambton Generating Station in 1977. The most recent evaluation of a hanging chain barrier was in 1989 (Bengeyfield & Smith 1989). In this study a chain curtain was tested as part of a hybrid barrier system (water hammer, chain curtain, and strobe lights) at Puntledge Diversion Dams to determine their effectiveness at guiding coho smolts to a bypass.

4.1.9 Visual Keys

Visual keys play an important role in fish behavior, including courtship, predator avoidance and schooling. The use of various visual keys has been investigated as means to influence fish behavior. For visual keys to work the fish need to be able to see and react to the stimuli. This limits the ability of visual keys to locations with low turbidity. Visual keys may also require artificial lighting to allow the visual stimuli to be seen at night. There has been limited research with regards to the use of visual keys for reducing entrainment at water withdrawals. Pavlov (1969) was able to reduce entrainment rates by up to 91% when compared to dark conditions, when using an artificial reference point (tree branches, weeds, etc.) in conjunction with illumination.

4.1.10 Hybrid barriers (e.g., strobe light / air bubble curtain)

Hybrid systems generally are designed to take advantage of two or more effective behavioral devices in attempts to achieve a greater level of success than would occur with any of the selected devices used alone. Also, because the effectiveness of behavioral devices can be species- and size-specific, the use of multiple devices may afford protection to a wider range of species and age classes. Often, devices that have been evaluated as an integrated fish protection system take advantage of different behavioral responses to enhance effectiveness. Many systems have been designed with behavioral deterrents (e.g., strobe lights, sound) and attractants (underwater mercury lights, overhead lights). Deterrent devices typically are placed at a location to repel or guide fish from an intake, and attractants are deployed near safe areas or bypasses. Behavioral technologies also may be used in combination with other types of fish protection devices (e.g., screens, narrow-spaced bar racks).

The results of hybrid behavioral system evaluations have been equivocal: In some cases efficiency is improved, in others efficiency is decreased. Generally, the gains in effectiveness when two or more devices have been combined as a fish protection system have not been substantial (EPRI 1994a). Though some evaluations have illustrated the potential of hybrid barriers, a study conducted with sound, strobe lights, and an air bubble curtain demonstrated that these systems used in combination or alone, did not reduce entrainment of potamodromous fishes at a hydroelectric project (Winchell et al. 1997; EPRI 1999; PSEG 2005). Fish protection systems that incorporate fish deterrent and attractant devices may be more appropriate than systems with multiple deterrents. At the Richard B. Russell Project, the use of high-frequency sound to repel blueback herring from pumpback intakes and overhead lights to attract them to low-velocity safe areas proved to be very effective. Also, Fish Guidance Systems LTD has developed hybrid systems that use sound, light, and/or air bubbles to create a stimulus "fence" that has shown some success in repelling or guiding fish at water diversions and intakes.

4.1.11 Offshore Intake

Offshore intakes may produce lower entrainment rates for large water withdrawals compared to shoreline intakes if the offshore location is an area of low biological productivity. The expectation of lower entrainment rates at offshore intakes is based on the general assumption that biological productivity is greater in nearshore habitats, resulting in greater abundances of fish, particularly early life stages (ichthyoplankton and juveniles). Offshore intakes are often designed with velocity caps or other features (e.g., narrow-spaced bar racks or wedgewire screens) to further reduce fish entrainment.

4.1.12 Velocity Cap

Velocity caps are a common feature at many submerged intakes. They offer some degree of protection to juvenile and adult fish by acting as a behavioral barrier. A velocity cap is a flat structure that sits horizontally over a submerged intake opening. The velocity cap creates a horizontal, "net-like" flow pattern rather than a vertical flow. It has been shown that fish generally respond more actively to horizontal flow accelerations than vertical flow accelerations (USEPA 1976). A sketch showing the effects of a velocity cap on flow vectors is presented in Figure 4-4.

Quantitative studies of a velocity cap versus an open-pipe intake were undertaken at the Scattergood Generating Station near Los Angeles, California during 2006-2007. The intake at Scattergood has a velocity cap and the discharge pipe is uncapped. The station is able to reverse flow and withdraw through the discharge, which it does periodically to heat-treat biofouling organisms in the intake pipe. Reduction in involvement was variable by species. Total reduction in numbers of fish entering through the capped intake was 97% compared to the open discharge (Beck et al. 2007).

As a physical structure, the velocity cap intake may offer cover to fish during severe weather events. The R. E. Ginna Power Plant on Lake Ontario has a submerged velocity cap intake located offshore at a depth of 30 ft. Lifton and Storr (1978) noted a predominance of fish on the down-wave and down-current side of the intake and a significant increase in fish numbers near the intake when wind velocities exceeded 10 miles per hour. The authors postulated that fish use the intake structure as shelter. Although an offshore intake can provide habitat structure attractive to fish, it is possible that this effect could also increase the potential for fish to be exposed to an intake resulting in increased entrainment.

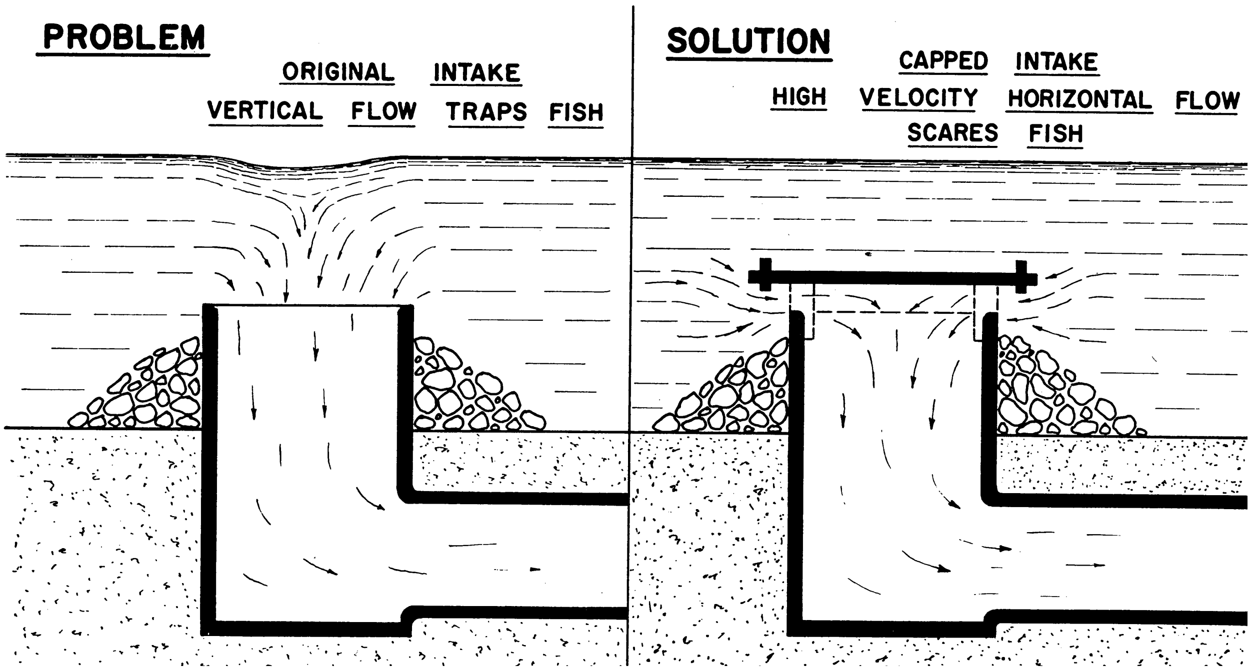

Figure 4-4 Effect of a Velocity Cap on the Velocity Vectors at a Submerged Intake (Weight 1958)

4.1.13 Veneer Intake

The veneer intake is a unique submerged intake design employed at the Darlington Nuclear Station on Lake Ontario. This intake consists of a center non-porous section located over a vertical riser pipe surrounded by a porous section with 14-cm (5.5-inches) wide slot openings, as shown in Figure 4-5. Fish protection is provided by a combination of low and uniform velocities (e.g., 0.5 ft/se average and 1 ft/sec maximum) and unwillingness of fish to pass through the openings. The results of entrainment sampling conducted at Darlington indicate that the veneer intake results in an 80% reduction in juvenile and adult fish and a 60% reduction in eggs and larvae when compared to a shoreline surface intake with no fish protection (SENES 2011). Some of this reduction may be associated with being located offshore in a less productive area.

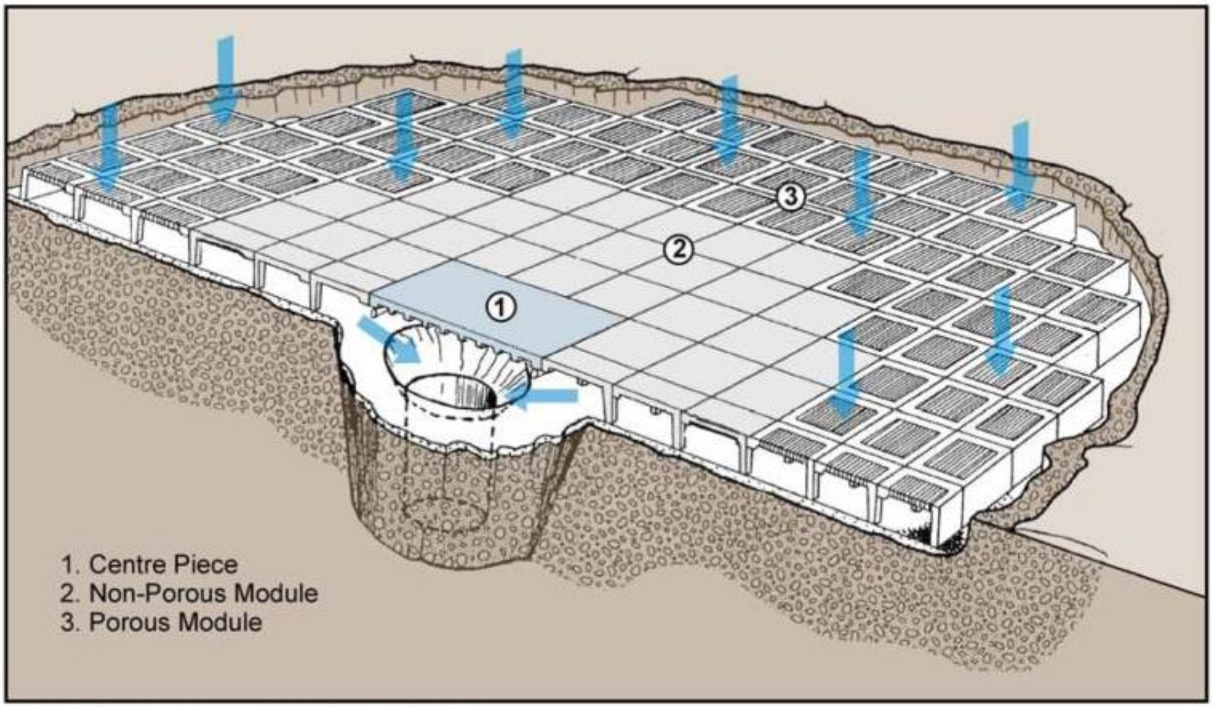

Figure 4-5 Design for Darlington Veneer Intake (Christie et al. 1984)

4.2 Fish Collection Systems

Fish collection systems operate by collecting organisms entrained within the intake flow and transporting them back to the source waterbody in a safe location. Most of these technologies are very similar to exclusion technologies except they have design features to improve their biological efficacy.

4.2.1 Coarse-mesh Traveling Water Screens Modified for Fish Protection

Conventional traveling water screens (detailed later under physical barriers) were originally designed to prevent debris in the cooling water at thermal power plants from clogging the steam condensers. Beginning in the 1970s, these traveling screens were modified to improve the survival of fish collected on the screen mesh. The modifications included continuous operation of the screens, addition of a fish lifting bucket, addition of a low-pressure spraywash, and a fish friendly return to the source waterbody. The first modifications to traveling screens to protect fish were made in 1976 at the Surry Station on the estuarine portion of the James River in Virginia. The Ristroph screen, named for the engineer who designed them, had a screen basket equipped with a water-filled lifting bucket to hold collected organisms as they were carried up with the rotation of the screen (White and Brehmer 1977). As each bucket passes over the top of the screen, fish are rinsed into a collection trough by a low-pressure spraywash system. Once collected, the fish are transported using gravity or fish-friendly pumps through a fish return line back to a safe release location in the source waterbody. Modified screens typically operate continuously to reduce impingement duration. Such features have subsequently been incorporated into through-flow, dual-flow, and center-flow screens.

Advances in Ristroph screen design have been developed through extensive laboratory and field experimentation. Hydraulic buffeting in the fish lifting buckets, which was identified as an injury mechanism by Fletcher (1990), was reduced through improvements in bucket design during the 1980s and 90s. A sketch showing the change in hydraulic conditions in an old style and a Fletcher modified bucket is provided in Figure 4-6. Evaluations of the latest generation of modified traveling screens have generally shown improved survival over previous screen designs (PSEG 1999; PSEG 2004; Beak 2000a, 2000b; Fletcher 1990; Consolidated Edison 1996).

Laboratory evaluations by the Electric Power Research Institute (EPRI 2006a) evaluated the mortality, injury, and scale loss rates of 10 species of freshwater fish impinged and recovered with a modified traveling screen. Survival of juvenile and adult fish off coarse-mesh modified traveling water screens is species specific. The United States Environmental Protection Agency (USEPA) has identified coarse-mesh modified traveling water screens as a best technology available in the Final 316(b) Rule to reduce impingement mortality of juvenile and adult fish (USEPA 2014).

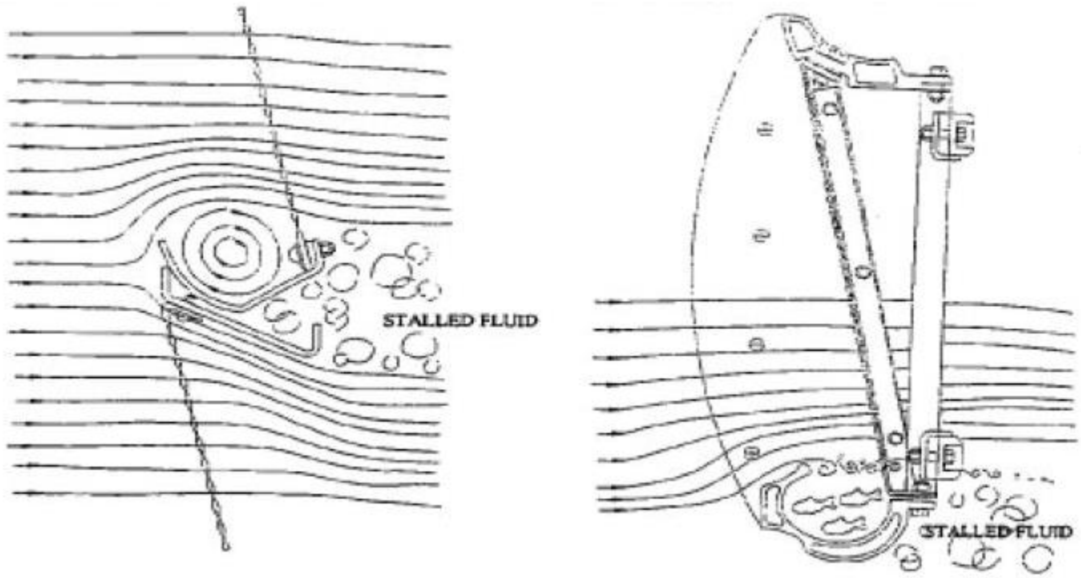

Figure 4-6 Section of an Old Fish Basket Design (Left) and a New Fish Basket Design (Right) Illustrating the Flow Field Created by Each (Ronafalvy et al. 2000)

4.2.2 Fine-mesh Traveling Water Screens Modified for Fish Protection

In addition to the fish handling provisions noted above, traveling water screens have been further modified to incorporate screen mesh with openings as small as 0.5 mm to collect fish eggs and larvae and return them to the source waterbody. For many species and early life stages, mesh sizes of 0.5 to 2.0 mm are required for effective screening (Figure 4-7). These meshes can either be installed on a permanent basis or seasonally when eggs and larvae are present. Through-flow, dual-flow, and center-flow screens can all be fitted with fine-mesh screen material. Generally, fine-mesh screen systems have proven to be reliable in operation and have not experienced unusual clogging or cleaning problems as a result of the small mesh size. The potential for clogging with fine-mesh cannot be ignored, however, as site-specific factors may lead to increased clogging.

A number of fine-mesh screen installations have been evaluated for biological effectiveness at power plant intakes. Results of these studies indicate that survival is highly species- and life stage-specific. Species such as bay anchovy (*Anchoa mitchilli*) and *Alosa* spp. have shown low survival, while other species such as striped bass, white perch, yellow perch and invertebrates show moderate to high survival. Therefore, evaluating fine-mesh screens for potential application at a water intake requires careful review of all available data on the survival potential of the species and life stages to be protected. Pilot scale studies at the site being considered may be recommended if available data are limited. In addition to field studies, fine mesh screen survival data is available from extensive laboratory studies (Taft et al. 1981, ESEERCO 1981, SWEC 1980). In these studies, larval life stages of striped bass, winter flounder (*Pseudopleuronectes americanus*), alewife, yellow perch, walleye (*Sander vitreus*), channel catfish (*Ictalurus punctatus*), and bluegill were impinged on a 0.5-mm screen mesh at velocities ranging from 0.5 to 3.0 ft/sec and for durations of 2, 4, 8, or 16 minutes. As in the field evaluations, survival was variable among species, larval stages, impingement duration, and velocity.

Figure 4-7 Traveling Water Screen with Fine-mesh Overlays (Courtesy of Alden)

4.2.3 Bilfinger Multi-Disc™ Screening System

Bilfinger (formerly Passavant-Geiger) Multi-Disc Screens (Multi-Disc) are a variation on traveling water screens. The main components of the Multi-Disc screens are the sickle-shaped mesh panels, one central chain guide-way integrated in the supporting structure, one revolving chain, one lower guide, a spray water device, debris/fish buckets, a debris/fish collection/return trough, a drive unit with overload protection, and a splash guard. A Multi-Disc screen is shown in Figure 4-8. The drive unit for Multi-Disc screens is directly mounted on the main shaft, eliminating the need for an additional chain-drive assembly. The drive unit can operate the screen at variable speeds between 16 and 71 ft/min. There are no rotating elements (shafts, wheels, or bearings) permanently submerged and exposed to the raw water, allowing all maintenance work to be carried out at the operating deck level without dewatering the screen bay.

These screens have a through-screen flow pattern with raw water flowing directly through the mesh panels without change in flow direction. The total submerged screening area (the descending and ascending mesh panels as well as mesh panels in the lower guiding section) screens raw water. Fish and debris are retained on the mesh panels and moved in debris/fish buckets to the discharge position above deck as the screen band travels through the water column. The screen panels can be fitted with meshes as small as 0.5 mm. Fish impinged on the mesh below this bucket are sluiced via an opening in the lower panel frame into the bucket of the adjacent mesh panel below. As each screen panel rotates to descend for another cleaning cycle, a spraywash system washes fish and debris remaining on the screen into the fish/debris bucket where they are transferred to a return trough located at the upstream side of the head section and then routed to a common fish return trough on the downstream side of the screen. Both the ascending and descending side of the screen are located on the upstream side eliminating debris carryover. This feature also results in the intake water only needing to pass through the screen once, limiting head loss.

These screens have been used extensively in Europe and are currently being used at several facilities in the United States. The DC Cook Nuclear Power Plant, located on Lake Michigan, was the first major installation in the US. The screens at this facility do not have fish buckets. Currently the Salem Generating Station is in the process of evaluating Multi-Disc Screens with a smooth drilled plastic mesh and other fish protection features. The Potomac Generating Station (Potomac) in Maryland recently retrofitted their intake with Multi-Disc Screens. One of the screens at Potomac incorporated fish protection features and was used to study the biological efficacy of these screens. An in-situ pilot study of Multi-Disc screens was conducted in 2007 at Potomac (EPRI 2007b). During this study, overall impingement numbers were low, but the survival of the impinged fish was comparable to that seen on modern Ristroph-style screens.

Figure 4-8 Bilfinger Multi-Disc Screen with Fish Lifting Buckets (Courtesy of Bilfinger)

4.2.4 Hydrolox™

Hydrolox Inc. (Hydrolox) has developed a polymer-based traveling screen with fish handling capabilities. This screen's operation is similar to conventional traveling screens with a few significant differences. The screen material and the sprockets are made of a lightweight polymer, which results in a lighter weight screen compared to standard traveling water screens. Because the screen mesh is made out of molded polymers the minimum mesh size is limited to

1.75-mm. Also, the top sprocket of the screen is offset from the bottom sprocket allowing gravity to assist in fish/debris removal as shown in Figure 4-9.

Hydrolox screen has several advantages when compared to more conventional screens. Using polymers instead of steel or other metals reduces the cost of the screens and replacement parts as compared to other fish-friendly traveling water screens. With lighter weight materials, the operating costs of these screens are also reduced. By going beyond vertical, the descending side of the Hydrolox screen has improved debris handling and removal characteristics. Hydrolox screens use a single continuous mesh and have no moving parts under water reducing the amount of effort required to replace the screen mesh and conduct routine maintenance on the screen.

Recent laboratory testing of Hydrolox screens has shown that impingement survival rates for several freshwater species are comparable to those observed in laboratory tests using more traditional modified traveling screens. Hydrolox screens both with and without fish protection features have been installed at several fossil-fuel and hydroelectric power plants, as well as several small water diversions. A test screen with fish handing capabilities was tested at the E.F. Barrett Generating Station on Long Island, New York (ASA 2008). Despite initial operating issues, the screen operated successfully during the tests. The impingement survival was comparable to the higher range achieved with other traveling water screens with fish protection features and was higher than that from the conventional traveling water screen in an adjacent screen bay. The only species that showed significant mortality were Atlantic menhaden and bay anchovy; both of which are known to be highly susceptible to stress-induced mortality.

Figure 4-9 Hydrolox Screen Mesh and Fish Bucket (Courtesy of Alden).

4.2.5 Beaudrey Water Intake Protection (WIP) Screen

Beaudrey Water Intake Protection (WIP) Screens are the most recent variation of a traveling water screen. As with the other recently introduced collection systems, the WIP screen has several features that are improvements over more conventional screens. These screens incorporate large, filter disks that are divided into several pie-shaped wedges that rotate on a center axle (Figure 4-10). Each screen filter disc rotates perpendicular to the net intake flow, eliminating any potential for debris carryover. As the disk rotates, each "wedge" passes under a stationary suction scoop mounted over one section of the filter disc. Fish and debris impinged on the screen are removed under suction as they rotate past the scoop. A fish-friendly pump, one which is designed to handle fragile materials, is used to transport impinged organisms and debris to a return trough. The filter discs rotate at approximately 2 rotations per minute, limiting the maximum impingement time to 30 seconds. This screen was tested in 2008 at Omaha Public Power District's North Omaha Station located on the Missouri River (EPRI 2009). The results of this study showed good survival of fish and other organisms removed from the screens.

Figure 4-10 Beaudrey WIP Screen (Courtesy of Beaudrey)

4.2.6 Fish Pumps

Several pumps have demonstrated the ability to safely transfer fish with little to no mortality. These pumps can be used as a standalone technology where the flow is withdrawn through the pumps and does not undergo additional processes that could harm fish and where there is access to sufficient habitat for fish that pass through the pumps, such as dilution and flood control pumps. However, they are more commonly used when coupled with a collection system such as WIP Screens or fish guidance systems such as angled screens and louvers. Several pumps, including the Hidrostal and Archimedes screw pumps, have undergone extensive evaluation and demonstrated the ability to transfer fish with little or no mortality (Liston et al. 1993; ESEERCO 1981; Frizell et al. 1996; McNabb et al. 2003; Weber et al. 2002). Recently a fish-friendly axial pump has been successfully tested in Europe (Vis H. & Kember, 2012). The three species evaluated in this test (Anguillidae, Cyprinidae, and Percidae) all showed 100% survival under test conditions. A Hidrostal pump system was tested with fish eggs and larvae at the Big Bend Station in Tampa, FL. Survival was high for all aquatic organisms (Brueggemeyer et. al., 1988)

Fish pumps can be used in conjunction with other collection or diversion technologies to transport fish to a safe location. Fish pumps can also be used as a standalone option if the pumped system is designed to limit physical or chemical stress on the organisms and return them to a safe location.

4.3 Diversion Systems

Fish diversion systems operate by guiding fish to a bypass that returns them to the receiving waters. Bypasses can be either gravity or pump-fed depending on the specific technology and site characteristics.

4.3.1 Louvers and Angled Bar Racks

Louvers and bar racks both use evenly spaced, vertical slats to guide fish to a bypass. The spacing of the slats can act as a physical barrier for many larger fish and a behavioral barrier for smaller fish. Louver slats are oriented perpendicular to the approaching flow, whereas bar racks have slats positioned at perpendicular to the support structure (Figure 4-11). At steeper angles, bar racks can produce hydraulic conditions similar to those of louvers. Results of louver/bar rack studies to date have varied by species and site. Numerous studies have demonstrated that louvers and angled bar racks can have guidance efficiencies as high as 80 to 95% for a variety of species over a wide range of conditions (EPRI 1986; Stira and Robinson 1997; Bowen et al. 1998; Amaral et al. 2002). Most of the louver installations in the U.S. are in the Pacific Northwest at water supply intakes in riverine environments and at hydropower intakes in the Northeast.

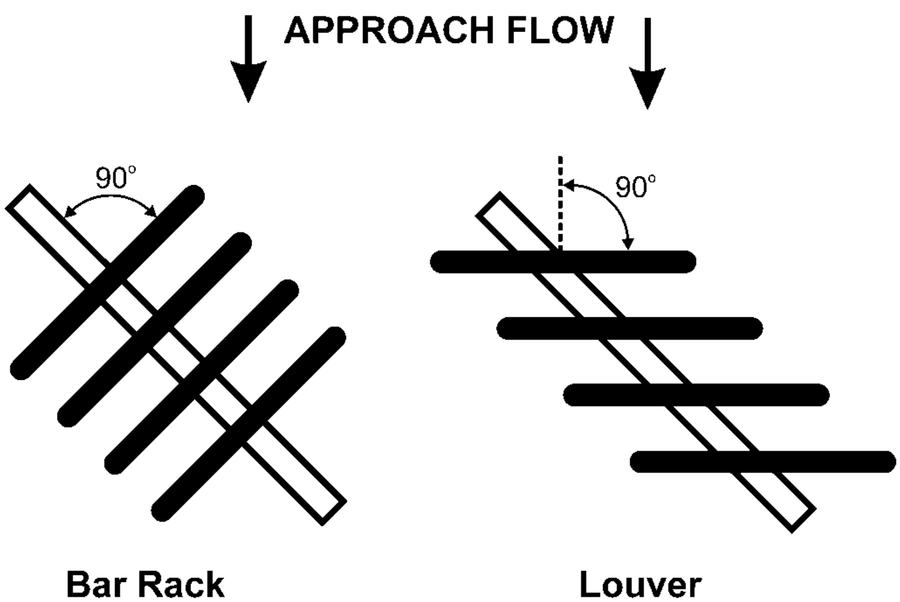

Figure 4-11 Orientation of Angled Bar Racks and Louvers Slats. The Structures Depicted Are Angled at 45 Degrees to the Approach Flow (EPRI 2001)

4.3.2 Angled Screens (fixed, traveling, and rotary drum)

A variety of species have been shown to guide effectively on screens given suitable hydraulic conditions. Angled screens work by guiding fish past an intake and into a bypass, similar to louvers and angled bar racks. The main difference between these technologies and angled screens is that angled screens typically have finer spaced openings, that act as a physical barrier to larger and smaller fish. An example of an angled screen system is shown in Figure 4-12. Angled screens require uniform flow conditions, a fairly constant approach velocity, and a low through-screen velocity to be biologically effective. Angled screen systems have been installed and biologically evaluated at a number of water intakes on a prototype and full-scale basis. Angled screen diversion efficiency varies by species but has generally been high for the many species evaluated (LMS 1985, 1992; Davis et al. 1988). Survival following diversion and pumping (to return fish to their natural environment, as required) has been more variable. Overall survival rates of relatively fragile species following diversion may not exceed 70%. Hardier species should exhibit survival rates approaching 100% (LMS 1985, 1992; Davis et al. 1988).

Angled fish diversion screens leading to bypass and return pipelines are being used extensively for guiding salmonids in the Pacific Northwest (Neitzel et al. 1991; EPRI 2007a). These screens are mostly of the rotary drum or vertical, flat panel (non-moving) types. Other angled screen applications have involved the use of conventional traveling water screens modified to provide a flush surface on which fish can guide to a bypass. Like other angled screens, suitable hydraulic conditions at the screen face and a safe bypass system are required for the screens to effectively guide the fish protecting them from entrainment and return them to the source water body (Pearce and Lee 1991).

Figure 4-12 Angled Hydrolox Traveling Water Screen Diversion System (Courtesy Hydrolox)

4.3.3 Eicher Screen

The Eicher screen is a passive pressure screen that has been proven effective for diverting salmon at hydroelectric projects. These screens are composed of a flat wedgewire panel placed at a shallow angle (15-20^{o}) within a section of penstock, as shown in Figure 4-13. As fish move through the penstock, they encounter the screen and are diverted to a fish bypass where they are transported downstream of the dam. The slot size used on these screens varies from approximately 1.0 mm to 3.2 mm wide. Better hydraulic performance through the screens can be achieved by varying the slot width along the length of the screen with a narrower mesh on the bottom, upstream end and a wider slot on the upper, downstream end.

The first prototype of an Eicher Screen was constructed and installed in a 9-ft diameter penstock at a hydroelectric project in the Pacific Northwest. Field testing of the screen conducted in 1990 and 1991 demonstrated that the Eicher screen effectively diverted over 98% of the steelhead, coho, and chinook smolts (EPRI 1992b). Dual Eicher screens were installed at B. C. Hydro's Puntledge Project and have been an effective downstream passage system for juvenile salmonids. Survival of chinook and coho salmon smolts exceeded 99%, and survival of steelhead, sockeye, and chum salmon fry was 100%, 96%, and 96%, respectively, at penstock velocities up to 6 ft/sec (Smith 1997).

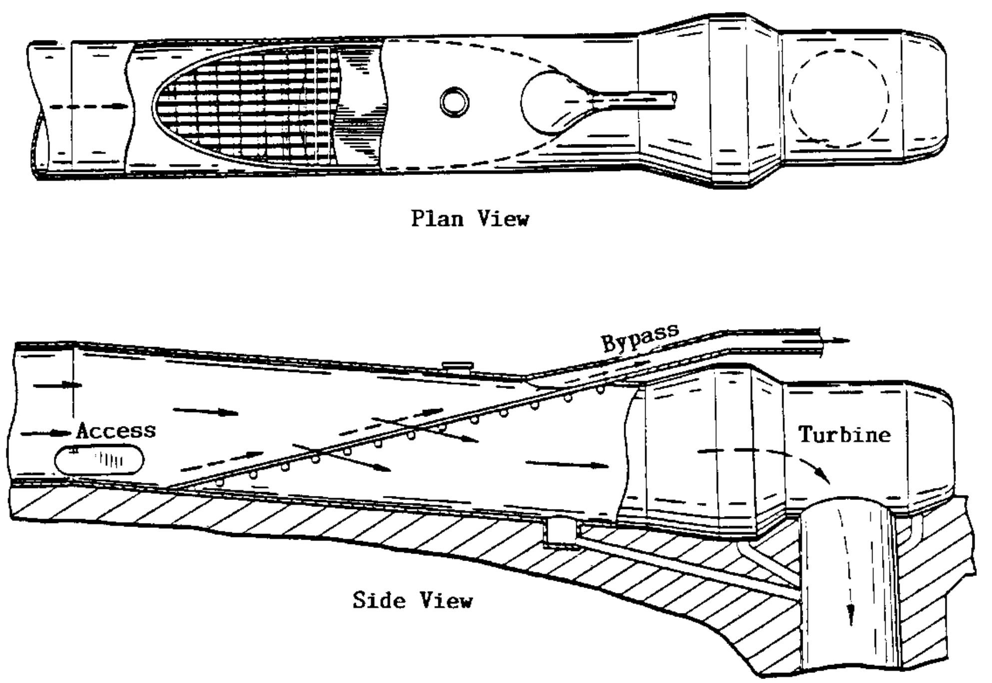

Figure 4-13 Eicher Screen (Wert 1988)

4.3.4 Modular Inclined Screens

The Modular Inclined Screen (MIS) was developed and tested by EPRI (EPRI, 1994b, 1996; Amaral et al.1999). The MIS is designed to protect juvenile and adult life stages of fish at all types of water intakes. An MIS module consists of an entrance with trash racks, dewatering stop logs in slots, an inclined screen set at a shallow angle (10 to 20 degrees) to the flow, and a bypass for directing diverted fish to a transport pipe, as shown in Figure 4-14. The screen is made of flat panel wedgewire with slots aligned parallel to the flow. The only slot size tested to date is 2.0 mm. The module is completely enclosed and is designed to operate at relatively high water velocities ranging from 2.0 to 10.0 ft/sec, depending on species and life stages to be protected.

The MIS was evaluated in laboratory studies to determine the design configuration which yielded the best hydraulic conditions for safe fish passage and to determine the biological effectiveness of the optimal design in diverting selected fish species to a bypass (EPRI 1994b; Amaral et al. 1999). Biological tests were conducted in a large flume with juvenile walleye, bluegill, channel catfish, American shad, blueback herring, golden shiner, rainbow trout (two size classes), brown trout (*Salmo trutta*), Chinook salmon (*Oncorhynchus tshawytscha*) , coho salmon (*Oncorhynchus kisutch*), and Atlantic salmon (*Salmo salar*). Screen effectiveness (diversion efficiency and latent mortality) was evaluated at water velocities ranging from 2.0 ft/sec to 10 ft/sec and screen slot openings of 2.0 mm. Diversion rates approached 100% for all species, except American shad and blueback herring, at water velocities up to at least 6 ft/sec. Based on the laboratory results, a pilot-scale evaluation of the MIS was conducted at the Niagara Mohawk Power Corporation's Green Island Hydroelectric Project on the Hudson River near Albany, NY (EPRI 1996; Amaral 1999). The results obtained in this field evaluation with rainbow trout, largemouth and smallmouth bass, yellow perch, bluegill, and golden shiners were similar to those obtained in laboratory studies (Taft et al. 1995).

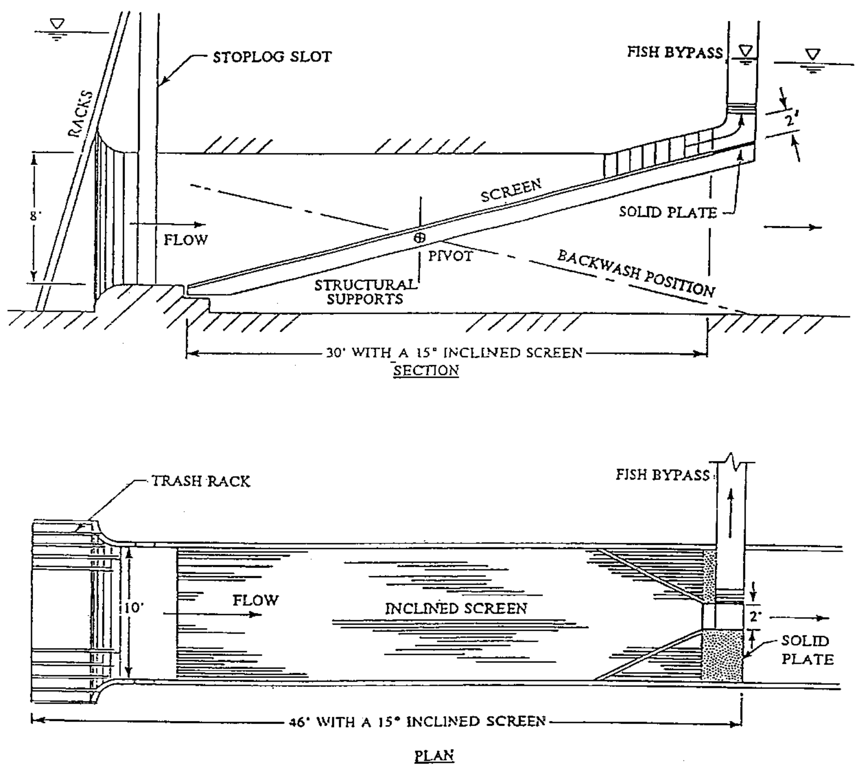

Figure 4-14 Modular Inclined Screen (Taft et al. 1995)

4.3.5 Inclined-Plane Screens

Inclined-plane screens function by diverting fish upward in the water column and into bypasses. Inclined-plane screens have been reasonably successful in several small-scale applications at hydroelectric projects. Several types have been investigated for diverting fish (primarily salmonids) to bypasses. In some cases, the screens are used to "skim" downstream migrants from surface waters of power pools to a collection area. Once concentrated, the fish are transported to a release point. To date, this technology has only been used at relatively low flow intakes.

4.3.6 Horizontal Traveling Water Screens

Horizontal traveling water screens are similar to the traveling water screens used as part of an angled screen guidance structure. The difference is that the screen rotates horizontally transporting debris and impinged organisms downstream past the intake or to a bypass entrance. Hydrolox Inc. has recently started manufacturing horizontal traveling water screens for use at irrigation intakes (Hydrolox 2013).

4.3.7 Surface Collectors

Surface bypass and collection systems are downstream passage devices designed to take advantage of a known fish behavior to facilitate passage around hydro projects. Outmigrating juvenile fish, specifically salmonids, are known to orient to surface flows and are therefore most attracted to bypass and collection devices located in the surface waters. This type of downstream passage device is both species and life stage specific and was developed in the early 1980's to pass juvenile salmonids in the Columbia and Snake Rivers. Its original form took the shape of a surface flow attraction channel at the Wells Dam on the Columbia River that guided juvenile salmonids to safe downstream passage via the spillway. The original design has been modified in response to site-specific differences between hydro projects. Results of biological evaluations to date have been highly variable largely due to site-specific hydraulic factors and species-specific biological factors.

4.4 Physical Barriers

Physical barriers are used to physically exclude fish or other organisms from entrainment at water intakes. They are usually used in combination with low water velocities (< 2 ft/sec) to allow organisms to swim away from the face of the structure. They can also be used in conjunction with other fish protection technologies to potentially enhance effectiveness. Some physical barriers appear to be duplicative (in terminology) to technologies that fall under different categories, but variations in system components (e.g. fish buckets, low-pressure spraywash) operation (e.g. continuous rotation) and arrangement (e.g. angled bar racks) result in these technologies protecting fish by a different mode of action.

4.4.1 Fixed Screens

Fixed (stationary) flat-panel screens have been used at water intakes and continue to be used at many facilities with little to no debris loading or in conjunction with effective debris removal systems. If sized to provide low intake velocities, these screens can be used to reduce entrainment, as well as prevent impingement. Fixed screen installations are relatively common at water diversions and some hydro projects in California and the Pacific Northwest, where they are frequently used in the presence of a sweeping current to divert fish past the screen to meet strict design and operational criteria developed for protecting juvenile salmonids.

4.4.2 Traveling Screens (i.e. through-flow, dual-flow, center-flow, drum, etc.)

Traveling water screens are a common feature at large intakes (cooling water). These screens were originally designed to separate debris from the intake flow. These screens are used where debris is present, because the screen rotation combined with a high-pressure spray wash is sufficient to maintain these screens in a clean condition under all but the most extreme debris loading conditions. At most facilities the traveling water screens are operated only intermittently for maintenance, or more frequently when debris loading is high. A typical intake with through-flow traveling water screen is shown in Figure 4-15. Three other common types of traveling water screens are shown in Figure 4-16. These screens typically employ 3/8 inch square or similar mesh. These screens are very similar to fish-friendly traveling water screens but do not include fish-friendly features. The ability of traveling screens to act as a barrier to fish, while not resulting in fish impingement on the screen mesh, is dependent on many site-specific factors such as size of the fish, intake velocity, location of screens, and presence of escape routes. As barrier devices, traveling screens cannot be considered for protection of early life stages of aquatic organisms that have little or no motility. While traveling water screens exclude larger organisms from the cooling water, without fish protection features these screens can result in mortality. Impingement on the screening surface, until the screen is rotated, restricts fish operculum movement and therefore the ability to breathe. When the screens are rotated, impinged organisms can slide off the screens back into the water and become re-impinged.

Figure 4-15 Typical Through-flow Traveling Water Screen Arrangement

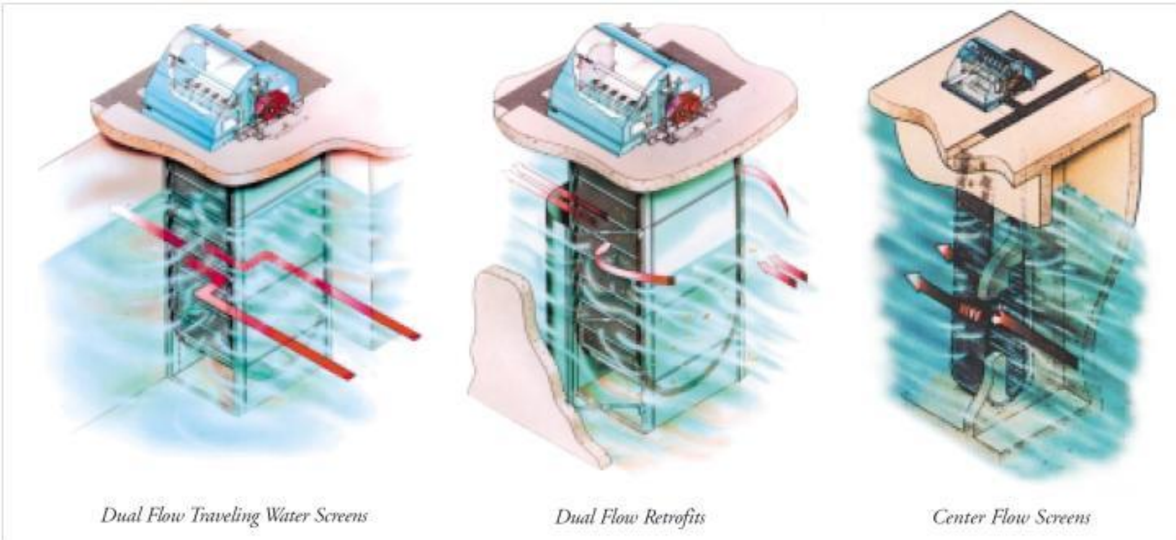

Figure 4-16 Various Types of Traveling Water Screens (Courtesy of U.S. Filter[3])

4.4.3 Drum Screens

Drum screens have been used at irrigation and hydroelectric facilities to physically block fish passage; primarily larval and juvenile salmonids. Drum screens are widely used throughout Europe and other countries; but, not as frequently in North America. Drum screens consist of a cylindrical-shaped screen that rotates around a central axis. Intake water flows through the screen panels into the center section of the screen. This screened water then flows out of the center section parallel to the axis of rotation. A schematic showing a drum screen is provided on

[3] U.S. Filter is now part of Evoqua Water Technologies LLC.

Figure 4-17. One advantage of these screens is that they eliminate carryover. However, drum screens require a larger footprint than traveling water screens. Many drum screen installations have been found to be biologically ineffective due to poor orientation, lack of suitable bypasses and inability to maintain adequate seals. These deficiencies have led to fish impingement and ineffective blockage of fish passage. Most of the drum screens now being designed for water diversions are installed at an angle to the ambient water flow and are designed to actively guide fish to bypasses.

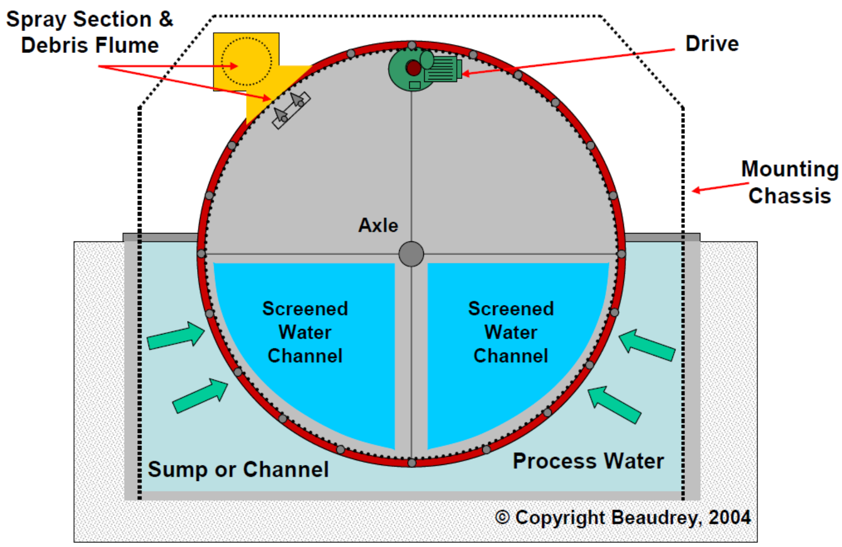

Figure 4-17 Typical Flow Pattern of a Drum Screen (Courtesy Beaudrey)

4.4.4 Bar Rack Barriers

Bar racks (also known as trash racks) are common features at large water withdrawals and hydroelectric projects. These racks are used to prevent large debris from impacting and potentially damaging secondary screening devices, turbines, or pumps. For fish protection purposes, bar rack clear slat spacings are typically 2 inches or less. When paired with low velocities, bar racks may act as a behavioral barrier for fish that can physically pass through the slots. Recent advances have been made in cleaning and maintaining bar racks. However, these advances were not designed to increase biological effectiveness. Angled bar racks and louvers are commonly used to guide fish to a bypass as described in Section 4.3.1.

4.4.5 Infiltration Intakes

Infiltration intakes work by withdrawing water through the substrate at the deployment location. Where the substrate is porous (i.e. sand) the natural substrate can be used. If the natural substrate is not suitable an artificial filter bed can be created. The velocity associated with these intakes is nearly imperceptible and would eliminate potential entrainment. The low velocities can also protect some planktonic organisms and life stages (USEPA 1976). Several types of infiltration intakes are available. Vertical wells withdraw water from simple vertical shafts. Horizontal wells, such as radial wells and directionally drilled horizontal wells, use horizontal elements to increase withdrawal zone and are capable of withdrawing larger flows than vertical wells. Slant wells withdraw water through a series of slanted shafts. Artificial filter beds are constructed by excavating an area of the natural substrate, installing perforated pipes and backfilling with a specially graded filter medium. Infiltration intakes have been used for withdrawals of up to 34 million gallons per day (Cartagena desalinization plant in Spain).

4.4.6 Porous Dikes

Porous dikes and other rock structures such as rock cribs are similar to breakwaters, except they are designed to allow water to pass through the pores in the structure while preventing passage of juvenile and adult fish. Such structures have been shown to be effective at reducing entrainment of juvenile and adult fish in both experimental (Bell et al. 1974, Alden 1976, Ketschke 1981) and full-scale studies (Michaud 1981, Michaud 2009). These barriers have not consistently reduced entrainment of smaller organisms and in some cases resulted in an increase in entrainment of eggs and larvae of species that prefer the rocky habitat created by these barriers. A porous dike was installed at the WE Energies Port Washington Power Plant in 2008, to reduce environmental impacts of the water withdrawal and prevent operational impacts associated with large influxes of *Cladophora* (Michaud 2009). This barrier has operated as designed since its installation.

4.4.7 Filtrex Filter System

The Filtrex Filter System (FFS) is a relatively new fish protection technology. This technology has been shown to eliminate entrainment of eggs, larvae, juvenile and adult fish in laboratory studies and during limited field testing. The FFS tested for use at water intakes consists of filter elements approximately 5 inches long and 1.5 inches in diameter, comprised of stacked plastic wafers fastened together with a central spring as shown in Figure 4-18. Grooves between stacked wafers provide filtration of 40 microns (0.04 mm) and the flow capacity of each filter element is approximately 8 gallons per minute (gpm) with a through slot velocity of approximately 0.2 ft/sec (Normandeau 2007). The FFS uses a backwash system to maintain clean filter elements. During backwashing the stacked wafers are allowed to separate by compressing the central spring and a backwash flow removes debris. Each cluster of filter candles is isolated with automatic gates and valves and backwashed individually. For the backwash to properly function, an ambient sweeping current is needed to transport debris past the filters. There are no set recommendations for the magnitude of the required sweeping current, but it should be greater than the through-mesh velocity. The cleaning efficacy of the filters has only been tested with a 1.1 ft/sec sweeping flow (ARL 2007).

Figure 4-18 Filtrex Filter Elements (Courtesy of Alden)

4.4.8 Cylindrical Wedgewire Screens

Cylindrical wedgewire screens are physical barriers used to reduce entrainment of organisms at all types and sizes of water intakes. The level of protection offered by these screens is based on the screen slot size (0.5 mm through 9.5 mm). These screens are designed to function passively; that is, to be effective, a combination of low through-mesh velocity and ambient cross-currents in the water body should be present to carry organisms with limited motility and debris past the screens. A schematic of a typical submerged cylindrical wedgewire screen is provided in Figure 4-19.

Wedgewire screens utilize wire that is "V" or wedge-shaped in cross-section. The wire is secured to a framing system to form a slotted screening element. In order for cylindrical wedgewire screens to reduce entrainment, the following conditions must exist: (1) sufficiently small screen slot size to physically block passage of the smallest life stage to be protected; (2) low through-slot velocity (typically ≤ 0.5 ft/sec); and (3) ambient currents providing a continuous sweeping velocity across the screen. Where all of these conditions are present, wedgewire screens can reduce entrainment of eggs, larvae, juvenile and adult fish (Hanson et al. 1978; Lifton 1979; Weisburg et al. 1987; Cumbie and Banks 1997; Ehrler and Raifsnider 1999). Where only juvenile and adult fish require protection, larger slot sizes in locations with lower sweeping currents can provide biologically effective screening.

Cylindrical wedgewire screens have been used at a myriad of water intakes and water bodies. This technology is scalable and has been successful installed at low and high-flow intakes in lakes, rivers, and estuaries. Typically these screens are either mounted directly to submerged pipes or connected to a bulkhead structure. Bulkhead mounting these screens allows them to be removed for maintenance or bypass. The water body type and installation location plays a major role in the debris and biofouling conditions at the screens. Where debris and biofouling are minimal, a cleaning system may not be needed. This is the case at both the Campbell #3 and Elm Road intakes located in Lake Michigan. Two types of automatic screen cleaning systems are available; air backwash or brush cleaned. Both cleaning methods have demonstrated effective performance.

