

# 83  
(ON WEB)

## **Fish Protection at Cooling Water Intake Structures: A Technical Reference Manual**

1014934

---



# **Fish Protection at Cooling Water Intake Structures: A Technical Reference Manual**

1014934

Technical Update, December 2007

EPRI Project Manager

D. Dixon

## **DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES**

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

**Alden Research Laboratory, Inc.**

**This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.**

### **NOTE**

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail [askepri@epri.com](mailto:askepri@epri.com).

Electric Power Research Institute, EPRI, and TOGETHER...SHAPING THE FUTURE OF ELECTRICITY are registered service marks of the Electric Power Research Institute, Inc.

Copyright © 2007 Electric Power Research Institute, Inc. All rights reserved.

## CITATIONS

---

This report was prepared by

Alden Research Laboratory, Inc.  
30 Shrewsbury Street  
Holden, MA 01520

Principal Investigators  
J. Black  
T. Hogan

This report describes research sponsored by the Electric Power Research Institute (EPRI).

This publication is a corporate document that should be cited in the literature in the following manner:

*Fish Protection at Cooling Water Intake Structures: A Technical Reference Manual*. EPRI, Palo Alto, CA: 2007. 1014934.

2017-10-10

10/10/17

10/10/17

10/10/17

10/10/17

10/10/17

10/10/17

10/10/17

## PRODUCT DESCRIPTION

---

This report reviews fish protection technologies at, but not limited to, cooling water intake structures (CWISs). The document is a status report and synthesis of technology-specific information released by EPRI in 2004 and includes case studies that have been published or released since the 2004 report. In this update, EPRI details all available information on fish protection technologies. Information that is most applicable to CWISs is emphasized, but studies at hydroelectric, irrigation, and other water intakes also are presented.

### **Results & Findings**

The report presents site descriptions, study equipment and methods, and effectiveness results for each of more than 28 fish protection technologies reviewed. The discussion of each technology is presented in the following order: full-scale applications at CWISs; other full-scale applications (for example, hydroelectric and irrigation); and pilot and laboratory studies. The status of each technology is presented along with comments on important factors that influence the potential for effective application at a given site. The report also includes a section that allows users to find references to fish protection technologies based on species.

### **Challenges & Objective(s)**

The project's main objectives were to gather all available information on permanent installations of fish protection technologies and related research efforts; assess the current status of each technology; and provide summaries of study methods and results for guidance in future technology evaluations.

### **Applications, Values & Use**

Knowledge of fish protection technologies that have potential application at CWISs can help power generating companies reduce impingement and entrainment losses. Site-specific design and operational considerations will determine the best location for installing a given technology. Information in this report can be used as input to evaluate alternatives and make such determinations.

### **EPRI Perspective**

The case studies in this report demonstrate that the potential biological effectiveness and engineering practicability of a given technology will be site-specific. The studies also demonstrate that a technology's effectiveness will be strongly influenced by species and life stages to be protected, plant design and operating characteristics, and environmental factors of a geographic location and waterbody type.

## **Approach**

In updating its 2004 report, EPRI conducted a comprehensive literature search and surveyed industry and resource agency professionals for information on technology evaluations. EPRI reviewed the information for relevance and summarized appropriate publications and personal communications describing the evaluations and effectiveness results. The focus of these efforts was to disseminate information on the evaluation and application of existing and emerging fish protection technologies installed at CWISs. For those technologies that have not been fully developed, EPRI identified additional information to better define their potential effectiveness. Additionally, many studies have occurred at other types of water intakes or have evaluated technologies in controlled experiments or field trials. Such research also is included in this report.

## **Keywords**

Clean water act §316(b)  
Fish protection technologies  
Best technology available (BTA)  
Cooling water intake structures



# CONTENTS

---

<b>1 INTRODUCTION.....</b>	<b>1-1</b>
Section 316(b) of the Clean Water Act .....	1-1
Purpose of Technology Review .....	1-2
Approach and Report Organization .....	1-2
Future Direction .....	1-5
<b>2 TRAVELING WATER SCREENS.....</b>	<b>2-1</b>
Introduction .....	2-1
Unmodified Traveling Screens.....	2-2
Modified Traveling Screens .....	2-3
Case Studies – CWIS Application .....	2-12
Dunkirk Steam Station .....	2-12
Huntley Steam Station .....	2-20
Salem Generating Station.....	2-27
Potomac Generating Station – Geiger Screen .....	2-30
Calvert Cliffs Nuclear Power Plant .....	2-37
Somerset Station .....	2-38
Arthur Kill Station .....	2-40
Oswego Steam Station .....	2-45
Belle River Power Plant.....	2-47
Roseton Generating Station .....	2-49
Brayton Point Station .....	2-55
Prairie Island Generating Plant.....	2-57
Big Bend Station .....	2-59
Indian Point Generating Station.....	2-66
Brunswick Steam Electric Plant.....	2-73
Danskammer Point Generating Station .....	2-78
Mystic Station .....	2-82
Barney M. Davis Power Station .....	2-83
Bowline Point Generating Station.....	2-86

Oyster Creek Generating Station .....	2-91
Hanford Reservation.....	2-93
Surry Power Station.....	2-95
Case Studies – Laboratory Studies .....	2-96
Laboratory Study, Redondo Beach, CA .....	2-96
Laboratory Study, ESEERCO / Alden Research Laboratory.....	2-105
Laboratory Study, Tennessee Valley Authority .....	2-105
Laboratory Study – EPRI / Alden.....	2-107
Laboratory Study – Hydrolox / Alden.....	2-114
<b>3 STATIONARY SCREENS .....</b>	<b>3-1</b>
Introduction .....	3-1
Case Studies – CWIS Application .....	3-1
Bruswick Steam Electric Plant.....	3-1
<b>4 DRUM SCREENS .....</b>	<b>4-1</b>
Introduction .....	4-1
Rotary Drum Screens .....	4-1
Angled Rotary Drum Screens .....	4-1
Case Studies – Rotary Drum Screens - Water Diversion Field Tests .....	4-4
Eagle Point Irrigation District .....	4-4
Irrigation Canal No. 1, City of Yakima, WA.....	4-4
Patterson Irrigation District .....	4-4
Pacific Power and Light .....	4-4
Various Sites – Idaho.....	4-5
Woodbridge Fish Facility .....	4-5
Glenn-Colusa Irrigation District.....	4-5
Savage Rapids Diversion System .....	4-5
Case Studies – Rotary Drum Screens – Hydroelectric Field Tests .....	4-6
White River Hydroelectric Plant.....	4-6
Case Studies – Angled Rotary Drum Screens – Water Diversion Field Tests .....	4-6
Yakima River Basin .....	4-6
<b>5 CYLINDRICAL WEDGEWIRE SCREENS .....</b>	<b>5-1</b>
Introduction .....	5-1
Case Studies – CWIS Application .....	5-3
Logan Generating Plant.....	5-3
Cope Station .....	5-5

Eddystone Generating Station.....	5-5
Jeffrey Energy Center.....	5-6
Chalk Point Station .....	5-9
Charles Point Recovery Facility.....	5-11
Oyster Creek Nuclear Generating Station .....	5-11
St. John's River, FL .....	5-13
J. H. Campbell, Unit 3.....	5-14
Case Studies – Hydroelectric Application.....	5-14
Arbuckle Mountain Hydroelectric Project.....	5-14
Case Studies – Laboratory and Field Evaluations.....	5-15
Laboratory Test EPRI/EPA, Alden Research Laboratory.....	5-15
Laboratory Evaluation – Delmarva Power and Light .....	5-20
Field Evaluation - Narragansett Bay, RI; Portage River, OH; and Chesapeake Bay, VA .....	5-25
<b>6 BARRIER NETS .....</b>	<b>6-1</b>
Introduction .....	6-1
Case Studies – CWIS Application .....	6-6
Dallman Generating Station, Lake Springfield, Illinois .....	6-6
Bowline Point Generating Station, Hudson River, New York .....	6-7
Chalk Point Station .....	6-10
J.P. Pulliam Plant, Fox River, Wisconsin.....	6-12
Laskin, Colby Lake/Partridge River, Minnesota .....	6-14
Baker River, Baker River, Washington.....	6-15
Arkansas Nuclear One, Dardanelle Reservoir, Arkansas .....	6-16
LaSalle County Generating Station, Cooling Pond, Illinois .....	6-16
Crystal Falls, Paint River, Michigan.....	6-16
Highline Irrigation Canal, Highline Lake, Colorado.....	6-17
Case Studies – Hydroelectric Application.....	6-17
Ludington Pumped Storage Plant, Lake Michigan, Michigan.....	6-17
Pine Hydroelectric Project, Pine River, Wisconsin .....	6-19
Brule Hydroelectric Project, Brule River, Wisconsin.....	6-21
Hayward Hydroelectric Project, Namekagon River, Wisconsin.....	6-22
Banks Lake, Columbia River, Washington .....	6-22
Puntledge Hydroelectric Project, British Columbia.....	6-23
<b>7 AQUATIC FILTER BARRIER.....</b>	<b>7-1</b>
Introduction .....	7-1