Cylindrical wedgewire screens are continuously submerged making them more prone to biofouling than other screening technologies. Several studies have investigated the use of different screen materials to reduce the impacts of biofouling (Wiersema et al. 1979,Weisberg et al. 1986, USBR 2007). The results of these studies indicate that the use of copper alloys can reduce either the amount or attachment strength of biofouling organisms when compared to stainless steel screens. An effective automatic screen cleaning system, (USBR 2014), has also been shown to reduce biofouling. Depending on the deployment location these screens can be susceptible to damage from large debris or boat traffic. In colder climates these screens are also susceptible to frazil ice formation.

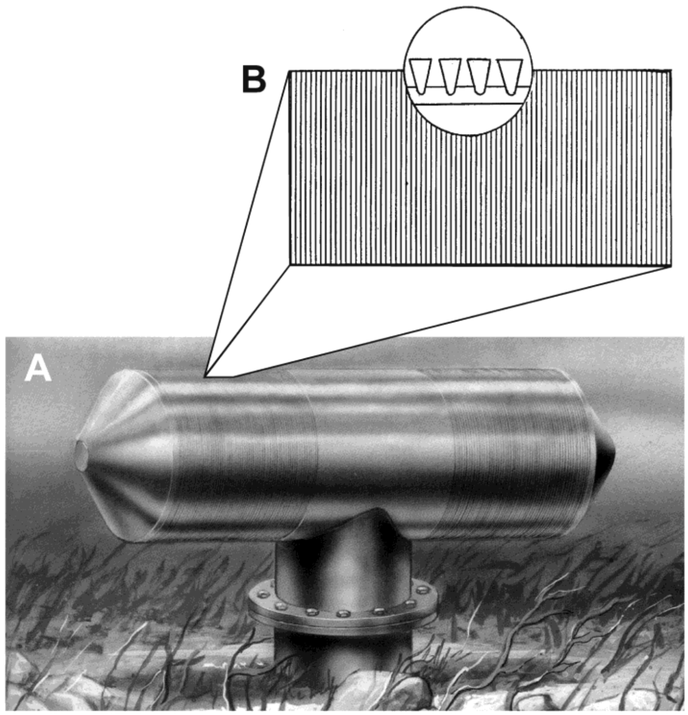

Figure 4-19 Depiction of a Cylindrical Wedgewire Screen Installation (A) and Close-up View of Slotted Wedgewire Screen Elements (B) (EPRI 2003)

4.4.9 Perforated Pipe Screens

Perforated pipe screens are very similar in design and operations to cylindrical wedgewire screens. The only difference between the screens is that perforated pipe intakes use perforated metal plates instead of V-wire. Application of this type of intake has been very limited but it has been used successfully to provide makeup water for the Columbia Generating Station (formerly Washington Nuclear Power Unit Number 2 on the Columbia River in Washington). The ambient velocities past the Columbia Generating Station screens ranged from 5 -7 ft/sec.

An entrainment study was conducted at the Columbia Generating Station to determine the effectiveness of these screens to reducing the entrainment of Chinook salmon fry (Mudge et al. 1981). During the study no Chinook salmon eggs or fry were entrained, indicating that the perforated pipe intakes can be considered an applicable technology where entrainment of Chinook salmon is a concern. These screens have not been tested with other species.

4.4.10 Barrier Net

Coarse-mesh barrier nets have been effectively applied at several power plant cooling water intake structures (CWISs), as well as a number of hydroelectric projects where entrainment is of concern, including the Ludington Pumped Storage Plant. Under the proper hydraulic conditions (primarily velocity less than (0.08 m/sec (0.25 ft/sec)) and without heavy debris loading, barrier nets have been effective in blocking fish passage into water intakes. Debris cleaning and biofouling control can be labor-intensive (Michaud and Taft 1999; EPRI 2006c). Barrier nets have also been effective at guiding fish downstream past intakes (FirstLight 2012). Fine-mesh barrier nets have been tested at several facilities as a method for reducing entrainment of smaller organisms. To date operation and maintenance issues with fine-mesh nets have prevented any full-scale installations.

Being a “soft” technology, barrier nets are more prone to damage due to debris and ice. In high energy environments, such as rivers, barrier nets should not be placed in the main current. Deflector or skimmer walls may also be needed to reduce interaction with large debris. In northern climates icing can be a concern. In smaller lakes and reservoirs, small circulators or bubblers can be used to keep the area around a net ice free during the winter. Ice flow and pack ice that do not originate in the vicinity of the net are not affected by deicing methods preventing year round barrier net installation on rivers and large lakes.

4.4.11 Aquatic Filter Barrier

The aquatic filter barrier (AFB) is a relatively recent technology for the protection of all life stages of fish and other organisms at water intakes. The ABF is a full-depth filter curtain consisting of polyester fiber strands which are pressed into a water-permeable fabric mat. A picture of a perforated AFB is provided in Figure 4-20. For intake applications, two layers of this permeable fabric mat sandwiching coarse netting are used. This coarse netting, adds structural integrity to the barrier reducing tearing. An air backwash system that sends a burst of air between the two filter layers is used to shake loose debris impinged on the surface of the AFB. This cleaning system is effective at removing loose debris, but is not effective at removing aquatic organisms and other biofouling agents (Henderson et at. 2001).

In some cases, the AFB has been perforated to increase flow rates. In addition to the small opening size, the AFB uses very low through-fabric velocities, 0.04 L/min/cm^2 (10 gpm/ft^2) to reduce entrainment. With such a low design flow, AFB installations at the flows required for once-through cooling of hydroelectric operations tend to have a large surface area. Such large deployments can reduce both habitat and visual properties near the deployment location. AFB is a soft technology and should only be installed where large debris is not present. AFB is also subject to icing concerns in northern climates. To date there has only been one large deployment of the AFB at a water intake.

Figure 4-20 Close-up of Perforated AFB Material (Courtesy of Alden)

4.4.12 Closed Loop Pump Storage System

Closed-loop pump storage systems transfer water between two artificially created waterbodies. These systems may be connected to a natural waterbody to provide the initial fill and for evaporative make-up water. Closed-loop systems are typically considered low-impact because once filled they do not require large withdrawals from natural waterbodies. Withdrawals from natural water bodies can be reduced further by using gray water and other anthropogenic water sources.

There are currently two licensed closed-loop pump storage facilities operating in the U.S. (FERC 2015), Eagle Mountain (Project # 13123) and the Olivenhain-Hodges Pumped Storage Project (Project # 12473), both are located in California. There are pending license applications for closed-loop projects in Utah and upstate New York, as well as several additional facilities located throughout the country that have been issued or are waiting for preliminary permits (FERC 2015).

5 Identification of Fish Species and Life Stages Potentially at Risk to Entrainment at LPSP

Biological considerations play an important role in determining the feasibility of fish protection technologies for application at any type of water intake. Biological effectiveness (i.e., ability to reduce entrainment) will depend, in part, on certain physical and life history characteristics of fish species that encounter an intake. Fish size, swimming ability, and responses to various stimuli and environmental conditions encountered at an intake will influence the ability of fish to avoid entrainment by being repelled, guided, screened, and/or collected by a fish protection system. Species and life stage abundances and temporal occurrences will also influence entrainment risk and technology performance. Therefore, to complete the feasibility assessment of all identified technologies with potential application to LPSP and to make reasonable comparisons of effectiveness among them, it is important to identify all species and life stages that may be encountered at LPSP and estimate their relative abundances and determine when they are most likely to occur on a daily and seasonal basis.

The primary biological task for Phase 1 was to develop a comprehensive list of fish species and life stages in the project vicinity using data available from state and federal resource agencies, tribal entities, entrainment studies conducted at LPSP prior to the barrier net installation, and data collected during annual barrier net monitoring. The seasonal net monitoring data, which have been collected annually for over 20 years, provide the most comprehensive occurrence and relative abundance information for adult fish in the vicinity of LPSP. However, because the sampling for annual monitoring targets collection of fish greater than 4 inches in length and is only conducted during the seven month period that the barrier net is installed each year (April 15 – October 15), fish smaller than 4 inches are underrepresented and there is no information on presence and abundance for the period when the net is not in place. Historical data are also available from sampling conducted in Lake Michigan and the upper impoundment in the 1970's after the LPSP came online in 1973.

The data and information obtained from both the identification of potential technologies and species will be used to complete the Phase 2 and 3 feasibility assessments. In the Phase 2 report a matrix of fisheries information will be developed, to allow for a qualitative evaluation of entrainment potential on a seasonal basis. This biological information along with site-specific engineering information will then be used to screen the list of entrainment abatement technologies to identify technologies potentially suitable for LSPS.

Species collected during seasonal barrier net monitoring conducted annually from 1993-2014 are presented in Table 5-1. Species classified as "species of concern" are either target species of the monitoring program or have been identified as a concern by at least one entity involved with the LPSP relicensing. "Representative" species have been classified by Alden as species that will be the focus of the technology feasibility assessments. Technology performance estimates for some of these species of concern and representative species will be used to estimate performance for others with similar body shapes, swimming abilities, and habitat preferences (e.g., benthic, pelagic, nearshore) (Table 5-2). Some species have been classified as both species of concern and representative. Other species that were collected during sampling in Lake Michigan and the upper reservoir during the 1970's, but that have not been observed in the seasonal barrier net monitoring collections, are listed in Table 5-3. Life stage occurrences are also noted on Table 5-1 and were based on all available data and professional judgment, not just from the barrier net monitoring dataset. The species and life stages listed in Tables 5-1 and 5-3 may be modified following the review of additional data that have been or will be provided to the Alden by entities involved with field sampling efforts on Lake Michigan.

Table 5-1 Summary of fish species collected during seasonal barrier net monitoring (1993-2014). Representative (R) and species of concern (C) will be the focus of the technology feasibility assessment. Life stages are ichthyoplankton (I), juvenile (J), and adult (A) and were determined from all available data (i.e., not just barrier net monitoring data)

Family	Common Name	Scientific Name	Life Stages Present	Barrier Net Monitoring Species Status	Barrier Net Trophic Category	Representative or Species of Concern for Fish Protection Assessment
Acipenseridae	Lake sturgeon	*Acipenser fulvescens*	A	Nontarget	--	C
Amiidae	Bowfin	*Amia calva*	A	Nontarget	--	R
Catostomidae	Black buffalo	*Iciobus niger*	A	Nontarget	--	--
	Lake chub	*Couesius plumbeus*	A	Nontarget	--	--
	Longnose sucker	*Catostomus catostomus*	A	Nontarget	--	--
	Quillback	*Carpiodes cyprinus*	A	Nontarget	--	--
	Redhorse spp.	*Moxostoma spp.*	J, A	Nontarget	--	--
	White sucker	*Catostomus commersoni*	J, A	Nontarget	--	R
Centrarchidae	Black crappie	*Pomoxis nigromaculatus*	I, J, A	Nontarget	--	--
	Largemouth bass	*Micropterus salmoides*	J, A	Nontarget	--	--
	Pumpkinseed	*Lepomis gibbosus*	J, A	Nontarget	--	R
	Rock bass	*Ambloplites rupestris*	J, A	Nontarget	--	--
	Smallmouth bass	*Micropterus dolomieu*	J, A	Nontarget	--	R
Clupeidae	Alewife	*Alosa pseudoharengus*	I, J, A	Target	Forage Fish	C/R
	Gizzard shad	*Dorosoma cepedianum*	I, J, A	Nontarget	--	--
Cottidae	Mottled sculpin	*Cottus bairdi*	J, A	Nontarget	--	--
	Slimy sculpin	*Cottus cognatus*	A	Nontarget	--	--
Cyprinidae	Common carp	*Cyprinus carpio*	A	Nontarget	--	R
	Common Shiner	*Notropis cornutus*	A	Nontarget	--	--
	Longnose dace	*Rhinichthys cataractae*	I, J, A	Nontarget	--	--
	Spottail shiner	*Notropis hudsonius*	I, J, A	Nontarget	--	R
Esocidae	Northern pike	*Esox lucius*	A	Nontarget	--	R
Gasterosteidae	Threespine stickleback	*Gasterosteus aculeatus*	J, A	Nontarget	--	R
Gobiidae	Round goby	*Neogobius melanostomus*	J, A	Nontarget	--	R
Ictaluridae	Black bullhead	*Ictalurus melas*	A	Nontarget	--	--
	Channel catfish	*Ictalurus punctatus*	A	Nontarget	--	R
Lepisosteidae	Longnose gar	*Lepisosteus osseus*	A	Nontarget	--	--
Lotidae	Burbot	*Lota lota*	I, J, A	Nontarget	--	--
Moronidae	White perch	*Morone americana*	A	Nontarget	--	R
Osmeridae	Rainbow smelt	*Osmerus mordax*	I, J, A	Target	Forage Fish	C
Percidae	Walleye	*Sander vitreus*	J, A	Target	Game Fish	C/R
	Yellow perch	*Perca flavescens*	I, J, A	Target	Game Fish	C
Percopsidae	Trout-perch	*Percopsis omiscomaycus*	I, J, A	Nontarget	--	--
Petromyzontidae	Sea lamprey	*Petromyzon marinus*	A	Nontarget	--	R
Salmonidae	Brook trout	*Salvelinus fontinalis*	A	Nontarget	--	--
	Brown trout	*Salmo trutta*	J, A	Target	Game Fish	C
	Rainbow trout (steelhead)	*Oncorhynchus mykiss*	J, A	Target	Game Fish	C/R
	Lake trout	*Salvelinus namaycush*	J, A	Target	Game Fish	C
	Chinook salmon	*Oncorhynchus tshawytscha*	J, A	Target	Game Fish	C
	Coho salmon	*Oncorhynchus kisutch*	J, A	Target	Game Fish	C
	Lake Herring	*Coregonus artedi*	I, J, A	Nontarget	--	C
	Chub (Bloater)	*Coregonus hoyi*	I, J, A	Target	--	C
	Lake whitefish	*Coregonus clupeaformis*	I, J, A	Nontarget	--	C/R
	Round whitefish	*Prosopium cylindraceum*	A	Nontarget	--	--
Sciaenidae	Freshwater drum	*Aplodinotus grunniens*	A	Nontarget	--	--

Table 5-2 Representative fish species that will be the focus of the technology feasibility assessment and the species they will represent for estimates of biological effectiveness. Some species are classified as representative without representing other species if they are considered unique and cannot be represented by other species.

Representative Species	Species Represented
bowfin	--
white sucker	all catostomids
pumpkinseed	black crappie
smallmouth bass	rock bass, largemouth bass
alewife	gizzard shad
common carp	--
spottail shiner	common shiner
northern pike	longnose gar
threespine stickleback	--
round goby	mottled sculpin; slimy sculpin; longnose dace
channel catfish	black bullhead; burbot
white perch	freshwater drum
walleye	trout-perch
sea lamprey	--
rainbow trout	brook trout
lake whitefish	round whitefish

Table 5-3 Summary of species collected during entrainment studies conducted in the 1970's.

Family	Common Name	Scientific Name	Collection Location
Centrarchidae	bluegill	*Lepomis macrochirus*	upper reservoir; lake
Cottidae	fourhorn sculpin	*Myoxocephalus quadricornis*	all locations
	deepwater sculpin	*Myoxocephalus thompsonii*	upper reservoir; lake
Cyprinidae	goldfish	*Carassius auratus*	upper reservoir
	fathead minnow	*Pimephales promelas*	upper reservoir
Gasterosteidae	ninespine stickleback	*Pungitius pungitius*	all locations
Ictaluridae	brown bullhead	*Ameiurus nebulosus*	upper reservoir
Percidae	johnny darter	*Etheostoma nigrum*	all locations

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Ludington Pumped Storage Project
Fish and Aquatic Resources Study

PHASE 2 REPORT

EVALUATION OF ENTRAINMENT ABATEMENT TECHNOLOGIES

Prepared for

Consumers Energy Company

Prepared by

ALDEN Research Laboratory, Inc.

November 25, 2015

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Acronyms and Abbreviations

Acronym / Abbreviation	Definition
AFB	Aquatic Filter Barrier
ASA	Applied Science Associates Analysis & Communication
BAFF	Bio-Acoustic Fish Fence
CEC	Consumers Energy Company
CFD	Computational Fluid Dynamics
cfs	Cubic Feet Per Second
CPC	Consumers Power Company
CWIS	Cooling Water Intake System
dB	Decibel
EPRI	Electric Power Research Institute
ESEERCO	Empire State Electric Energy Research Corporation
ESP	Environmental Solution Professionals
FERC	Federal Energy Regulatory Commission
ft	Foot / Feet
ft/sec	Feet Per Second
FVES	Flow Velocity Enhancement System
GLFC	Great Lakes Fishery Commission
GPS	Global Positioning System
Hz	Hertz
JAF	James A. Fitzpatrick Power Plant
kHz	Kilohertz
kW	Kilowatt
kWh	Kilowatt-hours
lbs	Pounds
LMS	Lawler, Matusky & Skelly Engineers
LPSP	Ludington Pumped Storage Project
MWh	Megawatt-hours
MW	Megawatt
O&M	Operation and Maintenance
Pa	Pascal
PDC	Pulsed Direct Current
PNNL	Pacific Northwest National Laboratory
o.c.	On Center
SAT	Scientific Advisory Team to the Great Lakes Fisheries Trust
SCWLP	Springfield City Water, Light, and Power
Sec	Second
SPL	Sound Pressure Level

Acronym / Abbreviation	**Definition**
SWEC	Stone & Webster Engineering Corporation
SWES	Stone & Webster Environmental Services
UCC	Underwater Construction Corporation
USACE	United States Army Corps of Engineers
μPa	Micropascal

Executive Summary

This report presents the second phase of a three phase study intended to identify water intake fish protection technologies with potential for deployment at the Ludington Pumped Storage Project (LPSP), and to assess the anticipated effectiveness of these technologies as compared to the existing technology: a seasonal barrier net. The Phase 1 Report compiled a comprehensive list of available fish protection technologies and species of fish that may be affected. This Phase 2 report provides an assessment of the potential for entrainment abatement technologies to be successfully applied at LPSP. Entrainment abatement technologies are technologies that do not require substantial structural changes to the project intake. These options include behavioral barriers (e.g. electric fields, strobe light, or sound deterrents) or other non-structural (relative to the project) components such as the barrier net or an aquatic filter barrier. The Phase 3 Report will assess engineering alternatives which are the more substantive alternatives that require civil/ structural changes to the project.

The first step in evaluating any fish protection technology is to have a good understanding of biological and life history parameters for affected species. A matrix summarizing the biological, temporal, and spatial information for each species and life stage that occur in the vicinity of LPSP was developed. This information allowed the biological efficacy of potential technologies to be included as an important component of the technology screening process.

The technology screening process was conducted in two phases. The first phase was an initial preliminary screening of available and developing technologies with a focus on biological and engineering aspects of each technology as they relate to reducing entrainment at large water withdrawals. The second phase of the screening process was a feasibility assessment that evaluated the technologies with respect to site-specific biological and engineering considerations at LPSP. Technologies considered for this Phase 2 study were identified in the Phase 1 Report. Technologies determined to have reasonable potential for application at LPSP were carried forward to conceptual designs, expected biological effectiveness, operations and maintenance (O&M) issues, uncertainties and risks, and order-of-magnitude cost estimates.

Based on the results of the screening of entrainment abatement technologies, the following four alternatives were determined to be biologically effective, commercially available, and have distinct advantages over other potential alternatives with respect to application at the LPSP:

- The existing barrier net;
- modifications to the existing barrier net with and without an ultrasonic anti-biofouling system;
- a longer net with 1/2-inch bar mesh to reduce entrainment of smaller fish (less than 4 inches in length); and
- The existing barrier net with a full-scale ultrasonic deterrent system to further reduce entrainment of alewife.

None of these concepts would extend the current operational period for the use of a barrier net (April 15 – October 15) to full-year application. Each concept is summarized below and its expected capital, total O&M, and relative biological effectiveness as compared to the existing net are provided in Table S-1.

Table S-1: Summary of entrainment abatement technologies that show potential for application at LPSP.

Alternative	Total Capital Costs (2015 $)[1]	Total Annualized (2015 $)[2,3,4]	Incremental Annualized (2015 $)[2,3,4]	Estimated Biological Effectiveness
Existing Barrier Net	NA	$2,817,000	$0	Estimated 91% reduction in entrainment.
Modifications to the Existing Barrier Net without Ultrasonic Anti-biofouling	$5,967,000	$3,756,000	$939,000	Would improve the integrity of the existing net.
Modified Barrier Net with Ultrasonic Anti-biofouling	$10,600,000	$4,854,000	$2,037,000	Would improve the integrity of the existing net and reduce biofouling.
Longer Barrier Net with ½-inch Bar Mesh	$15,125,000	$5,861,000	$3,044,000	Would reduce the velocity at the net and the entrainment of smaller life stages that can currently swim through the net.
Existing Barrier Net with a Full-Scale Ultrasonic Deterrent System	$18,854,000	$5,209,000	$2,392,000	Expected to reduce entrainment of alewife.

1. Includes costs incurred during the initial installation and lost generation during construction.
2. Annualized over 10 years with a 7% discount rate.
3. Includes capital, labor, component replacement and replacement power costs.
4. Does not include the cost of fisheries compensation.

The existing barrier net is installed annually from April 15 to October 15. Winter conditions in Lake Michigan prevent the net from being installed year round. The existing net design is the baseline to which all other fish protection alternatives were compared, when assessing for biological and engineering performance. With over 20 years of deployment and monitoring data available, the existing barrier has averaged 86.7% exclusion for all species, and 83.4% and 94.5% for game and forage fish, respectively. This meets the 80% gamefish and 85% forage fish barrier net exclusion standards currently in place.

There is potential for fish to pass over the existing net during submergence events. The collection of fish too large to pass through the existing mesh from gill nets at sampling stations inside the net indicates this may be occurring. The design of the existing barrier has been modified to reduce submergence events. Several additional modifications, including increased flotation, additional anchors, and wider top and bottom skirts, were selected as potential methods to reduce net submergence and increase biological effectiveness as part of an incremental adaptive management plan. In addition to these modifications, an ultrasonic anti-biofouling system was considered to reduce biofouling on sections of the net that have historically been affected during submergence events.

A new longer net was evaluated as an alternative that would provide greater protection to smaller fish (less than 4 inches) with a finer mesh. This longer net would have lower flow velocities passing through the net during pumping and generating compared to the existing design. The lower velocities would reduce the stress on the net and would be expected to result in fewer submergence events. The new net would be equipped with 1/2-inch bar mesh, replacing the existing 3/4-inch mesh that is currently used for the offshore panels (i.e., section parallel to shore).

A full scale ultrasonic sound deterrent system used in conjunction with the existing barrier net could be installed to further reduce the entrainment of alewife, which comprise, on average, 74% of the fish collected during gill netting conducted annually outside of the barrier net over the course of the installation period. This technology would not be effective at reducing entrainment of any other species that occur in the vicinity of the project.

1 Introduction

Ludington Pumped Storage Project's (LPSP) current Federal Energy Regulatory Commission (FERC) license (P-2680-108) expires on June 30, 2019. Re-licensing was initiated on January 21, 2014 when a Pre-Application Document and Notice of Intent were submitted to FERC. Initial agency consultation was held on May 21, 2014 and the agencies collectively filed a study request to "comprehensively identify and evaluate the feasibility and effectiveness of all available measures, including additional technologies and project design and operational changes, to eliminate or reduce to the greatest possible extent, fish entrainment and mortality caused by operation of the project."

A study plan that includes a Fish and Aquatic Resources Study was approved by FERC on December 1, 2014. The goal of the Fish and Aquatic Resources Study is to identify and assess existing entrainment abatement technologies and engineering alternatives that may have potential for application at LPSP, in addition to or in place of the seasonal fish barrier net, in an effort to further reduce fish entrainment. To meet this goal, the study was divided into the following primary components:

- Phase 1: Identification of Entrainment Abatement and Engineering Alternatives
- Phase 2: Feasibility Assessment of Entrainment Abatement Technologies
- Phase 3: Feasibility Assessment of Engineering Alternatives

Entrainment abatement technologies are technologies that do not require substantial changes to the project intake structures. These options can include behavioral barriers (e.g. electric fields, strobe light, or low frequency sound) or other non-structural (relative to the project) components such as the barrier net. Engineering alternatives are technologies that require more substantive civil/structural changes to the project/project intake structures. These can include options that require modifications to existing structures or a whole new structure (e.g. porous dike).

A primary goal of the Phase 1 report was to identify potential data sources and technologies to be reviewed and assessed as part of Phase 2 and 3 efforts (Alden 2015). Information was obtained through a literature search that included canvassing Alden Research Laboratory Inc.'s (Alden's) extensive library on fish protection technologies and soliciting information from the scientific advisory team (SAT) members and other pertinent organizations and individuals who were known to have experience with fish protection technology design, testing, and/or installation. A second goal of Phase 1 was to develop a comprehensive list of fish species and life stages that occur in the vicinity of the LPSP. Data available from state and federal resource agencies, tribal entities, entrainment studies conducted at LPSP prior to the seasonal barrier net installation, and data collected during annual barrier net monitoring were used to develop this list. The data and information obtained from both the identification of potential technologies and species provided a basis for the Phase 2 and 3 feasibility assessments.

The Phase 2 efforts, as presented in this report, include a biological characterization of affected species, a review and preliminary screening of entrainment abatement technologies, and a detailed feasibility assessment (with respect to biological, engineering, and cost considerations) of technologies determined to have reasonable potential for application at LPSP. Additionally, project design and operation and the barrier net design and effectiveness are summarized and reviewed. The characterization of affected species includes a matrix of biological and life history information developed for each species and includes a qualitative assessment of entrainment potential on a seasonal basis. This biological information, along with a review of existing performance and engineering data, was used to conduct a preliminary screening of entrainment abatement technologies and to make a determination of potential for application at LPSP. Technologies determined to have reasonable potential for application were carried forward for a detailed feasibility assessment that included expected biological effectiveness, development of conceptual designs, and order-of-magnitude cost estimates.

A comprehensive review and feasibility assessment of fish protection technologies was completed in 1988 to identify alternatives with potential for effective application at LPSP (SWEC 1988). This study led to the selection of a barrier net as the most viable technology for reducing fish entrainment at LPSP based on a thorough examination of biological and engineering issues and considerations. Since the completion of the 1988 study and subsequent installation of the original net design, three additional technology reviews have been completed for the LPSP to determine if any new developments in available fish protection technologies indicated an alternative technology may have greater biological effectiveness than the barrier net, or could improve the net's ability to reduce fish entrainment (LMS 2001; ESP 2006, 2011). These technology reviews formed a starting point for the current review and screening of available technologies presented in this report. Brief summaries of the information covered in the previous reviews are provided as part of the current review of each alternative. Options that were identified in the previous evaluations, as well as others identified by study participants but not included in the Phase 2 report, will be evaluated in the Phase 3 report.

2 Project Description

The LPSP is located on approximately 1,000 acres along the shoreline of Lake Michigan about 4 miles south of the city of Ludington, MI. The plant operates by pumping water from Lake Michigan during periods of low power demand and cost (i.e., typically during nighttime hours) to an upper reservoir. When demand for electricity and the cost of energy is higher (i.e., typically during daytime hours), the water in the upper impoundment is returned to Lake Michigan through one or more of the six pump-turbine runners to generate electricity.

The LPSP is jointly-owned by Consumers Energy Company (CEC) and DTE Energy. It has an 842-acre upper reservoir with a storage capacity of up to 27 billion gallons of water and an initial allowable generating capacity of 1,657.5 megawatts (MW) (a description of ongoing unit upgrades and increases in generating capacity and pumping and generating flow rates is provided below). Each of the six penstocks leading to the pump-turbine runners is about 1,300 foot (ft) long and the diameter varies from 28.5 ft to 24.0 ft. The upper reservoir operates between water level elevations of 942 ft and 875 ft for generation and pumping operations. Typical operating head for generation ranges from 362 to 295 ft assuming a normal lake elevation at 580 ft. The lower reservoir (Lake Michigan) facilities include the powerhouse, a concrete apron, and a tailrace formed by two combination sheet pile/rock jetties and a breakwater rock structure. The tailrace is approximately 1,100 ft wide and 2,715 ft long, extending from the powerhouse to the center of the breakwater. The breakwater is approximately 1,700 ft long by 20 ft wide at its crest, which is at elevation 590.0 ft. The two combination sheet pile/rock jetties extend approximately 1,600 ft west from the powerhouse with a top elevation of approximately 590 ft. Flow enters into the tailrace from Lake Michigan when pumping to the upper reservoir and exits from the tailrace into Lake Michigan during generation. A barrier net that is approximately 12,850 ft long is installed on a seasonal basis (April 15 to October 15) in Lake Michigan outside the jetties and breakwater to reduce fish entrainment during pumping operations (more detailed information on the barrier net design is provided in Section 4.2). An aerial photo of LPSP is shown on Figure 2-1.

The 516 ft wide powerhouse contains six reversible pump-turbine/motor-generator units. The top elevation of the powerhouse is at elevation 600.0 ft with the draft tube invert elevation at 522.1 ft. The draft tubes for each unit have two 30.5 ft by 22.2 ft rectangular openings where the powerhouse meets the concrete apron. The draft tubes transition to a 21.7 ft circular opening over 84.5 ft while turning 90 degrees vertically leading to the pump-turbine runners. The concrete apron extends horizontally approximately 73 ft from the powerhouse where it then slopes from elevation 522.13 ft to 551.67 ft over approximately 120 ft.

An amendment to the Project's FERC license allowing an overhaul-upgrade of all six turbine-generator units was issued in May 2012. The amendment increased the allowable generating capacity from 1,657.5 MW to 1,785 MW. The over 40-year-old pump-turbine units are scheduled to be replaced one per year from 2013 through 2019. At the time of this study one unit overhaul-upgrade has been completed and the second is in progress. Upon completion, the upgrades are expected to increase pumping rates by 22.2% and generating rates by 14.5%; resulting in an estimated maximum pumping flow of 84,096 cubic feet per second (cfs) (14,016 cfs per unit) and an estimated maximum generating flow of 89,670 cfs (14,945 cfs per unit).

These flows were used for physical and computer-based modeling conducted in 2011, and are considered to be conservative estimates (Alden 2011).

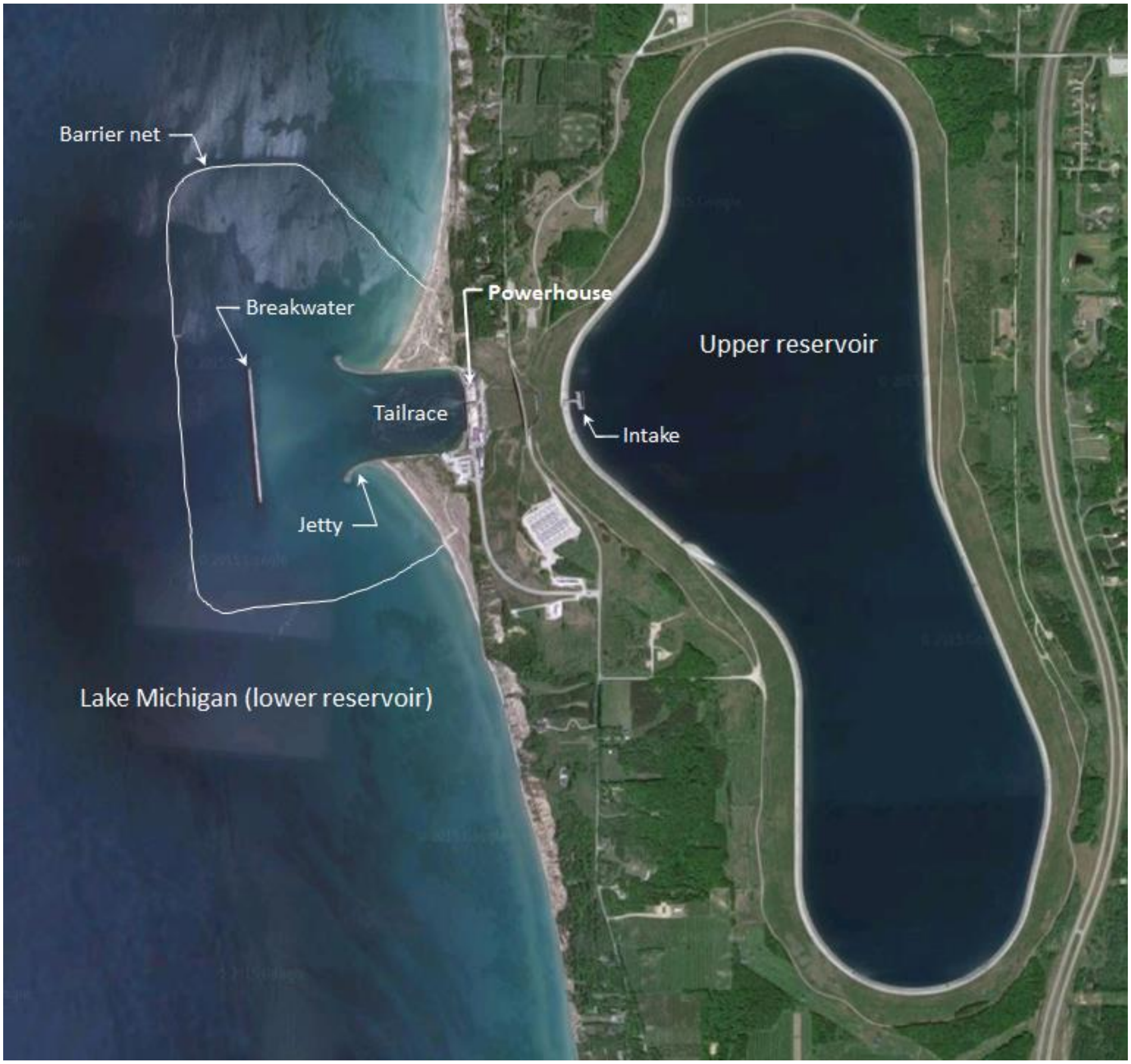


Figure 2-1: Ludington Pumped Storage Project Site Plan

3 Biological Information for Affected Fish Species

An important aspect of assessing the potential for fish protection technologies to be successfully applied at LPSP is a good understanding of biological and life history parameters for affected species. This includes knowing what species and life stages are present in the vicinity of the LPSP lower reservoir intake and when they would likely be at risk to entrainment (i.e., diurnal, monthly, and seasonal presence). Additionally, technology performance and effectiveness for any given species and life stage can be influenced to varying degrees by site-specific hydraulic and environmental conditions. Swimming capabilities would also be important and can vary considerably among species and life stages.

To develop a thorough understanding of entrainment risk, biological information and data for the species and life stages present in the vicinity of the LPSP intake were compiled and reviewed. Information sources included historical data from biological sampling conducted in the 1970's before and after the project came online, the initial technology assessment conducted for LPSP (SWEC 1988), barrier net monitoring data, and fisheries sampling efforts conducted in Lake Michigan by various organizations (with a focus on data collected on the eastern side of Lake Michigan near the LPSP, as well as north and south of the project). Information relevant to the biological assessment of each fish protection technology was used to develop species matrix that includes a qualitative determination of entrainment risk at the LPSP during pumping operations.

For the development of the species matrices, species identified as occurring in the vicinity of the project, either recently or historically, were categorized as barrier net target or non-target species (as determined by the FERC-approved Settlement Agreement), type of fishery (gamefish, forage fish, and other), and family. Additionally, three species were identified as species of particular concern by stakeholders in the relicensing of the LPSP with respect to the potential for entrainment and any subsequent population effects. This resulted in three primary groupings (target, non-target species of concern, and non-target general) being used for the development of biological information for species potentially affected by entrainment at the LPSP and for consideration in the review of alternatives (Section 5).

3.1 LPSP 1988 Technology Assessment Biological Considerations

The initial technology feasibility assessment conducted by SWEC (1988) provided a brief review of biological considerations used for the evaluation of each technology. The biological information included in SWEC (1988) was developed from the fishery resource studies conducted in the vicinity of the LPSP from 1972 to 1980. As discussed above, these studies provided a large amount of information on relative abundance and temporal presences of species and life stages that occurred near the project at the time, as well as data on entrainment, reservoir residence, and turbine mortality. Alewife, rainbow smelt, johnny darter, ninespine stickleback, sculpin species, yellow perch, and spottail shiner were identified as the most abundant species, whereas Chinook and coho salmon and lake, brown, and rainbow (steelhead) trout were identified as important sport fish that occurred in relatively low abundance. With respect to life stage, SWEC (1988) noted that any technology considered for LPSP would be most effective with larger adult fish with stronger swimming capabilities and have limited effectiveness with early life stages (ichthyoplankton and small juveniles).

Larval fish presence in the vicinity of the LPSP was determined to be low in April and May with increasing numbers in June and peaks in abundance in July and August. Temporal variability in larval abundance was attributed primarily to differences in spawning times for the various species occurring near the project. Most larvae entrained during pumping operations were identified as alewife, johnny darter, rainbow smelt, and yellow perch. Citing data from 1980, SWEC (1988) reported that smaller fish entrained at LPSP were primarily alewife (83.5%) and rainbow smelt (16.0%), with the dominant life stages being young-of-the-year and yearling fish less than 5 inches in length. Similar to larvae, abundance of these smaller fish peaked in the period of June through August.

Peak occurrence of salmonids at LPSP reported by SWEC (1988) was from late summer through fall (primarily Chinook and coho salmon and steelhead and brown trout). Steelhead were also shown to have smaller peaks in March and April based on data from sampling in the upper impoundment.

3.2 Barrier Net Monitoring Data

The barrier net monitoring data, as described in Section 4.5, is collected during annual gill net sampling conducted inside and outside of the barrier net to estimate its effectiveness in reducing entrainment risk of species that occur in the vicinity of the LPSP. In addition to measuring barrier net effectiveness, the gill net catches provide data describing species presence, relative abundance, and occurrence nearshore and offshore at varying depths. Also, with more than 20 years of sampling effort, historical trends in species presence and abundance can be evaluated for fish populations in the vicinity of the LPSP. However, a limitation of the barrier net monitoring data is that the gill nets are designed to catch fish greater than 4 inches in length. Therefore, data on juveniles less than 4 inches are lacking.

Since 1993, the total number of fish collected during annual gill netting at the LPSP has declined considerably (Table 3-1; Figure 3-1). The total catch in 2014 was about 94% less than the peak in 1994. Most of the species collected have experienced declines in gill net catch numbers since the initial years of monitoring (Figure 3-1).

Of the 45 species collected, alewife has been the most abundant, accounting for 47.5 to 91.3% of the annual catch. Other species that have comprised more than 5% of the annual catch during one or more years include yellow perch, lake trout, spottail shiner, and, in more recent years, round goby. Percent composition has increased for some of the salmonids (brown and lake trout and Chinook salmon) in recent years, but catch numbers have generally decreased for these species from previous highs. Species for which more than a 1,000 total fish have been collected from 1993 to 2014 typically account for more than 98% of the annual catch (Table 3-2).

To demonstrate trends in species composition in the vicinity of the LPSP since 1993, five-year running averages of percent composition were calculated for the most abundant species (i.e., total catch from 1993 to 2014 greater than 1,000 fish) (Figure 3-2). The five-year mean for alewife decreased from a high of about 80% for the period of 2000-2004 to about 60% for the most recent five-year period (2010-2014). The five-year mean for yellow perch steadily declined from a high of about 9% for the period of 1993-1997 before increasing again beginning with the five-year period of 2001-2005. The mean percent composition of lake trout has increased over the last 10 years and more recently for brown trout, whereas it remained relatively constant for other salmonids. Spottail shiner mean percent composition has decreased since initial highs in the 1990's. Mean barrier net effectiveness for the most abundant species currently ranges from about 70 to 90%.

As described above, the barrier net monitoring program, which began in 1989, has documented a considerable change in species abundance and composition of the near-shore fish community in the vicinity of the LPSP over the past 25 years. As reported by CEC and DTE (2014) and seen in the data presented here, the annual monitoring program catch averaged less than 10,000 fish per year from 2002 to 2012, several times lower than the gill net catches recorded at the beginning of the monitoring program, and it has continued to decline in more recent years (2013 and 2014). In particular, abundance of alewife and yellow perch have decreased substantially from initial levels recorded when the barrier net was first evaluated in 1989. The declining trends in abundances of barrier net target and non-target species are consistent with historical lake-wide trends reported by other researchers (Bunnell et al. 2009; Makauskas and Clapp 2010). In contrast to the declines observed for most species, round goby catches have increased over the last 10 years of barrier net sampling. However, a large decline in the round goby catch was noted in 2014. Population levels of the various sport and commercial fisheries and forage fish of Lake Michigan have been influenced by the introduction of non-native invasive species.

Table 3-1: Number of target and non-target species collected in annual gill net samples outside and inside the barrier net. Other Non-target Species only include species for which more than 100 fish were collected (all size groups combined) over the 22-year sampling period.

	Target Species									Non-target Species of Concern			Other Non-target Species													
Year	**BNT**	**CHIN**	**COHO**	**LT**	**RBT**	**YP**	**AW**	**RSM**	**CHUB**	**LKH**	**LW**	**LS**	**BURB**	**CP**	**FD**	**GSD**	**LNS**	**REDH**	**RGY**	**RWF**	**SMB**	**STSH**	**TPER**	**WEYE**	**WS**	**Total**
1993	316	298	186	292	40	8006	23368	520	78	--	22	3	109	33	224	473	165	204	--	750	8	3136	5	150	1039	39425
1994	445	417	146	206	75	3822	37661	1159	14	--	2	2	89	40	322	791	63	279	--	537	8	1572	--	190	993	48833
1995	192	386	67	202	36	2809	34878	388	--	--	--	3	28	49	597	1588	42	262	--	504	36	2340	3	179	767	45356
1996	516	421	69	342	178	3472	34342	215	1	2	--	3	19	39	310	714	27	201	--	665	8	6270	2	98	669	48583
1997	398	675	120	106	85	929	17805	209	8	--	--	1	19	40	350	261	26	117	--	1188	3	2715	12	137	520	25724
1998	194	261	62	143	17	193	28206	162	20	1	--	4	15	60	406	787	11	184	--	833	15	2314	2	238	455	34583
1999	151	286	64	338	24	956	10469	141	3	1	--	5	13	21	408	249	5	110	--	659	17	7712	3	171	190	21996
2000	132	401	111	176	6	68	34178	21	3	--	--	1	4	29	377	145	8	191	--	477	4	724	10	140	232	37438
2001	118	271	26	154	11	43	16076	49	10	--	--	4	5	6	313	55	8	145	--	351	7	288	6	168	268	18382
2002	80	205	246	76	8	18	7848	13	8	--	2	4	2	7	291	182	6	165	--	382	3	689	25	197	261	10718
2003	95	198	9	199	16	70	4736	12	--	23	1	--	1	8	199	25	5	100	13	192	--	464	13	92	111	6582
2004	84	424	22	288	15	37	16188	10	--	29	9	3	--	18	304	213	5	61	65	241	5	943	60	124	121	19269
2005	64	316	21	228	4	40	9310	20	16	--	--	1	--	2	161	180	3	75	44	116	4	250	--	156	98	11109
2006	56	265	20	118	8	911	9025	3	--	--	66	4	3	17	234	226	--	92	127	19	5	677	--	126	34	12036
2007	77	165	16	202	8	175	3512	1	13	--	9	2	1	16	202	224	--	90	135	96	--	81	--	126	17	5168
2008	65	201	12	416	13	212	7030	13	360	--	28	2	--	9	278	40	4	59	246	82	2	67	--	149	34	9322
2009	152	214	15	435	15	130	7188	14	89	--	40	7	2	20	123	34	3	59	186	128	2	171	--	99	47	9173
2010	124	62	21	279	4	50	2218	2	14	1	7	6	1	3	177	89	1	69	415	122	8	280	--	86	42	4081
2011	92	218	34	567	12	725	6953	1	--	16	14	7	--	7	172	15	3	28	864	329	3	446	--	95	126	10727
2012	113	79	43	143	12	532	7781	2	4	10	4	6	--	3	82	86	--	33	535	203	14	308	--	44	73	10110
2013	125	169	12	148	20	1250	4081	3	3	68	7	1	2	3	184	14	--	46	682	182	10	508	--	76	20	7614
2014	192	129	16	88	34	187	1550	--	--	41	--	1	1	9	101	2	1	26	167	80	1	70	--	37	48	2781
Total	**3781**	**6061**	**1338**	**5146**	**641**	**24635**	**324403**	**2958**	**644**	**192**	**211**	**70**	**314**	**439**	**5815**	**6393**	**386**	**2596**	**3479**	**8136**	**163**	**32025**	**141**	**2878**	**6165**	**439010**

Table 3-2: Percent composition of target and non-target specie in annual gill net samples collected outside and inside the barrier net. Only species for which more than 1,000 fish were collected (all size groups combined) over the 22-year period are included.

	Target Species							Non- Target Species								
Year	Brown Trout	Chinook Salmon	Coho Salmon	Lake Trout	Yellow Perch	Alewife	Rainbow Smelt	FW Drum	Gizzard Shad	Redhorse Spp	Round Goby	Round Whitefish	Spottail Shiner	Walleye	White Sucker	Total
1993	0.80	0.76	0.47	0.74	20.29	59.23	1.32	0.57	1.20	0.52	0.00	1.90	7.95	0.38	2.63	98.76
1994	0.91	0.85	0.30	0.42	7.82	77.09	2.37	0.66	1.62	0.57	0.00	1.10	3.22	0.39	2.03	99.36
1995	0.42	0.85	0.15	0.45	6.19	76.84	0.85	1.32	3.50	0.58	0.00	1.11	5.16	0.39	1.69	99.50
1996	1.06	0.87	0.14	0.70	7.14	70.67	0.44	0.64	1.47	0.41	0.00	1.37	12.90	0.20	1.38	99.40
1997	1.55	2.62	0.47	0.41	3.61	69.17	0.81	1.36	1.01	0.45	0.00	4.62	10.55	0.53	2.02	99.18
1998	0.56	0.75	0.18	0.41	0.56	81.53	0.47	1.17	2.27	0.53	0.00	2.41	6.69	0.69	1.32	99.54
1999	0.69	1.30	0.29	1.53	4.34	47.50	0.64	1.85	1.13	0.50	0.00	2.99	34.99	0.78	0.86	99.39
2000	0.35	1.07	0.30	0.47	0.18	91.25	0.06	1.01	0.39	0.51	0.00	1.27	1.93	0.37	0.62	99.78
2001	0.64	1.47	0.14	0.84	0.23	87.36	0.27	1.70	0.30	0.79	0.00	1.91	1.57	0.91	1.46	99.58
2002	0.74	1.91	2.29	0.71	0.17	73.02	0.12	2.71	1.69	1.54	0.00	3.55	6.41	1.83	2.43	99.12
2003	1.44	3.00	0.14	3.02	1.06	71.83	0.18	3.02	0.38	1.52	0.20	2.91	7.04	1.40	1.68	98.82
2004	0.44	2.20	0.11	1.49	0.19	83.98	0.05	1.58	1.11	0.32	0.34	1.25	4.89	0.64	0.63	99.22
2005	0.58	2.84	0.19	2.05	0.36	83.71	0.18	1.45	1.62	0.67	0.40	1.04	2.25	1.40	0.88	99.61
2006	0.46	2.20	0.17	0.98	7.56	74.92	0.02	1.94	1.88	0.76	1.05	0.16	5.62	1.05	0.28	99.06
2007	1.49	3.18	0.31	3.90	3.38	67.79	0.02	3.90	4.32	1.74	2.61	1.85	1.56	2.43	0.33	98.80
2008	0.70	2.15	0.13	4.46	2.27	75.31	0.14	2.98	0.43	0.63	2.64	0.88	0.72	1.60	0.36	95.38
2009	1.65	2.33	0.16	4.74	1.42	78.26	0.15	1.34	0.37	0.64	2.03	1.39	1.86	1.08	0.51	97.93
2010	3.02	1.51	0.51	6.80	1.22	54.10	0.05	4.32	2.17	1.68	10.12	2.98	6.83	2.10	1.02	98.44
2011	0.86	2.03	0.32	5.28	6.75	64.78	0.01	1.60	0.14	0.26	8.05	3.07	4.16	0.89	1.17	99.37
2012	1.12	0.78	0.43	1.41	5.26	76.92	0.02	0.81	0.85	0.33	5.29	2.01	3.04	0.43	0.72	99.42
2013	1.64	2.22	0.16	1.94	16.39	53.50	0.04	2.41	0.18	0.60	8.94	2.39	6.66	1.00	0.26	98.32
2014	6.88	4.63	0.57	3.16	6.70	55.58	0.00	3.62	0.07	0.93	5.99	2.87	2.51	1.33	1.72	96.56

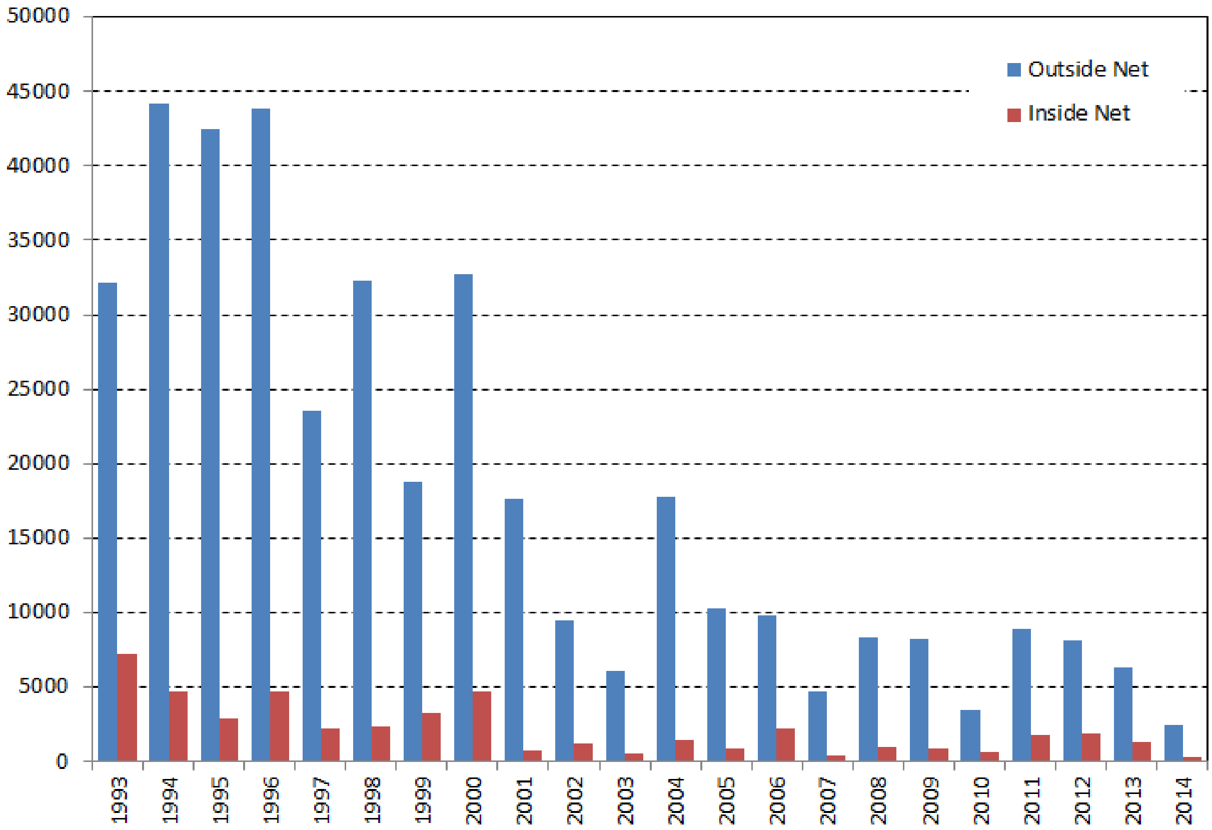


Figure 3-1: Annual total catch (all species and size groups combined) for gill net samples collected inside and outside of the barrier net, 1993-2014.