Case Studies – CWIS Application .....	7-2
Lovett Generating Station .....	7-2
Bethlehem Energy Center .....	7-7
Case Studies – Field Evaluations .....	7-7
Pisces .....	7-7
Case Studies – Laboratory Evaluations.....	7-8
NYSDEC .....	7-8
Electric Power Research Institute – Alden Research Laboratory, Inc.....	7-9
<b>8 POROUS DIKES.....</b>	<b>8-1</b>
Introduction .....	8-1
Case Studies.....	8-1
Wisconsin Electric Power Plants – CWIS Field Test.....	8-1
Brayton Point – Laboratory and Field Trials .....	8-2
Laboratory Evaluation – Kinetrics .....	8-3
Laboratory Evaluation – Consumers Power .....	8-4
<b>9 FISH PUMPS .....</b>	<b>9-1</b>
Introduction .....	9-1
Case Studies – CWIS Application .....	9-1
Darlington Nuclear Generating Station.....	9-1
Sioux Power Plant .....	9-2
Monroe Power Plant .....	9-7
Case Studies – Water Diversion Applications .....	9-9
Red Bluff Research Pumping Plant.....	9-9
Tracy Fish Collection Facility .....	9-17
Case Studies – Hydroelectric Application.....	9-24
R. H. Saunders Generating Station .....	9-24
Case Studies – Laboratory Evaluations.....	9-24
Laboratory Study – Ontario Hydro.....	9-24
Laboratory Study – ESEERCO.....	9-26
Laboratory Study – Nine-mile and Mystic Stations.....	9-31
<b>10 ANGLED SCREENS.....</b>	<b>10-1</b>
Introduction .....	10-1
Case Studies – CWIS Application .....	10-3
Oswego Steam Station .....	10-3
Brayton Point .....	10-5

Danskammer Point .....	10-7
Case Studies – Hydroelectric Application.....	10-9
White River Hydroelectric Project.....	10-9
Weeks Falls Hydroelectric Project.....	10-12
Case Studies – Laboratory and Field Studies .....	10-13
Field Study Newhalen River, Alaska .....	10-13
Laboratory Evaluation – U.S. Fish and Wildlife Creston National Fish Hatchery.....	10-15
Laboratory Study, Redondo Beach, CA .....	10-18
Laboratory Study – ESEERCO.....	10-22
Laboratory Study – Tennessee Valley Authority .....	10-25
Laboratory Study – Alden Research Laboratory .....	10-27
Laboratory Study - California.....	10-30
Laboratory Study – University of California, Davis .....	10-30
<b>11 HIGH VELOCITY SCREENS.....</b>	<b>11-1</b>
Introduction .....	11-1
Modular Inclined Screens (MIS) .....	11-1
Eicher Screens.....	11-2
Case Studies – Hydroelectric Field Application.....	11-3
Green Island .....	11-3
Puntledge Hydroelectric Project .....	11-4
T. W Sullivan Plant .....	11-5
Elwha Hydroelectric Project.....	11-6
Case Studies – Laboratory Studies .....	11-8
Laboratory Study – Denver, CO .....	11-8
EPRI / Alden Laboratory Study.....	11-13
Hydraulic Model Study – Alden .....	11-13
EPRI / University of Washington Laboratory Study.....	11-14
<b>12 ANGLED BAR RACKS AND LOUVERS .....</b>	<b>12-1</b>
Introduction .....	12-1
Introduction .....	12-1
Case Studies – Hydroelectric and Water Diversion Applications .....	12-2
Grand Falls – Windsor Hydroelectric Project.....	12-2
T. W. Sullivan Hydroelectric Project .....	12-6
Vernon Hydroelectric Station .....	12-6
Tracy Fish Collection Facility .....	12-7