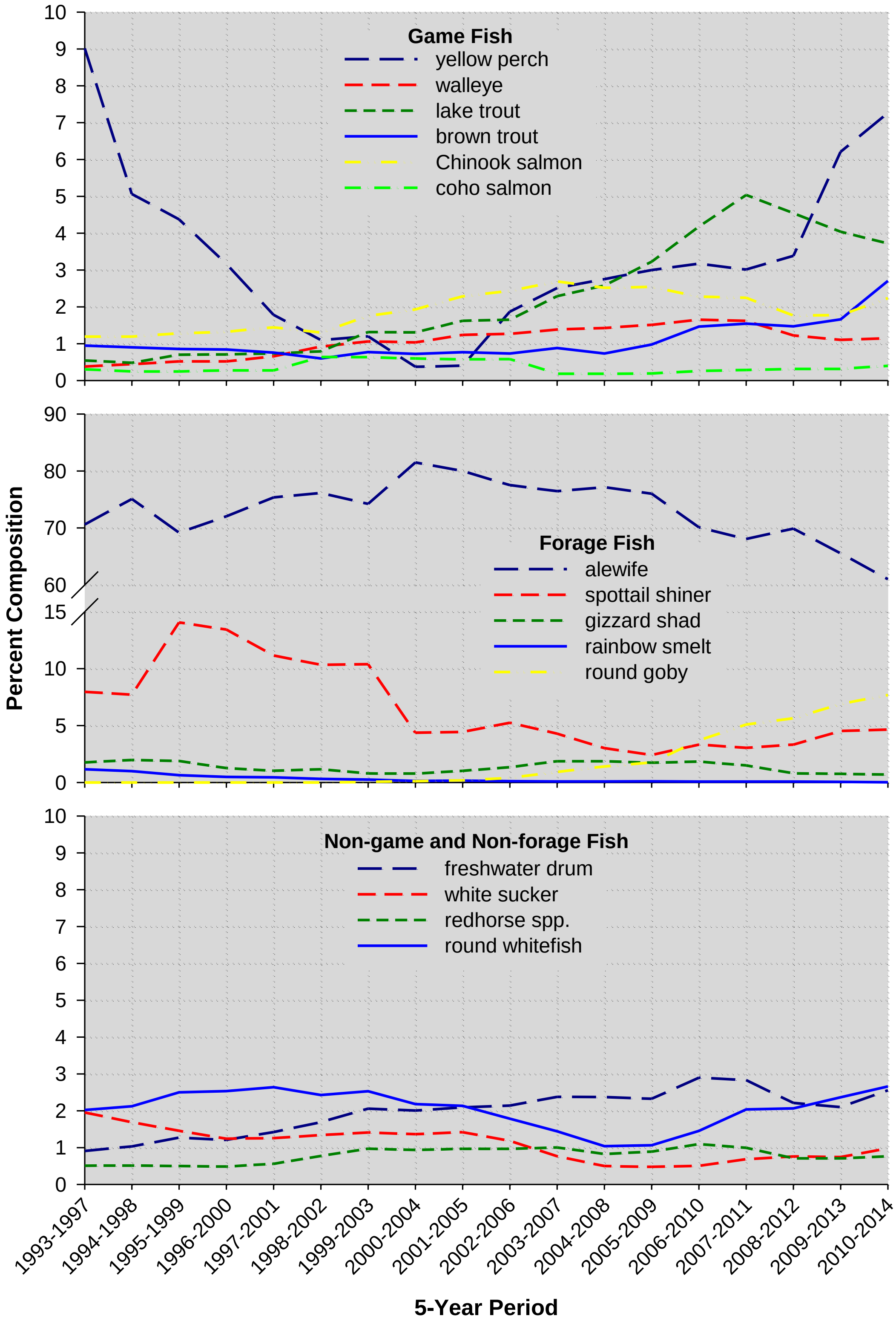


Figure 3-2: Five-year running average of species composition in gill net samples collected outside the barrier net from 1993 to 2014. Only species for which more than 1,000 fish were collected (all size groups combined) over the 22 year period are included.

3.3 Current Biological Conditions and Species Matrix

Using available information and data for species that occur in the vicinity of the LPSP, a matrix was developed (Table 3-3; Table 3-4; Table 3-5; and Table 3-6) summarizing biological, temporal, and spatial information for each relevant to the application of fish protection technologies at the LPSP. This information was developed for each species that has been shown to occur in the vicinity of the project based on recent or historical fishery survey data, including gill net sampling conducted for the annual evaluation of barrier net effectiveness. Qualitative judgements of entrainment risk and effects are also included based on assessment of the information provided for each species.

The temporal information includes seasonal monthly and diurnal presence and the spatial information includes primary occurrence in either nearshore or offshore habitats and at what location in the water column each species is most likely to occur. Although some species and life stages likely occur in the vicinity of the project during winter months, there was limited information on presence for the months of November through March for most species. Also, the annual barrier net monitoring data indicate that the abundance of most species and life stages in the vicinity of the LPSP decreases considerably in the winter. Relative abundance reported by the initial technology assessment for LPSP (SWEC 1988) is also provided, as well as a classification for abundance in recent years.

Based on the information in the species matrix, a qualitative estimate of entrainment risk and effect was developed for each species and life stage. Entrainment risk refers to the potential for a species to be entrained if it is present near the intake without any protection measures in place. The risk level is determined with consideration for relative abundance, primary habitat (off shore versus nearshore), and life stage. Entrainment risk was considered low if species and life stage presence was limited to only one or two months of the year and fish were located primarily offshore. Low risk of entrainment was also assigned to species with a relative abundance classification of rare. A moderate risk of entrainment was assigned to species and life stages that were present over longer time periods of the year and were found primarily in nearshore habitats, or those classified as common or abundant. A high risk of entrainment was typically assigned to species and life stages with a classification of very abundant and were present over extended periods of the year (multiple seasons). The information in the species matrix was considered in the review and feasibility assessment of fish protection technologies with respect to which technologies may have the greatest potential to reduce entrainment of high risk species and life stages.

Entrainment risk for most species and life stages was classified as low or moderate due to rare occurrence in the project area and/or presence being limited to certain seasonal periods. Alewife was the only species classified as having a high risk of entrainment, primarily due to its classification of very abundant, but also because juveniles and adults are present over several months and occur in offshore and nearshore habitats.

Table 3-3: Species matrix for fish classified as target species for the barrier net monitoring program.

Family	Common Name	Scientific Name	Life Stages	Occurence: Seasonal	Occurence: Monthly	Occurence: Diurnal	Abundance Reported by SWM (1988)	Current Abundance	Primary Habitat Relative to Shore	Depth	Entrain-ment Risk
Game Species											
Salmonidae	Brown trout	*Salmo trutta*	J	SP-FA	May-Nov	N>D	C	C	NS	S	**M**
			A	SP-FA	Apr-Nov	N>D	C	C	NS	S	**M**
	Chinook salmon	*Oncorhynchus tshawytscha*	J	SU-FA	Jun-Oct	N>D	C	C	OS	S	**M**
			A	SU-FA	Jun-Oct	N>D	C	C	OS	S-B-M	**M**
	Coho salmon	*Oncorhynchus kisutch*	J	FA	Sep-Nov	N>D	C	R	OS	S-M	**L**
			A	FA	Sep-Nov	N>D	C	R	OS	S-M-B	**L**
	Lake trout	*Salvelinus namaycush*	A	SU-FA	Jun-Oct	N>D	C	C	NS	S-B-M	**M**
	Rainbow trout (Steelhead)	*Oncorhynchus mykiss*	J	FA-SP	Oct-May	N>D	C	R	NS	S-B	**L**
			A	FA-SP	Oct-May	N>D	C	R	NS	S-B	**L**
Percidae	Yellow perch	*Perca flavescens*	I	SP-SU	May-Jul	D/N	A	C	OS	B	**M**
			J	SP-SU	Apr-Aug	D/N	A	C	OS	B	**M**
			A	SP-SU	Apr-Aug	D/N	A	C	OS	B	**M**
Forage Species											
Clupeidae	Alewife	*Alosa pseudoharengus*	I	SU/FA	Jun-Sep	N>D	VA	VA	OS	S-M	**H**
			J	SP/SU	May-Aug	N>D	VA	VA	OS	S-M-B	**H**
			A	SP/SU	May-Aug	N>D	VA	VA	OS	S-M-B	**H**
Osmeridae	Rainbow smelt	*Osmerus mordax*	I	SP/FA	May	N>D	VA	R	OS	S-B-M	**L**
			J	SP/FA	May/Oct	N>D	VA	R	OS	S-B-M	**L**
			A	SP/FA	May/Oct	N>D	VA	R	OS	S-B-M	**L**
Other Species											
Salmonidae	Bloater (Chub)	*Coregonus hoyi*	J	SU	Jun-Aug	N>D	VA	R	OS	B	**L**
			A	SU	Jun-Aug	N>D	VA	R	OS	B	**L**

Life Stages: I, ichthyoplankton; J, juvenile; A, adult
Seasonal: SP, spring; SU, summer; FA, fall
Diurnal: D, day; N, night
Abundance: VA, very abundant; A, abundant; C, common; R, rare
Habitat: NS, nearshore; OS, offshore
Depth: S, surface; M, mid; B, bottom
Entrainment Risk: L, low; M, moderate; H, high

Table 3-4: Species matrix for fish identified as species of concern by one or more interveners in the relicensing of the LPSP. These species are also classified as non-target species for the barrier net monitoring program.

Family	Common Name	Scientific Name	Life Stages	Occurence			Abundance Reported by SWM (1988)	Current Abundance	Primary Habitat Relative to Shore	Depth	Entrain-ment Risk
				Seasonal	Monthly	Diurnal					
Forage Species											
Salmonidae	Lake Herring	*Coregonus artedi*	I	FA-WI	Oct-Dec	D/N	NR	R	NS	S-M-B	**L**
			J	FA-WI	Oct-Dec	D/N	NR	R	OS	S-M-B	**L**
			A	FA-WI	Oct-Dec	D/N	NR	R	OS	S-M-B	**L**
	Lake whitefish	*Coregonus clupeaformis*	I	SP	Apr-May	N	R	R	NS	B	**L**
			J	FA	Oct-Nov	N	C	R	OS	B-S	**L**
			A	FA	Oct-Nov	N	C	R	OS	B	**L**
Other Species											
Acipenseridae	Lake sturgeon	*Acipenser fulvescens*	A	SP-FA	Apr-Nov	D/N	R	R	OS	B	**L**

Life Stages: I, ichthyoplankton; J, juvenile; A, adult
Seasonal: SP, spring; SU, summer; FA, fall
Diurnal: D, day; N, night
Abundance: VA, very abundant; A, abundant; C, common; R, rare
Habitat: NS, nearshore; OS, offshore
Depth: S, surface; M, mid; B, bottom
Entrainment Risk: L, low; M, moderate; H, high

Table 3-5: Species matrix for game and forage fish classified as non-target species for the barrier net monitoring program.

Family	Common Name	Scientific Name	Life Stages	Occurence			Abundance Reported by SWM (1988)	Current Abundance	Primary Habitat Relative to Shore	Depth	Entrain-ment Risk
				Seasonal	Monthly	Diurnal					
Game Species											
Centrarchidae	Black crappie	*Pomoxis nigromaculatus*	I	SU	Aug	N	R	R	NS	B	**L**
			J	SU-FA	Jul-Sep	D/N	R	R	NS	S-B	**L**
			A	SU-FA	Jul-Sep	D/N	R	R	NS	S-B	**L**
	Largemouth bass	*Micropterus salmoides*	J	SU-FA	Jun-Sep	D/N	NR	R	NS	S	**L**
			A	SU-FA	Jun-Sep	D/N	NR	R	NS	S	**L**
	Pumpkinseed	*Lepomis gibbosus*	J	SU-FA	Jun-Sep	D/N	NR	R	NS	S	**L**
			A	SU-FA	Jun-Sep	D/N	NR	R	NS	S-M	**L**
	Rock bass	*Ambloplites rupestris*	J	SU-FA	Jun-Sep	D/N	NR	R	NS	B-S	**L**
			A	SU-FA	Jun-Sep	D/N	NR	R	NS	S-B	**L**
	Smallmouth bass	*Micropterus dolomieu*	J	SU-FA	Jun-Sep	D/N	NR	R	NS	S-B	**L**
			A	SU-FA	Jun-Sep	D/N	NR	R	NS	S-B	**L**
	Bluegill	*Lepomis macrochirus*	I	SU-FA	Aug-Nov	D/N	R	R	NS	B	**L**
			J	SU-FA	Jun-Sep	D/N	R	R	NS	M-B	**L**
			A	SU-FA	Jun-Sep	D/N	R	R	NS	M-B	**L**
Esocidae	Northern pike	*Esox lucius*	A				NR	R	NS	B-M	**L**
Salmonidae	Brook trout	*Salvelinus fontinalis*	A				NR	R	NS	S	**L**
Forage Species											
Clupeidae	Gizzard shad	*Dorosoma cepedianum*	I	FA	Oct	D/N	R	C	NS	S	**M**
			J	SP-FA	April-Oct	D/N	R	C	NS	S-B-M	**M**
			A	SP-FA	April-Oct	D/N	R	C	NS	M	**M**
Moronidae	White perch	*Morone americana*	A	SU-FA	Jul-Sep	D/N	NR	R	NS	S-B	**L**
Salmonidae	Round whitefish	*Prosopium cylindraceum*	A	SP-FA	Apr-Nov	N	C	C	OS	B-S	**M**

Life Stages: I, ichthyoplankton; J, juvenile; A, adult
Seasonal: SP, spring; SU, summer; FA, fall
Diurnal: D, day; N, night
Abundance: VA, very abundant; A, abundant; C, common; R, rare
Habitat: NS, nearshore; OS, offshore
Depth: S, surface; M, mid; B, bottom
Entrainment Risk: L, low; M, moderate; H, high

Table 3-6: Species matrix for fish considered neither game or forage species and classified as non-target species for the barrier net monitoring program.

Family	Common Name	Scientific Name	Life Stages	Occurence: Seasonal	Occurence: Monthly	Occurence: Diurnal	Abundance Reported by SWM (1988)	Current Abundance	Primary Habitat Relative to Shore	Depth	Entrain-ment Risk
Other Species											
Amiidae	Bowfin	*Amia calva*	A	No Data	No Data	D/N	NR	R	NS	S	**L**
Catostomidae	Black buffalo	*Iciobus niger*	A	No Data	No Data	D/N	NR	R	NS	S-B	**L**
	Longnose sucker	*Catostomus catostomus*	A	SP-FA	Apr-Nov	N>D	C	R	NS	S-B-M	**L**
	Quillback	*Carpiodes cyprinus*	A	SU-FA	Jul-Sep	D/N	NR	R	NS	S	**L**
	Redhorse spp.	*Moxostoma spp.*	J	SU-FA	Jul-Sep	D/N	NR	C	NS	S-B	**M**
			A	SU-FA	Jul-Sep	D/N	NR	C	NS	S	**M**
	White sucker	*Catostomus commersoni*	J	SP-FA	Apr-Nov	N>D	C	C	OS	S-B	**M**
			A	SP-FA	Apr-Nov	N>D	C	C	OS	B	**M**
Cottidae	Mottled sculpin	*Cottus bairdi*	J	SU	Jun-Aug	N	NR	R	OS	B	**L**
			A	SU	Jul-Aug	N	NR	R	OS	S-B	**L**
	deepwater sculpin	*Myoxocephalus thompsonii*	I	SP-SU	April-Aug	N	C	R	NS	B	**L**
			J	FA	Nov	N	C	R	NS	B	**L**
			A	FA	Nov	N	C	R	NS	B	**L**
	Slimy sculpin	*Cottus cognatus*	A	SP-SU	May-Aug	N	NR	R	OS	B	**L**
Cyprinidae	Common carp	*Cyprinus carpio*	A	SP-FA	Jul-Aug	D/N	NR	R	NS	S-B-M	**L**
	Lake chub	*Couesius plumbeus*	A	No Data	No Data	D/N	NR	R	OS	B	**L**
	Common Shiner	*Notropis cornutus*	A	SP-FA	Apr-Nov	D/N	NR	R	NS	S-B-M	**L**
	Longnose dace	*Rhinichthys cataractae*	I	SP-FA	May-Sep	D/N	NR	R	NS	B	**L**
			J	SP-FA	May-Sep	D/N	NR	R	NS	B	**L**
			A	SP-FA	May-Sep	D/N	NR	R	NS	B	**L**
	Spottail shiner	*Notropis hudsonius*	I	SU	June-Aug	N	A	A	NS	S	**M**
			J	SP-FA	Apr-Nov	D/N	A	A	NS	S-B	**M**
			A	SP-FA	Apr-Nov	D/N	A	A	NS	S-B	**M**
	Lake emerald shiner	*Notropis atherinoides*	I	SU	June-Aug	N	R	UNK	OS	S	**L**
			J	SU	May-Aug	D/N	R	UNK	OS	S	**L**
			A	SU	May-Aug	D/N	R	UNK	OS	S	**L**

Life Stages: I, ichthyoplankton; J, juvenile; A, adult
Seasonal: SP, spring; SU, summer; FA, fall
Diurnal: D, day; N, night
Abundance: VA, very abundant; A, abundant; C, common; R, rare
Habitat: NS, nearshore; OS, offshore
Depth: S, surface; M, mid; B, bottom
Entrainment Risk: L, low; M, moderate; H, high

Table 3-6 (Continued)

Family	Common Name	Scientific Name	Life Stages	Occurence: Seasonal	Occurence: Monthly	Occurence: Diurnal	Abundance Reported by SWM (1988)	Current Abundance	Primary Habitat Relative to Shore	Depth	Entrain-ment Risk
Other Species (continued)											
Gasterosteidae	Threespine stickleback	*Gasterosteus aculeatus*	J	No Data	No Data	D/N	NR	R	NS	S-B	**L**
			A	No Data	No Data	D/N	NR	R	NS	S-B	**L**
	Ninespine stickleback	*Pungitius pugitius*	I	SU-FA	Jun-Sep	N	C	UNK	NS	B	**M**
			J	SP-SU	Apr-Aug	D/N	C	UNK	NS	B	**M**
			A	SP-SU	Apr-Aug	D/N	C	UNK	NS	B	**M**
Gobiidae	Round goby	*Neogobius melanostomus*	J	SP-SU	May-Jul	D/N	NR	C	OS	S-B	**M**
			A	SP-SU	May-Jul	D/N	NR	C	OS	S-B	**M**
Ictaluridae	Black bullhead	*Ictalurus melas*	A	SU-FA	Aug-Sep	D/N	NR	R	NS	B	**L**
	Channel catfish	*Ictalurus punctatus*	A	SU-FA	Aug-Sep	D/N	NR	R	NS	B	**L**
Lepisosteidae	Longnose gar	*Lepisosteus osseus*	A	SP-FA	May-Sep	D/N	NR	R	NS	S-B	**L**
Lotidae	Burbot	*Lota lota*	I	SP-SU	Apr-Jun	N	C	R	OS	B	**L**
			J	SP-FA	Apr-Nov	N	C	R	OS	S	**L**
			A	SP-FA	Apr-Nov	N	C	R	OS	S	**L**
Percidae	Johnny darter	*Etheostoma nigrum*	I	SU-FA	July-Sept	N	C	UNK	NS	B	**M**
			J	SP-FA	May-Oct	N>D	A	UNK	NS	B	**M**
			A	SP-FA	May-Oct	N>D	A	UNK	NS	B	**M**
	Walleye	*Sander vitreus*	J	SP-FA	May-Oct	N	R	C	OS	B-S-M	**M**
			A	SP-FA	May-Oct	N	R	C	OS	S-B-M	**M**
Percopsidae	Trout-perch	*Percopsis omiscomaycus*	I	SU	Aug	N	R	R	NS	S-B	**L**
			J	SP-FA	May-Sept	N	C	R	NS	S-B	**L**
			A	SP-FA	May-Sept	N	C	R	NS	S-B	**L**
Petromyzontidae	Sea lamprey	*Petromyzon marinus*	A	No Data	No Data	D/N	NR	R	OS	S-B	**L**
Sciaenidae	Freshwater drum	*Aplodinotus grunniens*	A	SP-FA	May-Oct	D/N	NR	C	OS	S-B-M	**M**

Life Stages: I, ichthyoplankton; J, juvenile; A, adult **Seasonal:** SP, spring; SU, summer; FA, fall **Diurnal:** D, day; N, night
Abundance: VA, very abundant; A, abundant; C, common; R, rare **Habitat:** NS, nearshore; OS, offshore **Depth:** S, surface; M, mid; B, bottom
Entrainment Risk: L, low; M, moderate; H, high

4 Existing Barrier Net Design, Maintenance, and Biological Effectiveness

To effectively determine the applicability of alternative fish protection technologies at the LPSP intake, it is important to understand the design and effectiveness of the existing barrier net which, with various improvements in design, has been installed annually since 1989 to reduce fish entrainment. That is, the potential performance of other technologies, from biological and engineering perspectives, needs to be examined in context to the performance of the barrier net in order to determine if any alternative can provide equal or greater fish protection as a standalone system or when used in conjunction with the barrier net. The 25 years of barrier net operation and evaluation also provide valuable environmental, hydraulic, and biological data that will likely influence the performance of any technology installed at the project. Consequently, a detailed review of the barrier net design, maintenance, and biological effectiveness is provided in this section.

4.1 Design

A seasonal barrier net has been installed at LPSP annually since 1989 to reduce entrainment of Lake Michigan fish into the upper impoundment during pumping operations (Reider et al. 1997). The FERC issued an order in 1988 for the installation of the net as an interim fish protection measure; it became a permanent solution as part of Offer of Settlement accepted by FERC in 1996. The barrier net is required to be deployed from April 15 through October 15. Winter conditions prevent the barrier net from use during the remainder of the year. However, there is strong evidence from fisheries studies that fish abundance decreases significantly in the vicinity of the project during winter months (Liston et al. 1981).

The following design summary of the LPSP barrier net is based on a detailed description from the 2012 (CEC 2012) and the 2014 (CEC 2014) barrier net specification sheet. The LPSP seasonal barrier net is 12,850 ft in length and consists of a total of 62 individual net panels. The net is formed by five general sections: an east section, north and south sections, and an angled return from both the north and south sections (Figure 4-1). The 62-panel barrier net is comprised of 51 panels that are 200 ft long, two panels that are 175 ft long, two panels that are 100 ft long, and seven panels that are 300 ft long. Table 4-1 summarizes each of the 62 panel lengths.

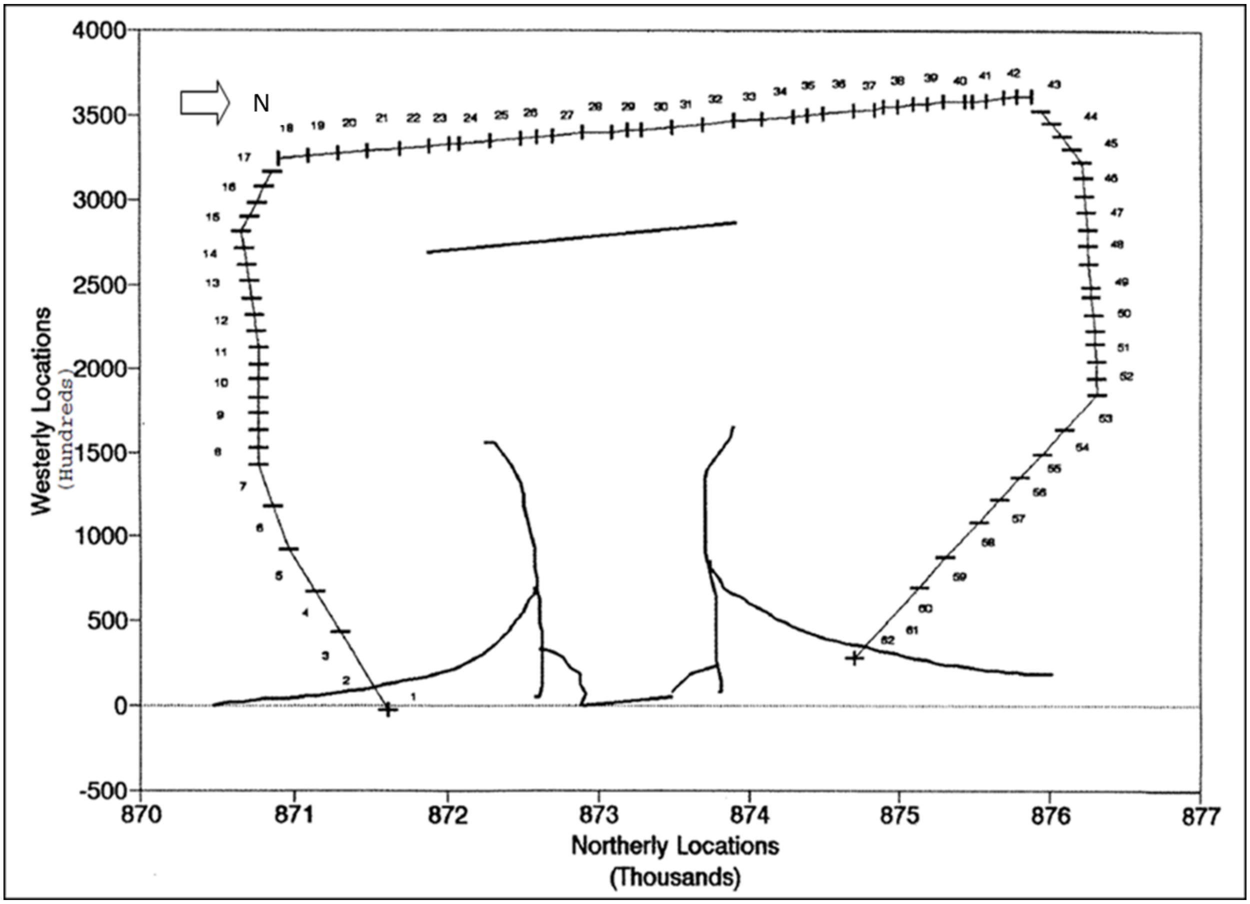


Figure 4-1: Overview of Primary Net Sections and Panels at LPSP

The first 1,175 ft of net from the shoreline, in both the north and south wings (panels 1-5 and 58-62), is made of ½-inch bar mesh (1-inch stretch), while the remainder of the net (panels 6-57) is constructed with ¾-inch bar mesh (1½-inch stretch). The intent of using the ½-inch bar mesh near shore is to improve the net's effectiveness in excluding small fish, which typically inhabit shallow waters in early summer.

The main mesh panels are constructed of twisted knotted netting fabricated from Spectra 900 or Dyneema SK65 material. Each net panel is completely encompassed by border lines and the main net is diamond hung. The diamond hung net allows the net material to stretch and flex in the horizontal and vertical direction, providing a stronger net due to a more uniform distribution of forces to the riser and border lines. All of the main net panel connections to adjacent net panels are constructed using closed thimbles. Net panel dimensions are summarized in Table 4-1.

Panels 1-8, 24-31, and 49-62 are equipped with flotation of 15.4 lb buoyancy at 12-inch on-center (o.c.), increments. Panels 9-23 and 32-48 are equipped with flotation of 21.2 lbs buoyancy at 12-inch o.c. increments. The stresses are higher in these corner areas during generation due to the higher velocity.

In addition to the individual net sections, components include the top and bottom skirts, top skirt float lines, top skirt floats, permanent anchor pilings, lead lines, top and bottom border line, end border line, riser line, main net float line, and main net floats.

Each panel except Nos. 1 and 62 (which are located wholly on shore and are not in the water), have a bottom skirt affixed to the main net bottom border line and a top skirt attached to the top border line. The top border line is a continuous line along the top of the main net panel to which the net mesh, float line, riser line, and top skirt are attached. The bottom border line is present along the bottom of the main net panels to which the bottom skirt and lead line chain are attached. The end border lines extend from the bottom border line up to the top border line. The netting mesh is tied with hanging twine to all the border lines to ensure that each mesh is attached.

Riser lines are continuous vertical lines spaced 20 ft o.c. and between the end lines. The top end is attached to the top border line and the bottom end is attached to the bottom border line. A float line is used to attach the top border line to the floatation devices. The main net riser lines are installed to transmit the lake current and wave forces from the top and bottom lines to the permanent bottom anchors.

The top skirt is a continuous panel extending from Panel 2-61. The top skirt is made of polyethylene netting with a mesh size that matches each main net panel's mesh size. A 10 ft wide top skirt is used for Panels 2-5 and 58-61, and is 20 ft wide for Panels 6-57. The top skirt is attached to the main net top border line extending toward the exterior perimeter, and has floats providing 3.2 lb/ft buoyancy on the free side, as seen in Figure 4-3. The top skirt acts as a seal along the water's surface, preventing fish from swimming over the top of the net

The bottom skirt extends from Panel 2 through 61. The bottom skirt is made out of #18 nylon netting that matches the mesh size of each main net panel. For Panels 2 through 5 and 58 through 61 the bottom skirt is 10 ft wide and is 20 ft wide for Panels 6 through 57. The bottom skirt is attached to the main net bottom lead line extending toward the exterior perimeter, and has 6-inch pieces of chain, spaced every 12 inches o.c., attached as weights on the free side, as seen in Figure 4-3. The bottom skirt acts as a seal along the lake bed, preventing fish from swimming under the net.

The barrier net is anchored in place in Lake Michigan using a series of permanent bottom anchor piles generally spaced about 100 ft apart. An anchor chain is attached from each anchor pile to the barrier net panel's lead line at each of the permanent bottom anchors. The lead line attachment is made via yoking using a 3/8-inch diameter coated Samson Tenex (12 strand polyester) rope attached to every other chain link. The barrier net panel's lead line distributes the stress from the anchor points to the rest of the barrier net panels. Figure 4-2 provides an overview of the barrier net and the barrier net specifications are provided in Table 4-2.

Indicator buoys are located approximately 400 ft outside of the net. These buoys are spaced every 250 ft to the south and west of the net and every 125 ft to the north of the net. Most of these buoys are typical regulatory buoys indicating to keep out of the area between the buoy line and the net. Seven of the buoys are lighted. The arrangement of the buoys is shown on Figure

4-2. A sectional view across the net showing a lighted buoy and the top and bottom skirts along is provided in Figure 4-3.

Table 4-1: Panel dimension chart

Panel Number	Panel Length (ft)	Panel Height (ft)	
		End #1	End #2
1	175	2.0	12.5
2	200	12.5	15.0
3	200	15.0	17.5
4	300	17.5	21.25
5	300	21.25	25.0
6	300	25.0	28.75
7	300	28.75	32.5
8	200	32.5	35.0
9	200	35.0	37.5
10	200	37.5	40.0
11	200	40.0	42.5
12	200	42.5	45.0
13	200	45.0	47.5
14	200	47.5	50.0
15	200	50.0	52.5
16	200	52.5	55.0
17 and 43	100	55.0	55.0
18 thru 42	200	55.0	55.0
44	200	55.0	52.5
45	200	52.5	50.0
46	200	50.0	47.5
47	200	47.5	45.0
48	200	45.0	42.5
49	200	42.5	40.0
50	200	40.0	37.5
51	200	37.5	35.0
52	200	35.0	32.5
53	300	32.5	32.5
54	200	32.5	32.5
55	200	32.5	30.0
56	200	30.0	27.5
57	200	27.5	25.0
58	300	25.0	21.25
59	300	21.25	17.5
60	200	17.5	15.0
61	200	15.0	12.5
62	175	12.5	2.0

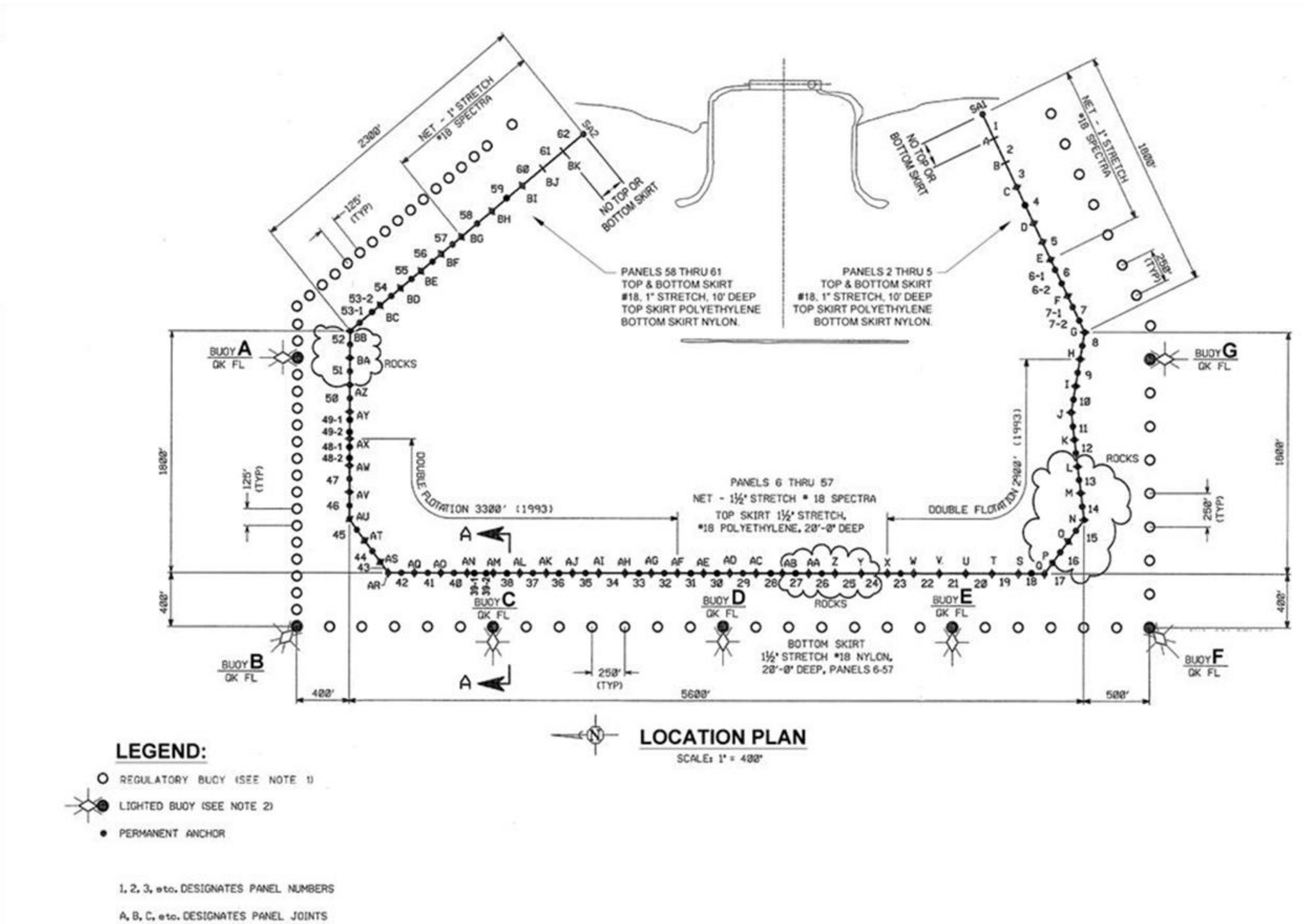
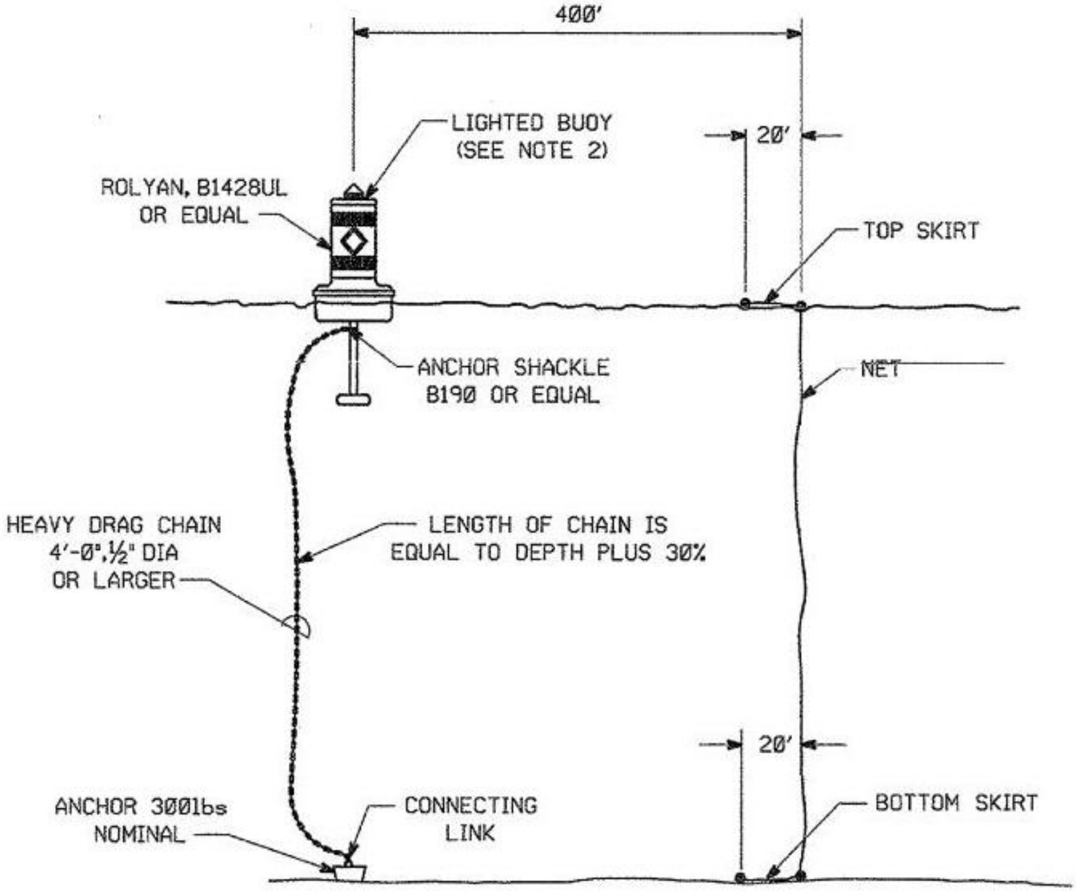


Figure 4-2: Plan view of the barrier net



SECTION A-A
LIGHTED BUOY

SCALE: NONE

Figure 4-3: Section view of the barrier net showing a lighted indicator buoy

4.2 Barrier Net Installation and Removal

The LPSP barrier net installation and maintenance have been completed by Underwater Construction Corporation, Inc., (UCC) for the past 20 years. The general process for installing the barrier net has remained the same since 1991. Net panels are constructed off-site and joined in lengths that fit on semi-trailers for transportation to a staging area. UCC has used the Oxy Chemical Sand Dock on Pere Marquette Lake in Ludington, Michigan in the past to transfer the panels to two deck barges (panels 1-31 on one deck barge and panels 32-62 on the second deck barge) using a mobile crane.

Major subsections of the net panels are sewn and shackled together on the barges in preparation for installation. The barges are then moved to the installation site with the aid of a tug boat.

Site preparations include the locating and freeing of the anchor chains of the permanent lake bottom anchors. Anchors locations are found with the aid of a Global Positioning System (GPS) unit and divers with underwater metal detectors.

Removal of the barrier net in the fall of each year involves divers, a barge and crane and typically takes approximately three to four days depending on weather. Cleaning is done as the barrier net panels are transferred onshore using a high-pressure pump. The barrier net is cleaned at the Oxy Chemical Sand Dock and inspected and stored in individual boxes at CEC's warehouse in Ludington, Michigan. Repair or replacement of the barrier net panels takes place over the winter.

Table 4-2: Barrier Net Design Specifications

Net Material	Dyneema SK 75
Mesh Size: Panels 1-5, 58-62 Panels 6-57	½” bar ¾” bar
Net Depth	2’ – 55’
Border Rope Material	Samson Amsteel Blue
Top Floats: Panels 1-8,24-31,49-62 Panels 9-23,32-48	Badinotti’s RX-7 PVC Floats Badinotti’s RX-10 PVC Floats
Hanging Twine	#18 Spectra
Knot Spacing	Every 2 Mesh
Bottom Chain	½” hot-dip galvanized long link lashing chain
Riser Line Spacing (main net)	20’
Top Skirt Material	# 18 Polyethylene
Top Skirt Depth: Panels 2-5, 58-61 Panels 6-57	10’ - ½” Bar 20’ – ¾” Bar
Top Skirt Floats	Baolong BL-6 EVA
Bottom Skirt Chain	3/8” Grade 30 proof coil chain
Bottom Skirt Material	# 18 Nylon
Bottom Skirt Specs: Panels 1-5, 58-62 Panels 6-57	½” Bar #18, 10’ ¾” Bar #18, 20’

4.3 Operation and Maintenance

In general, the barrier net is operated from April 15 until October 15. An operational monitoring program log is in place to document the operational condition of the barrier net and help assure timely corrective actions and maintenance. The operational monitoring program includes twice-daily surface inspections and twice-weekly subsurface inspections. Surface and subsurface observations of the barrier net are used to determine maintenance activities. Surface observations are performed daily from the bluffs and whenever possible from a 30-ft inspection vessel.

Installation of the barrier net typically takes approximately three to four days depending on weather. The seam between panels 31 and 32 is sewn together and the net is installed by moving from anchor to anchor, assuring a firm connection and proper positioning before deploying additional netting. During barrier net installation, in the high current areas, plant generation is limited to two units (except in case of an emergency). This coordination improves the efficiency of barrier net installation. Installation status is provided to System Operations on a daily basis.

When installation is interrupted by severe weather or darkness, the barrier net is cut at a panel joint and secured at an anchor. Upon resuming installation, the panels are disconnected from the anchor to allow on-board sewing to the remainder of the barrier net prior to proceeding with the installation. Replacement of anchors is completed on an as-needed basis. In addition to the installation of the barrier net, lighted and spar navigational buoys are also installed annually at the site.

Subsurface inspections are performed by UCC divers using dive equipment and the inspection vessel. Under its current contract with Consumers, UCC is responsible for cleaning and repairing the net on a daily basis to maintain its reliability.

Cleaning of the net is an ongoing operation. Individual net panels are typically cleaned by divers on a regular basis. Cleaning is done in place with modified, pressure-washing units. The levels of debris and required maintenance are highly dependent upon a variety of factors as the debris found on the net is biological in nature and growth varies with varying conditions. The most common type of debris is algae (Cladophora spp.), which both grows and accumulates on the net; however, Dreissenid mussels (zebra and quagga) also foul the net at times. The amount of algae at any given time is dependent upon factors including temperature, light level, nutrient levels, and storm events. Typically, the divers clean each panel once per month; however, panels which are in the direct discharge path may be cleaned twice per month.

Following cleaning, the net panel is typically left with minimal debris. Throughout the period in between cleanings, the top and bottom 2-3 ft of the net typically remain clean due to the wave action and dragging of the net on the lake bed, respectively. The remaining portion of the net (excluding the top and bottom 2-3 ft) reportedly becomes up to 80% clogged with debris during the period between cleanings (approximately one month for the majority of panels and two weeks in the area of direct discharge).

The most commonly seen operational issue with the barrier net is submergence. During 6-unit generation it is common for up to 8 panels to be submerged for several hours. Minimal information with regards to panel submergence during pumping is available. Although there are some records of submergence during pumping and non-operating conditions, submergence observations are visual and typically taken during the day while pumping typically occurs during the night. In addition to generation/flow, the level of debris (primarily algae) is a significant contributor to the likelihood of submergence; when levels of algae are high, portions of the net are more likely to submerge. No correlation was found between submergence events and wind speed (Alden 2011).

4.4 Operational Impacts

Alden conducted a study of operational impacts on the barrier net in 2011 (Alden 2011). The following discussion is a summary of existing impacts on the net as a result of operations as discussed in the report.

A review of the barrier net under current operating conditions (velocities, pressures, configuration, debris, etc.) indicates that there are frequent net panel submergence events when the top of one or more panels moves below the water surface. Although there has been no direct correlation between barrier net effectiveness and the submergence of net panels, these events present an opportunity during which fish can swim directly over the net and enter the intake area where they are at risk to turbine entrainment. It is possible that some of the fish that have been caught during annual gill netting, and which were too large to pass through the barrier net mesh, bypassed the net during a submergence event.

Correspondence with UCC and a review of the submergence data indicate that net submergence typically occurs during generation, most often when four or more units are operating. Submergence of net panels has also occurred, although infrequently, during pumping and when the plant is not operational. These events are most likely influenced by a combination of debris loading and biofouling, wave action, and/or lake currents. The locations where submergence typically occurs are between panels 11 through 17 and 36 through 47 (Figure 4-4).

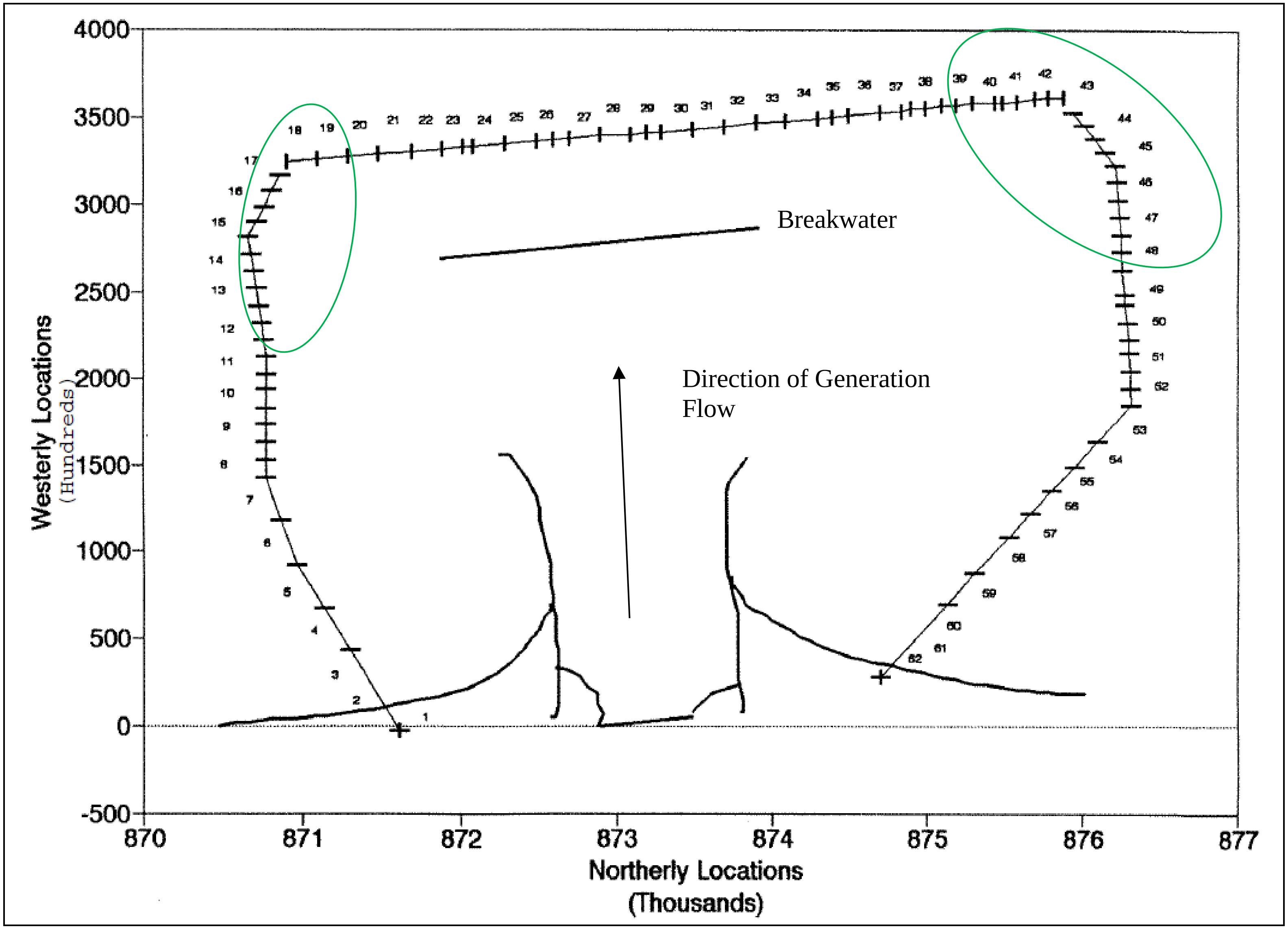


Figure 4-4: Locations of Submergence along the Barrier Net as indicated by green circles (Alden 2011)

The generation flow discharges at a high velocity between the jetties before encountering the breakwater wall. The breakwater wall dissipates some of the energy and splits the flow toward the northern and southern offshore corners of the net. Although the split flow has lower velocities than in the initial tailrace discharges, it contributes to contribute to submergence in the areas identified in Figure 4-4 (velocity patterns are discussed in more detail below). It should be noted that these velocity patterns are evident only during the generation. Historical submergence observations from April 2008 through May 2011 are summarized in Table 4-3.

The existing floats in the area where submergence occurs provide 21.2 lbs/ft buoyancy. When the net is clean this should be sufficient to prevent submergence. As debris loading of the net increases so do the forces on the net. The amount of buoyancy needed to prevent submergence under different levels of slack in the net and with up to 50% of the net material plugged was calculated as part of the 2011 barrier net evaluation (Alden 2011) and is presented in Table 4-4. With a taut net and 50% plugging, 28.5 lb/ft of buoyancy is needed to prevent submergence, which is greater than what is currently provided. At times divers have reported up to 80% of the net is plugged with debris and biofouling. Although this was not modeled, the amount of buoyancy required when the net is 80% plugged would be greater than what is shown in Table 4-4.

The data were further analyzed to evaluate the effect of the number of units generating on the number of panels submerged during submergence events (Figure 4-5). Although the number of panels that submerge during each of the six operational scenarios varies, there is a general increase in the numbers of panel submerged with the number of units that are generating (Figure 4-5).

Table 4-3: Submergence Events as a Function of Pumping and Generating (April 15, 2008 through May 2011) (Data from Alden 2011)

Operation	Total Number Observations	Total Number of Observed Net Submergence Events	Percentage Total Observations	Average Number Panels Submerged	Maximum Number Panels Submerged
Pumping	119	7	5.8%	1.9	4
Generating	379	271	71.3%	6.2	15
No Plant Operations	264	5	1.9%	1.6	3

Table 4-4: Estimation of Typically Required Buoyancy Assuming Maximum CFD Pressure Values (Existing Conditions) at "Hot Spots" (Alden 2011)

Net slack condition	Buoyancy Required (lb)	
	0% Debris	50 % Debris
A (max slack)	5.2	15.6
B	5.2	16.0
C	5.8	18.4
D (min slack, taut net)	8.6	28.5

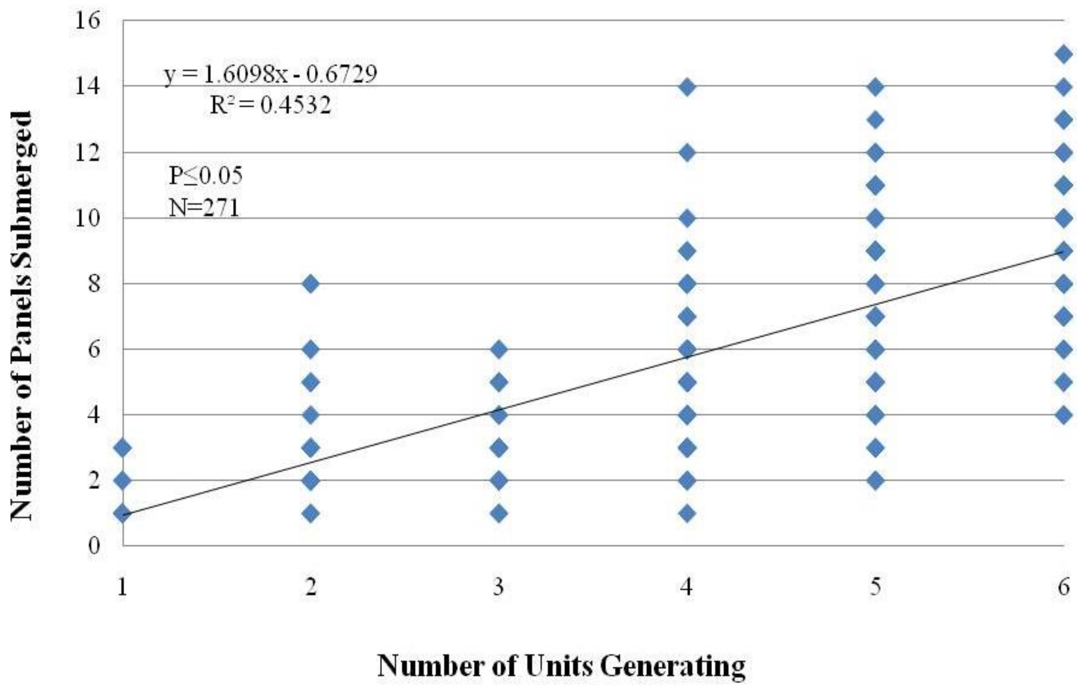


Figure 4-5: Correlation between Number of Units Generating and Submergence Events (2008 through June 15, 2011) (Alden 2011)

A computational fluid dynamic (CFD) hydraulic model was developed to evaluate the hydraulic impacts of the anticipated increase in pumping and generating capacity at the LPSP. The specific objectives of the numeric model study were to identify changes in water velocity and flow patterns for the existing versus the proposed operating conditions and to provide flow conditions (velocity and pressure) at the barrier net under various operating conditions to allow assessment of physical impacts to the barrier net under increased flows. A full discussion of the analysis and results can be found in Alden 2011.

As shown in Figure 4-5, there is a clear relationship between the higher velocities (more units generating) at the net and submergence occurrence during generation. The CFD analysis was used to assess velocities associated with the existing and upgraded flow rate. Figure 4-6 and Figure 4-7 show the results of the CFD analysis with all six units generating. The CFD results demonstrate that flow exiting the jetties is deflected off the breakwater resulting in discharge jets that do not have enough distance to dissipate before hitting the net. Figure 4-8 and Figure 4-9 show the results of the CFD analysis for six units pumping which provides a visual estimation of the existing and upgraded velocity conditions. Horizontal planes are shown at elevation 555 ft and 575 ft. Elevation 555 ft is the lowest elevation where significant portions of the topography are missing due to the bottom topography. Elevation 575 ft represents water surface conditions.

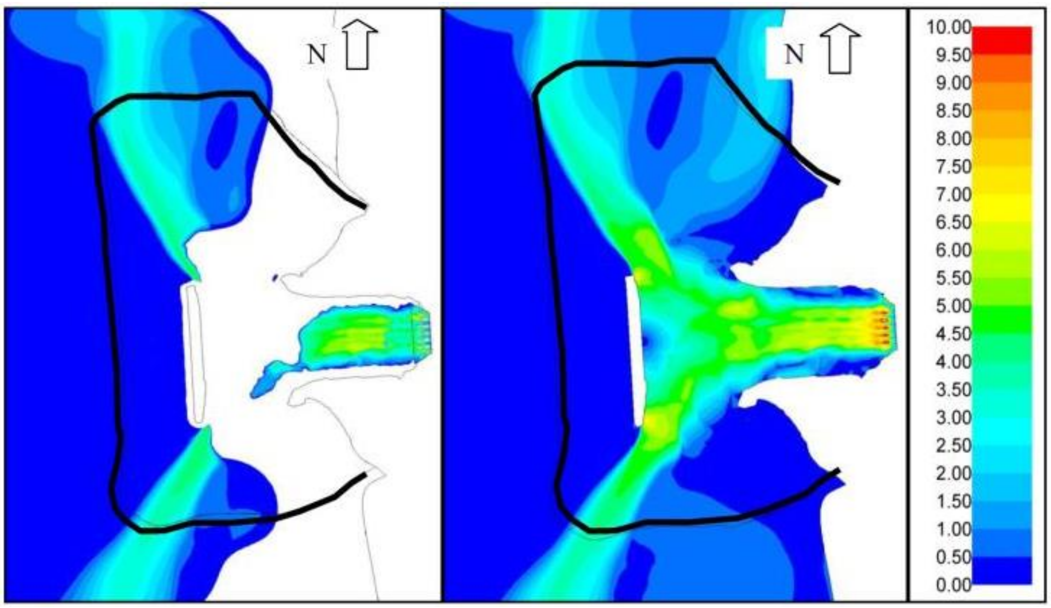


Figure 4-6: CFD Velocity Results (ft/sec) for Existing 6 Unit Generating Flows, No Debris at Elevation 555 ft (left) and Elevation 575 ft (right) (Alden 2011)

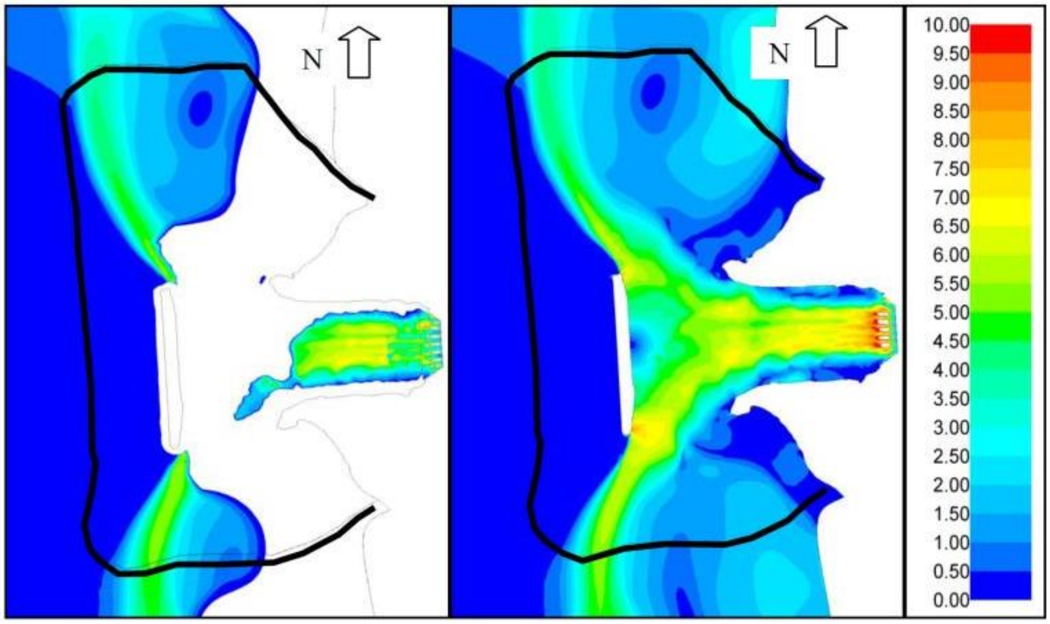


Figure 4-7: CFD Velocity Results (ft/sec) for Proposed 6-Unit Generation Flows, No Debris at Elevation 555 ft (left) and Elevation 575 ft (right) (Alden 2011)

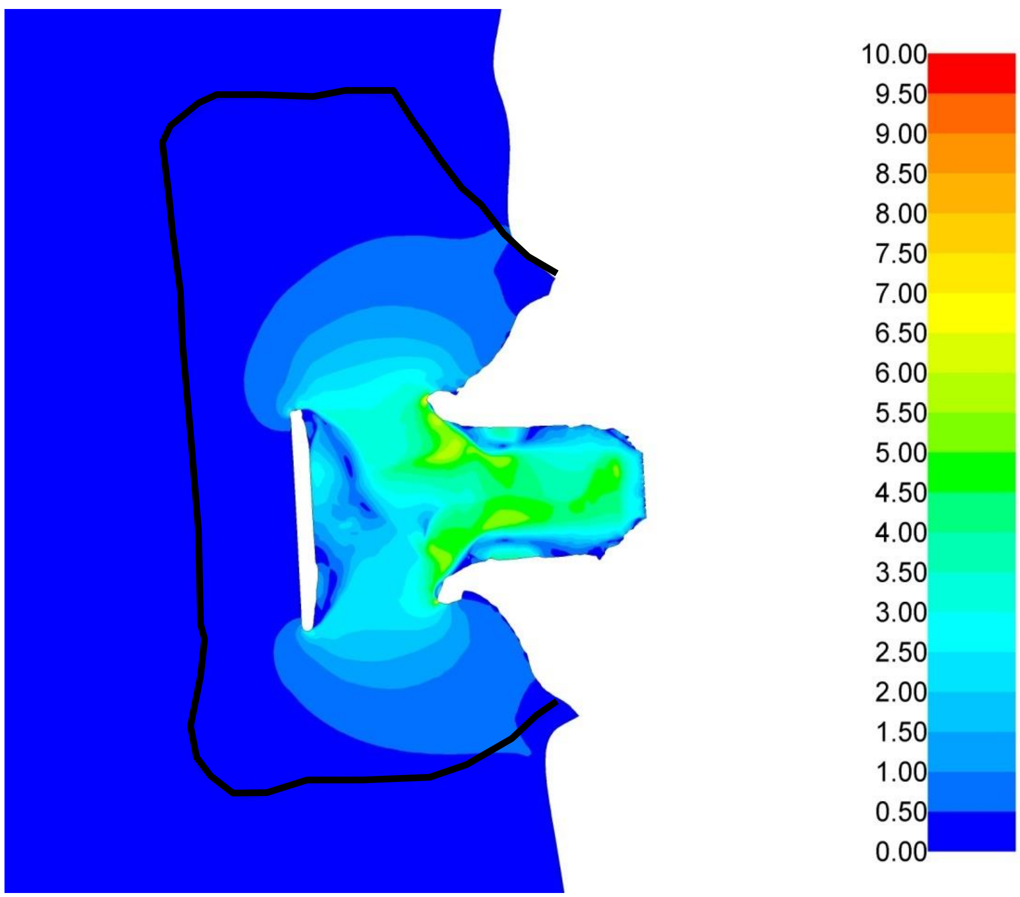


Figure 4-8: CFD Estimated Surface Velocities (ft/sec); Pumping at Existing Capacity; 575 ft; ambient current = 0.2 ft/s (Alden 2011)

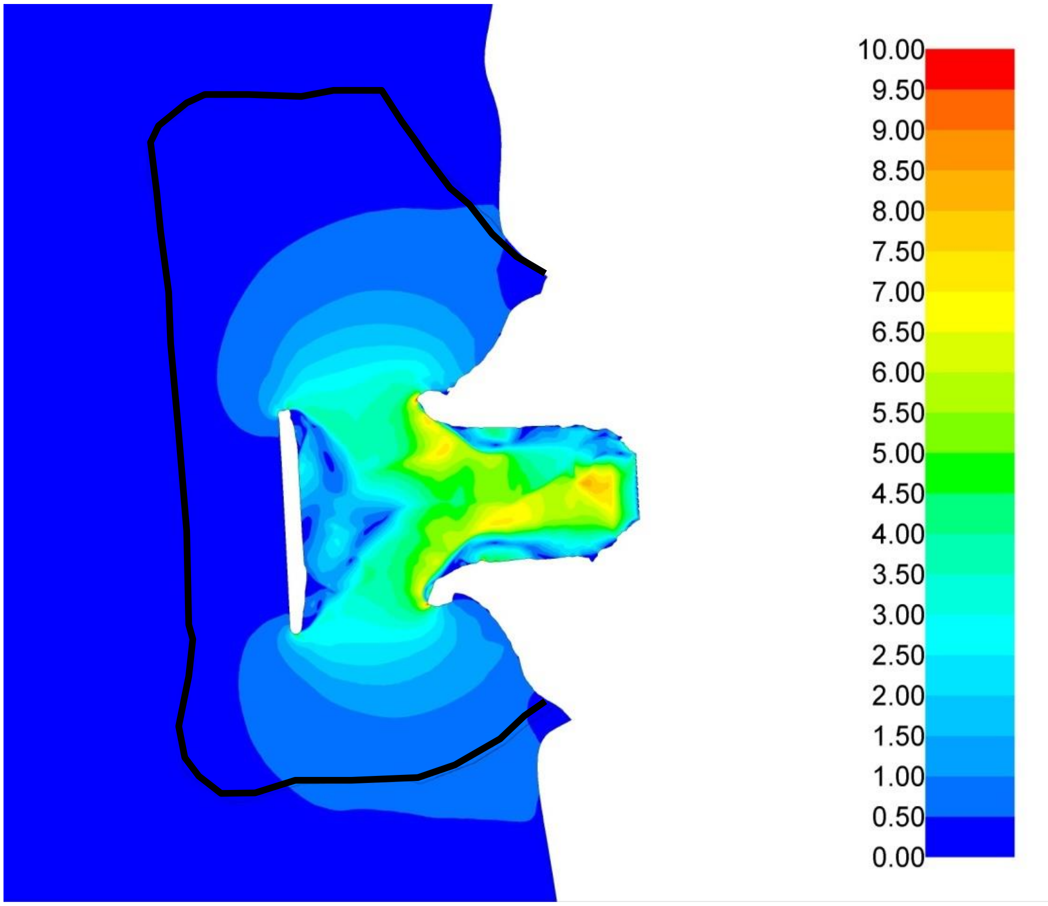


Figure 4-9: CFD Estimated Surface Velocities (ft/sec); Pumping at Upgraded Capacity; 575 ft (Alden 2011).

For the purpose of the velocity review the net was divided into 20 sections (Figure 4-10). Estimates for the average and maximum approach velocity of each net section are summarized in Table 4-5. Prior to turbine upgrades-overhauls, the net average approach velocity was estimated to be 0.7 ft/sec during generation and 0.2 ft/sec during pumping. These values slightly increase after the upgrades to 1.0 and 0.3 ft/sec, respectively. The maximum estimated velocities before and after upgrades occur during generation at the north-west and south-west areas of the barrier net, or sections 5, 6, 14, and 15 (Figure 4-10). These results correlate with the historic submergence observations. It should also be noted that the velocities approaching sections 1-3 and 17-20 (Table 4-5) are moving towards LPSP during generation due to large eddies that form at these locations.

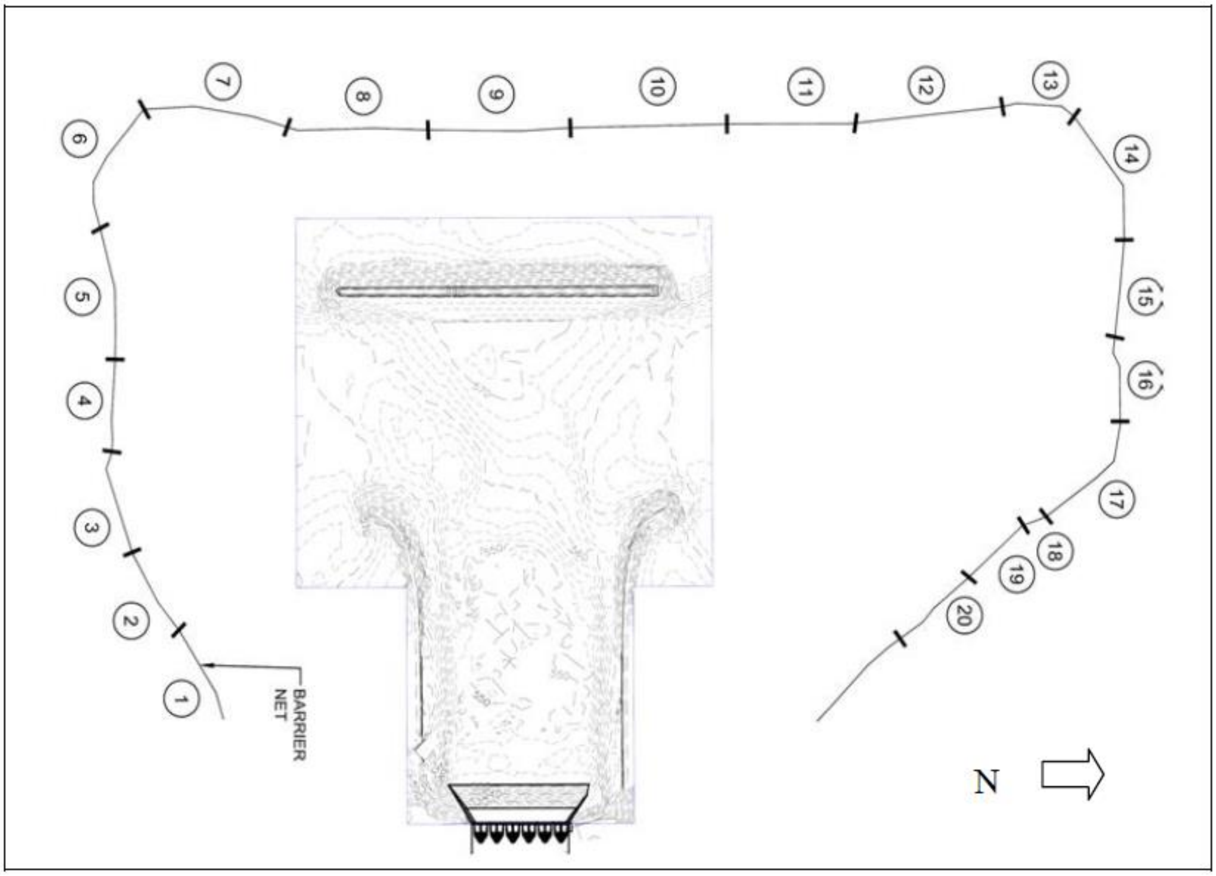


Figure 4-10: CFD Net Section Locations (Alden 2011).

Table 4-5: Estimated Barrier Net Approach Velocities from CFD Modeling (Data from Alden 2011) [1]

Section No.	Generating Flows Prior to Upgrades		Generating Upgraded Flows		Pumping Flows Prior to Upgrades		Pumping Upgraded Flows	
	Average Approach Velocity (ft/sec)	Max Approach Velocity (ft/sec)	Average Approach Velocity (ft/sec)	Max Approach Velocity (ft/sec)	Average Approach Velocity (ft/sec)	Max Approach Velocity (ft/sec)	Average Approach Velocity (ft/sec)	Max Approach Velocity (ft/sec)
1	0.2	0.3	0.1	0.2	0.2	0.4	0.2	0.6
2	0.3	0.4	1.1	1.8	0.4	0.5	0.6	0.7
3	0.4	0.6	1.4	1.9	0.4	0.5	0.5	0.7
4	0.5	0.6	1	1.4	0.4	0.4	0.5	0.6
5	1.0	3.2	2.4	5.4	0.3	0.4	0.4	0.5
6	2.1	3.9	1.7	5.4	0.2	0.3	0.3	0.4
7	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3
8	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.3
9	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3
10	0.1	0.2	0.1	0.1	0.2	0.3	0.3	0.3
11	0.2	0.2	0.1	0.1	0.2	0.3	0.3	0.3
12	0.2	0.3	0.2	0.3	0.2	0.3	0.3	0.3
13	0.4	1.7	0.4	0.5	0.2	0.2	0.2	0.3
14	2.3	3.3	2.5	4	0.2	0.2	0.2	0.3
15	1.2	1.7	1.6	2.5	0.2	0.2	0.2	0.3
16	0.6	1	1	1.4	0.2	0.2	0.2	0.3
17	0.9	1.4	1.3	2.1	0.2	0.3	0.2	0.3
18	1.2	1.5	1.9	2.3	0.2	0.3	0.3	0.4
19	1.5	2	2.2	2.7	0.3	0.4	0.3	0.4
20	0.8	1.9	1.3	2.7	0.4	0.5	0.4	0.6
Average	**0.7**	**1.2**	**1.0**	**1.8**	**0.2**	**0.3**	**0.3**	**0.4**

1. Red font indicates areas prone to submergence.

4.5 Biological Effectiveness

The biological effectiveness of the LPSP barrier net is monitored annually as required by the FERC-accepted Settlement Agreement. The following are the biological performance standards that were developed for the barrier net with respect to designated target species and size groups (Table 4-6):

- 80% effectiveness for game fish (salmonids and yellow perch combined) over five inches in length.
- 85% for large forage fish (alewife and smelt combined) over five inches in length.

The target species listed in Table 4-6 were specifically identified in the FERC-approved Settlement Agreement as species of primary interest with respect to barrier net effectiveness and for which barrier net effectiveness standards are applied annually. More recently, walleye have been included as a game fish species of special interest for purposes related to the State (non-FERC) Settlement Agreement (i.e., for calculation of compensation for fish lost to entrainment during pumping operations). In addition to the above performance standards, barrier net effectiveness is reported annually for specified size groups of designated target species (Table 4-6) and for non-target species (i.e., all other species collected during the annual evaluation of net performance that are not classified as a target species).

The annual evaluation of barrier net effectiveness consists of gill net sampling conducted twice per week (weather permitting) during the period that the net is in place (April 15 – October 15). Sampling is conducted at four locations outside the net and four locations inside (Figure 4-11). The study design for annual sampling requires that equivalent gill nets are fished for the same amount of time at paired stations inside and outside of the barrier net in order to achieve equal sampling effort for the comparisons of catch at outside and inside locations. Differences in catch abundance and species composition between sample stations outside and inside the net are attributed to the presence of the net. Gill nets used at nearshore locations (sample stations 1, 2, 3, and 4) are 6-ft deep and offshore locations (sample stations 5, 6, 7, and 8) are 24-ft deep, which are the approximate water depths at each location. The gill nets have eleven 30-ft long panels with 11 different stretch mesh sizes ranging from 1 to 7 inches.

Gill net data from the four outside sample locations are considered to be representative of species presence and abundance in the vicinity of the LPSP project if the barrier net were not present, whereas inside samples are considered to be indicative of the net's ability to prevent fish from entering the inside area and being exposed to entrainment during pumping operations. The gill nets are assumed to be effective at capturing species of interest greater than 4 inches, whereas the barrier net effectiveness standards were set to assess the protection of fish greater than 5 inches.

Effectiveness is calculated with using the following method:

$$\textit{Percent Effectiveness} = [(T_O - T_I) / T_O] \times 100$$

Where T_O is the total outside catch and T_I is the total inside catch. This approach has been used to calculate effectiveness for individual species or groups of species by size or for all size groups combined, as well as for all fish combined. The effectiveness monitoring plan and calculation method are agreed upon by FERC and the Settlement Parties.

Table 4-6: Designated target species and size groups, as listed in the FERC-approved settlement agreement (walleye are not included in this table because they were not identified as target species in the settlement agreement), that are the focus of the annual barrier net effectiveness assessments. Performance standards apply to gamefish and forage fish greater than 5 inches in length.

Category	Common Name	Scientific Name	Size Groups (inches)
Game fish	Chinook salmon	*Oncorhynchus tshawytscha*	>4-5, 5-12, 12-20, >20
	coho salmon	*Oncorhynchus kisutch*	>4-5, 5-12, >12
	lake trout	*Salvelinus namaycush*	>4-5, 5-12, >12
	rainbow trout (steelhead)	*Oncorhynchus mykiss*	>4-5, 5-12, >12
	brown trout	*Salmo trutta*	>4-5, 5-12, >12
	yellow perch	*Perca flavescens*	>4-5, >5
forage fish	rainbow smelt	*Osmerus mordax*	>4-5, >5
	alewife	*Alosa pseudoharengus*	>4-5, >5
no category	bloater(chub)	*Coregonus hoyi*	>4-5, >5

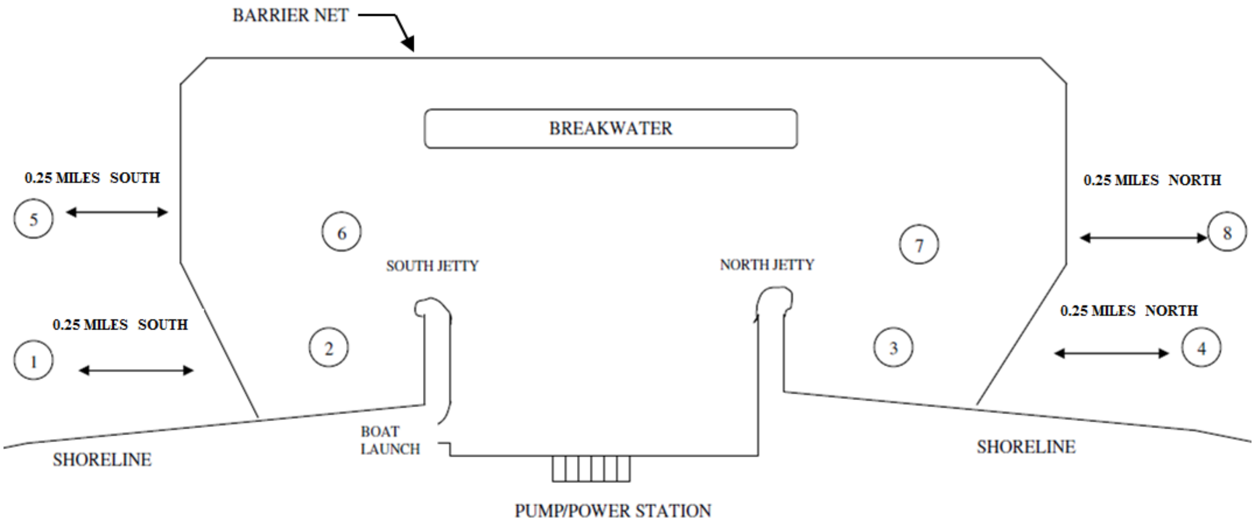


Figure 4-11: Gill net sampling stations (numbered circles) used for barrier net effectiveness monitoring.

To assess the effectiveness of the barrier net and to determine fish species presence and relative abundance in the vicinity of the project, CEC provided Alden with annual gill net sampling data collected inside and outside the barrier net from 1993 through 2014. The assessment of these data for fish species presence and abundance is described in Section 3 and focuses on the gill net catches outside the barrier net. The assessment of barrier net effectiveness is provided below.

The effectiveness of the LPSP barrier net was assessed for the established performance criteria listed previously for all target game and non-game species, and for all non-target species. For the period of evaluation (1993-2014), the mean annual barrier net effectiveness for large game and forage fish species (> 5 inches in length) is 83.8% (range: 70.1 to 96.3%) and 94.5% (range: 80.7 to 98.9%), respectively. For large gamefish, mean effectiveness is 70.9% for salmonids and 93.1% for yellow perch. Mean effectiveness for walleye, which was added to the list of target game species in 2002 for compensation purposes, was 92.1% (this estimate includes fish with lengths between 4 and 5 inches, which have comprised the majority of walleye collected during gill netting). For large forage species, mean effectiveness is 94.5% for alewife and 86.5% for rainbow smelt. Effectiveness estimates were not calculated for all years for rainbow smelt due to low collection numbers (< 20). As seen in Table 4-7, the mean annual effectiveness was 86.7% for all species combined, 89.8% for all target species combined, and 70.9% for all non-target species combined.

Table 4-7: Annual, mean, and range of barrier net effectiveness (%) for all species combined, all target species combined, all-non target species combined, and target game and forage species greater than 5 inches in length (walleye are included as a target game fish, but are not a target species for barrier net monitoring as identified in the FERC Settlement Agreement) .

				Game Fish > 5 inches				Forage Fish > 5 Inches		
Year	All Species	All Target Species	All Non-target Species	Salmonids	Yellow Perch	Walleye[1]	All Game Fish	Alewife	Rainbow Smelt	All Forage Fish
1993	77.5	80.4	60.1	80.1	76.1	95.8	76.6	80.7	77.0	80.7
1994	89.4	90.6	77.5	74.3	95.1	93.3	90.7	90.2	91.0	90.3
1995	93.1	95.4	76.8	86.2	99.3	96.5	96.3	96.3	93.1	96.3
1996	89.1	95.6	47.7	74.0	98.5	94.6	91.6	97.4	78.3	97.2
1997	90.5	95.8	64.5	72.4	96.4	95.4	83.1	97.6	87.6	97.5
1998	92.7	96.3	67.8	86.1	99.0	95.6	89.3	96.8	90.5	96.7
1999	82.5	96.0	58.5	89.3	99.6	97.6	94.3	99.2	78.4	98.9
2000	85.7	86.5	71.9	86.3	90.3	99.3	86.7	96.4	100.0	96.4
2001	95.6	96.5	84.4	79.3	100.0	98.8	81.1	97.2	80.5	97.2
2002	87.0	90.9	69.5	84.5	100.0	98.5	85.0	90.8	--	90.8
2003	91.0	93.9	76.8	78.9	100.0	96.6	80.0	98.3	--	98.2
2004	91.6	93.9	69.3	69.6	80.0	95.8	70.1	95.5	--	95.4
2005	91.4	92.1	85.0	89.8	100.0	96.7	90.3	92.6	88.9	92.6
2006	76.9	78.3	67.7	74.2	95.4	92.3	79.8	89.5	--	89.5
2007	91.2	91.9	88.7	80.5	80.0	88.5	80.4	94.3	--	94.3
2008	88.1	88.5	85.4	81.7	86.1	96.5	82.7	92.2	--	92.2
2009	89.3	91.4	65.6	75.1	89.3	73.1	77.1	97.0	--	97.0
2010	82.2	89.2	64.4	77.4	100.0	89.7	78.9	94.5	--	94.5
2011	79.5	81.7	69.4	77.3	92.6	92.0	82.1	96.2	--	96.2
2012	76.4	77.8	67.0	70.7	81.1	58.1	76.5	95.3	--	95.2
2013	78.4	81.2	68.6	76.6	96.2	94.4	91.4	94.3	--	94.1
2014	88.6	92.1	73.3	71.9	92.9	87.9	78.7	97.3	--	97.3
Mean	86.7	89.8	70.9	78.9	93.1	92.1	83.8	94.5	86.5	94.5
Range	76.4 - 95.6	77.8 - 96.5	47.7 - 88.7	69.6 - 89.8	76.1 - 100.0	58.1 - 99.3	70.1 - 96.3	80.7 - 99.2	77.0 - 100.0	80.7 - 98.9

1. Walleye estimates include all fish greater than 4 inches in length.

For the purposes of the feasibility assessment of all fish protection technologies, effectiveness estimates were also calculated for individual barrier net target species, species of concern (as designated in the Phase 1 report), and non-target species for which greater than 1,000 fish were collected during gill net sampling conducted inside and outside of the barrier net (combined) annually from 1993 to 2014 (i.e., data from all years combined) (Table 4-8). These effectiveness estimates provide species-specific baseline performance standards for which each technology (or combination of technologies) would need to be meet (or exceed) in order to be considered as a viable alternative for application at the LPSP. This includes whether an alternative technology could be applied as means to enhance the performance of the barrier net.

When the data from all years are combined, the species listed in Table 4-8 represent about 99.6% of all fish collected during annual barrier net monitoring. Alewife represents about 74% of the total combined annual gill net catch, followed by spottail shiner at 7.3% and yellow perch at 5.6% (Table 4-8). Rainbow trout (steelhead) and bloater have been the least abundant target species collected during gill netting, each comprising 0.15% of the combined annual catch. All of the other species collected each comprise less than 2% of the gill net catch. Annual variations in species composition are provided in Section 3(see Table 3-2). The three species that were identified as species of concern (lake whitefish, lake herring, and lake sturgeon) by intervening parties to the FERC relicensing each comprise 0.05% or less of the total annual gill net catch, indicating a low relative abundance in the vicinity of the project. No more than seven lake sturgeon were collected during any given year and of the 70 sturgeon collected from 1993 to 2014, only five were collected inside the net. About 75% of the total catch of lake herring and lake whitefish were collected outside the net.

The mean barrier net effectiveness for target salmonid species ranges from 40.1% for rainbow trout to 87.8 for lake trout. Mean effectiveness estimates for the other two game fish target species, yellow perch and walleye, are 86.9 and 92.1%, respectively. Mean effectiveness for the two forage species, alewife and rainbow smelt, is 91.0 and 86.5%, respectively. Barrier net effectiveness was not calculated for lake sturgeon for any of the sample years because all annual catches were considered too low to provide a reliable estimate (i.e., < 20/year). For the other two species identified as species of concern, lake herring and lake whitefish, mean barrier net effectiveness estimates are 61.9 and 71.2%, respectively. For the seven non-target species that had total gill net catches across all sample years greater than 1,000, mean effectiveness estimates range from 31.3 for spottail shiner to 96.3% for freshwater drum (Table 4-8). Mean effectiveness is greater than 75% for gizzard shad, round goby, white sucker and redhorse species, whereas it is 49.4% for round whitefish (Table 4-8).

The size groups applied to fish collected during gill net sampling varied by barrier net category (target or non-target), trophic category of target species (game and forage fish), and species for salmonids (larger Chinook salmon are broken into different size categories than the other target salmonids) (Table 4-9). Most salmonids collected during the annual barrier net monitoring sampling were greater than 12 inches in length. Most yellow perch were greater than 5 inches and most walleye were reported to be greater than 4 inches. Alewife and rainbow smelt collected during annual sampling were mainly greater than 5 inches, but there were greater catches of alewife 4 to 5 inches in length during several years. Non-target species were reported to be over 4 inches in length; with only round goby having a significant proportion of fish recorded as being less than 4 inches. The low proportion of target and non-target species that were reported to be less than 4 inches is expected given the gill nets were designed to primarily capture fish greater than 4 inches in length.

Table 4-8: Barrier net effectiveness (%) for target species, species of concern, and non-target species for which more than 1,000 total fish were collected over all sample years (catches inside and outside the barrier net combined). For all species, all size groups are combined and annual effectiveness was not calculated if less than 20 fish were collected in any given year (indicated by dashes). Effectiveness estimates of 0% indicate more fish were caught inside the barrier net than outside.

	Target Species									Species of Concern			Non-Target (>1000 fish collected over all years)							
Year	BNT	CHIN	COHO	LT	RBT	AW	RSM	YP	CHUB	LS	LW	LKH	FD	GSD	REDH	RGY	RWF	STSH	WEYE	WS
1993	71.5	82.2	85.2	85.5	0.0	82.1	76.5	76.2	0.0	--	90.0	--	75.6	91.0	82.1	--	43.4	26.7	95.8	97.9
1994	69.5	81.2	62.3	83.0	61.1	90.6	91.0	94.7	--	--		--	91.9	80.5	91.0	--	22.8	66.2	93.3	95.6
1995	76.9	81.6	90.2	95.9	87.5	96.0	93.1	90.5	--	--	--	--	98.5	95.5	91.7	--	57.2	38.5	96.5	96.5
1996	82.5	73.6	64.7	86.8	0.0	97.3	78.5	86.9	--	--	--	--	97.4	76.9	91.4	--	4.4	30.6	94.6	95.3
1997	89.4	62.2	44.2	91.8	58.3	97.5	87.6	92.2	--	--	--	--	97.7	93.9	98.3	--	27.8	54.7	95.4	94.1
1998	72.4	84.0	100.0	94.1	--	96.6	90.5	99.0	0.0	--	--	--	96.7	90.2	89.8	--	6.3	52.0	95.6	96.6
1999	93.7	86.1	87.7	92.0	50.0	97.3	78.4	89.6	--	--	--	--	99.5	100.0	99.1	--	0.0	53.0	97.6	99.5
2000	82.1	89.5	76.7	87.2	--	86.5	100.0	90.3	--	--	--	--	99.5	84.0	99.5	--	62.1	10.0	99.3	97.8
2001	80.8	74.0	70.0	85.9	--	97.2	80.5	100.0	--	--	--	--	96.7	47.2	97.9	--	81.8	33.5	98.8	96.9
2002	68.9	75.8	93.5	84.8	--	91.4	--	100.0	--	--	--	--	89.4	96.0	96.9	--	12.7	32.8	98.5	96.8
2003	82.7	71.4	--	86.9	--	95.5	--	90.6	--	--	--	72.2	99.5	95.8	93.6	--	90.9	28.1	96.6	97.2
2004	83.3	53.3	16.7	85.7	--	95.0	--	80.6	--	--	--	29.4	96.9	96.6	87.0	72.5	59.1	34.3	95.8	95.7
2005	81.5	89.1	68.8	93.0	--	92.3	88.9	94.7	--	--	--	--	98.7	87.5	84.6	81.1	85.1	58.8	96.7	94.6
2006	72.7	72.6	0.0	87.6	--	77.9	--	83.7	--	--	0.0	--	99.6	88.7	96.6	70.4	--	28.6	92.3	97.0
2007	88.4	63.6	--	90.2	--	94.2	--	75.0	--	--	--	--	100.0	87.4	96.6	86.6	82.9	52.7	88.5	--
2008	72.5	66.9	--	88.2	--	91.2	--	82.2	33.3	--	100.0	--	97.8	100.0	94.6	74.5	82.9	0.0	96.5	93.8
2009	73.3	79.8	--	75.0	--	94.4	--	83.9	0.0	--	94.7	--	95.8	90.3	90.7	59.1	35.9	1.2	73.1	85.4
2010	73.5	22.9	0.0	90.2	--	91.7	--	78.0	--	--	--	--	98.3	0.0	74.5	69.9	87.0	14.6	89.7	60.0
2011	54.0	54.7	78.6	87.1	--	84.2	--	60.6	--	--	--	--	98.8	--	35.3	79.7	50.5	46.7	92.0	22.5
2012	67.1	58.9	46.4	85.6	--	78.2	--	77.4	--	--	--	--	93.5	100.0	73.1	78.4	76.2	0.0	58.1	67.3
2013	81.0	60.3	--	91.2	18.2	77.3	--	94.0	--	--	--	82.8	97.2	--	90.5	81.6	28.3	24.8	94.4	--
2014	75.3	64.2	--	84.2	45.5	96.9	--	92.5	--	--	--	63.3	99.0	--	76.2	84.0	40.0	0.0	87.9	82.9
Mean	77.0	70.4	61.5	87.8	40.1	91.0	86.5	86.9	8.3	--	71.2	61.9	96.3	84.3	87.8	76.2	49.4	31.3	92.1	88.2
Range	54.0-93.7	22.9-89.5	0.0-100.0	75.0-95.9	0.0-87.5	77.3-97.5	76.5-100.0	60.6-100.0	0.0-33.3	--	0.0-100.0	29.4-82.8	75.6-100.0	0.0-100.0	35.3-99.5	59.1-86.6	0.0-90.9	0.0-66.2	58.1-99.3	22.5-99.5
N (all years)	3781	6061	1338	5146	641	324403	2958	24635	644	70	211	192	5815	6393	2596	3479	8136	32025	2878	6165
% Collected	0.86	1.38	0.30	1.17	0.15	73.83	0.67	5.61	0.15	0.02	0.05	0.04	1.32	1.46	0.59	0.79	1.85	7.29	0.66	1.40

SPECIES CODES: AW, alewife; BNT, brown trout; CHIN, chinook salmon; CHUB, bloater (chub); COHO, coho salmon; FD, freshwater drum; GSD, gizzard shad; LKH, lake whitefish; LS, lake sturgeon; LT, lake trout; LW, lake whitefish; RBT, rainbow trout; REDH, redhorse spp.; RGY, round goby; RSM, rainbow smelt; RWF, round whitefish; STSH, spottail shiner; WEYE, walleye; WS, white sucker; YP, yellow perch.

Table 4-9: Percentage of catch for designated size groups of target and non-target species collected during annual gill net sampling conducted outside of the barrier net.

Category	Species	< 4 in (all spp)	> 4 in (non-target spp)	4-5 in (all target spp)	> 5 in (target non-salmonid spp)	5-12 (target salmonids)	> 12 (target salmonids)
Target Game Fish	Chinook salmon	0.0	--	5.3	--	37.7	57.0
	coho salmon	0.0	--	0.3	--	3.1	96.6
	lake trout	0.0	--	0.0	--	0.1	99.9
	rainbow trout	0.0	--	0.0	--	9.3	90.8
	brown trout	0.0	--	0.0	--	18.9	81.1
	yellow perch	0.2	--	6.2	93.5	--	--
Target Forage Fish	alewife	0.2	--	19.4	80.4	--	--
	rainbow smelt	0.0	--	0.1	99.9	--	--
Target Other	bloater (chub)	0.0	--	1.3	98.7	--	--
Non-target Species of Concern	lake herring	0.0	100.0	--	--	--	--
	lake whitefish	0.0	100.0	--	--	--	--
	lake sturgeon	0.0	100.0	--	--	--	--
Non-target >1000 collected 1993-2014	freshwater drum	0.0	100.0	--	--	--	--
	gizzard shad	1.1	98.9	--	--	--	--
	redhorse spp	0.0	100.0	--	--	--	--
	round goby	62.4	37.6	--	--	--	--
	round whitefish	0.0	100.0	--	--	--	--
	spottail shiner	0.6	99.4	--	--	--	--
	walleye	0.0	99.1	--	0.9	--	--
	white sucker	0.0	100.0	--	--	--	--

For many of the target and non-target species, barrier net effectiveness does not vary considerably between the size groups applied to each species (Table 4-10). Effectiveness for Chinook salmon increased for fish greater than 5 inches in length. However, differences in barrier net effectiveness are relatively small between salmonids classified as 5 to 12 inches and greater than 12 inches, with some salmonid species having slightly lower effectiveness for the larger of these two size groups (Table 4-10). Effectiveness for alewife increases from 74.8% for fish less than 4 inches in length to 94.4% for fish greater than 5 inches. The largest size based increase in effectiveness occurs with yellow perch, with an increase in effectiveness from 27.3% for 4 to 5 inch fish to 89.8 for fish greater than 5 inches. There were only minor differences in effectiveness between the two size groups applied to non-target species (< 4 inches and > 4 inches).

Table 4-10: Estimated barrier net effectiveness by specified size groups for target species, species of concern, and non-target species for which more than 1,000 total fish were collected over all sample years (1993-2014). Zero percent effectiveness for bloater indicates more fish were caught inside the barrier net than outside.

Group	Species	All Species < 4 in	All Non-Target Species > 4 in	All Target Species 4-5 in	Target Non-salmonids/ Salmonids > 5 / 5-12 in	Target Salmonids > 12 in
Target Game Fish	Chinook salmon	--	--	53.0	74.9	75.5
	coho salmon	--	--	--	81.8	75.0
	lake trout	--	--	--	--	87.5
	rainbow trout	--	--	--	40.5	39.7
	brown trout	--	--	--	66.2	81.0
	yellow perch	0.0	--	27.3	89.8	--
Target Forage Fish	alewife	74.8	--	83.4	94.4	--
	rainbow smelt	--	--	--	86.6	--
Target Other	bloater (chub)	--	--	--	0.0	--
Non-target Species of Concern	lake herring	--	69.4	--	--	--
	lake whitefish	--	65.4	--	--	--
	lake sturgeon	--	92.3	--	--	--
Non-target >1000 collected 1993-2014	freshwater drum	--	96.7	--	--	--
	gizzard shad	81.0	88.8	--	--	--
	redhorse spp	--	91.8	--	--	--
	round goby	76.4	79.5	--	--	--
	round whitefish	--	40.7	--	--	--
	spottail shiner	43.9	42.0	--	--	--
	walleye	--	94.4	--	91.7	--
	white sucker	--	94.9	--	--	--

The current barrier net layout creates an acute angle with the shoreline on the north side of the project, and less so on the south end. This configuration, where the net meets the shore, has potential to limit the movement of fish that are following the shoreline in either direction. This could lead to greater fish abundance at these locations or increased risk of entrainment of smaller fish if they reside within these areas or are unable to follow the net offshore. The initial net configuration was developed with the intent of locating the northwest corner of the net as far as practicable from the breakwater structure in an effort to reduce through-net velocities during pumping and generating. The northern on-shore anchor point was angled toward the project in order to limit the infringement of the lake rights of neighboring homes, to keep the anchors on

LPSP property, and to avoid technical difficulties that would accompany anchoring to the steep and rugged bluffs that line the shore north of the project.

To better understand the behavior of fish in the vicinity of the LPSP where the net meets the shore, statistical analyses were performed comparing fish monitoring data from the north sampling stations to those in the south. Arcadis (in press) analyzed monitoring data from the last five years to determine if there were any catch differences among the sampling stations. The analysis concluded there were no significant differences between corresponding north and south stations (P>0.05) both inside and outside the barrier net. A similar study was conducted by CEC with data dating back to 2005, using only data from the inside near-shore stations at the 6' depth contour, and separate analyses for alewife 4-5" and alewife > 5". Pairwise t-tests indicated the mean difference between the north and south stations were not significantly different from zero (P>0.05) in all cases.

Additional hypothesis testing was conducted by CEC on the mean difference in proportion values of the nearshore north and south monitoring stations. The mean difference in proportion is defined as:

$$\frac{Outside\ Station\ Catch}{Station\ Pair\ Total\ Catch} - \frac{Inside\ Station\ Catch}{Station\ Pair\ Total\ Catch} = Difference\ in\ Proportion$$

This value is calculated each week for each pair of monitoring stations (see monitoring plan details above) and submitted as part of an annual report to FERC. If fish were congregating at one shoreline-net interaction more than the other, a disparity may become evident between the two nearshore monitoring station pairs. Pairwise t-tests showed no significant difference (P>0.05) in the mean difference in proportion at these locations

Although these results do not completely disprove the theory that the net represents an obstacle that disrupts fish movements along the shoreline, they do suggest that the acute angle on the north side of the net does not significantly reduce barrier net effectiveness at this location.

5 Review and Preliminary Screening of Entrainment Abatement Technologies

Entrainment abatement technologies were identified during Phase 1 efforts and are defined as technologies that do not require substantial structural changes to the intake or areas surrounding the intake. These options include behavioral deterrents (e.g. electric fields, strobe light, or low frequency sound) or other non-structural (relative to the project) components, such as the barrier net. Entrainment abatement technologies identified during Phase 1 efforts are presented in Table 5-1. All other fish protection technologies (e.g., screening systems, porous dike, and offshore intakes) are considered engineering alternatives, which were also identified and listed in the Phase 1 report. Engineering alternatives will be evaluated for feasibility of application at the LPSP as part of the Phase 3 efforts.

Table 5-1: Entrainment Abatement Technologies Considered for Application at Ludington

Mode of Protection	Technology
ENTRAINMENT ABATEMENT TECHNOLOGIES	
Behavioral deterrence/guidance	Sound (infrasonic, sonic, ultrasonic, impulsive/high impact) Light (strobe, continuous) Chemicals Electric barriers Air bubble curtain Water jet curtain (current inducers; FVES™) Hanging chains Visual cues Multi-technology behavioral system
Physical barrier/guidance	Barrier net Aquatic filter barrier

This section provides a review of entrainment abatement technologies, with a focus on recent developments and applicability for use at LPSP. It should be noted that the behavioral deterrence/guidance technologies likely would only be used in conjunction with the existing barrier net, given that avoidance responses varies widely among species and effectiveness has typically been low to moderate for most technologies. The secondary purpose of this section is to provide the biological and engineering basis used in the initial screening of entrainment abatement technologies. The evaluation builds on conclusions from the SWEC (1988) report and the five-year technology updates, to the extent possible, by including more recent information and data for existing or new or modified technologies. New information was used to identify any changes or enhancements to the applicability of entrainment abatement technologies at the LPSP.

The entrainment abatement technologies were initially screened to determine whether they have reasonable potential for successful application at LPSP and should be carried forward to the feasibility assessment (Section 6). These screenings were based on consideration of biological effectiveness. Each technology was evaluated based on its ability to meet or exceed the level of protection offered by the current barrier net as either a replacement for the net or to enhance the net's effectiveness. Technologies that passed this initial screening were then considered for the feasibility assessment (Section 6), which includes engineering feasibility, and applicability at the LPSP (e.g., with respect to project design and environmental and hydraulic conditions). Results of this screening were used to select alternatives for the detailed evaluation (Section 7), which includes conceptual designs and a review of design, construction, operation and maintenance and operation impacts and expected biological effectiveness and risks.