---

Holyoke Canal – Hadley Falls Hydroelectric Project .....	12-9
Red Bluff Diversion Dam .....	12-10
Case Studies – Laboratory Evaluations.....	12-13
EPRI / Alden Research Laboratory Study .....	12-13
Laboratory Evaluation – EPRI / Alden Research Laboratory .....	12-19
Laboratory Evaluation – Alden Research Laboratory.....	12-21
Laboratory Evaluation - Conte Anadromous Fish Research Center .....	12-23
Laboratory Evaluation - Conte Anadromous Fish Research Center .....	12-24
Laboratory Study – Alden Research Laboratory .....	12-25
Laboratory Study – Redondo Beach Generating Station .....	12-25
<b>13 LIGHTS .....</b>	<b>13-1</b>
Introduction .....	13-1
Strobe Lights.....	13-1
Mercury Lights .....	13-9
Other Light Sources .....	13-13
Case Studies – Strobe Light – CWIS Field Tests .....	13-17
Milliken Steam Electric Station .....	13-17
Roseton Generating Station .....	13-18
Pickering Generating Station.....	13-20
Case Studies – Strobe Light – Hydroelectric/Water Diversion Field Tests .....	13-21
Hiram M. Chittenden Locks .....	13-21
White Rapids Hydroelectric Project.....	13-22
Burbank 3 Intake Channel .....	13-22
McNary Dam .....	13-23
Mattaceunk Hydroelectric Project.....	13-23
Four Mile Hydroelectric Project .....	13-25
Rolfe Canal Hydroelectric Project.....	13-25
Fort Halifax Hydro-Electric Station .....	13-26
York Haven Hydroelectric Project.....	13-27
Hadley Fall Hydroelectric Project .....	13-30
Puntledge Generating Station .....	13-30
Rocky Reach Dam.....	13-31
Seton Creek.....	13-32
Case Studies – Strobe Light – Cage and Open Water Tests.....	13-32
Dworshak Dam .....	13-32
Kingsford Hydroelectric Project .....	13-34

Hiram M. Chittenden Locks .....	13-35
Roza Diversion Dam .....	13-37
Ludington Pumped Storage .....	13-38
R. H. Saunders Generating Station .....	13-39
Case Studies – Strobe Light – Laboratory Studies .....	13-40
Laboratory Study - Saimaa Fisheries Research and Aquaculture Station, Finland .....	13-40
Laboratory Study – Pacific Northwest National Laboratory (PNNL) .....	13-42
Laboratory Study – University of Maryland .....	13-43
Laboratory Study – San Onofre Nuclear Generating Station .....	13-44
Laboratory Study – Lee County Hyacinth Control District .....	13-45
Laboratory Study - Marine Biology Unit at Fawley, U.K. ....	13-46
Laboratory Study – EPRI / University of Washington .....	13-46
Laboratory Study – EPRI / University of Iowa .....	13-48
Laboratory Study, McIninch and Hocutt .....	13-48
Laboratory Study – Ontario Hydro .....	13-49
Laboratory Study - Simon Fraser University .....	13-50
Case Studies – Mercury Light – Hydroelectric Field Tests .....	13-52
Weldon Dam, Mattaceunk Project .....	13-52
Various Dutch Stations and Water Bodies .....	13-52
York Haven Hydroelectric Project .....	13-53
Poutès Dam .....	13-53
Wanapum Dam .....	13-54
Wapatox Canal Fish Screening Facility .....	13-54
Hadley Falls Hydroelectric Project .....	13-56
Annapolis Tidal Generating Station .....	13-57
Bellows Falls Hydroelectric Project .....	13-57
Priest Rapids Dam .....	13-58
Cabot Station .....	13-58
Case Studies – Mercury Lights – Cage Studies .....	13-59
Kingsford Hydroelectric Station .....	13-59
Case Studies – Mercury Lights – Laboratory Studies .....	13-60
Laboratory Study – EPRI / University of Washington .....	13-60
Laboratory Study – Ontario Hydro .....	13-61
Case Studies – Other Light – Hydroelectric Field Tests .....	13-61
Richard B. Russell Pumped Storage Project .....	13-61
Halsou Hydroelectric Plant .....	13-62