5.1 Preliminary Screening Criteria

Entrainment abatement technologies were assessed to determine their applicability at LPSP. Each potential option was evaluated based on consideration of both biological effectiveness and engineering feasibility. For a technology to be considered biologically effective, available data and information would have to demonstrate that it had reasonable potential to exceed or provide the same level of protection as the barrier net as either a standalone replacement for the net or as a means to enhance the biological performance of the net. From an engineering standpoint, the design of an alternative technology would have to demonstrate it could be installed, operated, and maintained under the environmental and operating conditions experienced in the vicinity of the LPSP intake. To assist with determinations of biological effectiveness and engineering feasibility, screening criteria were developed to guide the review and assessment of each entrainment abatement technology. These criteria will also be applied to engineering alternatives included in the Phase 3 assessments.

The screening criteria developed for the Phase 2 and 3 technology assessments were based, in part, on the criteria used in the initial technology review and assessment conducted for the LPSP (SWEC 1988). The criteria used by SWEC (1988) included some technology and project-specific design parameters that have changed since 1988. For example, the ongoing turbine upgrades will result in increased pumping and generating flow rates and different operating conditions. Such information is not explicitly identified as part of the preliminary screening of each technology provided in this section. Technology and project design and operational considerations specific to the LPSP are discussed as part of the feasibility assessment for each technology carried forward (Section 6) based on the results of the preliminary screening.

The first step in the evaluation process was to assess the potential biological effectiveness of each technology option being considered. Entrainment abatement technologies that did not meet the established biological criteria were eliminated from further consideration. Options that met the biological criteria were evaluated for engineering feasibility (Section 6). Options that did not meet the engineering criteria were eliminated from further consideration. Conceptual designs, order-of-magnitude cost estimates, and biological effectiveness estimates were developed for the remaining entrainment abatement technologies as part of the secondary screening process and detailed assessment (Section 7).

5.1.1 Biological Screening Criterion

***Proven Biological Effectiveness*:** Entrainment abatement technologies must have a proven ability to reduce entrainment of the species (or species similar in morphology, behavior, and life history) and life-stages present at LPSP (the focus was on barrier net target species, species of concern, and representative species as previously defined in Phase 1). The ability to reduce entrainment at water intakes must have been demonstrated during pilot or full-scale field studies, or through laboratory studies for which results indicate a strong potential for successful application if applied at projects with similar design features, velocities, and flow rates as LPSP.

***Seasonal Performance*:** At a minimum, the biological performance of entrainment abatement technologies was required to endure under the physical, hydraulic, and/or environmental conditions at LPSP that occur during the current annual deployment period of the barrier net (April 15 to October 15). Options considered for year round application must be able to maintain biological performance under winter conditions as well.

***Comparison to Existing Barrier Net*:** Entrainment abatement technologies used alone or in conjunction with other options were required to demonstrate strong potential to reduce entrainment rates equivalent to or greater than the existing barrier net. Options that increase the effectiveness of the existing barrier net were considered.

5.1.2 Engineering Screening Criterion

***Commercial Availability*:** Entrainment abatement technologies needed to be commercially available for water withdrawals with similar velocity and flows as LPSP or require relatively minor adaptations to prepare for full-scale application similar in size to what would be required for an installation at LPSP. For this criterion, commercially available was defined as a technology or measure that has been installed and in use on a permanent basis for multiple years and has shown to satisfactorily perform its intended function and has not resulted in significant adverse impact to the environment or plant operation. New technologies, with limited operating data, were evaluated using best professional judgment to determine if they could be considered commercially available or at a stage in development that would not require significant effort to produce a full-scale application.

***Design Performance*:** The proposed alternative needed to be able to achieve applicable design and engineering performance objectives during both generating and pumping operations. Options must not have had a significant effect on the reliability or efficiency of generating or pumping operations at LPSP. This included the demonstrated ability to properly function and be maintained under current physical, hydraulic, environmental, and biofouling conditions similar to LPSP. Options designed for year round installation had to also have been able to operate and be maintained under sub-freezing, frazil and pack ice conditions.

Technologies that show potential based on laboratory or pilot-scale evaluations, but had limited or no operational experience under physical, hydraulic, and environmental conditions similar to LPSP, may have been retained for further analysis based on best professional judgment.

***Regulatory Approval*:** The LPSP licensees needed to be able to obtain approval for the installation and operation of a technology or measure from state and federal resource and regulatory agencies. For this criterion, the anticipated major issues associated with the application of each technology or measure that was to be considered by state and federal agencies was identified and the potential magnitude of the impact assessed. This included meeting environmental, safety, and generating requirements.

***Space Requirement*:** Adequate space was required to be available to construct a technology and operate it as designed and intended. The approximate footprint of the technology and associated infrastructure needed to fit within available space on the site or, alternatively, at offsite areas that would not negatively impact other lake users and would likely receive regulatory approval. Complicating factors including, impacts to navigation, property ownership, and safe access were also considered.

5.2 Review of Technologies and Preliminary Screening Determinations

5.2.1 Sound

The use of sound as a fish deterrent for reducing entrainment at water intakes has been studied for over 50 years. Sound signals have also been used in attempts to attract fish, but the primary focus for use of this technology at water intakes has been on deterrence. Sound deterrents are typically classified by signal frequency as follows: (1) infrasonic (< 50 hertz (Hz)); (2) sonic (50 Hz to 10 kHz); and (3) ultrasonic (> 10 kHz). Species-specific responses to each of three frequency ranges are dependent on hearing capabilities.

Fish hearing is characterized by the detection of density disturbances through a water medium (Popper et al. 2003). Sound wave energy is detected in the near field as an oscillatory movement of water particles and in the far field as a change in acoustic pressure. Fish use two sensory systems to detect sound, the inner ear and lateral line (Coombs and Braun 2003; Popper et al. 2003). The inner ear is capable of detecting sound over relatively long distances, whereas the lateral line is only capable of detecting signals that originate within one or two body lengths of a fish. The lateral line is typically responsible for detecting infrasonic and lower frequency signals (less than 50 Hz to 100 to 200 Hz). The inner ear is also capable of detecting signals below 50 Hz, but can perceive frequencies up to 1,000 to 5,000 Hz depending on the species. However, it has been shown that clupeid species in the sub-family Alosinae (e.g., American shad, alewife, blueback herring, and Atlantic menhaden) can detect and will actively avoid ultrasonic signals greater than 80 kHz (Mann et al. 1997, 1998, 2001; Plachta and Popper 2003).

Fish species are typically categorized as hearing specialists or non-specialists based on their hearing capabilities. Hearing specialists can detect sound anywhere from below 50 Hz up to about 5,000 Hz, whereas hearing non-specialists detect sounds from below 50 Hz up to as high as 1,500. Actual hearing sensitivities and detectable frequency ranges vary considerably among species within both hearing classifications (Table 5-2). Fish species that occur in the vicinity of the LPSP include both hearing specialists (e.g., alewife, catostomids, cyprinids, percids, sciaenids, and ictalurids) and non-specialists (e.g., lake sturgeon, salmonids, and centrarchids).

Table 5-2: Summary of fish hearing data with reference to the most sensitive frequency and corresponding threshold sound pressure level (SPL).

Common Name	Family	Scientific Name	Hearing Specialist	Most Sensitive Frequency (Hz)	Threshold SPL (dB//μPa)	Primary Reference
lake sturgeon	Acipenseridae	*Acipenser fulvescens*	no	250	135	Nedwell et al. 2005
bluegill	Centrarchidae	*Lepomis macrochirus*	no	400	119	Scholik and Yan 2002
American shad	Clupeidae	*Alosa sapidissima*	yes	130000	147	Mann et al. 1997
American shad	Clupeidae	*Alosa sapidissima*	yes	800	93	Higgs et al. 2004
Atlantic herring	Clupeidae	*Clupea harengus*	yes	50-200	75	Enger 1967
Atlantic croaker	Sciaenidae	*Micropogonias undulatus*	yes	300	86	Ramcharitar and Popper 2004
black Drum	Sciaenidae	*Pogonias chromus*	yes	200-300	87	Ramcharitar and Popper 2004
common carp	Cyprinidae	*Cyprinus carpio*	yes	500	58	Popper 1972
common carp	Cyprinidae	*Cyprinus carpio*	yes	1000	58	Popper 1972
common carp	Cyprinidae	*Cyprinus carpio*	yes	1000	74	Kojima et al. 2005
fathead minnow	Cyprinidae	*Pimephales promelas*	yes	1000	77	Scholik and Yan 2001
silver carp	Cyprinidae	*Hypophthalmichthys molitrix*	yes	750	105	Nedwell et al. 2005
silver carp	Cyprinidae	*Hypophthalmichthys molitrix*	yes	2000	105	Nedwell et al. 2005
bighead carp	Cyprinidae	*Aristichthys nobilis*	yes	1600	105	Nedwell et al. 2005
lake chub	Cyprinidae	*Couesius plumbeus*	yes	800	71	Popper et al. 2005
channel catfish	Ictaluridae	*Ictalurus punctatus*	yes	400-1500	93	Fay and Popper 1975
European perch	Percidae	*Perca fluviatilis*	no	100	87	Wolff 1967
pike-perch	Percidae	*Sandra lucioperca*	no	100	100	Wolff 1968
paddlefish	Polyodontidae	*Polyodon spathula*	no	250	125	Nedwall et al. 2005
Atlantic salmon	Salmonidae	*Salmo salar*	no	160	95	Hawkins and Johnstone 1978

5.2.1.1 LPSP 1988 Technology Assessment: Sound

The SWEC (1988) fish protection technology assessment prepared for LPSP indicated that extensive research had been conducted with various types of sound signals designed to repel or attract fish. The general conclusion from the SWEC (1988) review of sound deterrent and attraction studies was that, as a whole, the results were equivocal and there was no clear or concise information at the time that suggested any form of this technology would have the ability to effectively reduce entrainment of one or more fish species at the LPSP intake. In particular, the SWEC (1988) review noted that the use of sound to repel fish can be complicated by species-specific responses (or lack thereof) to different types of sound signals based on differences in hearing capabilities. The focus of sound deterrent and attraction studies conducted prior to 1988 was on low frequency and high-energy impulse signals created by standard transducers, air guns, and impact devices (poppers and hammers). Sound deterrent research reviewed by SWEC (1988) included laboratory and field investigations conducted with various marine, estuarine, and freshwater species. Although some avoidance and startle reactions were observed during these studies, responses were not always strong, occurred in the nearfield, and/or diminished with time or repeated exposures. One of the studies reviewed by SWEC (1988) was conducted with a hammer device at LPSP, the results of which indicated the number of fish in a specified test area was not reduced in comparison to control trials (EPRI 1990). Testing with poppers included laboratory and pilot-scale field evaluations in attempts to repel fish at cooling water intakes of steam-electric generating stations on the Great Lakes. Although avoidance was shown for some species (including alewife, yellow perch, and some salmonids), no permanent installations of popper devices at cooling water intakes in the Great Lakes were noted by SWEC (1988).

5.2.1.2 LPSP 5-Year Technology Updates: Sound

The 2001 technology assessment update for LPSP (LMS 2001) included a detailed review of sound deterrent research conducted since the SWEC (1988) report was completed. This research included evaluations of infrasonic, sonic, and ultrasonic signals for repelling fish at water intakes. Testing of infrasonic generating devices primarily involved evaluations of juvenile salmonid responses, during laboratory and small-scale field trials. Sonic signals were tested during cage and field tests juvenile salmonids and a variety of riverine species, including an evaluation of a system installed at the intake of the White Rapids Project on the Menominee River. Ultrasound was also tested during cage and field trials, primarily for its ability to repel Alosine species (e.g., alewife, blueback herring, and American shad). Based on the results of field trials, a permanent ultrasonic deterrent system was installed at the cooling water intake of the James A. Fitzpatrick Nuclear Power Plant on Lake Ontario as means to reduce entrainment of alewife.

Based on the review of sound deterrent research, LMS (2001) concluded that ultrasound could be used to successfully repel alewife away from the LPSP intake, but that effectiveness was unlikely to exceed the biological performance of the barrier net. It was also concluded that the results of testing with infrasonic and sonic deterrents indicated uncertainties in their biological effectiveness, depending on species, and the ability to apply them on a large scale. Consequently, without additional information on responses of species targeted for protection at LPSP and/or how such systems could be designed for installation and operation on a very large scale, infrasonic and sonic deterrents were not considered viable alternatives for application at LPSP. The 2006 and 2011 technology updates (ESP 2006, 2011) also included a review of recent research on sound deterrent technologies and drew similar conclusions to those of the 2001 technology review (i.e., ultrasound was effective for alewife but would not perform better than the barrier net; infrasonic and sonic frequencies needed additional biological evaluation and engineering development before they could be considered for deployment at LPSP).

5.2.1.3 Updated Summary of Sound Deterrent Research and Applications

Infrasonic Deterrents

Sound signal frequencies of 50 Hz and less have typically been classified as infrasound. Signals at these low frequencies produce a strong nearfield effect (particle motion) that can be detected by both the lateral line and inner ear systems of most fish species. Fish auditory research has shown the relative importance of hearing systems with respect to vectorial (particle motion) and scalar components (acoustic pressure) and how they influence sound perception and behavioral response (Lu and Popper 2001). Based on this basic research, fish response to sound is probably more related to particle motion than acoustic pressure in the nearfield.

Initial studies of infrasound as a fish deterrent were conducted by Knudsen et al. (1992, 1994) and demonstrated that a piston-type particle motion generator operating at 10 Hz was effective in repelling Atlantic salmon smolts in a tank and in a small diversion channel. Based on the results of these initial studies, testing was conducted with anadromous salmonids in the Northwest U.S., but the results were mixed (i.e., avoidance varied among species and devices tested; Ploskey and Johnson 2001; Mueller et al. 2001) and were not considered sufficient to support additional testing or the installation of full-scale systems.

An infrasound generator was also evaluated as means to repel riverine species during cage tests conducted at the Kingsford Hydroelectric Project in Wisconsin as part of light and sound studies conducted by EPRI (Winchell et al. 1997; EPRI 1998b). However, results from these cage tests showed little or no response to infrasound by largemouth and smallmouth bass, yellow perch, walleye, and sunfish (*Lepomis*) species. Rainbow trout displayed agitation, but no directional avoidance. Consequently, infrasound was not included in a follow-up field study conducted at a hydro project intake downstream of the Kingsford Project that evaluated sonic frequencies, strobe light, and an air bubble curtain.

The United States Army Corps of Engineers (USACE) conducted an evaluation of two infrasound devices, an Argotech 215 sonic transducer, and strobe lights in cage tests at the Chittenden Locks near Seattle, Washington (Ploskey and Johnson 2001). One infrasound generator (described as a particle motion generator with a rotating head through which water was pulsed) failed to elicit a startle response or directional avoidance from yearling coho salmon and sub-yearling coho and Chinook salmon. The other device (a piston-type generator) elicited avoidance when sub-yearling coho and Chinook salmon were within 4 ft of the source. In a similar study, the response of juvenile salmonids (rainbow and brook trout and Chinook salmon) to an infrasound source was evaluated during laboratory tests conducted at the Pacific Northwest National Laboratory (PNNL) (Mueller et al. 2001). The results from this study indicated slight responses from rainbow trout, no responses from two size groups of brook trout, strong responses from wild Chinook salmon, and slight responses from hatchery Chinook.

In a more recent study, an infrasonic generator was evaluated for its ability to repel riverine fishes at a power plant in Belgium (Sonny et al. 2006). The nuclear power plant is located on the River Meuse and has a conventional shoreline intake. Two infrasound transducers were deployed 2.6 m deep on either side of one of the 12 intake culverts. Fish densities were monitored downstream of the infrasound transducers with hydroacoustics. A total of 16 on-off trials were conducted and the numbers of fishes entering the intake canal were compared. The predominant taxon was cyprinids (roach, bleak, and bream), representing 93% of the fishes collected from the downstream traveling screens. A total of 689 fishes were detected during this study. Statistically significant reductions of 82, 86, 57, and 44% were realized in 4 of the 12 intake culverts with the stimulus on; with no significant reduction in the other 8 culverts. When considered collectively, the stimulus reduced passage of fishes by 48% through all 12 culverts. The results from this study indicated there may be potential for repelling some freshwater species (particularly cyprinids) with infrasound at cooling water intakes. However, the authors also indicate that intake velocity must be low enough to allow fish to escape from the infrasound stimulus and that equipment reliability has to be improved.

The initial studies of Atlantic salmon responses to infrasonic signals indicated that infrasound had potential to be an effective deterrent since there was a physiological basis to the response of fish to particle motion (and possibly a behavioral basis with respect to predator detection). However, the ability of infrasound to effectively repel fish has not been demonstrated during studies conducted in the U.S with juvenile salmonids and several freshwater species, most of which also occur in the vicinity of the LPSP. Mechanical unreliability of the generators tested and limited effective range (less than 30 ft) have also contributed to less interest in the continued development of infrasound generators as fish deterrents at water intakes. Most significant, however, from the perspective of an application at the LPSP, is that repulsion of fish by infrasound typically occurs only within a few feet of the source. Consequently, any use of an infrasound device at LPSP would likely require thousands of infrasound generators since fish would have to encounter a source at a very close distance in order to be repelled. Additionally, species that have been tested with infrasound that occur at the LPSP (walleye, yellow perch, largemouth and smallmouth bass, sunfish species, rainbow trout, and Chinook and coho salmon) have demonstrated anywhere from no response to moderate startle and/or avoidance. Also, many of the species that occur at the LPSP have not been tested with infrasound and their responses to this stimulus are unknown. Of the two applications that showed promise in Europe, one was in a lake at an intake with a much lower withdrawal flow compared to LPSP and the other was a shoreline intake on a river, also with a lower intake flow rate.

Sonic Deterrents

Sonic signals (typically between 100 and 1,000 Hz) have been extensively evaluated as a method for repelling fish at water intakes in the U.S. and Europe (EPRI 1994, 1998a, 2007). Testing of sonic deterrents in the U.S. has been conducted with several anadromous salmonids and estuarine and freshwater species (EPRI 1998b; Goetz et al. 2001; Maes et al. 2004; PSEG 2005). The results of these studies have not demonstrated any clear and consistent avoidance of sonic signals by most species. Consequently, there are currently no permanently installed sonic deterrent systems as a means to reduce fish entrainment at any type of water intake in the U.S.

Sonic deterrent systems have consisted of standard acoustic transducers emitting various types of sound signals (e.g., pure tones, white noise, pulsed broadband, etc.), as well as mechanical sound generators of various types that have typically been developed for various industrial uses. Impact devices (water hammers) are mechanical devices that produce a high-energy low frequency sound and have been investigated for fish deterrence, primarily at cooling water intakes in the 1980's and 1990's (EPRI 1994, 2007). These devices were easily modified to vary their output frequency. Earlier research had shown some promise for effective use of these devices, but impact sound generators generally have not been shown to effectively and consistently repel any species in actual field applications (EPRI 1998).

Pneumatic devices are another type of mechanical sound generator that has been investigated as a fish deterrent (EPRI 1990, 1994). These devices produce sound energy through the explosive release of air from a pressurized chamber. Frequencies ranging from 20 to 1,000 Hz can be generated during continuous or intermittent operation of these devices. More recently, Smith-Root, Inc. has developed a water gun for repelling fish. This device uses a small piston to create a high velocity water jet and pressure wave and a low frequency pulse (http://www.smith-root.com/services/ansd/fish-deterrence-and-passage/acoustic-pressure/). There is currently no information or data available on the effectiveness of the Smith-Root water hammer as a deterrent to fish at water intakes. Similar to impact sound generators, the effectiveness of pneumatic sound generators in repelling fish has been variable and these devices currently are not considered as viable technology for reducing entrainment of fish at water intakes.

Studies conducted by American Electric Power (AEP) at its Racine Hydroelectric Plant on the Ohio River indicated that fish were repelled by sonic, high amplitude sound produced by a submerged generator (Loeffelman et al. 1991; Klinect et al. 1992). Coincident side-scan sonar observations of forebay fish distributions and sound measurements suggested that the sound was influencing fish distribution and reducing entrainment of fish into the turbine. In subsequent studies conducted along the forebay shoreline, it was demonstrated that the intake sound spectrum from the Racine units repelled fish when it was played through underwater speakers. Based on these observations, AEP began experiments with a patented sound "tuning" system used to develop sounds that were considered to have potential for repelling selected fish species. However, after extensive experiments under controlled conditions and in the field, the sound system developed from the Racine studies has been discounted as viable fish deterrent technology and has not been applied as a permanent technology at any water intake or investigated further in the past 15 years.

An acoustic sound system was evaluated for its ability to repel several freshwater fishes during cage tests conducted at the Kingsford Hydroelectric Project located on the Menominee River (Winchell et al. 1997; EPRI 1998a, 1998b; Michaud and Taft 2000). Several light devices and an infrasound generator also were evaluated during this study. Behavioral stimuli that elicited avoidance responses during cage tests were considered for evaluation during field studies conducted at the White Rapid Hydroelectric Project located downstream of Kingsford. Species that were evaluated for response to acoustic signals at the Kingsford site included rainbow trout, walleye, yellow perch, golden shiner, bullhead (*Ameiurus*) species, black crappie, sunfish (*Lepomis*) species, and largemouth and smallmouth bass. With the exception of golden shiner and black crappie, each species demonstrated some level of avoidance to various acoustic signals. Avoidance reactions of bullhead, sunfish, and smallmouth bass were classified as weak. Avoidance behaviors exhibited by rainbow trout, walleye, yellow perch, and largemouth bass were classified as moderate. The center frequency of signals that produced avoidance reactions from rainbow trout was 6,000 Hz. Center frequencies for signals that elicited avoidance from walleye included 566, 673, 1,350, and 2,990 Hz. Effective signals for yellow perch were centered at 673, 953, 1,000, and 2,000 Hz. Largemouth bass demonstrated avoidance to signals with center frequencies of 283, 600, 673, 2,000, 2,500, 2,990, and 5,500 Hz.

Based on the results from the cage tests conducted at the Kingsford Project, sound signals with center frequencies of 673, 2,000, 2,990, and 5,000 Hz were selected for evaluation during the field studies conducted at the White Rapids Project (Winchell et al. 1997; EPRI 1998a, b; Michaud and Taft 2000). Strobe lights and an air bubble curtain also were evaluated during this study. Acoustic transducers and strobe lights were deployed on the trash racks of Unit 1 in attempts to repel fish from the intake. The number of fish collected in full-flow tailrace nets that sampled the entire discharge of Unit 1 was used to estimate fish entrainment during periods when sound and either lights or the air curtain were operated together or alone and during control periods (i.e., no devices operating). Tests were conducted during sampling periods in July, September, and October. Statistical analysis of entrainment data from treatment and control periods showed that the signals tested, whether transmitted alone or in combination with strobe light or an air bubble curtain, did not produce a significant reduction in total fish entrainment through the Unit 1 turbine. Similarly, significant reductions in entrainment were not detected when data were analyzed by species, family, and size class. Many of the species collected during the White Rapids study also occur at the LPSP, or are closely related (i.e., of the same genus and/or family).

A study at the Plant Barry Steam Station on the Mobile River in Alabama also demonstrated that variety of freshwater and estuarine fish species (threadfin and gizzard shad, blue and channel catfish, freshwater drum, bay anchovy and hogchoker) could not be effectively repelled at a water intake based on impingement rates on the station’s traveling water screens when a low-frequency (0.4 to 3.15 kHz) sonic deterrent system was operated (Baker 2008).

In contrast to the Plant Barry study, a sonic system developed by Fish Guidance Systems, LTD has been installed at several cooling water intakes in Europe based on existing evidence that considerable reductions in impingement can be achieved for estuarine species. Maes et al. (2004) conducted a field evaluation of a sound deterrent system at the Doel Nuclear Power Plant in Belgium. Twenty large sound projectors were installed at the offshore intake head of the cooling water intake system. Sounds were emitted at a 0.2 sec repetition rate and were between 20 and 600 Hz. On-off trials were conducted to evaluate the deterrent efficiency of the sounds projectors. Gobies represented 78% of fishes collected and results indicated that impingement on the onshore screens was reduced by 59.6% for all species during the sound-on trials.

Extensive testing at several sites in the U.S. have shown that entrainment of anadromous salmonids, various freshwater species, and estuarine fishes cannot be significantly reduced at water intakes with sonic deterrents (Hanson et al. 1997; Winchell et al. 1997; EPRI 1998b; Goetz et al. 2001; Ploskey and Johnson 2001). Given that many of the fish species that have been evaluated during these studies are the same or similar to species that occur at the LPSP, it is unlikely that sonic deterrents could effectively repel fish and reduce entrainment to a significant degree at the project. Additionally, sonic deterrents have not been applied on a scale as large as Ludington with respect to the intake flow rate.

Ultrasonic Deterrents

The most successful applications of sound have involved the use of ultrasonic signals (> 80 kHz) as a means to repel herring and shad species of the subfamily Alosinae (Clupeidae family). Most of these applications have focused on alewife, blueback herring, and/or American shad (Nestler et al. 1992; Ross et al. 1993, 1996; Schilt and Ploskey 1997). Alewife is the most abundant species encountered at the LPSP intake and likely could be effectively repelled with an ultrasonic deterrent installed at the project. This would include repulsion of juvenile alewife which are small enough to pass through the mesh on the existing barrier net. However, no other species that occurs at LPSP has the ability to detect ultrasound and, therefore, alewife would be the only species protected by an ultrasonic system.

Following several years of development and testing, an ultrasonic deterrent system was accepted for permanent installation as the best technology available for reducing entrainment of alewife (adults and juveniles) at the James A. Fitzpatrick Power Plant (JAF) located on Lake Ontario. Initial cage test studies demonstrated that juvenile alewife consistently avoided several ultrasound signals at high sound pressure levels (Dunning et al. 1992). Other species (e.g., white perch, striped bass) that were tested did not exhibit any avoidance to ultrasound. The results of the cage tests led to studies that assessed the feasibility of deploying a full-scale sound system at the intake of JAF, including a short-term demonstration test of the full-scale system (Ross et al. 1993; Dunning 1997). The sound system ensonified the entire JAF intake with a minimum sound pressure level (SPL) of 190 decibel (dB) (re 1 :Pa) and had signal frequencies of 122 to 128 kHz. Initial testing indicated there was an 87% decrease in alewife impingement with the ultrasonic system operating and the station generators at full power. After some modifications were made to the sound system design, alewife impingement on the intake screens was reduced by about 85% during periods of full cooling water flow withdrawal and by about 88% when the plant was in a non-generating mode with only two intake pumps operating for service water.

An ultrasound system has also been incorporated into an integrated fish protection system designed to reduce blueback herring entrainment at the Richard B. Russell Pumped Storage Facility on the Savannah River in Georgia (Nestler et al. 1995; Ploskey et al. 1995). The system is comprised of a high-frequency (118-130 kHz) acoustic deterrent, an array of sodium incandescent light attractants, and 3.2-mm wedgewire overlays on the trash rack. During sound-on treatments, entrainment of blueback herring was reduced by 56%.

Several peer-reviewed studies have provided insight into the mechanisms and behavioral responses of clupeids to ultrasonic sound (Mann et al. 1997, 1998, 2001; Plachta and Popper 2003; Higgs et al. 2004)). These studies demonstrated that a several species in the sub-family Alosinae can detect ultrasound up to almost 200 kHz, while other clupeids such as sardines and anchovies (including bay anchovy) are not able to detect ultrasound, but can detect sounds to above 5,000 Hz. Mann et al. (1997) proposed that the ultrasound responses of one Alosine species, American shad, evolved to detect and evade echolocating predators (e.g. dolphins). Plachta and Popper (2003) have shown that the avoidance response to ultrasonic pulses is very strong and highly directional (i.e., away from the source).

It is evident from the studies conducted to date that ultrasonic deterrent systems have potential for application for repelling Alosines at water intakes. Responses of Alosine species to frequencies greater than 80 kHz have been clearly observed during many studies. The field studies conducted at the JAF Plant demonstrated that when site-specific biological and hydraulic characteristics were considered and factored into the system design, ultrasound can effectively repel alewife away from a cooling water intake. Ultrasound has also been incorporated into a multi-technology fish protection system installed at the Richard B. Russell Pumped Storage Project to reduce entrainment of blueback herring. The body of research available from both hydroelectric and other types of power plants supports the conclusion that ultrasound could be used to effectively repel alewife away from the LPSP intake during pumping operations.

5.2.1.4 Preliminary Screening Determination for Sound Deterrents

The review of sound deterrent systems indicates that only ultrasound has the potential for effective application at the LPSP intake. Extensive research with infrasonic and sonic deterrent systems have failed to demonstrate that signals in these frequency ranges have the ability to strong repel a wide range of fish species at water intakes. There have been limited successful applications of infrasonic and sonic deterrents in Europe, but these applications have occurred at intakes that are very different from the LPSP with respect to size, location, flow rate, and environmental conditions. Consequently, infrasonic and sonic signals are unlikely to produce strong and consistent avoidance responses for many, if not all, of the species that occur at the LPSP. Ultrasonic deterrents would only be effective for alewife because other species are unable to detect such high sound frequencies. Because alewife is the most abundant species at the project, ultrasound could be considered as an enhancement measure for the barrier net, potentially increasing current effectiveness levels for this species from about 90% to 98% (assuming 80% effectiveness for ultrasound). This would include increased protection for juvenile alewife, many of which are likely small enough (< 4 inches in length) to fit through the barrier net mesh.

5.2.2 Light (strobe, continuous)

The use of strobe lights as a means for repelling fish from water intakes has been evaluated during numerous studies over the last 25 years (EPRI 1994, 1998a, 2007). Continuous light sources (e.g., mercury, incandescent, vapor) have been considered primarily as a method to attract fish to bypasses. Effective applications of strobe and continuous light for fish protection purposes have been mixed, varying by species and project (EPRI 1994, 1998a, 2007). Water clarity can be an important factor affecting the ability of lights to repel or attract fish, particularly in turbid systems where light transmissivity can be significantly reduced.

5.2.2.1 LPSP 1988 Technology Assessment: Light

The SWEC (1988) fish protection technology assessment prepared for LPSP indicated that extensive research had been conducted with various types of light sources designed to repel or attract fish. The general conclusion from the SWEC (1988) review of light was that, as a whole, the results were equivocal and there was no clear or concise information at the time that suggested any form of this technology would have the ability to effectively reduce entrainment of one or more fish species at the LPSP intake. In particular, the SWEC (1988) review noted that the use of light to repel fish can be complicated by species-specific responses (or lack thereof) to different types of lights.

5.2.2.2 LPSP 5-Year Technology Updates: Light

The 2001 technology assessment update for LPSP (LMS 2001) included a detailed review of various light source research conducted since the SWEC (1988) report was completed. Based on this review, LMS (2001) concluded that, although lights may have potential to repel some fish away from the LPSP intake, effectiveness was unlikely to exceed the biological performance of the barrier net. The 2006 and 2011 technology updates (ESP 2006, 2011) did not include detailed assessments of any types of light technologies for consideration for use at LPSP.

5.2.2.3 Updated Summary of Light Deterrent Research and Applications

Avoidance responses have been demonstrated by a variety of fish species during laboratory and field studies with various types of light sources. Study results have shown that several salmonid species can be repelled with strobe light (Nemeth and Anderson 1992; Amaral et al. 2001; Johnson et al. 2001; Maiolie et al. 2001; Mueller et al. 2001). Clupeid species (shads and herrings) have also exhibited avoidance of strobe lights in laboratory studies, as well as at hydroelectric projects (EPRI 1992a). Unlike some salmonids and clupeids, avoidance responses of freshwater fishes have been less evident (EPRI 1998). However, several studies have indicated that some riverine/lacustrine species may avoid strobe light (McCauley et al. 1996; Amaral et al. 2001; Ichthyological Associates 1997) and that passage into water intakes may be reduced by this technology (McCauley et al. 1996). Conversely, a recent study at the Plant Barry Steam Station on the Mobile River in Alabama did not detect any reductions in impingement during strobe light operation for a wide array of species, including blue and channel catfish, freshwater drum, and threadfin and gizzard shad (EPRI 2008).

Prior to field applications, laboratory or field cage tests or small-scale pilot studies have been performed to determine fish responses and optimum parameters for repulsion by strobe light (e.g., flash rate, intensity, direction of light). Many studies have focused on salmonid species (Amaral et al. 2001; Maiolie et al. 2001; Mueller et al. 2001; Ploskey and Johnson 2001; Johnson et al. 2001; Brown and Bernier 2000). Various degrees of avoidance have been demonstrated for kokanee salmon, steelhead trout, coho salmon, Chinook salmon, and Atlantic salmon. Cage and field tests with riverine fishes have shown less promising results (EPRI 1998b; EPRI 2008). However, in a limited series of cage tests, adult smallmouth were repelled by strobe lights operated at flash rates of 300 and 450 flashes per minute (Amaral et al. 2001).

Several laboratory studies with strobe lights have been conducted to evaluate the effect of variables such as flash rate, light intensity, water velocities, and light and dark acclimation of test fish on eliciting avoidance responses. Stauffer et al. (1983) examined the responses of three estuarine species to three light intensities during tests with two flow rates (0.6 and 1.5 ft/sec), two flash rates (300 and 600 flashes/minute), and two acclimation conditions (light and dark). The results of this study showed that avoidance responses of white perch were strongest for a flash rate of 300 flashes/minute under low ambient light and low water velocity conditions. Spot showed the strongest avoidance at 600 flashes/minute and with low water velocities after being acclimated to darkness. Menhaden did not show a significant difference in avoidance between strobe flash rates, but did demonstrate stronger avoidance to both strobe rates under low ambient light and higher water velocity conditions than under higher ambient light and low water velocity. In a similar study also using white perch, spot, and menhaden, Sager et al. (1999) reported fish responses to strobe light at a flash rate of 120 to 600 flashes/minute and concluded that the strongest avoidances were elicited at frequencies of 300 flashes/minute or less.

A key variable for the application of strobe lights as a fish deterrent is water turbidity. Most laboratory studies that have evaluated fish responses to strobe light have been conducted in very clear water. In the field, however, it is assumed that elevated turbidity levels limit the effective range of strobe light transmissivity. Although, a laboratory study conducted by McIninch and Hocutt (1987) demonstrated that two estuarine species (spot and white perch) had stronger avoidance reactions at the highest turbidity level tested. White perch avoidance was approximately 14% at low turbidity and 34% at high turbidity. Spot showed 64% avoidance in low turbidity and 81% avoidance in high turbidity. In contrast to the results of McIninch and Hocutt (1987), Maiolie et al. (2001) cited greater water clarity as a factor that resulted in kokanee avoiding strobe light at greater distances from the stimulus source during winter months compared to at other times of the year. The contrasting results from these studies demonstrate that strobe light responses are species-specific and probably strongly influenced by environmental conditions.

Field studies conducted at sites where entrainment and impingement of non-salmonid species is an issue have shown considerable variation in strobe light effectiveness among the species evaluated. For example, studies conducted at Roseton Generating Station (Hudson River) using an air bubble curtain, pneumatic gun, and underwater strobe demonstrated variability in effectiveness for white perch, pumpkinseed, blueback herring, alewife, striped bass, and bay anchovy. The overall results from studies conducted at this site (Matousek et al. 1988; EPRI 1994) indicated that none of the devices or combination of devices was effective as a behavioral barrier for all species at all times. Behavioral barrier effectiveness was species-specific and related to time of day

Field studies at Milliken Station on Cayuga Lake in NY (Stafford-Glase et al. 1999) also yielded very mixed results among species that were collected in entrainment samples with and without strobe lights operating. The effectiveness of the strobe light varied among species and life stage and between seasons and study years. Statistically significant reductions in entrainment of juvenile alewife, adult alewife, and yellow perch occurred from December to mid-July. During the late summer and fall, juvenile alewife and yellow perch appeared to be attracted to the lights based on significant increases in entrainment rates.

Although the results of field studies have varied among sites, species, and seasons, there is evidence that strobe light can elicit consistent avoidance responses from some fish species. Clupeids (herrings and shads), for example, have repeatedly demonstrated repulsion by strobe lights at hydroelectric facilities (EPRI 1992b, 1994a). Studies conducted over several years at the York Haven Hydroelectric Project demonstrated that juvenile American shad repeatedly avoided strobe lights placed in front of the turbine intakes and that they were successfully guided to the sluiceway for downstream passage (EPRI 1990, 1992a; Martin et al. 1991, Martin and Sullivan 1992).

In addition to being evaluated as primary barrier systems, strobe lights also have been assessed as components of multi-technology fish protection systems that include other devices such as screens, narrow-spaced bar racks, bypasses, and/or other behavioral systems (EPRI 1994, 1998a, 1998b, 1999). As a secondary system, strobe lights have the potential to incrementally increase fish protection effectiveness. For instance, experiments were conducted with strobe lights, poppers, and an air bubble curtain during 1985 and 1986 near the Pickering Generating Station on Lake Ontario as part of a multi-year research program developed by EPRI to evaluate behavioral systems for fish exclusion. The Pickering study examined the response of alewife to the devices that were tested. The effectiveness indices for the strobe light/air bubble combination, strobe light/popper combination, and all three devices combined were 67.1%, 70.9%, and 54.1%, respectively (Patrick et al. 1988). In a similar field evaluation of a multiple behavioral barrier system, McCauley et al. (1996) found mean percent reductions for bullhead species, the most abundant species collected, to be 82%, 80%, and 69% for strobe/air combined, strobe light alone, and air bubble curtain alone, respectively. For golden shiner, mean percent reductions were 94%, 86%, and 55% for strobe/air, strobe light alone, and air bubble curtain, respectively.

5.2.2.4 Preliminary Screening Determination for Light

The review of studies that have investigated light as a fish deterrent or attractant demonstrates that avoidance responses are species specific and may not be consistent for species that do respond depending on environmental and hydraulic conditions and site configuration. Studies with salmonids and clupeids (including alewife) have demonstrated the ability of strobe light to repel these species in the lab and field, but the strength of responses and effectiveness rates have varied and most studies conducted at water intakes have not produced sufficiently positive results to warrant a permanent installation. Avoidance responses to strobe light have been less evident for freshwater species that have been evaluated in lab and field studies, many of which occur at the LPSP. In particular, strobe lights were ineffective at reducing turbine entrainment of any of the species encountered at the White Rapids Project on the Menominee River. The results of this study present the strongest evidence that strobe lights would be ineffective at LPSP for most of the species that occur at the site.

Due to the lack of consistently strong avoidance responses, there have been no permanent installations of strobe light systems at hydro projects or cooling water intakes in the U.S. There also is no evidence that permanent installations have occurred in other parts of the world, as well. The only permanent installation of a strobe light deterrent system in the U.S. is at the entrance to a filling culvert at the Ballard ship locks in Seattle, Washington, where the lights are used to repel juvenile salmonids migrating downstream to Puget Sound from Lake Washington. The intake configuration and flow rates at this site are very different than those of the LPSP and the results are not considered transferable to salmonids encountered at the LPSP.

Based on the information reviewed, strobe lights used alone or in conjunction with the barrier net are unlikely to provide any additional reductions in fish entrainment at the LPSP beyond what is currently achieved with the barrier net alone. Studies of various continuous light sources have also demonstrated a lack of strong and consistent avoidance responses for a variety of species and may actually attract some species. Consequently, strobe and continuous light sources are not considered a viable technology for application at the LPSP either used alone or in conjunction with the barrier net.

5.2.3 Chemicals

Certain chemicals have been shown to attract or repel a wide array of organisms. Chemicals such as copper, zinc, and chlorine that are used as biocides may repel fish at sub-lethal levels (Bell 1973); however, there is only limited research on their application as repellants. More recently, semiochemicals, the chemicals that organisms use to communicate with each other, have been used to repel or attract organisms. The most recognizable semiochemicals are pheromones. Recent studies have evaluated the use of different sea lamprey pheromones to attract adult sea lamprey to traps. These studies have shown that male sea lamprey mating pheromone and sea lamprey migratory pheromone can increase the trapping efficiency enhancing sea lamprey control (GLFC 2013). Several fish species of the superorder *Ostariophysi* are known to release semiochemicals when attacked to warn the rest of the school of the presence of predators (Kapoor 2004 et al.). The use of these chemicals has not been tested for use as a fish repellent.

5.2.3.1 LPSP 1988 Technology Assessment: Chemicals

The SWEC (1988) fish protection technology assessment prepared for LPSP indicated that limited research had been conducted with various types of chemicals designed to repel or attract fish. The general conclusion from the SWEC (1988) review was no clear or concise information at the time that suggested any form of this technology would have the ability to effectively reduce entrainment of one or more fish species at the LPSP intake. In particular, the SWEC (1988) review noted that the quantity and cost of chemicals would be prohibitive.

5.2.3.2 LPSP 5-Year Technology Updates: Chemicals

The 2001 technology assessment update for LPSP (LMS 2001) included a detailed review of chemical research conducted since the SWEC (1988) report was completed. No additional data were discovered. The 2006 and 2011 technology updates (ESP 2006, 2011) did not include assessment of chemicals for consideration for use at LPSP.

5.2.3.3 Updated Summary of Chemical Deterrent Research and Applications

Carbon dioxide (CO_2) is the only chemical deterrent that has been evaluated in recent years as a fish deterrent (Clingerman et al. 2007, Dennis III et al. 2015, Kates et al. 2012, & Suski et al. 2015). Many of these studies, while experimental in nature have demonstrated that CO_2 has the potential to act as a non-physical barrier to influence the behavior and movement of several fish species. CO_2 gas exposure has been shown to induce numerous physiological and behavioral responses in fishes including an elevation in stress response, a reduction in blood pH, ion loss, equilibrium loss and anesthesia (Suski et al. 2015). Clingerman et al. (2007) observed behavioral response of Rainbow trout (*Oncorhynchus mykiss*) at dissolved CO_2 concentrations of 60-120 mg/L. This study demonstrated that 80-90% of the trout evaluated swam from the treatment tank, through a transfer pipe and into a secondary tank after CO_2 concentrations in the treatment tank exceeded 60 mg/L (Clingerman et al. 2007). Kates et al. (2012) demonstrated similar behavioral modifications and induced active avoidance at CO_2 concentrations of 70-120 mg/L for Silver carp (*Hypophthalmichthys molitrix*), Bighead carp (*Hypophthalmichthys nobilis*), Largemouth bass (*Micropterus salmoides*) and Bluegill (*Lepomis macrochirus*).

Additional experiments conducted with larval and juveniles of these four species demonstrated a higher tolerance for earlier life stages, with CO_2 concentrations elevating to approximately 200 mg/L before avoidance behavior was observed (Dennis III et al. 2015). Studies conducted with juvenile (transformers) and adult Sea lamprey (Petromyzon marinus) demonstrated a similar tolerance behavior across life stages, with transformers displaying active avoidance at CO_2 concentrations of approximately 160 mg/L while adults avoidance starting at concentrations almost 50% lower, approximately 85 mg/L (Suski et al. 2015). While these studies have demonstrated the potential of CO_2 to alter fish behavior and movement they have not addressed how this technology could be applied on a large scale at water intakes or how to overcome potential obstacles related to deployment of this technology (i.e. environmental impacts, infrastructure requirements).

5.2.3.4 Preliminary Screening Determination for Chemical Deterrents

Chemical deterrents have demonstrated the ability to both attract and repel fish, but only in laboratory or small-scale settings. They have not been investigated with most of the species that occur at the LPSP and they have not been applied, either experimentally or as full-scale system, as a method to reduce entrainment at large water withdrawals, where constant long term dosing would be necessary. Consequently, there currently is no evidence that any type of chemical deterrent could be applied as fish protection measure at the LPSP either as a standalone technology or in combination with the barrier net without a considerable amount of developmental research. Continuous dosing of any chemical into Lake Michigan in the vicinity of the LPSP would also raise concerns of ancillary environmental effects and could have difficulty gaining state and federal regulatory approval.

5.2.4 Electric Barriers

Electric fish barriers have been developed and evaluated as methods for blocking and/or guiding fish in several different types of applications. Electric barriers produce an energized electrical field that fish are expected to avoid after initial encounter. These technologies have been designed to block upstream movements of fish into hydroelectric project tailraces and draft tubes (e.g., adult salmonid spawning migrants seeking upstream passage) and stream reaches where their presence may be detrimental (e.g., Asian carp, adult lamprey), as well as to keep fish out of thermal effluent, and to reduce entrainment of fish into water intakes. Most successful applications to date have been to block upstream movement of fish, particularly adult lamprey attempting to reach spawning grounds in Great Lakes streams and rivers and adult salmonids attracted to hydro project tailraces where there are no upstream passage facilities. Electric barriers have also been installed to block the movement of invasive Asian carp species into waterbodies they have yet to colonize.

As a fish enters an electric field, it becomes part of the circuit with some of the current flowing through its body. A typical electric barrier system uses graduated fields of pulsed direct current (PDC) to create the energized field, which is considered safer for fish than alternating current (Reynolds 1996). Under site-specific conditions, PDC can attract fish to the anode of the electric field. This attraction is referred to as electrotaxis and refers to the orientation and movement of an organism in response to an electric current. Electronarcosis occurs at the narrow threshold where the electric field transfers from being an irritant/deterrent to causing immobilization. Creating a graduated electrical field along a spatial gradient (or operating the electric field in a sequential manner) provides varying stimulus levels across the barrier. In a graduated field, a weak deterrence is produced as fish approach and move into the electric field. If a fish is not deterred when it first senses the field it experiences an increasing electric gradient as it moves further into the field. At the strongest point of the electric field, fish typically turn sideways to avoid the maximum energy transfer that occurs along the length of the body. If a fish becomes immobilized, it will be swept downstream. Larger fish are affected to a greater degree by electric fields than smaller fish. Use of a graduated electric field should produce avoidance behavior for fish of all sizes before they become immobilized.

Electric fields have been configured in several different ways to produce avoidance responses for reducing entrainment at water intakes (or impingement on intake screens). However, applications at water withdrawals have been limited because there is potential for fish entering an electric field to experience electronarcosis and be passively entrained into the intake after being immobilized, particularly if intake approach velocities are high (greater than 2 ft/sec). An alternative use at some cooling water intake structures (CWIS) in Europe has been to use electric fields to stun fish swimming in front of intake traveling water screens so they can be quickly collected and returned to the source waterbody.

5.2.4.1 LPSP 1988 Technology Assessment: Electric Barriers

The SWEC (1988) fish protection technology assessment prepared for LPSP indicated that research had been conducted with various types of electric barriers designed to repel fish. The general conclusion from the SWEC (1988) review of electric barriers was that results were inconclusive. In particular, the SWEC (1988) review noted that the use of electric barriers to repel fish can be complicated by species-specific responses (or lack thereof), can result in rapid fatigue which allows for entrainment, and the electric field strength varies for different lengths of fish which could result in death/injury to non-target length classes. Consequently, this technology was dropped for consideration at LPSP.

5.2.4.2 LPSP 5-Year Technology Updates: Electric Barriers

The 2001 technology assessment update for LPSP (LMS 2001) included a search for electric barrier research conducted since the SWEC (1988) report was completed. No additional data were discovered that could be used for an updated assessment of this technology for use at LPSP. The 2006 and 2011 technology updates (ESP 2006, 2011) did not include assessments of electric barriers for application at the LPSP.

5.2.4.3 Updated Summary of Electrical Barrier Research and Applications

Electric barriers and guidance systems have been evaluated with wide range of fish species and sizes (Palmisano and Burger 1988; Swink 1999; Savino et al. 2001; Holliman 2010, Sparks et al. 2010; Moy et al. 2011). In the US, most electric barrier applications have been designed for application at hydro project tailraces and areas of thermal effluent from steam-electric plants. Electrical barriers have been used with a high degree of success to prevent the upstream movement of both invasive Asian carp species and non-indigenous common carp in the Midwest (Verrill and Berry 1995; Sparks et al. 2010). Electric barriers have also been used to control and prevent invasive sea lampreys from accessing spawning areas in tributaries of the Great Lakes (Swink 1999). Electric deterrent systems have also been investigated as means to divert downstream migrants away from hydropower intakes and have been installed at cooling water intakes (primarily in Europe) to prevent entrainment. In the U.S. an electrical barrier was used at the Connecticut Yankee Nuclear Plant to reduce entrainment of fish greater than 15 cm from the 1970's (Hyman et al. 1975) until the facility ceased operation in 1996. For downstream passage and water intake applications, effectiveness of electric barriers appears to be site-specific with water velocity being an important factor. Downstream guidance arrays have been used to contain desirable, triploid grass carp in Southeastern U.S. reservoirs (Maceina et al. 1999) and to limit downstream movements of invasive round gobies (Savino et al. 2001). Research has shown that electric arrays designed to guide downstream-moving fish are more effective when velocities approaching the barrier do not exceed about 0.5 to 0.8 m/s (1.6 to 2.6 ft/sec) (Demko et al. 1994; Pugh et al. 1970).

Many electric guidance barriers are bottom-mounted on a streambed using non-conductive, insulating concrete substrate. Electrode cables are positioned perpendicular to stream flow (the orientation that yields maximum energy transfer to fish) at 1-m spacing. These types of deployments are beneficial in environments where debris can be an issue (because this type of array is unaffected by floating debris). In areas where debris is not an issue, surface-suspended electrode arrays can be used. Most deployments use graduated electric fields for deterrence where voltage gradients increase the further that fish attempt to move into them. Newly emerging barrier technologies include the design of sequenced fields (where electrodes can be sequentially activated), bi-directional fields (where pulses are emitted in alternating "x" and "y" directions), temporary and portable arrays, and mid-water column arrays (for use in deep waters). A "sweeping" sequenced field for fish herding was recently successfully tested and evaluated by the U.S. Bureau of Reclamation (Svoboda and Horn 2013).

There are currently three vendors selling electrical barriers designed for reducing entrainment of fish at water intakes: Smith-Root, Bilfinger, and Neptun. In addition to a barrier system designed for intakes and canal entrances, Bilfinger has developed an Electric Immobilization System that uses a short electric pulse to immobilize fish in front of modified traveling screens at cooling water intakes (Bilfinger 2015). This prevents fish from exhausting themselves before being collected by the screen. Once impinged on the screens the immobilized fish are quickly transferred by a fish lifting bucket into a fish return sluice discharging into the source waterbody. Bilfinger's electric barrier system has been installed at more than 30 cooling water intakes, primarily in Germany. However, there are no publicly available reports describing evaluations of these systems and their effectiveness at reducing fish entrainment.

5.2.4.4 Preliminary Screening Determination for Electrical Barriers

There is only one documented use of a full-scale electrical barrier installation at a water intake in the U.S, but there have been many installations of electrical deterrent systems at cooling water intakes in Europe. Although data are not available to determine the effectiveness of the European applications, the wide spread use of this technology in Europe (mainly in Germany) suggests that it has potential to be an effective method for reducing fish entrainment at water intakes in other parts of the world as well. The potential effectiveness of electric barriers with all of the species and life stages that occur at LPSP cannot be determined with the available data and electric barriers are not expected to be effective with ichthyoplankton. Also, the ability of electric deterrent systems to operate in winter months under conditions similar to those at the LPSP is unknown. However, it is likely all fish perceive electric fields as a negative stimulus, but responses will vary among species and life stages depending on the field settings (frequency, voltage, etc.). Because all species are expected to avoid electric fields to some degree and there have been a large number of installations at water intakes in Europe, electric deterrents have been carried forward for a detailed feasibility assessment as a method for enhancing the effectiveness of the existing barrier net. This technology is not being considered as a stand-alone fish protection system because there is insufficient information to determine how well it would perform on a scale as large as the LPSP.

5.2.5 Air bubble curtain

Air bubble curtains, operate by creating a wall of bubbles across an intake opening. Air bubble curtains have been evaluated at a number of sites with a variety of species. Although air curtains have typically been shown to be ineffective (EPRI 1994, 1998a, 2007), they have been used in combination with other behavioral technologies, such as light and/or sound, to produce a more effective hybrid system. In addition to standard air injection, the use of CO_2 has also been investigated as a fish deterrent, including during recent studies targeting Asian carp (Dennis 2014) and sea lamprey (Suski et al. 2015), see Section 5.2.3.3.

5.2.5.1 LPSP 1988 Technology Assessment: Air Bubble Curtains

The SWEC (1988) fish protection technology assessment prepared for LPSP indicated that research had been conducted with various types of air bubble curtains designed to repel or attract fish. The general conclusion from the SWEC (1988) review of air bubble curtain studies was that, as a whole, the results were equivocal and there was no clear or concise information at the time that suggested any form of this technology would have the ability to effectively reduce entrainment of one or more fish species at the LPSP intake.

5.2.5.2 LPSP 5-Year Technology Updates: Air Bubble Curtains

The 2001 technology assessment update for LPSP (LMS 2001) included a search for air bubble curtain deterrent research conducted since the SWEC (1988) report was completed. No additional data were discovered. The 2006 and 2011 technology updates (ESP 2006, 2011) did not include assessments of air bubble curtains for consideration for use at LPSP.

5.2.5.3 Updated Summary of Air Bubble Curtain Research and Applications

Air bubble curtains are designed to repel fish by creating an aversive visual stimulus. Early work by Kuznetzov (1971) also suggested that the sound associated with bubbles may contribute to avoidance responses. Air bubble curtains generally have been ineffective in blocking or diverting fish in a variety of field applications and have often been discounted as a viable fish protection alternative, particularly if used alone (EPRI 1986).

Early laboratory work done by Bibko et al. (1974) demonstrated the effectiveness of an air bubble curtain in eliciting avoidance responses from gizzard shad and striped bass. This study indicated that spacing between bubbles is an important operating characteristic of air curtains. Both species that were tested in the study did not pass through the air curtain when the spacing between the bubbles was small (1 inch), but fish began to pass through when the openings were widened to 2 inches. Additionally, increased avoidance appeared to occur at higher temperatures.

Laboratory studies conducted by Patrick et al. (1985) with freshwater and estuarine species examined the effectiveness of an air bubble curtain operated alone and with strobe lights. The results of this study demonstrated that the effectiveness of the air bubble curtain alone ranged from 38% to 73%, whereas the effectiveness of the combined barrier ranged from 90% to 98%, depending on water velocity and turbidity level. Based on these results, it was concluded that a combined strobe light/air bubble curtain barrier had a higher level of effectiveness for deterring some of the species tested than an air bubble curtain used alone. McIninch and Hocutt (1987) obtained similar results to Patrick et al. (1985) during laboratory studies with white perch, menhaden, and spot. McIninch and Hocutt (1987) estimated that the effectiveness of the air bubble curtain alone was less than 50%. Exposure to the air curtain and strobe light combined resulted in greater avoidance for each of the three species tested.

McKinley and Patrick (1988), working with sockeye salmon smolts at the Seton Hydroelectric Station (British Columbia), concluded that air bubbles alone did not provide adequate protection from entrainment. When operated with strobe light, the combined system's effectiveness in repelling fish increased, but was still too low to be considered effective. Results of studies conducted at the White Rapids Hydroelectric Project indicate that an air bubble curtain operated alone or in combination with sonic sound or strobe light is not effective in repelling riverine species as well (EPRI 1998b). Matousek et al. (1988) demonstrated an effectiveness index of over 50% for alewife and blueback herring using air bubbles and strobe lights together at the Roseton Generating Station on the Hudson River in New York, whereas the estimated effectiveness of the air curtain alone was only 1.6%. Behavioral barrier evaluations were also conducted at the Indian Point Plant located on the Hudson River (Lieberman and Muessig 1978; Alevras 1974). Although results of these studies indicated that an air bubble curtain was ineffective in significantly reducing impingement on the intake traveling screens, the data suggested that air bubbles were a visual stimulus since their effectiveness was lower at night and at times of high turbidity.

A field study of the effectiveness of an air bubble curtain at the White Rapids Hydroelectric Project on the Menominee River (EPRI 1998b) did not demonstrate any significant reduction in entrainment of potamodromous fish during the two week test period. When used alone at Four Mile Hydroelectric Project on the Thunder Bay River in Michigan, an air bubble curtain reduced entrainment of bullhead and shiner species by 43% from control levels (McCauley et al. 1996). When combined with strobe lights, entrainment was reduced by 81% (McCauley et al. 1996). The ability of an air bubble curtain to repel out migrating Sockeye salmon was tested at the Seton Hydroelectric Station on the Fraser River in British Columbia (McKinley and Patrick 1988). When paired with a strobe light effectiveness was only about 11%, this was more effective than an air bubble curtain alone.

A recent study conducted by Welton et al. (2002) provides data supporting the use of air bubble curtains in combination with sound. This study describes the evaluation of a Bio-Acoustic Fish Fence (BAFF) developed by Fish Guidance Systems LTD of Great Britain. During this study, which was conducted at a hydroelectric project, guidance efficiency of Atlantic salmon smolts was estimated to be 20.3% to 43.8% during daytime and 72.9% to 73.8% during darkness. The diel differences in effectiveness were attributed to the ability of salmon smolts to visually find gaps in the BAFF during daytime hours through which they could pass downstream.

5.2.5.4 Preliminary Screening Determination for Air Bubble Curtains

Air curtains have typically been shown to be ineffective when used alone and appear to provide marginal benefits when used with other behavioral deterrent technologies (e.g., sound and lights). Evaluations of air bubble curtains have produced mixed results with a variety of species, some of which are the same or similar to those that occur at the LPSP. In particular, results of a field study conducted with freshwater species at a hydro project on the Menominee River (EPRI 1998b) indicated that an air curtain was ineffective at reducing turbine entrainment, whereas a study at a small hydro project in Michigan demonstrated an air curtain reduced entrainment of bullhead and shiner species by 43% when used alone and 81% when combined with strobe lights. Also, tests with an air curtain only produced an 11% reduction in entrainment of juvenile sockeye salmon at a hydro project in British Columbia (McKinley and Patrick 1988). The lack of consistently strong deterrence exhibited by fish exposed to air bubble curtains indicates that this technology would not be an effective method for reducing entrainment of fish at the LPSP at the levels currently achieved by the barrier net.

5.2.6 Water Jet Curtains and Current inducers

Water jet curtains have been tested in both the field and the laboratory (Bates and Vanderwalker 1964, SWEC 1976, ESEERCO 1981). Previous testing has examined the ability of water jets to exclude fish or guide them to a bypass. Chinook salmon were effectively guided using water jets (Bates and Vanderwalker 1964) and smelt and alewife were excluded from an intake (SWEC 1976).

Recently a new water jet concept, the Flow Velocity Enhancement System (FVES) developed by Natural Solutions LLC is a Venturi pump, or "eductor", and a pump that delivers high-pressure motive water to the Venturi. A small volume of water at high pressure is injected through narrow nozzles into a larger-diameter, underwater pipe, resulting in acceleration of larger volumes of water at lower velocity and pressure through the larger pipe. The eductor produces a plume of water consisting of a series of turbulent boils. The FVES may act as a behavioral barrier by guiding downstream migrating riverine fish that have evolved to follow turbulent river currents. The FVES has been tested at several facilities to determine its ability to guide downstream migrating fish (Coutant et al. 2013). The FVES has been tested for its ability to guide juvenile Chinook salmon on the Cowlitz River in Washington State and in the Netherlands to determine its ability to guide migrating silver eels to a trap, see Section 5.2.6.3.

5.2.6.1 LPSP 1988 Technology Assessment: Water Jet Curtains and Current Inducers

The SWEC (1988) fish protection technology assessment prepared for LPSP indicated that limited research had been conducted with various types of water jet curtains designed to repel fish. The general conclusion from the SWEC (1988) review of water jet curtains was that this technology was used to guide not repel fish. Also, a system of the size necessary for consideration for use at LPSP was impractical and the concept was dropped from further consideration.

5.2.6.2 LPSP 5-Year Technology Updates: Water Jet Curtains and Current Inducers

The 2001 technology assessment update for LPSP (LMS 2001) included a search for water jet curtain research conducted since the SWEC (1988) report was completed. No additional data were discovered. The 2006 and 2011 technology updates (ESP 2006, 2011) did not include assessments of water jet curtains for consideration for use at LPSP.

5.2.6.3 Updated Summary of Water Jet and Current Inducer Research and Applications

Water jet curtains have been tested in both the field and the laboratory (Bates and Vanderwalker 1964, SWEC 1976, ESEERCO 1981). Previous testing has examined the ability of water jets to exclude fish or guide them to a bypass. Chinook salmon were effectively guided using water jets (Bates and Vanderwalker 1964) and smelt and alewife were excluded from an intake (SWEC 1976).

More recently, current and turbulent flow inducers have been developed as methods to create flow paths that fish will follow away from intakes and towards bypasses. One of these technologies is the Flow Velocity Enhancement System (FVES) developed by Natural Solutions LLC. The FVES uses a pump and eductor to discharge a high-velocity jet. The eductor produces a plume of water consisting of a series of turbulent boils. The FVES may act as a behavioral barrier by guiding downstream migrating riverine fish that have evolved to follow turbulent river currents. The FVES has been tested at several facilities to determine its ability to guide downstream migrating fish (Coutant et al. 2013). The studies to date, while demonstrating some attraction and guidance by juvenile salmonids, have only produced limited data on the ability of the FVES and propeller-type current inducers to effectively reduce fish entrainment. They have not been investigated at any site similar in design and size as the LPSP and they have not been tested with most of the species that occur in the vicinity of the project.

5.2.6.4 Preliminary Screening Determination for Water Jet Curtains and Current Inducers

Water jets and current inducers have shown some promise for guiding fish away from water intakes and, in some cases, towards bypasses. However, the most recent development efforts for these technologies have focused on guiding juvenile salmonids migrating downstream through reservoirs and forebays to bypasses as they approach a hydro project. The available data are limited with respect to the species, life stages, and field settings and projects where they have been evaluated. Consequently, there currently are no available data or information that suggests these technologies could effectively repel or guide most of the species encountered at the LPSP or enhance the biological performance of the barrier net. Additionally, these technologies are unlikely to reduce ichthyoplankton entrainment and their performance under winter conditions typical of Lake Michigan has not been investigated.

5.2.7 Hanging chains

The use of hanging chains as a fish deterrent or barrier has been tested primarily in the lab (SWEC 1976, ESEERCO 1981 Patrick and Vascotto 1981). These studies provided some evidence that hanging chains could divert several species, but the positive results from lab studies typically have not been replicated in field evaluations. The most recent evaluation of a hanging chain barrier was in 1989 (Bengeyfield & Smith 1989). In this study a chain curtain was tested as part of a hybrid barrier system (water hammer, chain curtain, and strobe lights) at Puntledge Diversion Dams to determine their effectiveness at guiding coho smolts to a bypass. None of the technologies evaluated during this study, including hanging chains were considered effective.

5.2.7.1 LPSP 1988 Technology Assessment: Hanging Chains

The SWEC (1988) fish protection technology assessment prepared for LPSP indicated that research had been conducted with various hanging chain options designed to repel fish. The general conclusion from the SWEC (1988) review was that no form of this technology would have the ability to effectively reduce entrainment of one or more fish species at the LPSP intake.

5.2.7.2 LPSP 5-Year Technology Updates: Hanging Chains

The 2001 technology assessment update for LPSP (LMS 2001) included a search for hanging chain research conducted since the SWEC (1988) report was completed. No additional data were discovered. The 2006 and 2011 technology updates (ESP 2006, 2011) did not include assessments of hanging chains for consideration for use at LPSP.

5.2.7.3 Updated Summary of Hanging Chain Research and Applications

There have been no recent studies on the use of hanging chains as a method for reducing fish entrainment at water intakes.

5.2.7.4 Preliminary Screening Determination for Hanging Chains

Initial laboratory studies provided some evidence that hanging chains may have potential for application for reducing fish entrainment at water intakes. However, field studies were unable to replicate the positive results of lab studies and this technology has not received any recent attention as a viable fish protection technology. Consequently hanging chains are not considered a technology that could be used to effectively reduce entrainment at the LPSP or used in conjunction with the barrier net to improve its current effectiveness.

5.2.8 Visual cues

Visual cues can play an important role in fish behavior, including courtship, predator avoidance, and schooling. There likely are also visual aspects of fish responses to some physical and behavioral fish protection technologies. For visual cues to work as an intake protection technology, fish need to be able to see and react to a stimulus before they are subject to entrainment. This limits the application of visual cues to sites with low turbidity. Visual cues may also require artificial lighting to allow the stimulus to be detected under dark conditions.

5.2.8.1 LPSP 1988 Technology Assessment: Visual cues

The SWEC (1988) fish protection technology assessment prepared for LPSP indicated that research had been conducted with various visual cues designed to repel or attract fish. The general conclusion from the SWEC (1988) review was that this technology would not be applicable for use at LPSP. In particular, the SWEC (1988) review noted that the use of visual cues would only be effective during daylight and the concept was dropped from consideration for use at LPSP.

5.2.8.2 LPSP 5-Year Technology Updates: Visual cues

The 2001 technology assessment update for LPSP (LMS 2001) included a detailed review of visual cue research conducted since the SWEC (1988) report was completed. No additional data were discovered. The 2006 and 2011 technology updates (ESP 2006, 2011) did not include assessment of visual cues for consideration for use at LPSP.

5.2.8.3 Updated Summary of Visual cue Research and Applications

There has been limited research with regards to the use of visual cues for reducing entrainment at water withdrawals. However, in one study, Pavlov (1969) demonstrated a reduction in entrainment rates of up to 91% when using an artificial reference point (tree branches, weeds, etc.) in conjunction with illumination when compared to dark conditions with no reference points. There has not been any additional development or research of visual cues since the initial fish protection technology review was completed for the LPSP in 1988.

5.2.8.4 Preliminary Screening Determination for Visual cues

There currently is no evidence that visual cues can be an effective technology for reducing fish entrainment of any species or age classes that occur at the LPSP project, or if this type of stimulus could be used to improve the performance of the current barrier net.

5.2.9 Multi-technology behavioral system (Hybrid Systems)

Hybrid systems generally are designed to take advantage of two or more effective behavioral devices in attempts to achieve a greater level of success than would occur with any of the selected devices used alone. Also, because the effectiveness of behavioral devices can be species- and size-specific, the use of multiple devices may afford protection to a wider range of species and age classes. Often, devices that have been evaluated as an integrated fish protection system take advantage of different behavioral responses to enhance effectiveness. Many systems have been designed with behavioral deterrents (e.g., strobe lights, sound) and attractants (underwater mercury lights, overhead lights). Deterrent devices typically are placed at a location to repel or guide fish from an intake, and attractants are deployed near safe areas or bypasses. Behavioral technologies also may be used in combination with other types of fish protection devices (e.g., screens, narrow-spaced bar racks).

5.2.9.1 LPSP 1988 Technology Assessment: Multi-technology Behavioral System

The SWEC (1988) fish protection technology assessment prepared for LPSP indicated that extensive research had been conducted with various types of multi-technology systems designed to repel fish. The general conclusion from the SWEC (1988) review was that, although combinations of technologies may enhance overall effectiveness, they would not be highly effective for species at LPSP. Consequently, the concept was dropped from further consideration for use at LPSP.

5.2.9.2 LPSP 5-Year Technology Updates: Multi-technology Behavioral System

The 2001 technology assessment update for LPSP (LMS 2001) included a search for multi-technology behavioral system deterrent research conducted since the SWEC (1988) report was completed. No additional data were discovered. The 2006 and 2011 technology updates (ESP 2006, 2011) did not include assessments of multi-technology behavioral systems for consideration for use at LPSP.

5.2.9.3 Updated Summary of Multi-technology Behavioral System Research and Applications

The results of hybrid behavioral system evaluations have been equivocal. In some cases effectiveness has been improved, in others it has decreased. Generally, any increases in effectiveness realized by multi-technology behavioral deterrent systems have not been substantial (EPRI 1994). A study conducted with sound, strobe lights, and an air bubble curtain demonstrated that these systems used in combination or alone did not reduce entrainment of freshwater fishes approaching a hydroelectric project (Winchell et al. 1997; EPRI 1999). Fish protection systems that incorporate fish deterrent and attractant devices may be more appropriate than systems with multiple deterrents. At the Richard B. Russell Project, the use of high-frequency sound to repel blueback herring during pump back operations and overhead lights to attract them to low-velocity safe areas proved to be very effective. Also, Fish Guidance Systems LTD has developed hybrid systems that use sound, light, and/or air bubbles to create a stimulus “fence” that has shown some success in repelling or guiding fish at water diversions and intakes in Europe.

5.2.9.4 Preliminary Screening Determination for Multi-technology Behavioral Systems

Multi-technology behavioral systems have been extensively evaluated as methods for reducing fish entrainment at water intakes during lab and field studies with a wide range of species. Most multi-technology behavioral deterrents have produced only moderate incremental increases in biological effectiveness. Currently, the most common combination of behavioral stimuli is light, sound, and/or air curtains. Combining electric barriers with other behavioral technologies (e.g., current inducers and light) has also received some attention recently, but only limited experimental studies have been conducted with these combined systems. Studies conducted in Europe indicate that the BAFF (sound and air curtain) can be successful at reducing entrainment of salmon smolts at some small hydro project and estuarine cooling water intakes. However, there have been no applications of this technology at U.S. projects and data have only been reported for a study conducted with a system tested with salmonid smolts at a water diversion in California. The existing data for multi-technology behavioral deterrent systems currently do not support the use of these systems for reducing fish entrainment at the LPSP. It is unlikely any combination of behavioral deterrents could achieve the effectiveness rates currently exhibited by the barrier net or improve the biological performance of the net to a degree that would justify their installation.

5.2.10 Barrier net

Barrier nets have been effectively applied at several power plant cooling water intake structures (CWISs), as well as a number of hydroelectric projects where entrainment is of concern, including at the LPSP. Under acceptable hydraulic conditions and without heavy debris loading, barrier nets have been effective in blocking fish passage into water intakes. Debris cleaning and biofouling control can be labor-intensive (Michaud and Taft 1999; EPRI 2006). Barrier nets have also been effective at guiding fish downstream past intakes (FirstLight 2012). Fine-mesh barrier nets have been tested at several facilities as a method for reducing entrainment of smaller organisms. To date operation and maintenance issues with fine-mesh nets have prevented any full-scale installations.

Being a “soft” technology, barrier nets are more prone to damage due to debris and ice. In high energy environments, such as rivers, barrier nets should not be placed in the main current. Deflector or skimmer walls may also be needed to reduce interaction with large debris. In northern climates icing can be a concern. In smaller lakes and reservoirs, small circulators or bubblers can be used to keep the area around a net ice free during the winter. Ice flow and pack ice that do not originate in the vicinity of the net are not affected by deicing methods preventing year round barrier net installation on rivers and large lakes.

5.2.10.1 LPSP 1988 Technology Assessment: Barrier Net

The SWEC (1988) fish protection technology assessment prepared for LPSP indicated that extensive research had been conducted with various types of barrier nets designed to exclude fish. The barrier net option and several deployment alternatives underwent preliminary conceptual design and were carried forward for detailed design. Ultimately, the barrier net option outside the jetties was selected and installed at LPSP.

5.2.10.2 LPSP 5-Year Technology Updates: Barrier Net

The barrier net performance was reviewed during each of the 5-year technology updates (LMS 2001; ESP 2006, 2011). The effectiveness of these monitoring efforts is provided in Section 3.2.

5.2.10.3 Updated Summary of Barrier Net Research and Applications

Full-scale barrier nets have been installed at several hydro projects, cooling water intakes, and other types of water diversions (EPRI 1994, 1999). Most of these nets have been evaluated for effectiveness in preventing passage of target species and life stages. Important information on biofouling, debris loading, and engineering design considerations has also been gathered from some these installations and associated studies.

Based on the size of fish targeted for protection and/or debris loading and biofouling considerations, most net applications have used bar mesh sizes between ¼- and ¾-inches. Currently, the largest mesh barrier net in use for fish protection is at the Osage Hydroelectric Project on the Missouri River in Missouri. This net has a bar mesh of 2 inches and is designed to prevent turbine entrainment of larger fish. Another large-mesh net was installed at the Banks Lake irrigation dam (1.63 inch bar), which was designed to reduce entrainment of adult kokanee (about 8 to 20 inches in length) (Stober et al 1983). The smallest mesh size currently in use is at the Baker River Hydroelectric Project, where guide nets with 0.13-inch bar mesh were installed in a “V” configuration to guide fish to a collection system (PSE 2004). Bar mesh sizes less than one inch have generally been used to physically exclude fish less than 8 inches in length (Hutchinson and Matousek 1988; Reider et al. 1997; FERC 1997; PSE 2004), while also preventing entrainment of larger fish.

The only laboratory evaluation of barrier nets that was identified was conducted as part of a study specifically designed to assess fish protection alternatives for minimizing entrainment of paddlefish at the Osage Project (Alden 2003). During this study, entrainment and impingement rates of paddlefish 20 to 30 inches in length were estimated for nets with two mesh sizes (2 and 3 inch bar) and at four approach velocities (1.0, 1.5, 2.0, and 3.0 ft/sec). The percent of fish lost to entrainment and impingement for both mesh sizes was 16% or less at approach velocities of 1.0 and 1.5 ft/sec and was 62% or greater at approach velocities of 2 and 3 ft/sec. The combined entrainment/impingements rates for each test velocity were not significantly different between the two mesh sizes. Follow-up raceway testing was conducted for the Osage Project with additional species that occur in the reservoir. The results of these tests provided design parameters (2 inch bar mesh and approach velocities of 1.5 ft/sec or less) that were considered sufficiently protective for reducing entrainment of the target species. Consequently, a full-scale barrier net is installed at the Osage project on a seasonal basis (April – October).

The size of barrier nets has varied considerably among sites. In general, net size is mainly dependent on plant flow, design approach velocity, and bottom bathymetry upstream of an intake. That is, a net should be sized for a specified approach velocity at the expected range of discharge rates; bottom bathymetry will influence the selection of the net location with respect to the required depths needed to achieve the desired velocities over a specified length. Longer and deeper nets usually have lower approach velocities (i.e., more surface area through which flow passes).

With respect to target species and life stages, most barrier nets have been installed to minimize entrainment of juvenile and/or adult freshwater fishes. Riverine applications (i.e., hydro power impoundments) have been shown to be effective with centrarchids (basses, sunfishes, crappie), percids (yellow perch and walleye), catastomids (suckers), ictalurids (bullheads and catfishes), and salmonids (trout and salmon). Barrier nets have also been effective with juvenile and adult salmonids and clupeids (shads and herrings) in lake environments. Installations in estuaries have demonstrated effectiveness with anadromous clupeids (American shad and river herring), striped bass, white perch, and bay anchovy. Because most barrier net installations have relatively small mesh sizes (1 inch or less bar mesh) and low approach velocities (less than 0.5 ft/sec), all but the smallest life stages of fish (i.e., young-of-the-year fish less than 4 inches in length) likely are protected from entrainment. The results of field studies support this conclusion (Hutchinson and Matousek 1988; SWES 1990; Reider et al. 1997). However, this may not always be the case, given that a barrier net with 0.5 inch bar mesh installed at the Brule Hydroelectric Project was found to have reduced the entrainment of fish less than 2 inches in length by about 83% (Normandeau Associates 2000; FERC 2001).

One of the earliest barrier net installations was at the cooling water intake of the Bowline Generating Station located on the Hudson River in New York (LMS 1978; Hutchison and Matousek 1988). The Bowline net was installed to reduce the impingement of estuarine fishes on the station's traveling debris screens. Target species for this site include juvenile fish (bay anchovy, striped bass, white perch, American shad, and river herring) about 1 to 4 inches in length. The median reduction in impingement on the traveling screens after barrier net installation was 91% for all fish combined. Gilling or impingement of fish on the Bowline barrier net has not been reported. The low velocities approaching the net (less than 0.5 ft/sec) and the small mesh size (0.2-inch bar) likely prevent gilling and impingement from occurring, even for fish less than 4 inches in length. A fine-mesh net (0.1 inch bar) was also evaluated at Bowline (LMS 1994, 1996), but low abundance of the species of concern (bay anchovy) and damage to the net from excessive debris loading and biofouling resulted in inconclusive results.

Another barrier net installed in the late 1970's was located upstream of an irrigation diversion dam on Banks Lake in Washington State (Stober et al. 1983). This was a much longer and deeper net than the one installed at Bowline, and it also had a considerably larger mesh size (1.63-inch bar). The larger mesh reflects the difference in the size of fish that was targeted for protection at each site. The Banks Lake net was specifically designed to prevent mature kokanee (about 8 to 20 inches in length) from leaving the lake through an irrigation canal. The effectiveness of the net in preventing the passage of other species was also monitored. It was estimated that up to 96% of the kokanee population in the lake were retained annually (i.e., prevented from passing into the irrigation canal) after the net was installed compared to an annual average of 36% entrainment prior to installation. Although gilling of thirteen species of fish was observed during two years of the effectiveness study, the numbers gilled each year were low (typically less than 30 fish per species). The evaluation of the Banks Lake barrier net was the first study to demonstrate that a long and deep net with a relatively large mesh size could prevent fish entrainment with minimal gilling.

Following these early installations, barrier nets began to be considered more often as means to reduce fish entrainment at water intakes. Nets were installed at several other cooling water intakes in the 1980's and at several hydro projects in the late 1980's and the 1990's. Nets have been installed at three cooling water intakes in the Great Lakes (CPC 1984, 1985; Oswald 1999; Patrick et al. 2014) and at an intake in Illinois (SCWLP 2004). Mesh sizes evaluated at these sites have ranged from 0.25 to 1.25-inch bar with approach velocities of about 0.5 ft/sec or less.

In 2009, a 600-m long barrier net was installed at the Pickering Nuclear Generating Station (PNGS) on the north shore of Lake Ontario. This initial installation was patterned after the LPSP net with regards to mesh size (0.5-inch mesh), flotation system, net "skirts," anchoring system and seasonal deployment (Patrick et al. 2014).The PNGS net has been effective in excluding clupeids (gizzard shad and alewife) and several other freshwater fishes (e.g., yellow perch, white crappie). An evaluation of the PNGS net performance used hydroacoustics, DIDSON imaging sonar, gill nets, and impingement collections from the station's traveling water screens to determine biological effectiveness. A reduction in intake screen impingement biomass was reported to be 98%. All of the data from hydroacoustic monitoring, gill netting, DIDSON imaging sonar, underwater video, and station impingement sampling have demonstrated that the fish diversion barrier net has been effective at preventing fish from entering the PNGS intake and becoming impinged. The prevalence of a schooling species (i.e., Alewife) in the gill-net collections and DIDSON sonar results supported the conclusion that Alewife comprised the majority of the integrated acoustic backscatter detected by the hydroaoustic system. The gill-netting results and underwater video observations supported the data collected by the hydroacoustic system, which showed more fish on the outside of the barrier net than on the inside. The significant reductions in fish biomass (greater than 80%) impinged at the intake following installation of the barrier also supported that the net is an effective technology for reducing impingement at PNGS (Patrick et al. 2014).

The first barrier net employed at a hydro project (other than at the LPSP) was a system installed in 1990 at the Pine Hydroelectric Project located in Wisconsin (SWES 1990; Plante et al. 1997; Michaud and Taft 1999). The Pine net is about 260 ft long with a maximum depth of 35 ft. The mesh size is 0.5-inch bar and approach velocities are less than 0.5 ft/sec. The effectiveness of the Pine net in excluding riverine fishes from turbine entrainment was evaluated during several years of study (SWES 1991; Plante et al. 1997; Michaud and Taft 1999). The results of these studies indicate the net has effectively reduced entrainment at this site. Following the success of the Pine installation, barrier nets have been installed at three other Midwestern hydroelectric projects. These include the Brule Project on the Brule River in Wisconsin, the Hayward Project on the Namekagon River in Wisconsin, and the Crystal Falls Project on the Paint River in Michigan. Although net effectiveness data from studies conducted at these sites are limited, the resource agencies have generally concluded that the nets appear to be effective at reducing entrainment of riverine fishes and, consequently, that they should remain in use for fish protection purposes. Additionally, gilling and impingement on nets at these sites have not been reported or listed as concerns.

5.2.10.4 Preliminary Screening Determination for Barrier Nets

Barrier nets of various configurations have been effectively applied at a wide range of water intakes (e.g., steam-electric, hydro, water diversions), including the LPSP installation. Site-specific designs have successfully been developed to address biological considerations (size and swimming abilities of target species and life stages), local debris and biofouling conditions, hydraulic conditions, and ability to be deployed seasonally or year round. Although the LPSP is currently the longest barrier net deployed at a hydro project, deeper nets have been installed at the Upper Baker River (over 350 ft deep) and Osage (over 100 ft deep) hydroelectric projects for diversion of salmonids and exclusion of freshwater fish species, respectively. Similar to the LPSP net, performance evaluations at both of these applications have met fish guidance and protection goals.

Based on the results of the annual evaluation of the LPSP net (see Section 3.2) and the successful applications at several steam generating stations and hydroelectric projects, this technology is considered an effective method for reducing entrainment of fish at LPSP. However, limitations of the current net design are that it does not effectively exclude ichthyoplankton or small juveniles (< 4 inches in length) and it cannot be deployed under the winter conditions (primarily icing) experienced at LPSP. Consideration should be given to alternative or modified net design parameters and configurations that may further reduce entrainment rates at LPSP.

The existing LPSP barrier net is installed from April 15 to October 15 and the current design meets the entrainment reduction standards of 80% for target game fish and 85% for target forage fish over five inches in length. Therefore, the barrier net has been carried forward to the detailed feasibility assessment.

5.2.11 Aquatic Filter Barrier (AFB)

The aquatic filter barrier is a relatively recent technology for the protection of all life stages of fish and other organisms at water intakes and is currently marketed by Mackworth-Enviro

Consultants, Inc. The AFB is a full-depth filter curtain consisting of polyester fiber strands that are pressed into a water-permeable fabric mat. For intake applications, two layers of this permeable fabric mat sandwich a coarse-mesh netting. This coarse-mesh netting adds structural integrity to the barrier fabric reducing tearing. An air backwash system sends a burst of air between the two filter layers to shake loose debris impinged on the surface of the AFB. This cleaning system is effective at removing loose debris, but is not effective at removing aquatic organisms and other biofouling agents (Henderson et. at. 2001).

In some cases, the AFB is perforated to increase flow rates. In addition to the small opening size, the AFB uses very low through-fabric velocities, 0.04 L/min/cm^2 (10 gpm/ft^2) to reduce entrainment. With such a low design flow rate, AFB installations at once-through cooling and hydroelectric operations tend to have a large surface area, to accommodate the large flows. Such large deployments can reduce both habitat and visual properties near the deployment location. AFB is a “soft” technology and should only be considered where large debris is not present. AFB would also be subject to icing concerns in northern climates. To date there has only been one large deployment of the AFB at a water intake.

5.2.11.1 LPSP 1988 Technology Assessment: Aquatic Filter Barriers

The AFB was not an available technology in 1988 when SWEC prepared the fish protection technology assessment for LPSP.

5.2.11.2 LPSP 5-Year Technology Updates: Aquatic Filter Barriers

The 2001 technology assessment update for LPSP (LMS 2001) included a review of AFB research conducted since the SWEC (1988) report was completed. Although the AFB was considered to be biologically effective, from an engineering perspective LMS considered AFB to not be feasible or practical for LPSP. LMS contacted the president of Gunderboom, Inc., the former firm marketing AFB, who confirmed their assessment. The 2006 technology update (ESP 2006) also included a review of available data on the AFB and drew similar conclusions to those in the 2001 technology review. That is, from an engineering perspective the AFB was not feasible or practical for consideration at LPSP. ESP (2011) eliminated the AFB as a technology that could be reasonably considered for application at the LPSP.

5.2.11.3 Updated Summary of Aquatic Filter Barrier Research and Applications

To date there has only been one large deployment of the AFB; an AFB was installed at the Lovett Generating Station (Lovett) on the Hudson River in New York in 1994. A subsequent 11-year evaluation of the engineering and biological performance of the AFB was conducted. Biological evaluations conducted between 1995 and 2001 compared the entrainment rates of a protected intake to that of an unprotected intake. Later biological evaluations conducted between 2004 and 2006 evaluated a full-scale AFB installation at Lovett with comparisons made between the inside (protected) and the outside (unprotected) of the AFB. Reductions in entrainment were as follows during the biological evaluation program: 82% reduction in 1995 with a pore size of 20 µm (0.02 mm) (LMS 1996), 76% reduction in 1998 with a pore size of 0.5 mm (though effectiveness decreased over time, presumably due to the integrity of the barrier), 74% reduction in 1999 and 2000 with a pore size of 0.5 mm (though effectiveness decreased over time as before due to system integrity) (LMS 2001), 73% reduction in 2004 with a pore size of 0.5 mm (ASA 2004), 92% reduction in 2005 with a pore size of 0.5 mm (ASA 2006a), and a 89% reduction in 2006 with a pore size of 0.5 mm (ASA 2006b). Given the extremely low through-mesh velocities, impingement was considered a non-issue. However, the AFB is no longer functional due to the retirement and razing of Lovett.

Also, a full-scale AFB was installed at the Bethlehem Energy Center (BEC) on the Hudson River just south of Albany in Bethlehem, NY. Due to physical constraints the AFB was designed to be deployed in a fixed-panel arrangement in front of the cooling water intake structure. The pore size was 0.4 mm and the designed through-fabric flow rate was less than 0.5 ft/sec. Shortly after installation, the fixed-panel deployment experienced significant failures most likely due to boat-generated waves associated with commercial shipping traffic. Under repetitive wave action, the fabric was alternately stressed inward contributing to fabric stretch and outward (due to backflow) onto the fabric support frames causing abrasion. Prolonged exposure to wave action was the likely cause of fabric failure. The AFB has since been removed from the BEC site.

Finally, an AFB is currently a component of the intake protection features at the Taunton River Desalination Plant (TRDP) in Dighton, MA. The AFB is deployed seasonally in the spring to protect migratory river herring eggs and larvae from IM&E at the plant's intake. The effectiveness of the AFB is monitored as a permit requirement, though no data were available for review at this time.

Pilot and laboratory-scale research has revealed that biofouling on the AFB can decrease the flow capacity of the system (Henderson et al. 2001), that impingement of early life stages of American shad on the AFB did not significantly impact survival (Radle 2001), that the AFB is best deployed where ambient sweeping currents are available to carry debris away from the barrier, and that neither flow rate nor pore size significantly impact survival; rather exclusion and survival are very species-specific (EPRI 2007).

5.2.11.4 Preliminary Screening Determination for Aquatic Filter Barriers

Aquatic filter barriers could effectively reduce entrainment of all species and life stages (including ichthyoplankton) at the LPSP given the small mesh size that is used with this technology. The design of the AFB installed at Lovett is similar in concept to the existing barrier net at LPSP; supported by floats and anchors. The AFB could be considered a type of barrier net with a small mesh opening and a low flow capacity. Therefore, the AFB has been considered for the feasibility assessment at LPSP.

5.3 Summary of Preliminary Screening of Entrainment Abatement Technologies

Based on the results of the technology assessments and the application of the criteria described in Section 5.1, the initial screening of entrainment abatement technologies identified four technologies with reasonable potential for effective application at the LPSP (Table 5-3). These included the use of ultrasonic sound and electrical deterrents in conjunction with the barrier net, the barrier net used as a standalone technology and AFB. The screening process was as objective as possible based on available and accessible data and information from peer-reviewed and gray literature. However, in assessing the potential for effective application under physical, hydraulic, and environmental conditions in which a technology may never have been applied previously, Alden relied on firsthand experience with a given technology and used best professional judgment to make a determination of applicability to LPSP. Alternatives failing to meet all the criteria were eliminated from further consideration.

Each technology was qualitatively assessed to identify whether it had biological and/or engineering advantages over the other alternatives and the existing barrier net. For example, an intake technology that has been proven effective at reducing losses for the species at LPSP and under a variety of intake conditions has a biological advantage over one that has been proven effective with a few species or under limited intake conditions. Technologies that have proven to be at least marginally effective for some of the species at LPSP are identified as having limited biological effectiveness. From an engineering perspective, a technology is considered commercially available if it has been installed and in use on a permanent basis for multiple years and has shown to satisfactorily perform its intended function and has not resulted in significant adverse impact to the environment or plant operation. One technology may hold an advantage over another if the civil/structural and operation and maintenance requirements for its installation are substantially less. The results of the preliminary screening are summarized in Table 5-3.

Table 5-3: Summary of preliminary screening of entrainment abatement technologies.

Technology	Proven Biological Effectiveness	Commercially Available Alternative	Advantages Over The Existing Barrier Net	Potential for Application at LPSP	Applicability Rational
Behavioral Deterrents					
Sound (infrasonic, sonic, and ultrasonic)	**LIMITED**	**YES**	**NO**	**YES**	**Effective application limited to the use of ultrasound for repelling alewife. Potential to augment barrier net performance.**
Light (strobe, continuous)	LIMITED	YES	NO	NO	Low to moderate effectiveness with a limited number of species at LPSP.
Chemicals	NO	YES	NO	NO	Unknown efficacy with species at LPSP. Continuous dosing needed to provide a sustained barrier. No existing design for a full-scale application at water intakes.
Electrical barriers	**LIMITED**	**YES**	**NO**	**YES**	**Effective with wide array of species as a barrier to upstream movement in rivers, canals and tailraces; limited data demonstrating effectiveness at intakes. Potential to augment barrier net performance.**
Air bubble curtain	NO	YES	NO	NO	Not an effective technology when used alone.
Water jet curtain (current inducers; FVES™)	LIMITED	YES	NO	NO	Unknown efficacy for most species at LPSP. Engineering uncertainty for size and flow of LPSP.
Hanging chains	NO	YES	NO	NO	Not proven to be biologically effective in field applications.
Visual cues	NO	YES	NO	NO	Not proven to be biologically effective in field applications.

Table 5-3 (Continued)

Technology	Proven Biological Effectiveness	Commercially Available Alternative	Advantages Over The Existing Barrier Net	Potential for Application at LPSP	Applicability Rational
Behavioral Deterrents (continued)					
Multi-technology behavioral system	LIMITED	YES	NO	NO	Only effective on a limited number of species present at LPSP.
Physical Barriers					
Barrier net	**YES**	**YES**	**YES**	**YES**	**Monitoring data indicate existing barrier net meets established effectiveness criteria for target species. Design modifications or use in combination of other technologies may have potential to enhance existing performance.**
Aquatic filter barrier (Gunderboom)	**YES**	**YES**	**NO**	**YES**	**Effectively reduced entrainment of smaller life stages at a cooling water intake, yet at much lower flows than LPSP. Considered for feasibility assessment at LPSP.**

6 Feasibility Assessment of Selected Alternatives

The results of the preliminary screening identified four entrainment abatement technologies for potential application at LPSP; barrier nets, sound barriers, electric barriers, and aquatic filter barriers. These technologies have demonstrated the ability to reduce entrainment and are available for use at LPSP. Preliminary conceptual designs were prepared for the four technologies based on additional site and technology-specific criteria. These conceptual designed were used to identify any size or permitting constraints that may reduce the feasibility of a technology. Four conceptual designs utilizing the existing barrier net and two that would replace the net were evaluated, resulting in six total alternatives;

- Alternative 1 – Existing Barrier Net
- Alternative 2 – Potential Modifications to the Existing Barrier Net
- Alternative 3 – Longer Barrier Net with ½-inch Bar Mesh
- Alternative 4 – Existing Barrier Net with a Full-Scale Ultrasonic Deterrent System
- Alternative 5 – Existing Barrier Net with an Electrical Barrier
- Alternative 6 – Aquatic Filter Barrier

The conceptual designs were then subjected to a more detailed secondary screening to identify the biological and engineering advantages and disadvantages of each concept. A short description of each alternative and their justification for elimination or further evaluation is presented below.

The technology screening criteria used for the secondary screening takes into account site-specific factors such as station arrangement, local hydrology and meteorology. These factors are similar to what was used in the 1988 evaluation (SWEC 1988), except that the pumping and generating flows have been increased to reflect the replacement of the Hitachi turbines with new Toshiba turbines. The flows used in the 1988 evaluation and the updated flows are presented in Table 6-1.

Table 6-1 Summary of LPSP Flows

	1988 Evaluation			**2011 Evaluation**	
	Pumping	**Generating**		**Pumping**	**Generating**
Per Unit	11,700 cfs	12,667 cfs		14,016 cfs	14,945 cfs
All 6 Units	70,200 cfs	76,000 cfs		84,096 cfs	89,670 cfs

6.1 Alternative 1 – Existing Barrier Net

The existing barrier net has demonstrated the ability to reduce entrainment of target species by 91% (ESP 2011) when deployed, and is currently considered the best available technology to reduce entrainment at LPSP. Net modifications or other entrainment abatement technologies in combination with the existing barrier net may result in a greater reduction in entrainment and are considered as separate alternatives. The existing barrier net is included in the feasibility assessment to provide a baseline for comparison to all other potential entrainment reducing technologies.

6.2 Alternative 2 – Potential Modifications to the Existing Barrier Net

LPSP is currently upgrading the station units which will increase both generating and pumping flows. This increase in flow has potential to increase the frequency of barrier net submergence events (Alden 2011). Although submergence of the barrier net has not been correlated to a reduction in barrier net effectiveness for the original units, the submergence does represent a breach in barrier net integrity. Barrier net effectiveness will continue to be monitored as the units are upgraded.

Observations of barrier net submergence (Table 4-3) indicate these events can occur during pumping, generating, and when the plant is not operational (no pumping or generation). Submergence occurs most frequently at the northwest and southwest corners of the net due to relatively high velocities impacting the net at those locations especially during generation. In addition, the data indicate that the number of net panels that submerge generally increases as generating flows increase (Figure 4-5). Modifications to the barrier net could reduce the occurrence of submergence events, which create an opportunity for fish to swim over the net and become exposed to turbine entrainment. Such modifications could be considered as part of an adaptive management plan if it is demonstrated that an increase in barrier net submergence events resulting from the unit upgrades leads to a decrease in barrier net effectiveness.

Several modifications could be made to the existing barrier net to reduce submergence or to reduce potential for fish entrainment in identified areas of concern. The following measures could be considered incrementally as part of an adaptive management program:

- increase net buoyancy;
- increase the number of bottom seal anchors;
- increase the width of top and bottom skirts;
- reduce bio-growth with more frequent cleanings or an ultrasonic antifouling system;
- installation of flow dissipaters carefully designed to reduce velocity of flow impacting net in the southwest and northwest corners during generation;
- ensonification of the barrier net with ultrasound in targeted areas of concern to repel alewife (most abundant species); and
- reconfiguration of the near shore net panels.

Modifications to the current net design (first three bullets) could be made to the panels that currently submerge and can be expanded to include other panels as necessary. Increasing floatation at the top line of the net and the top skirt would increase the force required to submerge the net. The width of the top skirt could be increased (i.e., the net would have to submerge to a greater depth before any flow could pass over a longer top skirt). The bottom skirt could also be modified to maintain a better seal with the lake bottom under these conditions.

Seasonal algal growth appears to contribute to the probability of submergence events (Alden 2011). Reducing bio-growth on the net may, therefore, reduce net submergence. An ultrasonic antifouling system has demonstrated the ability to reduce biofouling at aquaculture net pens and may have potential to reduce biofouling of the LPSP net. In addition, more frequent manual barrier net cleaning (high-pressure water spraying) using procedures currently in place could be implemented to reduce bio-growth and accumulation on the net. Permitting for the above net modifications, including the ultrasonic antifouling system is not expected to be an issue.

Another method to reduce net submergence during generation would be to reduce the velocity of the flow impacting the net. This could be done by installing obstructions within the flow path, thereby deflecting the flow to a wider area prior to impacting the net. A matrix of baffles or piles could be installed within the flow path between the ends of the breakwater and the two corners of the net, shown as the green/yellow area on Figure 4-6 and Figure 4-7. Implementation of this option may not have advantages over other previously discussed methods to reduce barrier net submergence, and should only be considered after implementation of more direct methods of improving top and bottom net seal, assuming increased net submergence leads to a decrease in barrier net effectiveness.

An ultrasonic deterrent system that targets alewife (most abundant species at LPSP and only one in the vicinity of the project that can hear ultrasonic frequencies) could be considered with a focus on those areas of the net with a higher potential risk of fish entrainment, such as the northwest and southwest corners (due to submergence) and the near shore areas where smaller fish may be more abundant. Again, the more direct methods to improve the net seal in the high flow areas are preferred as these would be effective for all species. The barrier net panels in the near shore zone are currently more protective of smaller fish; however, the ½- inch bar mesh is often bio-fouled because of the smaller opening. Ensonification of the near shore areas would require careful design of support structures to withstand the near shore surf and icing conditions for components that are not removable for the winter.

The existing barrier net meets the northern shoreline at a slight acute angle and it meets the southern shoreline at a near perpendicular angle. Smaller fish tend to move along shore and the angle at which the net meets with the shoreline may temporarily block their movement and may result in a temporary increase in abundance at these locations and/or influence small fish to pass through the net. Reconfiguring these areas of the net, as shown on Figure 6-1, may result in better guidance around the net as fish move along shore. This new layout may reduce the potential for the concentration of smaller fish near the net at the shoreline and may thereby reduce the risk of entrainment. There are no data that indicate an increase in abundance of fish in these areas and no evidence to suggest such a new configuration will improve barrier net effectiveness. This new configuration on the north shore would enclose residential lake front property within the barrier net enclosure and would terminate on private property. Shoreline conditions vary with depth, and currently these new termination points are very steep, not easily accessible, and present challenges in sealing the net to shoreline. There is uncertainty whether this configuration is feasible given the shoreline topography, potential residential property issues, recreational impediments and added safety concerns. Therefore, this modification was not considered further due to the uncertainties of the benefit and challenges of implementation.

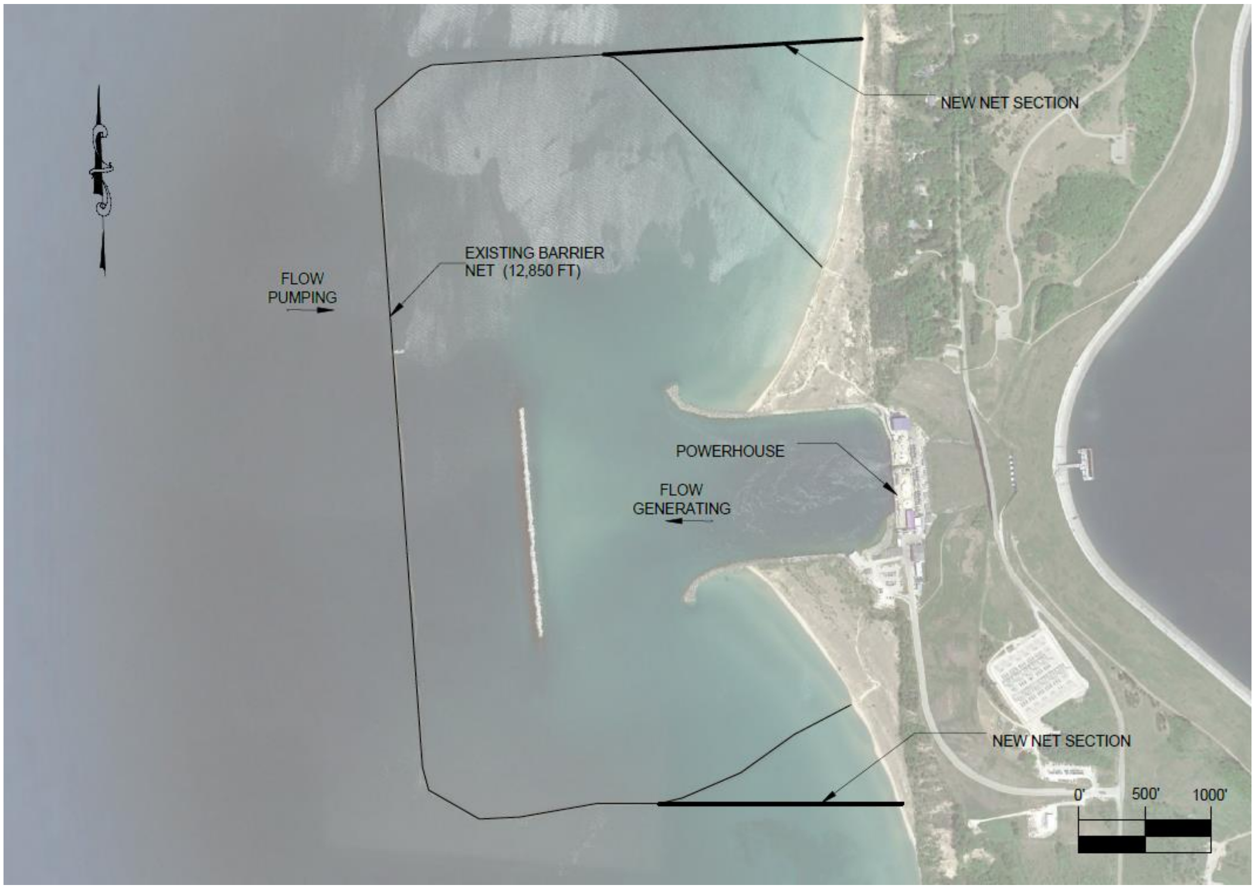


Figure 6-1: Alternate configuration for the existing barrier net

Summary: Several modifications to improve the existing barrier net were examined for potential efficacy and technical feasibility. If the existing barrier net effectiveness decreases as the plant upgrades are implemented, it may be that higher flow rate-induced submergence and possible lifting of the net bottom is compromising barrier net integrity. Modifications to the net could then be implemented as part of an adaptive management plan. We recommend the following incremental steps, as required:

- increase net buoyancy;
- increase the width of top and bottom skirts;
- increase the number of bottom seal anchors; and

- reduce bio-growth with more frequent cleanings or use of an ultrasonic antifouling system.

These measures have potential to improve the biological effectiveness of the existing barrier net by reducing potential for fish to bypass the net during submergence events that occur primarily during generation. Given that the potential exists for reduced barrier net effectiveness as the plant is upgraded, this alternative was selected for further evaluation.

Examinations of other modifications were less desirable or inconclusive with questionable benefits and significant technical challenges.

6.3 Alternative 3 – Longer Barrier Net with ½-inch Bar Mesh

A new barrier net configuration with a smaller mesh (1/2-inch bar) could be installed to provide greater protection for smaller fish (< 4 inches in length). A finer net mesh is heavier and has less open area than the existing net which results in higher drag forces acting on the net; therefore, a longer net with greater surface area is needed. A longer net, offset approximately 1000 feet from the existing net, would provide greater net area and locate the net in a lower velocity zone.

One possible configuration for this larger net is shown in Figure 6-2. The along shore movement of fish would be guided out and around the net with the shoreline net termination points at these locations. However, as discussed for Alternative 2, the shoreline conditions at these locations are very steep, not easily accessible, and present challenges in sealing the net to the shoreline. These challenges are exacerbated by the surf action at these shoreline locations. In addition, this configuration would enclose residential lake front property within the barrier net enclosure and would terminate on private property. There is uncertainty whether this configuration is feasible given the shoreline topography, potential residential property issues, recreational impediments and added safety concerns. Therefore, a similar configuration has been developed for consideration which locates the shoreline net termination points at the same locations as the existing net. This configuration (B) is shown in Figure 6-3.

Summary: This alternative has potential to provide greater protection of smaller fish (< 4 inches in length) than the existing barrier net. Configuration A would likely offer potentially greater guidance of fish around the net in either the southerly or northerly directions than Configuration B. However, there is no information or data that would indicate which option would provide greater potential for improving barrier net effectiveness. Configuration B eliminates the concerns regarding the shoreline attachment point of the net and property issues. Both configurations may pose a hazard to navigation and would require a Bottomland Conveyance permit. These may be formidable hurdles with regards to regulatory approval, but they are not considered to be insurmountable. Due to the uncertainties regarding the shoreline attachment points with Configuration A, Configuration B has been considered for further evaluation.

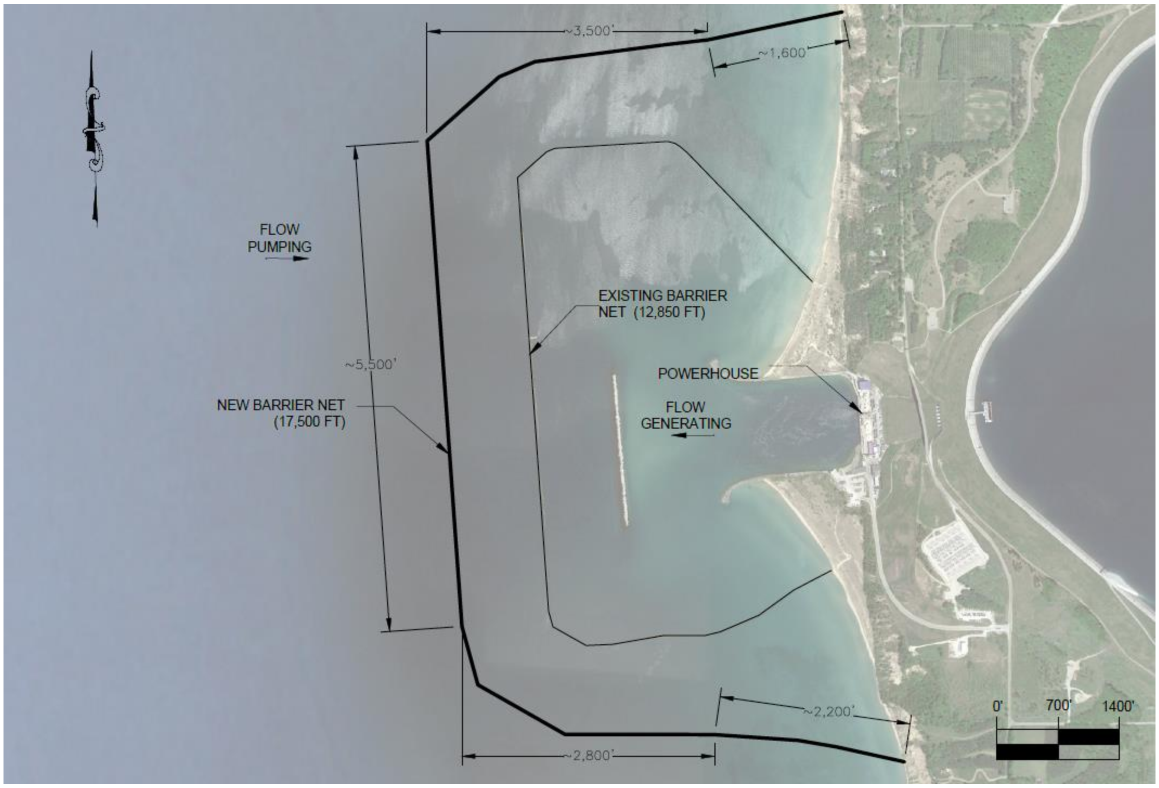


Figure 6-2: Longer barrier net configuration A

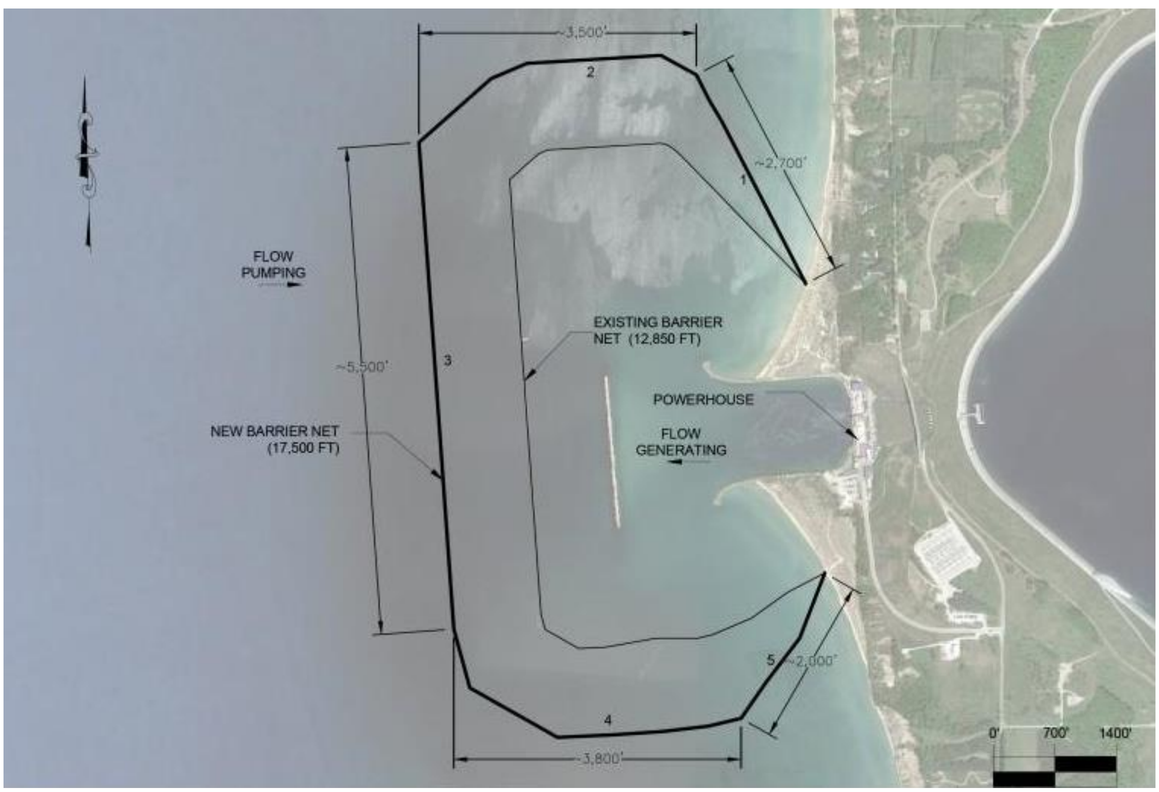


Figure 6-3: Longer barrier net configuration B

6.4 Alternative 4 – Existing Barrier Net with a Full-Scale Ultrasonic Deterrent System

A full-scale ultrasonic deterrent located adjacent to the existing barrier net could be used to ensonify the entire barrier net and repel alewife from approaching the barrier net. This could further reduce entrainment of juvenile alewife that the existing net may not physically exclude. However, an ultrasonic barrier of this size or one used in conjunction with a barrier has not been tested or installed.

Transducer arrays would be attached to a series of submerged piles placed inside the net. A single transducer array placed at approximately mid-depth would create a full depth sound field along the entire length of the net.

Underwater transmission cables would be buried in the lake bottom between LPSP and the transducers. The power supplies, distribution panels, amplifiers and controllers for the sound transducers would be located in buildings to be erected on the shoreline. Power to the control building would be obtained from the existing station service system. Operation of the ultrasonic barrier would be continuous when the barrier net is installed. The ultrasonic barrier would be removed during the winter; a period when alewife are not present in significant numbers.

All the equipment needed to support and operate the ultrasonic barrier would be located within the area enclosed by the existing net. This would not impact navigation and other water users in the area and should have a straight-forward permitting process.

The addition of the ultrasonic barrier would increase the overall O&M associated with the net. Power would be needed to operate the barrier (the amount of power required is a function on the number of transducers needed) which is expected to be in the kilowatt range. The ultrasonic signal is outside of the hearing range of humans; therefore, divers used to maintain the net would not be impacted by the sound field. Other than visual inspection of the transducers, divers are not expected to be needed to maintain the transducers once they are installed for the season.

Summary: This alternative would only be effective at reducing entrainment of juvenile and adult alewife which make up the majority or entrainment. An ultrasonic barrier of this scale and used in conjunction with a barrier net has not been tested or installed; therefore, there are uncertainties in the ability to successfully operate and maintain the barrier. However, this option is carried forward because of the potential to further reduce alewife entrainment.

6.5 Alternative 5 – Existing Barrier Net with an Electrical Barrier

An electric barrier could be added to the existing barrier net to deter motile fish and life stages from the barrier net. It is anticipated that as fish swim into the electrical field they will feel increasing discomfort and voluntarily change directions. The strength of the electric field would vary depending on whether LPSP is pumping, generating, or on standby.

Two rows of vertical electrodes, one anode and one cathode, would create a full depth electrical field along the entire length of the barrier net. Each electrode would be anchored to the lake bottom and suspended with floats. Underwater transmission cables would be routed between LPSP and the electric barrier. The equipment needed to support and operate the electric barrier would be located adjacent to the existing net. Ancillary equipment needed to operate the electric barrier would be located in buildings to be erected onshore.

There is limited data available on the effectiveness of electric barrier when the flow is directed towards the barrier, as would be the case during pumping at LPSP and the near shore regions during generation. The velocities towards the net during pumping are generally low and should not prevent fish from swimming away from the electric barrier. When generating, the flow across most of the barrier net is towards the lake. Under these conditions fish would be swimming against the flow, which is similar to proven electric barrier applications. While this option has potential to reduce entrainment of all the species at LPSP, there are no known installations of an electric barrier with a similar scale or arrangement as would be required at LPSP. An electric barrier would not result in a reduction in entrainment of ichthyoplankton and non-motile life stages.

The addition of an electric barrier would increase the overall O&M associated with the net. Power would be needed to operate the electric barrier (the amount of power required is a function on the voltage gradient needed) which is expected to be in the kilowatt range.

However, a drawback to electric barriers is that they work by creating an electric current in the water column that has the potential to harm humans. Signage and possibly an exclusion barrier would be needed to prevent interaction with lake users. Worker safety would also be an issue and would require the electric barrier to be deactivated when divers are working in the vicinity of the net. Permitting the electric barrier may be difficult due to worker and public safety concerns. However, an electric barrier is currently being used in the Chicago Sanitary Ship Canal; therefore, Alden expects that an electric barrier could be permitted at LPSP.

Summary: An electric deterrent could reduce the risk of fish bypassing the existing barrier net. An electric deterrent applied to the entire net may increase effectiveness for small fish that are capable of passing through the existing mesh. However, an electric system designed for small fish would not be effective with larger fish. Also, ichthyoplankton are unlikely to have the ability to avoid an electric field and may suffer damage. An electric deterrent designed for the full depth and length of the barrier net as means to reduce entrainment of smaller fish is not a currently available technology (i.e., significant research and development effort would be required to re-design existing electric deterrent technologies for an application of this size or to configure them for use with a barrier net). For these reasons, electrical deterrents are not considered for further evaluation as a technology that has potential for successful application at LPSP.

6.6 Alternative 6 – Aquatic Filter Barrier

Similar to the existing barrier net, an AFB could be installed as a physical barrier at the LPSP. However, unlike the barrier net, an AFB would also prevent entrainment of fish eggs and larvae and early juveniles. The design flow through an AFB is typically 10 gpm/ft^2, which results in an approach velocity of about 0.02 ft/sec. This low velocity combined with the AFB material could make AFB installed at the LPSP prone to biofouling. Approximately 40,247,000 ft^2 of AFB would be required to pass the maximum generating flow of 89,670 cfs. Assuming a 50 ft average depth, an AFB installed at LPSP would be over 15 miles long. An AFB of this size has never been installed and it is uncertain if the technology vendor (Mackworth-Enviro Consultants, Inc.) can provide a system of this size. Based on the biofouling potential and level of cleaning needed for the existing net, there are uncertainties whether such a large deployment could be safely and effectively maintained. The AFB would have a large visual impact as well and may significantly reduce access to Ludington Harbor and other shoreline areas within its length. The impact on navigation caused by an AFB is expected to make permitting an installation highly unlikely. Based on the required size of an AFB, the anticipated bio-fouling and debris issues, the visual, navigation and recreational impacts, and permitting issues, an AFB option was not considered for further evaluation.

6.7 Alternatives Selected for Detailed Evaluation

The feasibility level screening of entrainment abatement alternatives compared the biological and engineering advantages and disadvantages of each of the six alternatives selected from the initial screening (Section 5) to each other and to the existing barrier net. The feasibility level screening was used to determine which alternatives would be the most practical to construct and have the greatest potential protecting fish from entrainment at LPSP. The advantages and disadvantages of each of the six alternatives assessed as part of the feasibility level screening are provided in Table 6-2.

Table 6-2: Advantages and disadvantages of potential entrainment abatement alternatives.

Alternative	Advantages	Disadvantages	Selected for Detailed Evaluation
Alternative 1 – Existing Barrier Net	• Does not require modifications to the net or current O&M practices • Currently meets established effectiveness criteria for target species	• Does not protect smaller organisms • Does not provide year round protection	Yes • Baseline for other alternatives
Alternative 2 – Potential Modifications to the Existing Barrier Net	• Increases integrity of the existing net • Potential reduction in O&M	• Does not protect smaller organisms • Does not provide year round protection	Yes • Increased net integrity with the same footprint • Reduced submergence
Alternative 3 – Longer Barrier Net with 1/2-inch Bar Mesh over Entire Net Length	• Increased exclusion of smaller fish (less than 4 inches in length)	• New net anchors • Increased O&M • Greater visual impact • Greater navigational hazard • Does not provide year round protection	Yes • Excludes smaller organisms
Alternative 4 – Existing Barrier Net with a Full-Scale Ultrasonic Deterrent System (ensonification of entire net length)	• Does not require modifications to the existing net or current O&M practices • Increased exclusion of juvenile and adult alewife over entire net length	• Only enhances exclusion effectiveness for alewife • Does not provide year round protection • No existing installations of comparable scale • Requires installation of permanent support structures • Requires power to operate • Increased O&M	Yes • Alewife are the dominant fish found within the barrier net

Table 6-2 (Continued)

Alternative	Advantages	Disadvantages	Selected for Detailed Evaluation
Alternative 5 – Existing Barrier Net with an Electrical Barrier	• Potential for increased exclusion of smaller fish	• No existing installation of comparable scale • Unknown effect on range of fish sizes present • Requires installation of permanent anchoring system • Requires power to operate • Worker and public safety concerns • Does not provide year round protection • Increased O&M	No • May not be effective on wide range of fish sizes • Not proven to repel fish when flow is directed towards an intake
Alternative 6 – Aquatic Filter Barrier	• Reduces entrainment of ichthyoplankton and smaller fish (less than 4 inches in length)	• Approximately 15 mile length required to meet AFB flow rate design specifications • Potential navigation hazard • Impacts to recreation and shoreline access and use • Substantial cleaning effort required • Does not provide year round protection • No existing installation of comparable scale	No • Extreme navigation hazard • Permitting issues

Based on the conclusions from the second level screening, the following four alternatives were selected for detailed evaluation of feasibility for application at LPSP:

- Alternative 1 – Existing barrier net;
- Alternative 2 – Potential modifications to the existing barrier net;
- Alternative 3 – A longer barrier net with 1/2-inch bar mesh; and
- Alternative 4 – The existing barrier net with a full-scale ultrasonic deterrent system (i.e., ensonification of entire net length and depth).

These four options all include the continued use of a barrier net to physically exclude a large proportion of fish that could potentially enter the intake area where they would be at risk for entrainment. The existing barrier net option is intended to maintain the status quo. The other three alternatives (ultrasonic deterrent system used with the barrier net, modifications to the existing net, and installation of a longer barrier net with 1/2-inch bar mesh) are all designed to increase the level of protection offered by the existing net.

The existing barrier net was selected because it has been proven to be biologically effective and would not require any changes to the net support system or current O&M procedures.

Modifications to the existing barrier net are expected to improve the integrity of the net. This alternative also has engineering advantages over the addition of an ultrasonic system or a longer net because it does not require the installation of any new permanent structures, does not require power to operate, and will require a similar level of O&M as the existing barrier net.

A longer barrier net would better distribute the flow passing through the net and, therefore, is expected to be more biologically effective than the existing net. Use of 1/2-inch bar mesh over the entire length of a longer net would also provide greater protection to smaller fish (< 4 inches). However, this option would require new anchors and an increase in O&M.

An ultrasonic deterrent system along the full length of the existing net would further reduce the entrainment of juvenile and adult alewife, which is currently the most abundant species, but would require new anchors and power to operate the deterrent. None of the selected alternatives could be deployed year round or would provide protection for ichthyoplankton.

7 Detailed Evaluation of Selected Alternatives

This section presents detailed feasibility evaluations of the four technology alternatives previously selected as having the greatest potential for being applied at the LPSP for effectively reducing fish entrainment. In addition to biological performance expectations, the selected technologies are also considered to have engineering, design, and/or O&M advantages over other alternatives that were screened in Sections 5 and 6.

7.1 Existing Barrier Net

7.1.1 Design

Under the current FERC Settlement Agreement, the LPSP barrier net is required to be deployed annually from April 15 through October 15 to reduce entrainment of Lake Michigan fishes during pumping operations. The barrier net encompasses the LPSP intake/powerhouse area including the jetties and offshore breakwater. The net is constructed with 62 individual panels with a total length of 12,850 ft (see Figure 4-2). Net panels 1-5 and 58-62 have netting with 1/2-inch bar openings and panels 6-57, have 3/4-inch bar mesh. Each panel, with exception of panels 1 and 62 (which are located wholly on shore and are not in the water) includes a top skirt with top skirt float lines, top skirt floats, and a bottom skirt with weights and weight lines. All of the panels include lead lines, top and bottom border line, end border line, riser line, main net float line, and main net floats. Permanent anchor pilings are placed approximately every 100 ft along the net to secure the net to the lake bed. Additional details on the net design and construction are provided in Section 3.

7.1.2 Annual Installation and Removal

The LPSP barrier net is installed by April 15 and removed after October 15. Weather conditions prevent the use of the barrier net during winter months. The general process for installing the barrier net has remained the same since 1991. Net panels are constructed off-site and joined in lengths that fit on semi-trailers for transportation to a staging area. The panels are then transferred to barges for installation, where major subsections of the net panels are sewn and shackled together. Prior to installing the net panels the anchor locations are located and cleared; the anchor chains or the anchors may become buried during the winter requiring divers to free them.

Installation of the barrier net typically takes approximately three to four days depending on weather. During barrier net installation in the high flow velocity areas (i.e., corners near where flow passes between the jetties and breakwater) plant generation is limited to two units (except in case of an emergency). Lighted and spar navigational buoys are also deployed when the barrier net is installed each year.

Removal of the barrier net in the fall of each year also takes approximately three to four days depending on weather. Once removed, the barrier net panels are cleaned onshore using a high-pressure spray. The net panels are inspected after cleaning and stored in individual boxes at a

CEC warehouse in Ludington. Repair or replacement of barrier net panels takes place during the winter months.

7.1.3 Operation and Maintenance (O&M)

Cleaning of the net is a continuous operation. Individual net panels are cleaned in place using divers with modified, pressure washing units. Typically, each panel is cleaned once per month; however, panels which are in the direct discharge path may be cleaned twice per month. The most common type of debris on the net is algae (Cladophora spp.); however, Dreissenid mussels (zebra and quagga) also foul the net at times. Visual observations of the net to monitor submergence of net panels are made on a daily basis. A more detailed description of O&M is provided in Section 4.3.

7.1.4 Operational Impacts

Maintaining the existing barrier net does not result in any physical changes to the LPSP intake/powerhouse area. During installation and removal of the net only two LPSP units are operated, when divers are working near the high velocity areas of the net. Annually, this is expected to result in LPSP operating at reduced load for two days.

7.1.5 Expected Biological Efficacy

The biological efficacy of the existing barrier net is discussed in detail in Section 4.5. The efficacy of the net meets the standards set in the FERC Settlement Agreement (80% for game fish and 85% for forage fish over five inches in length). Mean annual barrier net effectiveness for all species combined (target and non-target) for the years of 1993 to 2014 was 86.7%, and 83.8% and 94.5% for all game fish and forage fish respectively.

7.1.6 Uncertainty and Risks

Submergence of the barrier net can occur during generation and may allow some fish to pass over the net and be subject to entrainment during pumping operations. Factors that influence submergence and expected changes in flow velocities and drag forces on the net as a result of the ongoing unit upgrades were evaluated in 2011 (Alden 2011). This study indicated that the number of units operating/flow and debris loading are important factors influencing the occurrence of submergence events and that the frequency of submergence may increase as a result of the unit upgrades (i.e., greater flow rates during generation and pumping). Although submergence may provide an opportunity for fish to pass over the net, there are no data indicating submergence events impact the barrier net effectiveness. Salmonids that are near the surface would be the most at risk during generation submergence events as they may be attracted to the flow and many of them would have sufficient swimming capabilities needed to negotiate the relatively high velocities passing over submerged net sections.

Barrier net bottom skirts lifting under high flow conditions have been observed by divers, but this has been rare and has generally resulted in placement of a new anchor.

7.2 Potential Modifications to the Existing Barrier Net

Modifications to the exiting barrier net could be implemented to improve the barrier net integrity and reduce submergence events, if a reduction in barrier net effectiveness is observed with the upgraded station unit flow. These modifications could be implemented incrementally, based on effectiveness data, as part of an adaptive management plan.

The CFD hydraulic model of the existing and upgraded flows for the LPSP intake/powerhouse area indicate a maximum velocity approaching the existing barrier net of 0.6 ft/sec during pumping operations with the net in a 50% clogged condition (Alden 2011). The CFD also shows two relatively high velocity jets during generation, one in the northwest corner of the net and the other in the southwest corner (Figure 4-7). The maximum velocity passing through the net with the existing units and six units generating is 4.0 ft/sec. These high velocities have resulted in net panels near the corners of the net to submerge during periods of full generation. As identified by Alden (2011), net panels 11 through 17 and 36 through 47 are most likely to submerge during submergence events (Figure 4-4). Under upgraded unit operation the velocities at these locations may increase to 5.4 ft/sec, exacerbating net submergence. The relatively high velocity jets passing over the net in these locations should prevent many fish from swimming over the net. However, if adjacent panels are also submerged the velocities may not be high enough to restrict fish from moving over the submerged net.

7.2.1 Design

Modifications to the barrier net are focused on increasing the overall integrity of the net by reducing net submergence during generation in the areas identified in Figure 4-4. If submergence of panels outside of this area becomes an issue, the net modifications could be applied to additional panels. The recommended modifications to the existing barrier net include:

- Additional floatation
- New net materials
- Increased width of the top skirt
- Changes to the bottom skirt and anchors
- Increased cleaning frequency

High velocities at the net along with debris loading increase the drag on the net and result in greater potential for submergence. The existing floatation located in the high velocity zones has a positive buoyancy of approximately 21.2 pounds per foot (lbs/ft). However, this is not sufficient to prevent submergence. The estimated buoyancy needed to prevent submergence under different levels of slack in the net and debris loading conditions under the upgraded flow conditions were estimated using the results of the CFD analysis (Table 7-1; Alden 2011). Up to 28.9 lbs/ft of buoyancy is needed to prevent submergence when the net is 50% clogged with debris and biofouling. Based on these results, increasing the flotation of the main net to 30 lbs/ft should reduce submergence during generation. However, this is not expected to eliminate all submergence events because diver inspections report up to 80% of the net could be plugged with debris and biofouling. For this analysis, increasing the buoyancy to 30 lb/ft was considered. The Alden (2011) evaluation would need to be expanded to include an 80% plugged scenario to determine the level of floatation needed to prevent submergence under this higher debris load.

Table 7-1: Estimation of required buoyancy assuming maximum CFD pressure values (upgraded flow conditions)

Net slack condition	Buoyancy Required (lbs/ft)	
	0% Debris	50% Debris
A (max slack)	7.0	15.8
B	7.2	16.2
C	8.4	18.6
D (min slack, taut net)	13.3	28.9

New net panels with lighter net materials in conjunction with strengthened framing and structural components could be used to increase the open area of the net. With an increased open area the drag forces on the net would decrease when the net is clean and may lessen the effects of debris and biofouling. Stronger net framing and structural components would need to be paired with this option to better transfer stress from the net material to the support system, reducing the probability of net failure.

Top skirt modifications also have potential to reduce submergence. The northwest and southwest corners of the existing barrier net have a 20 ft wide top skirt made of polyethylene netting. Increasing the top skirt width by 10 ft would increase the screening area of the top skirt by 50%, when submerged. UCC indicated that the top 2 to 3 ft of the net typically remains clean as a result of wave action. This wave action may also reduce biofouling of the top skirt. The existing top skirt has 3.2 lbs/ft of buoyancy, which is insufficient to prevent submergence. Additional floatation added to the top skirt would reduce submergence. For this analysis, new floats with 30 lbs/ft of buoyancy were assumed, the same as the upgraded buoyancy on the main net. The areas with the modified top and bottom skirt and additional floatation are identified in Figure 7-1.

UCC also indicated that the bottom 2 to 3 ft of the net typically remains clean as a result of dragging on the lake bed. This provides another opportunity to increase the effective net area during submergence events. Redesigning the bottom chains to allow the top of the bottom skirt to lift as the main net plugs would further increase the effective net area. A secondary 10-ft wide bottom skirt attached to the existing bottom skirt would be added to maintain a good bottom seal. Reducing the spacing of the fixed pile anchors to every 50 ft (currently at 100 ft spacing) and adding a fixed anchor chain between the anchors would help maintain the bottom seal when the bottom skirt is lifted. The additional fixed pile anchors and chains would also distribute the force of the additional flotation, reducing the chance of failure. As part of the bottom skirt modifications a new bathymetric survey of the net deployment area should be conducted. This study would identify areas where the bathymetry has changed since the initial barrier net deployment. The updated bathymetry will allow the net panels and bottom skirt modifications to be tailored to fit their deployment location.

Recently, an ultrasonic antifouling system manufactured by ASM International has demonstrated the ability to prevent bio-growth on nets used in aquaculture (ASM 2014). The ASM ultrasound system has been deployed in fresh, brackish, and saltwater environments and has demonstrated an ability to reduce Cladophora growth, the main source of biofouling on the LPSP barrier net. This system will however be ineffective at preventing fouling of the net from large drifting mats of Cladophora that are commonly encountered during the summer at the LPSP site. These systems work by projecting an ultrasonic signal on a section of net. Based on information from the manufacturer, these systems are effective at a range of 60-100 meters (200-328 ft) and had a projection angle of 70°. For the LPSP net, approximately 30 ultrasonic transducers located 150 ft from the net and spaced every 200 ft would be needed to reduce biofouling of the northwest and southwest corners of the net (Figure 7-1). Similar to that which would be required for the ultrasonic deterrent system described in Section 7.4, fixed-piles, power cables, and a control system would be needed for an ultrasonic antifouling system to reduce biofouling. A cross-sectional view of the anti-biofouling sound transducer showing the support piles along with the effective sound field is provided in Figure 7-2.

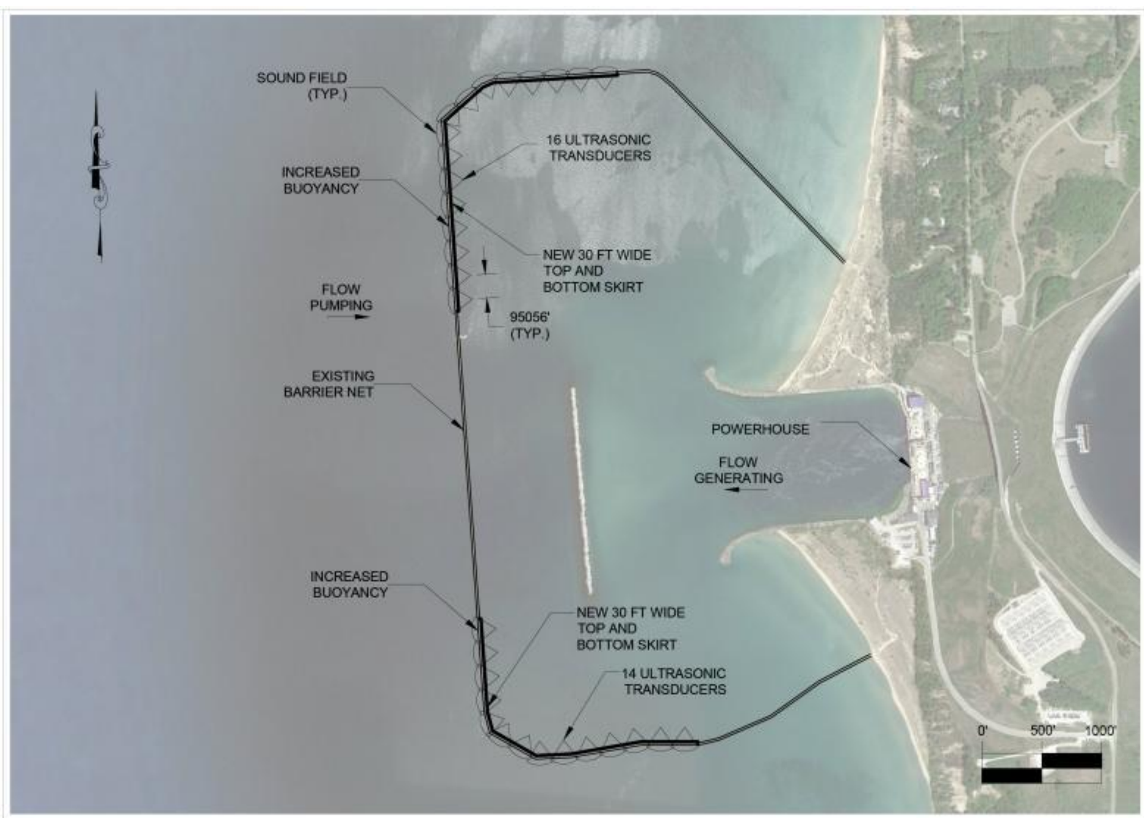


Figure 7-1: Modified Barrier Net with Ultrasonic Anti-fouling Transducers – Plan

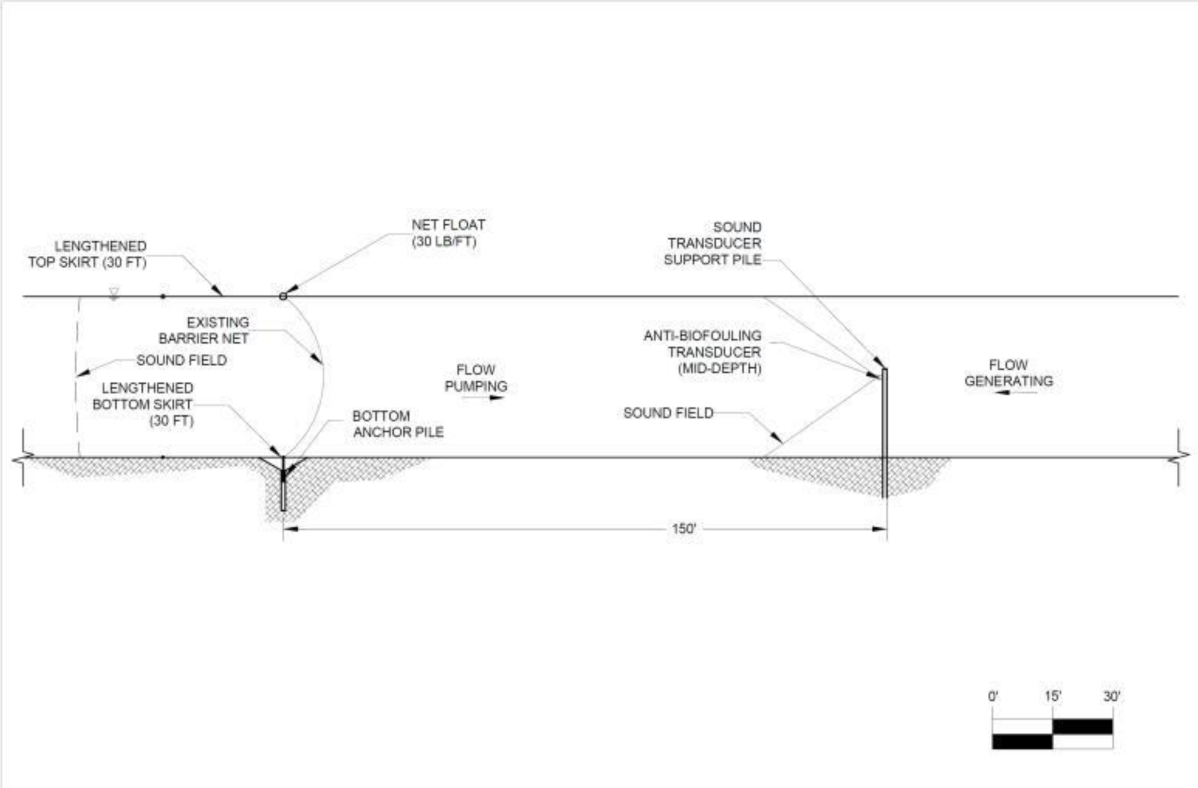


Figure 7-2: Modified Barrier Net with Ultrasonic Anti-biofouling Transducers – Section

7.2.2 Construction

These net modifications should be implemented incrementally to allow an evaluation of each modification on increasing barrier net effectiveness and reducing the number of submergence events. The net panel modifications would be prepared over the winter when the net is removed and placed into service in the spring when the existing barrier net is installed. These sections would be carefully observed during the following season. If the modifications are successful at increasing the integrity of the net then they could be applied to other net panels, if needed.

Additional lake anchors and the ultrasonic support piles and ancillary equipment would be installed when the net is not in place. Because these anchors and piles would be located near high velocity areas, generation would need to be reduced during their installation. LPSP is expected to be required to operate with only 2 units for 10 days during installation of the new net anchors and an additional 10 days for installation of the ultrasonic antifouling system.

7.2.3 Operation and Maintenance (O&M)

Typically, most of the net panels are cleaned once per month. The net panels that are in the direct discharge path for generation flows may, however, be cleaned twice per month. Divers are able to thoroughly clean the net panels, typically leaving them with minimal debris and biofouling. This cleaning regimen is not sufficient to prevent submergence of the existing net, which at times has occurred shortly after cleaning. Therefore, increased frequency of net cleaning alone may not be sufficient to reduce submergence events. Increased net cleanings could be part of an overall strategy including the identified physical modifications to the net to reduce net submergence. For estimating purposes maintaining the modified net is expected to require 10% greater effort than the existing net.

If additional net cleanings are not sufficient to maintain the net, the ultrasonic antifouling system has potential to reduce or eliminate biofouling. Limited information is available on operating an ultrasonic antifouling system. Therefore, a conservative estimate of power requirements and operations was used to estimate O&M costs. Each ultrasonic anti-biofouling transducer requires approximately 816 watts to operate. When all thirty of the transducers are operating, a peak power consumption of approximately 25 kW is expected. Operating the anti-biofouling system from April 15 through October 15 would require an additional 108 MWh per year assuming a 100% duty cycle (always on). A 10% reduction in manual cleaning was assumed as a result of installing an ultrasonic anti-biofouling system.

7.2.4 Operational Impacts

Modifying the barrier net does not require any physical changes to the LPSP intake and would not affect pumping or generating operations. Implementation of additional net anchors and ultrasonic support piles may require generation to be curtailed to reduce velocities during installation. Annual installation of the net and ultrasonic anti-biofouling system would require LPSP to operate at reduced load for approximately 6 days per year. Operating the anti-biofouling system is expected to require 108 MWh per year.

7.2.5 Expected Biological Effectiveness

The biological effectiveness of the existing barrier net is discussed in detail in Section 4.5. The effectiveness of the existing net design meets the standards set in the FERC Settlement Agreement (80% for game fish and 85% for forage fish over five inches in length). Fish swimming over the submerged portions of the net have been postulated to contribute to entrainment at LPSP. The only potential improvement would be if the net modifications and ultrasonic antifouling system eliminated or substantially reduced submergence events or damaged net panels.

7.2.6 Uncertainty and Risks

Any modifications to the net could have negative effects on the overall integrity of the net. This is particularly true for increasing buoyancy, which would increase stresses on the net support system and anchors. The modifications presented in this section incorporate additional lake bottom anchors to help relieve the stress on the existing anchors, but does not consider reinforced border and intermediate support lines, which may require strengthening. An adaptive management plan in which modifications to the net are made incrementally should be considered so that each modification could be tested on a small section of net before being applied across all the problem areas.

The ultrasonic antifouling system is a new technology that has not been tested for applications similar to LPSP and should be tested prior to full-scale implementation. Such a study could be conducted by ensonifying a small portion of the net and comparing the rate of biofouling to an untreated section. Costs for this study are not included in the total cost for this option.

Alden (2011) evaluated the drag stress and buoyancy requirements with 50% of the net plugged. A review of actual debris and biofouling conditions at the net indicate that at times the net may be up to 80% plugged. If the antifouling system is not effective at reducing biofouling and plugging of the net, an 80% plugged scenario should be modeled to determine the additional buoyancy needed to prevent submergence.

7.3 Larger Barrier Net with ½-inch Bar Mesh

A larger barrier net configuration with a smaller mesh would provide greater protection for smaller fish (< 4 inches) than the existing net.

7.3.1 Design

Replacing the existing LPSP barrier net with a new, longer net located farther away from the jetties and breakwater is expected to reduce the velocity approaching the net, especially during generation. This would reduce the stresses on the net, reducing submergence and allowing the use of a smaller mesh size. A new net with ½- inch bar mesh, located approximately 1,000 ft farther away from the intake/powerhouse than the existing barrier net, was assumed for this analysis.

The new net would be approximately 17,500 ft (3.3 miles) long (Figure 7-3). At this distance, the barrier net would be outside of the area modeled by Alden (2011). However, it is expected that at the proposed location the hydraulic forces at the net would be decreased during both pumping and generating operations. A bathymetric survey of proposed deployment location would be needed to determine the effective area of a new net. A rough approximation of the average velocity at the new net was estimated using the ratio of the net lengths. Velocities estimated using this method are expected to be higher than the actual velocities because this method does not take into account the increased water depth at the new net location. Using the average net velocities for the upgraded flow conditions estimated by Alden (2011), the average velocity at the net would drop from 1.0 ft/sec to 0.8 ft/sec during generation and from 0.3 ft/sec to 0.2 ft/sec during pumping. Localized velocities would vary along the net, but are generally expected to be lower than what currently occurs with the existing net.

The new net would share many features with the existing net and a modified net discussed, previously. The entire net would be made out of #18 Dyneema SK75 with 1/2-inch bar (1-inch stretch) mesh, to reduce entrainment of smaller fish through the net. The new net would be divided into 85, 200-ft long net panels with two, 250-ft long panels adjacent to the shoreline. Net sections 1 and 5, as identified in Figure 7-3, would be supported by fixed pile anchors spaced every 100 ft with approximately 15.4 lbs/ft of flotation. Net section 2, 3, and 4 would use anchors spaced every 50 ft and floats with 30 lbs/ft of buoyancy. The additional anchors and buoyancy was included in the design to prevent submergence and better distribute the stress on the net associated with the increase weight and drag with the finer mesh and increased water depth.

The top and bottom skirts would be installed on all but the two net panels closest to shore. The new top and bottom skirts would be the same width and use the same materials and construction techniques as the existing top and bottom skirts. Additional flotation would be added to the top skirt in sections 2, 3, and 4 (Figure 7-3).

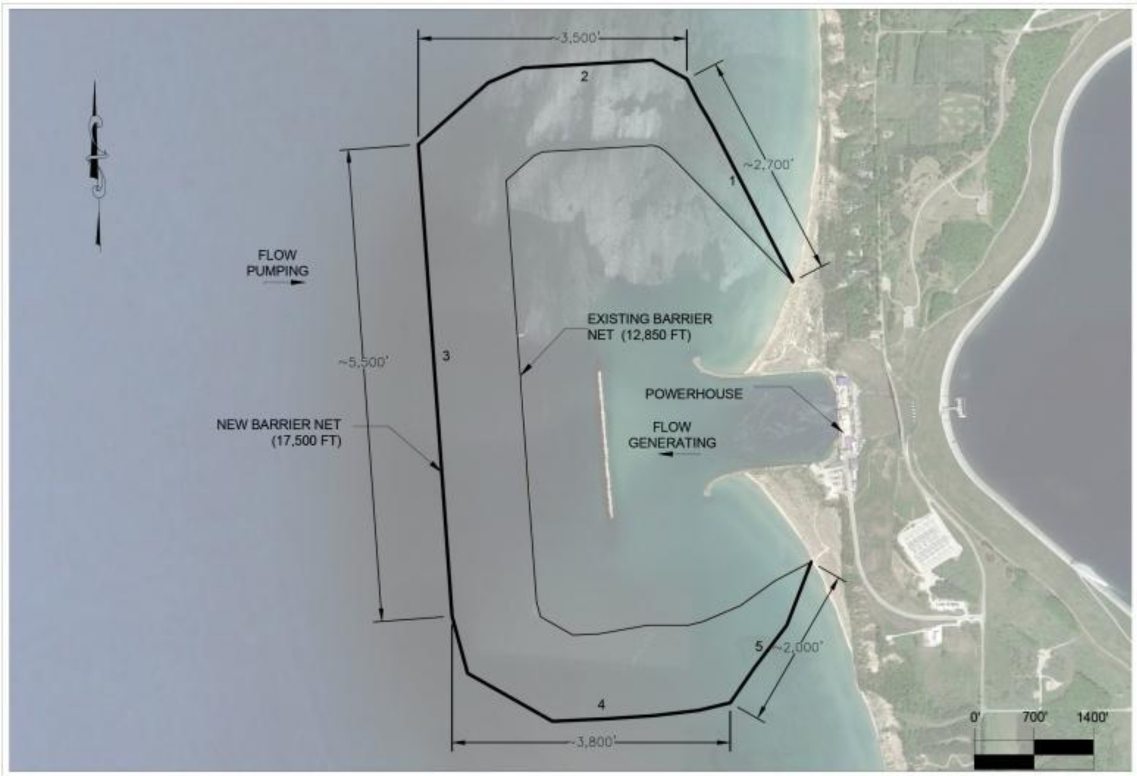


Figure 7-3: New longer barrier net with ½-inch bar mesh – plan

7.3.2 Construction

The new net panels would be fabricated off-site by the net manufacturer. These panels would be pre-assembled including the rope supports, top floats, and bottom chain. A detailed bathymetric survey of the lake bottom to define the bottom contours at the proposed deployment location would be needed to finalize the geometry for each of the net panels.

The anchor piles would be installed using a barge-mounted piling rig. Installation of the 248 fixed anchors is expected to require approximately 4 months. Once the anchor piles are in place, the anchor chains running between the piles would be installed. The final stage in construction would be the installation of the net using the same methods as currently employed. Assuming that 15 panels could be installed per day, it is expected that the entire net could be installed in six (6) days. A second net installation crew could be used to reduce the net installation time to three days.

LPSP would be able to remain operational during the entire construction process. Generation may have to be limited during the installation of the anchor piles and barrier net within the higher velocity zones near the northwest and southwest corners of the new net. Overall, it is anticipated that construction-related activities would require the LPSP to operate at reduced load for up to 3 weeks.

7.3.3 Operation and Maintenance (O&M)

The new net would have the same deployment schedule as the existing net (April 15 through October 15). The use of 1/2-inch bar mesh over the entire length of the new net could be more prone to fouling then the existing net that uses 3/4-inch bar mesh on the panels parallel to shore, which may lead to a need for more frequent cleaning. The total effort to clean the net was estimated to be 1.5 times the existing O&M cost per panel. A second net cleaning crew would be needed to maintain the longer net. If submergence still occurs with the longer net, ultrasonic net cleaners, as described in the modified net option, could be installed. Costs for ultrasonic cleaners are not included in the capital or O&M cost estimate for the longer net.

Visual inspections of the longer net should be conducted daily to identify problems such as submergence or excessive net displacement. This inspection would be performed similar to the ongoing observations for the existing net from shore using binoculars. Diver-based inspection and repair of the net would be conducted as part of the regular maintenance regimen.

7.3.4 Operational Impacts

Increasing the length of the barrier net does not require any physical changes to the LPSP intake and is not anticipated to affect pumping or generating operations. The new anchors would be installed during the shoulder seasons when the barrier net is not in place. This may require LPSP to operate at reduced load for up to 3 weeks. Modifications to the barrier net would be conducted during the winter when the net is not installed. Annual installation and removal of the new net is not expected to require LPSP to operate at reduced loads.

7.3.5 Expected Biological Effectiveness

The increased length of the barrier net may result in some reduction in entrainment due to reduced velocity through the net and a reduction in any fish that may be passing over the net during submergence events. The change to 1/2-inch bar for the entire net would reduce entrainment of smaller fish (< 4 inches in length). However, the magnitude of reduction could not be quantified because it is not known how much of entrainment of smaller fish occurs through the 3/4-inch bar portion of the existing net.

7.3.6 Uncertainty and Risks

The location of the new barrier net should result in lower velocities at the net during both pumping and generation. Under clean conditions, this would lead to lower stresses on the net during generation. The finer-mesh (1/2-inch bar) over the entire length of the net combined with additional floatation on the main portion of the net would likely increase stress and loading on the net components as it fouls, increasing the potential for failure of some of the net components (anchors, framing ropes, etc.).

A CFD model of a new longer net under expected pumping and generating operations with the new upgraded units is recommended to assist with the design of the new longer net. The flow field, velocities, and drag forces on a new net during pumping and generating could be estimated with the CFD model. The results for this analysis would be used to better locate the longer net and identify flow conditions (velocity and pressure) under various operating conditions. The velocity and pressure estimates could be used to refine the design of the net border and riser lines, floats, and anchors.

It has been suggested that the acute angle at which the north side of the net meets the shoreline may cause fish traveling southward along the coast to congregate at this location, which could result in increased entrainment of fish small enough to pass through the mesh. Hypothesis testing conducted on the fish monitoring data with the existing net has indicated that the acute angle on the north shore does not significantly reduce barrier effectiveness at this location (see Section 4.5). The larger barrier net configuration outlined above would increase the acuteness of this angle. Additional investigation of the location and concentration of fish as they navigate around the net would be useful in understanding the biological benefits of the longer net configuration.

The larger barrier net configuration will result in additional loss of public water space while deployed. The impact this may have on the local community with regards to activities such as recreation and navigation, must be taken into consideration. Also it may be difficult to obtain regulatory approval and Great Lakes Bottomland Conveyance permits due to the increased footprint.

7.4 Existing Barrier Net with a Full-Scale Ultrasonic Deterrent System

A full-scale ultrasonic deterrent system used in conjunction with the existing barrier net at LPSP has potential to reduce entrainment of juvenile and adult alewife, which is the most abundant species in the vicinity of the project. Although barrier net effectiveness has been high (> 90% for all size groups combined), an ultrasonic system would provide additional protection for the proportion of alewife that typically get past the net each year. In particular, barrier net effectiveness is about 75% for alewife less than 4 inches in length and 84% for fish between 4 and 5 inches. The use of an ultrasonic deterrent would likely increase the effectiveness rates for these size groups. Despite these potential benefits to alewife from the use of an ultrasonic deterrence, it should be noted that alewife abundance has declined drastically in Lake Michigan, including in the project area. If this trend continues, the benefit of installing an ultrasonic system at the LPSP to improve barrier net effectiveness for alewife will be greatly diminished and may render any consideration for installing this technology unnecessary.

This option would create an ultrasonic deterrent field along the entire length and depth of the barrier net that should be effective at repelling alewife away from the net. This should reduce entrainment of juvenile alewife that are currently not excluded by the net and large alewife that may bypass the net during submergence or storm related overtopping events. Alewife comprise about 74% of the total combined catch from gill netting conducted annually to monitor the barrier net effectiveness. Therefore, a reduction in alewife entrainment by the addition of an ultrasonic deterrent system could provide additional protection for this species, particularly for juveniles that are small enough to pass through the current net mesh.

Alewife abundance at LPSP is very seasonal peaking during June and July. Less than 3% of alewife collected during gill netting outside of the net are collected during April and October. Abundance is likely to be lower during winter months (November-March). The ultrasonic barrier would be removed during the winter to prevent ice damage.

7.4.1 Design

An ultrasonic deterrent system installed at LPSP would use wide-beam transducers similar to what has been deployed at the James A. Fitzpatrick Nuclear Power Plant to prevent alewife from approaching their intake. Based on previous studies and applications, the optimum ultrasonic signals for repelling Alosine species appear to be pure tones bursts using 122–128 kHz frequencies with a source level of 190 dB re 1 μPa at 1 m. For an application of this technology at the LPSP, the preliminary design assumes that sound transducers would be affixed to driven piles at approximately mid-water depth. The piles would be located approximately 75 ft inside of the net. At this location, the sound field of each transducer would extend the full depth of the water column up to 85 ft deep with a width of 260 ft. To create a full depth sound deterrent field with a minimum SPL of approximately 160 dB on the outside of the net, the piles would be spaced approximately 120 ft apart (Figure 7-4). An SPL of 160 dB was selected because this is the approximate minimum level that has been identified for eliciting strong avoidance responses from alewife (Ross et al. 1993; Dunning et al. 1997). An SPL greater than 150 dB would extend approximately 250 ft beyond the face of the net and should also result in some avoidance by alewife. The approximate coverage provided by the proposed sound transducer configuration where the SPL would be greater than 170 dB, 160 dB, and 150 dB are shown in Figure 7-4. A total of 110 sound transducers would be needed to provide complete coverage along the entire length and depth of the barrier net. Acoustic modeling of the sound field would be needed to be completed before finalizing the sound deterrent configuration.

The transducer support piles would be driven into the lake bottom at selected transducer locations. These piles would extend from the lake bottom to just above the mid-depth height. Keeping the piles submerged would reduce the visual impact of the piles and the potential for ice damage during the winter. An alternative support system may be needed in the near shore regions to prevent surf and ice damage. A cross-sectional view of one sound transducer showing the support pile and the estimated SPL contours is provided in Figure 7-5.

Each transducer would contain all the equipment necessary for signal generation, amplification, and transmission. The acoustic barrier would be controlled by nine control panels located onshore within a climate-controlled enclosure. Power cables would run along the lake bottom from the control structure to nine junction boxes mounted on select piles. These junction boxes would then distribute power to up to 13 transducers. The entire sound barrier would be powered by the LPSP’s in-house power system.

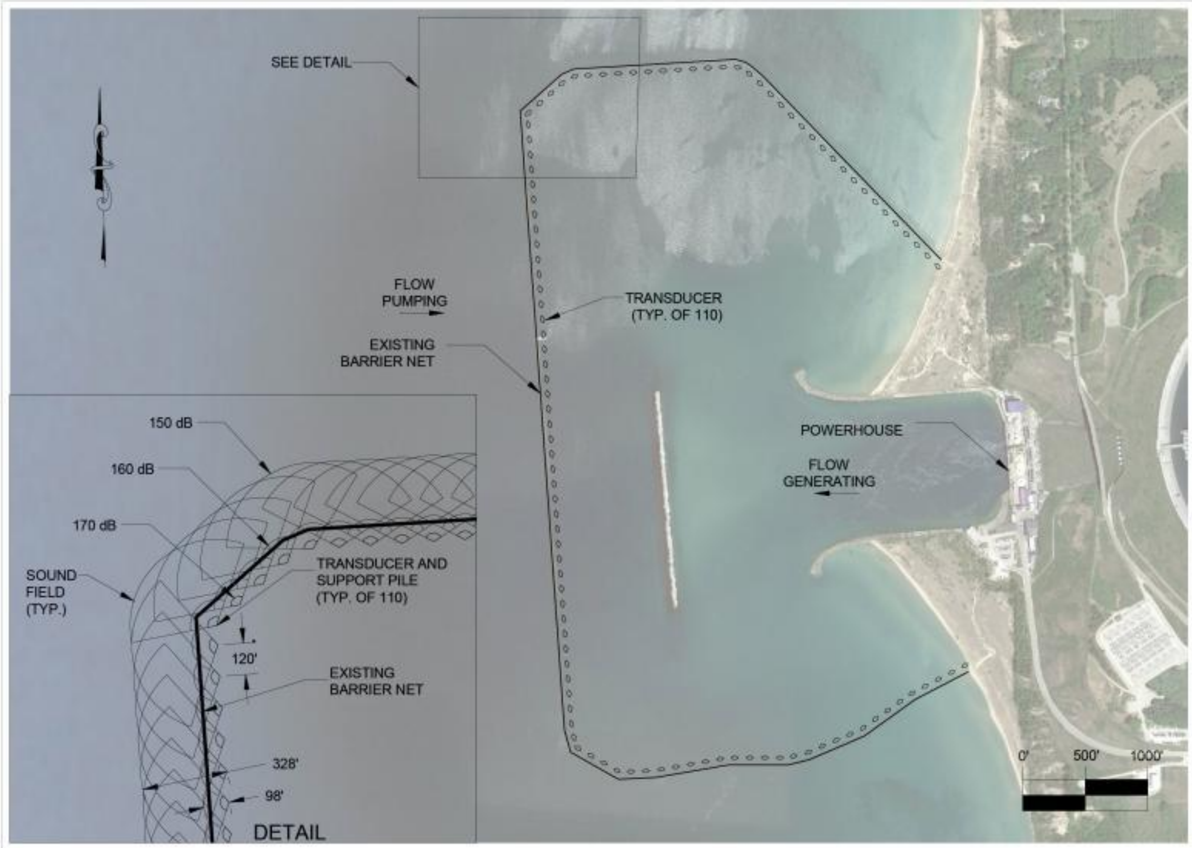


Figure 7-4: Existing barrier net with a full length sound barrier showing the SPL contours – Plan

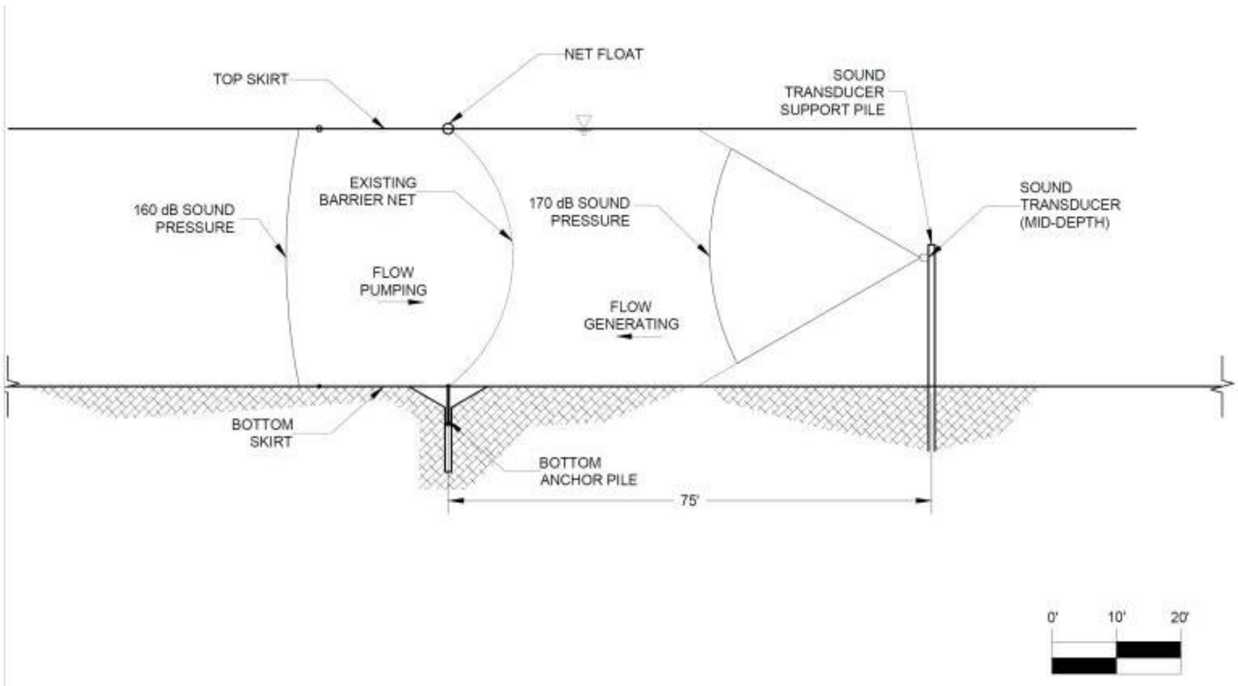


Figure 7-5: Existing barrier net with an ultrasonic barrier showing the SPL contours - Section

7.4.2 Construction

Installation of the support piles and sound system could be accomplished over a 4-month period. Installation would be sequenced to minimize impacts on plant operation. However, generation may need to be reduced during installation of the piles and transducers within the high velocity zones identified in the hydraulic evaluation of the turbine upgrades (Alden 2011). The support piles would be installed first, followed by power and cabling run along the lake bottom from onshore control systems to the junction boxes and the transducers. The transducers would be installed after installation of the ancillary equipment used to power and control the transducer arrays. Overall, it is anticipated that construction-related activities would require the project to operate at reduced load for approximately 2 weeks.

Onshore construction-related actives would include installation of a control system enclosure, connecting the control panel to the existing station power system, and modifying the station's existing control system to allow station operators to operate and monitor the status of the sound system. After the system is installed and operational, sound field measurements (i.e., SPL should be collected to validate the acoustic model used, to select the locations of the transducers, and to determine if there are any areas where the sound field may not be of sufficient amplitude to deter alewife (e.g., SPLs less than about 160 dB).

7.4.3 Operation and Maintenance

The sound deterrent system would be installed and operated for the same annual deployment period as the barrier net (April 15 through October 15). Installation and removal costs are included in the O&M costs for this option. After installation is completed the transducers would be inspected regularly to remove any biofouling and debris that may impair the sound waves. For cost estimating purposes, it was assumed that approximately 5% of the sound transducers and ancillary equipment would need to be replaced annually.

The sound system would operate on a 50% duty cycle (i.e., sound signals would be emitted with a sequence of 0.5 second on and 0.5 seconds off). Ultrasonic deterrents operated with a 50% duty cycle have demonstrated the ability to repel alewife while limiting power consumption. Each sound transducer requires approximately 350 watts to operate. During normal operations with all 110 sound transducers operating, the ultrasonic deterrent is expected to have a peak power consumption of approximately 39 kilowatt (kW). Operating the barrier from April 15 through October 15 would require approximately 85 megawatt-hour (MWh) per year.

7.4.4 Biological Effectiveness

Operation of the ultrasonic deterrent system would be continuous when the barrier net is installed, providing 24/7 protection for juvenile and adult alewife. This protection would include reducing the potential for juvenile alewife to pass through the net mesh and the potential for any size alewife from passing over the net during submergence events. Based on the performance of ultrasonic systems installed at cooling water intakes, the effectiveness of this technology for alewife at the LPSP could be as high as 80 to 90%. Given that the effectiveness of the barrier net for juvenile and adult alewife combined is about 90%, the addition of a sound deterrent system could provide an overall effectiveness of about 98% for this species (not including ichthyoplankton). Because alewife have been the most abundant species in the vicinity of the project since the barrier net was installed, the addition of a sound deterrent system could provide for relatively large decrease in fish entrainment. However, only alewife would benefit from the addition of ultrasonic sound. Also, ultrasonic deterrents have not been installed and operated at an intake similar in size to that of the LPSP intake (with respect to area and intake flow rate) and its use in conjunction with a barrier net has not been previously evaluated.

7.4.5 Operational Impacts

Operating the ultrasonic deterrent would require approximately 85 megawatt-hour (MWh) per year. This would be drawn from the existing station service. During installation and removal of the net and acoustic barrier only two LPSP units would be operated, when divers are working near the high velocity areas of the net. Annually this is expected to result in LPSP operating at reduced load for four days.

7.4.6 Uncertainties and Additional Studies

The ability of an acoustic deterrent to effectively reduce entrainment of Alosine species can be affected by site-specific conditions (primarily hydraulics and project configuration), but the biological effectiveness of ultrasonic deterrents has been well documented in the Great Lakes. The effectiveness monitoring conducted annually for the barrier net would also provide data to determine the effectiveness of a sound barrier at LPSP.

An acoustic model study should be conducted prior to the final design of the ultrasonic deterrent system to properly locate and orient the sound transducers to provide full coverage at the barrier net. The pressure waves radiating out from the sound transducers over the range of frequencies expected to be effective at LPSP would be modeled in this evaluation. The model results would provide a theoretical map of the sound field around the intake.

After installation of the sound barrier, a sound mapping field study should be conducted to verify the sound field of the ultrasonic deterrent system. This study would require the installation of hydrophones or a mobile survey conducted within the predicted sound field. Field measurements would record both the frequency and magnitude of the sound at specified distances and depths inside and outside of the barrier net. Any background noise and sound attenuation occurring at the barrier net would also be detected. If the sound field does not match what is required to create an effective sound barrier, the sound transducers could be adjusted until the desired sound field is achieved. Costs for both the numeric and field study are not included in the cost estimate for the installation of an ultrasonic deterrent system at the LPSP (Section 8).

8 Estimated Costs

Order-of-magnitude costs were developed for each of the fish protection alternatives evaluated in Section 7. These costs are composed of order-of-magnitude installation, O&M, and power requirements. The costs were estimated using material quantities and labor estimates developed from the conceptual designs. Most of the costing information is based on published materials and labor costs (RS Means 2013). The costs from 2014 were updated to 2015 dollars using a 1% inflation rate. This value was obtained from the consumer price index. Technology-specific costs are based on manufacturer input for LPSP along with estimates for other projects that were adjusted for identifiable differences in project sizes and operations. These costs allow a valid comparison of the cost difference between alternatives.

The estimated costs are based on the following:

- Present-day prices and fully contracted labor rates as of September 2015.
- Forty-hour work-week with single-shift operation for construction activities that do not impact plant operations; and, fifty-hour workweek with double-shift operation for construction activities that would impact plant operations.
- Direct costs for material and labor required for construction of all project features. The direct costs also include distributable costs for site non-manual supervision, temporary facilities, and support services incurred during construction. These costs have been taken as 20% of the materials and labor portion of the costs for each alternative.
- Indirect costs for labor and related expenses for engineering services to prepare drawings, specifications, and design documents. The indirect costs have been taken as 10% of the direct and distributable costs for each alternative.
- Allowance for indeterminants to cover uncertainties in design and construction at this preliminary stage of study. An allowance for indeterminants is a judgment factor that is added to estimated figures to complete the final cost estimate, while still allowing for other uncertainties in the data used in developing these estimates. The allowance for indeterminants has been taken as 25% of the direct, distributable, and indirect costs of each alternative.
- Contingency factor to account for possible additional costs that might develop but could not be predetermined (e.g., labor difficulties, delivery delays, weather). The contingency factor has been taken as 15% of the direct, distributable, indirect, and allowance for indeterminate costs of each concept.
- Construction-related shutdowns were minimized to the maximum extent possible. However, when shutdowns could not be avoided, a cost of $55/MWh and an average daily generation of 1,000 MWh per unit were used to determine the penalty associated with lost generation.

The project costs do not include the following items that are typically needed to obtain total capital cost estimates:

- Costs to perform additional laboratory or field studies that may be required, soil sampling, and wetlands delineation and mitigation.
- Costs to dispose of any hazardous or non-hazardous materials that may be encountered during excavation and dredging activities.
- CEC costs for administration of project contracts and for engineering and construction management.
- Costs for any ongoing biological monitoring studies required.
- Price escalation.
- Permitting costs.

Operations and maintenance (O&M) costs were determined for each of the selected technologies. These costs are based on the power, labor, and component replacement costs needed to operate and maintain each technology. They are based on the same assumptions used in calculating the capital costs.

The existing O&M costs do not include payments for fish lost to the project. With the existing arrangement, the average annual expenditure for lost fish is $2,500,000. This expenditure is expected to be reduced for each of the technologies. Quantifying this reduction was not conducted as part of this evaluation, and is not considered in the cost estimates. The existing O&M costs were provided by CEC for use exclusively in the Phase 2 and 3 reports.

The estimated project construction and O&M costs for the selected entrainment reducing options are presented in Table 8-1 through Table 8-4. These costs are summarized in Table 8-6. Existing O&M costs, provided by CEC, were used to estimate the total O&M and incremental O&M costs each option presented in Table 8-6. Total and incremental annualized costs were calculated for each option. Annualized costs provide a better estimate of the total and incremental cost burden faced by CEC for each of the feasible options. The annualized costs associated with both of these options are presented in Table 8-7. Two assumptions were made to annualize the costs:

- The capital costs were annualized over 30 years; and
- A 7% discount rate was used.

Table 8-1: Cost to Maintain the Existing Barrier Net

Average Annual O&M (Labor)[1]	$2,053,000
Average Number of Panels Replaced[1]	11.2
Average Replacement Cost per Panel[1]	$29,000
Average Annual Replacement Cost[1]	$325,000
Total Annual Direct Net Expenditures	**$2,378,000**
Estimated Annual Reduction in Generation (MWh)	8,000
Average Fisheries Cost	$2,500,000

1. Based on actual and estimated O&M and net replacement costs from 2011 through 2015.

Table 8-2: Modified barrier net without with ultrasonic anti-biofouling

Item	Estimated Cost
Direct Costs	
Mobilization and Demobilization	$183,000
Support Piles	$31,000
Net Panels	$1,076,000
Top Skirt	$268,000
Bottom Skirt	$275,000
Barges, Divers and Equipment	$183,000
Distributable Costs	$367,000
Direct Costs (2015$)	$2,383,000
Indirect Costs	$238,000
Subtotal	$2,621,000
Allowance for Indeterminates	$655,000
Allowance for Contingencies	$491,000
Total Estimated Project Costs (2015$)	$3,767,000

Impacts on Plant Operation	
Item	**Impact**
Construction	
Duration (months)	0.6
Reduced Generation (2 Units) (Days)	10
Total Annual Operation and Maintenance	
Labor ($)	$2,258,000
Component Replacement ($)	$357,000
Lost Generation (MWh)	12,000
Energy (MWh)	0
Peak Power (kw)	0

Table 8-3: Modified barrier net with ultrasonic anti-biofouling

Item	Estimated Cost
Direct Costs	
Mobilization and Demobilization	$302,000
Support Piles	$100,000
Net Panels	$1,076,000
Top Skirt	$268,000
Bottom Skirt	$275,000
Sound System	$727,000
Control Building	$28,000
Barges, Divers and Equipment	$542,000
Distributable Costs	$603,000
Direct Costs (2015$)	$3,921,000
Indirect Costs	$392,000
Subtotal	$4,313,000
Allowance for Indeterminates	$1,078,000
Allowance for Contingencies	$809,000
Total Estimated Project Costs (2015$)	$6,200,000

Impacts on Plant Operation	
Item	**Impact**
Construction	
Duration (months)	1.9
Reduced Generation (2 Units) (Days)	20
Total Annual Operation and Maintenance	
Labor ($)	$2,274,000
Component Replacement ($)	$400,000
Lost Generation (MWh)	24,000
Energy (MWh)	108
Peak Power (kw)	25

Table 8-4: Longer barrier net with ½-inch bar mesh

Item	Estimated Cost
Direct Costs	
Mobilization and Demobilization	$514,000
Support Piles	$236,000
Net Panels	$3,084,000
Top Skirt	$181,000
Bottom Skirt	$369,000
Indicator Buoys	$73,000
Barges, Divers and Equipment	$1,203,000
Distributable Costs	$1,029,000
Direct Costs (2015$)	$6,689,000
Indirect Costs	$669,000
Subtotal	$7,358,000
Allowance for Indeterminates	$1,840,000
Allowance for Contingencies	$1,380,000
Total Estimated Project Costs (2015$)	$10,578,000

Impacts on Plant Operation	
Item	**Impact**
Construction	
Duration (months)	4.3
Reduced Generation (2 Units) (Days)	20.7
Total Annual Operation and Maintenance	
Labor ($)	$4,200,000
Component Replacement ($)	$442,000
Lost Generation (MWh)	0

Table 8-5: Existing barrier net with a full-scale ultrasonic deterrent system

Item		Estimated Cost
Direct Costs		
Mobilization and Demobilization		$775,000
Support Piles		$218,000
Sound System		$6,382,000
Control Building		$28,000
Barges, Divers and Equipment		$1,116,000
Distributable Costs		$1,549,000
	Direct Costs (2015$)	$10,068,000
Indirect Costs		$1,007,000
	Subtotal	$11,075,000
Allowance for Indeterminates		$2,769,000
Allowance for Contingencies		$2,077,000
	Total Estimated Project Costs (2015$)	$15,921,000

Impacts on Plant Operation	
Item	**Impact**
Construction	
Duration (months)	4
Reduced Generation (2 Units) (Days)	13.3
Total Annual Operation and Maintenance	
Labor ($)	$2,143,000
Component Replacement ($)	$477,000
Lost Generation (MWh)	16,000
Energy (MWh)	85
Peak Power (kw)	39

Table 8-6: Cost comparison of feasible entrainment abatement technologies

Alternative	Initial Capital Costs			Annual Costs				
	Total Project Construction Costs (2015 $)	Replacement Power During Construction (2015 $)[1]	Total Capital Costs (2015 $)	Energy (2015 $)[1,2]	Labor (2015 $)[2]	Component Replacement (2015 $)[2,3]	Total Annual Costs (2015 $)[2]	Incremental Annual Costs (2015 $)
Existing Barrier Net	NA	NA	NA	$440,000	$2,053,000	$324,000	$2,817,000	$0
Modified Barrier Net	$3,767,000	$2,200,000	$5,967,000	$660,000	$2,258,000	$357,000	$3,275,000	$458,000
Modified Barrier Net with Ultrasonic Anti-biofouling	$6,200,000	$4,400,000	$10,600,000	$1,326,000	$2,274,000	$400,000	$4,000,000	$1,183,000
Longer Barrier Net with ½-inch Bar Mesh	$10,578,000	$4,547,000	$15,125,000	$0	$4,200,000	$442,000	$4,642,000	$1,825,000
Existing Barrier Net with a Full-Scale Ultrasonic Deterrent System	$15,921,000	$2,933,000	$18,854,000	$885,000	$2,143,000	$662,000	$3,690,000	$873,000

1. Assumes $55 per MWh.
2. Includes existing O&M effort required to maintain the barrier nets when applicable
3. For the existing barrier net, net replacement is considered a capital cost by the owners.

4.

Table 8-7: Annualized costs of the feasible entrainment abatement technologies

Alternative	Total Annualized Costs[1]	Incremental Annualized Costs[1]
Existing Barrier Net	$2,817,000	$0
Modified Barrier Net	$3,756,000	$939,000
Modified Barrier Net with Ultrasonic Anti-biofouling	$4,854,000	$2,037,000
Longer Barrier Net with ½-inch Bar Mesh	$5,861,000	$3,044,000
Existing Barrier Net with a Full-Scale Ultrasonic Deterrent System	$5,209,000	$2,392,000

1. Annualized over 10 years with a 7% discount rate

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ATTACHMENT 2

Wildlife Resources Study

2015 Work Summary – Wildlife Resources:

In April 2015 Consumers contracted with King and MacGregor, Environmental, Inc. ("K&M") to conduct the wildlife resources survey work. K&M used the information provided in the Pre-Application Document ("PAD") to develop an initial listing of the wildlife expected to be found in the Project Area. The Michigan Natural Features Inventory ("MNFI") was reviewed for a current listing of the threatened and endangered species that could be present within the Project Area (the MNFI database is maintained by the Michigan State University Extension).

In July 2015, a wildlife field survey was conducted to verify land cover types, habitats and document wildlife observations. Field crews walked through the Project Area (and the Port Sheldon site) documenting the dominant vegetative species and wildlife observations. The Port Sheldon survey was performed from the boardwalk and included the non-project areas visible from the walkway. [Note: K&M also conducted the botanical resources survey; the plant species lists in the wildlife report were documented during the botanical survey.]

Figures 1 and 2 illustrate the individual areas identified during the survey. There were 19 areas identified at the Project site (18 numbered areas plus the air field) with six main habitat areas. At the Port Sheldon site there were 4 main habitat areas identified adjacent to the recreation area.

The six main habitats identified within the Project Boundary are:

1. Forested Area (area's 5, 7, 8, 9, 10, 11, 12, 14, 15, 16, and 17)
2. Beach and Low Dunes (area's 1 and 4)
3. Bluff Slope (area's 2 and 3)
4. Old field/Shrub Thickets (portions of area's 7, 10, 11 and 18)
5. Reservoir Slope/Meadow (area 6)
6. Maintained recreation (Air Field and areas 13, 15 and 16)

The four main habitats adjacent to the Port Sheldon site are:

1. Riparian Edge (area between the boardwalk and the Pigeon River)
2. Wooded dune (area north of the boardwalk)
3. Beach and low dune (beach area north of the walkway)
4. Maintained/developed (homes and roadways north of the walkway)

Of the wildlife species observed (or evidence of their presence through scat, feathers, tracks, calls, etc.) during the field survey the only Rate Threatened or Endangered ("RTE") species identified was a young bald eagle flying over the reservoir. The vast majority of wildlife observations at the Project Site occurred along the shoreline or adjacent to Areas 1 and 2. There were no RTE species observed in the areas adjacent to the Port Sheldon Site.

A draft report was provided to Consumers for review on October 16, 2015. Comments were returned to K&M on October 28, 2015. A final report is scheduled to be ready by December, 31, 2015.

There were no variances to the FERC approved Wildlife Resources Study Plan.

Figure 1 – Ludington Project Site Main Habitat Areas

Figure 2 – Port Sheldon Site Main Habitat Areas

ATTACHMENT 3

Botanical Resources Study

2015 Work Summary – Botanical Resources:

In April 2015 Consumers contracted with King and MacGregor, Environmental, Inc. ("K&M") to conduct the botanical resources study. K&M used the information provided in the Pre-Application Document ("PAD") to develop an initial listing of the Rare Threatened and Endangered ("RTE") species that could be expected to be found in the Project Area. The Michigan Natural Features Inventory ("MNFI") was reviewed for a current listing of the threatened and endangered species that could be present within the Project Area (the MNFI database is maintained by the Michigan State University Extension).

In early August, 2015, the Port Sheldon botanical survey was conducted while the Ludington site botanical survey was conducted in late August. Comprehensive plant communities were documented during the site surveys. [Note: K&M also conducted the wildlife resources survey; the plant species lists in the wildlife report were documented during the botanical survey.]

Figures 1 and 2 illustrate the individual areas identified during the survey and the locations of the invasive species. There were 19 areas identified at the Project site (18 numbered areas plus the air field) with six main habitat areas. At the Port Sheldon site there were 4 main habitat areas identified adjacent to the recreation area.

The six main habitats identified within the Project Boundary are:

1. Forested Area (area's 5, 7, 8, 9, 10, 11, 12, 14, 15, 16, and 17)
2. Beach and Low Dunes (area's 1 and 4)
3. Bluff Slope (area's 2 and 3)
4. Old field/Shrub Thickets (portions of area's 7, 11, 12 and 18)
5. Reservoir Slope/Meadow (area 6)
6. Maintained recreation (Air Field and areas 13, 15 and 16)

The four main habitats adjacent to the Port Sheldon site are:

1. Riparian Edge (area between the boardwalk and the Pigeon River)
2. Wooded dune (area north of the boardwalk)
3. Beach and low dune (beach area north of the walkway)
4. Maintained/developed (homes and roadways north of the walkway)

There were no RTE species observed within the Project Boundary at the Ludington site or.in the areas adjacent to the Port Sheldon Site. A single Red mulberry tree (a state threatened species) was observed adjacent to the Project Boundary east of site 18 along the roadway. The report contains a listing of the non-native and invasive species that were observed in the different areas at the two locations.

A draft report was provided to Consumers for review on November 6, 2015. Comments were returned to K&M on November 17, 2015. A final report is scheduled to be ready by December, 31, 2015.

There were no variances to the FERC approved Wildlife Resources Study Plan.

Figure 1 Botanical Report Figure 2

Figure 1 Botanical Report Figure 2A

Figure 1 Botanical Report Figure 2B

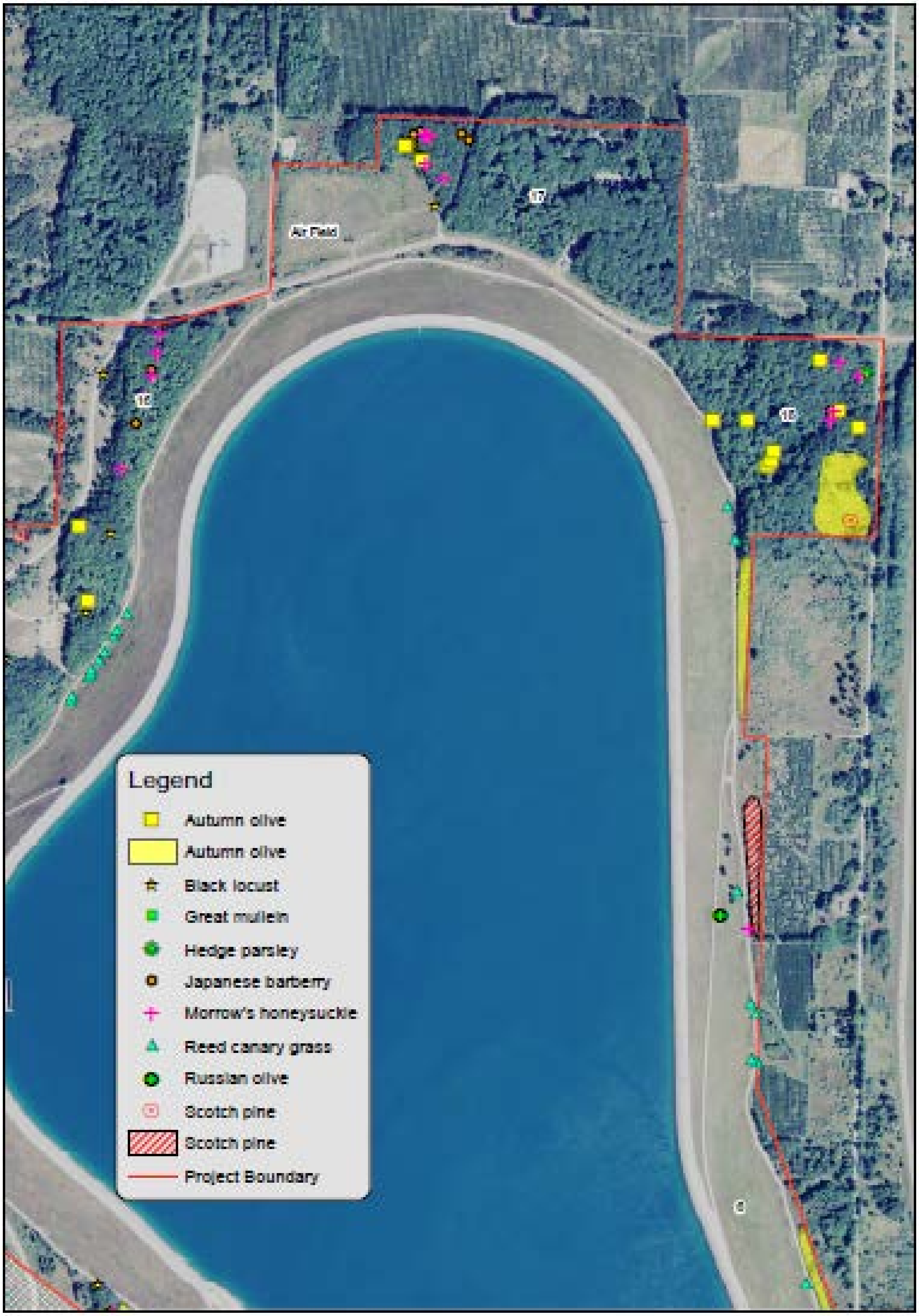


Figure 1 Botanical Report Figure 2C

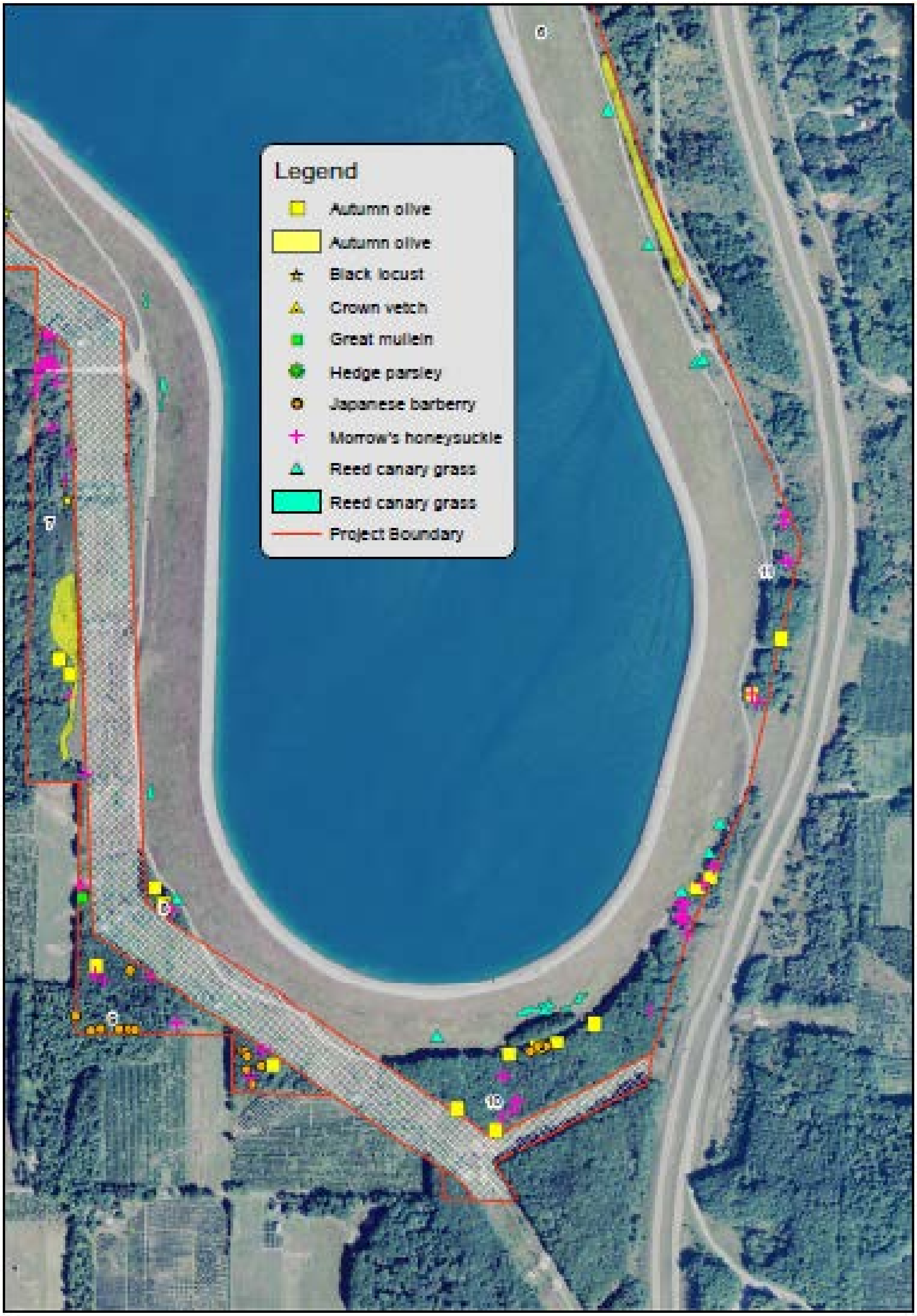
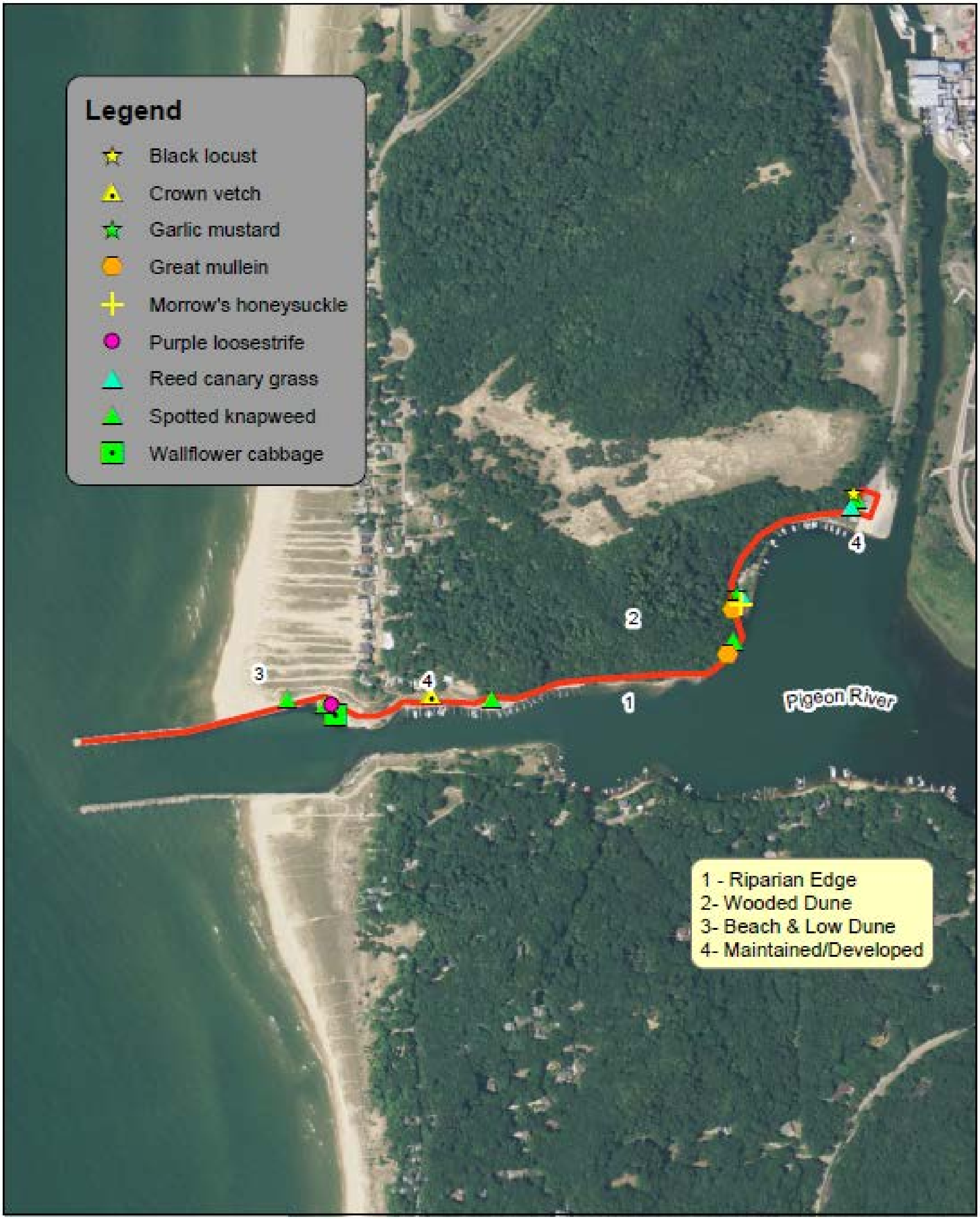

Legend
Autumn olive
Autumn olive
Black locust
Crown vetch
Great mullein
Hedge parsley
Japanese barberry
Morrow's honeysuckle
Reed canary grass
Reed canary grass
Project Boundary

Figure 2 Botanical Report Figure 3



ATTACHMENT 4

Summary

Recreation Resources

Initial Study Report Summary

December 2015

2015 Work Summary – Recreation Resources:

In March 2015 Consumers contracted with TRC Engineers, LLC ("TRC") to conduct the recreational resources study. Attached is the Initial Study Year Summary Report prepared by TRC providing additional detail of the 2015 activities.

In May 2015 TRC Staff visited the Ludington Project to conduct the recreation site and facility inventory and condition assessment.

TRC developed a field data collection schedule and trained field staff during March and April of 2015. Field work was initiated in April 2015 and continued through the end of October 2015, coincident with the closure of the recreation sites for the year.

TRC also obtained the available data for the recreation facilities with user registration or count information.

TRC has obtained and reviewed readily available municipal, county, state, federal and NGO recreation plans for information regarding recreation use within the Project boundary. Consultation with the municipal and county recreation departments and recreation/open space committees in those towns and counties located within the Project was initiated on October 22, 2015.

Data entry will continue until all of the collected information has been complied, scheduled to be completed by the end of 2015. Statistical analysis will begin upon the completion of the data entry. Consultation with the municipal and county recreation departments and recreation/open space committees in those towns and counties located within the Project will be documented in the final report. The final report will be completed in the 2nd quarter of 2016.

Two variances from the Recreation Resources Study Plan were noted. TRC Staff conducted only three (3) of the four (4) scheduled spot counts in June 2015 and did not conduct the additional spot count for the Fourth of July holiday weekend. Due to the robust amount of information collected during the calibration counts and recreation user surveys for these months, which included a calibration count and survey collection effort on the Fourth of July, TRC does not anticipate that the missed spot counts will adversely impact the results of the data analysis.

RELICENSING STUDY 4

RECREATION RESOURCES

INITIAL STUDY REPORT SUMMARY

LUDINGTON PUMPED STROAGE HYDROELECTRIC PROJECT (FERC NO. 2680-108)

Prepared for:

Consumers Energy Company and Detroit Electric Company
Hydro and Renewable Generation
330 Chestnut St.
Cadillac, MI 49601

Prepared by:

TRC
14 Gabriel Drive
Augusta, ME 04330

December 2015

1 STUDY SUMMARY

The Recreation Resources study includes: a Recreation Site and Facility Inventory and Condition Assessment and a Recreational Use Study. The purpose of the study is to compile existing data and develop additional information to support a new FERC license application for continued operation of the Project.

The primary goals of this study are to:

- Develop an inventory and condition assessment of the existing Project recreation facilities;
- Estimate the existing level of daytime and nighttime recreational use occurring at the Project;
- Develop a survey/questionnaire and administer the survey to Project recreational users to gather their perceptions and input on level of use, condition and adequacy, and potential enhancements of Project recreation facilities;
- Project future daytime and nighttime Project recreational use; and
- Identify entities that operate, maintain the existing Project recreation sites and facilities.

2 STUDY PROGRESS SUMMARY

2.1 Recreation Site and Facility Inventory and Condition Assessment

TRC conducted the recreation site and facility inventory and condition assessment in May 2015. The following sites were identified within the Project boundary: Mason County Campground (including Hull Airfield), Mason County Picnic Area, Upper Reservoir Observation Platform, Lake Michigan Overlook, and Pigeon Lake North Pier. Of these sites, three are recreation sites that are owned and managed by the Licensees and the remaining two are owned by the Licensees and managed by Mason County.

The recreation sites located within the Project boundary were found to provide a variety of recreational opportunities for the public, including fishing, camping, picnicking, walking, disc golfing, flying model aircraft, and sightseeing.

All of the recreation sites within the Project boundary were found to be meeting their intended function. All of the facilities were found to be in good condition.

At each recreation site, a standard recreational site/facility inventory and condition assessment form was completed, photos were taken and a GPS point was recorded for all FERC approved amenities.

2.2 Recreational Use Study

The Licensees are conducting a study to determine the existing recreational use at the Ludington Pumped Storage Project and an assessment for the need to enhance recreation opportunities and access at the Project. Data was collected using on-site visitor counts and intercept surveys at all recreation sites at the Project as listed in section 2.1. Field data will be supplemented with user registration data for Mason County Campground and the Mason County Picnic Area. Data from the recreation site and facility inventory and condition assessment will be used to determine the sufficiency of existing recreation facilities in meeting recreation demand at the Project and to assess the need to enhance recreation opportunities and access at the Project.

TRC developed a field data collection schedule and trained field staff during March and April of 2015. Field work was initiated in April 2015 and continued through the end of October 2015, coincident with the closure of the recreation sites for the year. TRC Staff conducted calibration counts at each Project recreation facility on four (4) days per month, which included two (2) randomly selected weekdays and two (2) randomly selected weekend days. For months containing a three-day holiday weekend (Memorial Day, Fourth of July, and Labor Day), an additional calibration count was conducted on one (1) holiday weekend day. Spot counts were conducted at each Project facility on four (4) days per month, which included two (2) randomly selected weekdays and two (2) randomly selected weekend days. For months containing a three-day holiday weekend, an additional spot count was conducted on one (1) holiday weekend day. User contact surveys were administered to one member of each recreation group encountered during the calibration counts.

For those Project recreation facilities with user registration or count information, TRC contacted the managing entities and have obtained the available data. All data being collected will be entered into electronic spreadsheets for statistical analysis which is anticipated to be completed by the end of 2015.

TRC has also obtained and reviewed readily available municipal, county, state, federal and NGO recreation plans for information regarding recreation use within the Project boundary. Consultation with the municipal and county recreation departments and recreation/open space committees in those towns and counties located within the Project was initiated on October 22, 2015 via email.

3 VARIANCES FROM STUDY PLAN AND SCHEDULE

The Recreation Resources Revised Study Plan indicated that spot counts would be conducted four (4) days per month on two (2) randomly selected weekdays and two (2) randomly selected weekend days. For months containing a three-day holiday weekend, an additional spot count would be conducted during the holiday weekend. TRC Staff conducted only three (3) of the four (4) scheduled spot counts in June 2015 and did not conduct the additional spot count for the Fourth of July holiday weekend. The requisite number of calibration counts and recreation user survey collection days were completed.

Due to the robust amount of information collected during the calibration counts and recreation user surveys for these months, which included a calibration count and survey collection effort on the Fourth of July, it is not anticipated that the missed spot counts will adversely impact the results of the data analysis.

4 REMAINING ACTIVITIES

Data entry will continue until all of the collected information has been complied. Statistical analysis will begin upon the completion of the data entry in 2015.

Consultation with the municipal and county recreation departments and recreation/open space committees in those towns and counties located within the Project will be documented in the final report.

The final report will be completed in the 2nd quarter of 2016.

ATTACHMENT 5

Historical Resources Survey

2015 Work Summary – Historical Resources

In April 2015 Consumers contracted with Mannik and Smith Group, Inc. ("M&S") to conduct the historical resources study. The historical resources study included the determination of the Area of Potential Effects ("APE") for the Ludington Project, any historic properties with the APE, and the effects, if any the Ludington Project operation would have on the historic properties.

In June M&S were provided copies of the June 2011 Ludington Project historical assessment, the July 2013 Phase I survey of 35 acres of project property and the September 2013 Phase I survey of 95 acres of project property. These two Phase I surveys were conducted to support removal of these two parcels from the Ludington Project boundary. Additionally, in September 2013 a Phase I survey was performed on approximately 0.2 acres of property within the Mason County campground prior to the campground staff constructing two camper cabins. The historic assessment and the three Phase 1 surveys were conducted by Commonwealth Cultural Resources Group.

In August M&S Staff visited the Ludington Project to review and document the existing site structures. Included in the review was the Port Sheldon recreation site. All architectural resources (above ground) were documented.

M&S determined that Project activities are limited to the property boundaries, as no physical, visual or auditory impacts are anticipated beyond those boundaries.

M&S recommend that the APE be limited to the LPSP project boundary, refer to Figures 1and 2.

M&S is completing a draft historical assessment report and is planning on having a final version available by January 1, 2016. The Historical Resources Report and the Archaeological Resources Report will be combined into a single report. Following review by the Licensees the final draft report will be provided to the Michigan State Historic Preservation Office (SHPO) for review and comment. Additionally the report will be provided to Tribal Historic Preservation Officer for the Saginaw Chippewa Indian Tribe. Following review by the SHPO and the Tribal Historic Preservation Officer, final reports will be filed with the Commission.

The historic resources study deviated from the Study Plan by not consulting with the SHPO regarding determination of the APE for the Project prior to conducting the filed survey and in the delay in providing a final report by November 15, 2015. Neither deviation is expected to impact the results of the historic resources study.

Figure 1 Ludington Pumped Storage Facility (hydroelectric facility) APE

Figure 2 Pigeon Lake North Pier (recreation facility) APE

ATTACMENT 6

Archaeological Resources Survey

2015 Work Summary – Archaeological Resources

In April 2015 Consumers contracted with Mannik and Smith Group, Inc. ("M&S") to conduct the archaeological resources study (in addition to the historic resources study).

In June M&S were provided copies of the June 2011 Ludington Project historical assessment, the July 2013 Phase I survey of 35 acres of project property and the September 2013 Phase I survey of 95 acres of project property. These two Phase I surveys were conducted to support removal of these two parcels from the Ludington Project boundary. Additionally, in September 2013 a Phase I survey was performed on approximately 0.2 acres of property within the Mason County campground prior to the campground staff constructing two camper cabins. The historic assessment and the three Phase 1 surveys were conducted by Commonwealth Cultural Resources Group.

M&S conducted the literature review and background research from May thru July 2015. A field crew assembled at the Ludington Project site for two weeks in August 2015 to conduct the Phase 1 field survey. During September and October M&S Staff processed and analyzed the numerous artifacts collected during the field survey. October and November were spent on determining National Registry of Historic Places ("NRHP") eligibility and preparing the report.

The M&S literature and archival research found two previously identified prehistoric sites within the Project boundary (destroyed during original project construction) and several historic and prehistoric sites within approximately 2 km of the Project boundary. There were no previous sites found within the Port Sheldon recreation area site boundary.

There were 28 field sites discovered during the Phase 1 survey, three sites were determined not to be archaeological sites, the remaining 25 sites were grouped into 15 archaeological sites. There were no archaeological sites determined for the Port Sheldon site.

M&S has determined that the five pre-historic sites identified are not NRHP eligible. Additionally, eight of the ten historic archaeological sites were also determined to not be eligible. The remaining two sites appear to be NRHP eligible, but will not be impacted by current Project operations. M&S recommends a geomorphological investigation be considered to determine whether there is the potential for buried archaeological deposits in dune contexts within the LPS Project area.

M&S is completing a draft archaeological assessment report and is planning on having a final version available by January 1, 2016. The Historical Resources Report and the Archaeological Resources Report will be combined into a single report. Following review by the Licensees the final draft report will be provided to the Michigan State Historic Preservation Office (SHPO) for review and comment. Additionally, the report will be provided to Tribal Historic Preservation Officer for the Saginaw Chippewa Indian Tribe. Following review by the SHPO and the Tribal Historic Preservation Officer, final reports will be filed with the Commission.

The archaeological resources study deviated from the Study Plan by not consulting with the SHPO and the tribes prior to conducting the field survey and in the delay in providing a final report by November 2015. Neither deviation is expected to impact the results of the archaeological resources study.