---

Various Hydroelectric Projects in the Northeast – Weldon Dam, Mattaceunk Hydroelectric Project, Rolfe Canal, Pejepscot Hydroelectric Project, Cabot Station .....	13-62
Rosa Diversion Dam.....	13-62
Case Studies – Other Light – Cage Tests .....	13-63
Kingsford Hydroelectric Project .....	13-63
Case Studies – Other Light – Laboratory Studies .....	13-63
Laboratory Study – University of Maryland.....	13-63
Laboratory Study - Marine Biology Unit, Fawley, UK .....	13-64
Laboratory Study – EPRI / University of Washington.....	13-65
Laboratory Study – San Onofre Nuclear Generating Station .....	13-65
<b>14 SOUND .....</b>	<b>14-1</b>
Introduction .....	14-1
Sound.....	14-1
Infrasound.....	14-2
Case Studies – Sound – CWIS Field Trials.....	14-6
Doel Nuclear Power Plant, Scheldt Estuary, Belgium .....	14-6
James A. Fitzpatrick Power Plant.....	14-7
Salem Generating Station.....	14-8
Arthur Kill Generating Station .....	14-10
Case Studies – Sound - Hydroelectric/Water Diversion Field Tests .....	14-11
White Rapids Hydroelectric Project.....	14-11
Cresent and Visher Ferry Hydroelectric Project.....	14-12
Kingsford Hydroelectric Project .....	14-12
Hiram M. Chittendon Locks .....	14-13
Richard B. Russell Pumped Storage Project.....	14-14
Pejepscot Hydroelectric Project.....	14-15
Georgiana Slough.....	14-15
Institute of Freshwater Ecology’s River Laboratories, Frome River, Dorset, UK and Blantyre Hydroelectric Station.....	14-17
Bonneville Dam.....	14-18
Fort Halifax Hydroelectric Project.....	14-18
York Haven Hydroelectric Project.....	14-19
Vernon Hydroelectric Project.....	14-19
Hadley Falls Hydroelectric Project.....	14-21
Wilkins Slough Pumping Station.....	14-21
Racine Hydroelectric Plant .....	14-22
Berrien Springs Hydroelectric Project and Buchanan Hydro Project .....	14-22



Lennox Generating Station .....	14-23
Seton Hydroelectric Station .....	14-24
Allegheny Reservoir.....	14-24
Case Studies – Sound - Cage and Open Water Tests .....	14-25
Hiram M. Chittendon Locks .....	14-25
Arthur Kill Generating Station .....	14-25
Cage Tests – NYPA and ESEERCO .....	14-26
Pickering Nuclear Generating Station .....	14-27
Manimota Bay, Japan .....	14-28
Case Studies – Sound – Laboratory Studies.....	14-28
Laboratory Study - Kinectrics .....	14-28
Case Studies – Infrasound – CWIS Application .....	14-29
Lake Borrevann, Norway; Tihange Nuclear Power Plant, River Muese, Belgium.....	14-29
Case Studies – Infrasound – Hydroelectric Tests .....	14-30
Kingsford Hydroelectric Project .....	14-30
McNary Dam.....	14-31
Roza Dam.....	14-31
Rolfe Canal Hydroelectric Project.....	14-32
Small Hydroelectric Intake, Sandvikselven, Norway .....	14-33
Case Studies – Cage and Open Water Tests.....	14-34
Laboratory and Field Study, River Imsa, Norway.....	14-34
Hiram M. Chittenden Locks .....	14-36
Sommaroyhamn, Norway .....	14-37
Case Studies – Infrasound – Laboratory Studies .....	14-37
Laboratory Study – Pacific Northwest National Laboratory (PNNL).....	14-37
Laboratory Study, Oregon State University .....	14-38
Laboratory Study, Norway .....	14-39
<b>15 AIR BUBBLE CURTAINS .....</b>	<b>15-1</b>
Introduction .....	15-1
Case Studies – CWIS Field Tests .....	15-2
Indian Point Generating Station.....	15-2
Roseton Generating Station .....	15-5
Pickering Nuclear Generating Station .....	15-5
Case Studies – Hydroelectric Field Tests.....	15-6
White Rapids Hydroelectric Project.....	15-6
Four Mile Hydroelectric Project .....	15-6

---

Seton Hydroelectric Station .....	15-6
Case Studies – Laboratory Studies .....	15-7
River Frome, UK .....	15-7
Laboratory Studies, Various Locations .....	15-10
Laboratory Study – Alden .....	15-11
<b>16 HYBRID BEHAVIORAL BARRIERS.....</b>	<b>16-1</b>
Case Studies – Field Evaluations .....	16-1
Deleware Bay – PSEG / Alden Research Laboratory .....	16-1
Case Studies – Laboratory Evaluations.....	16-7
Laboratory Study – PSEG / Alden Research Laboratory .....	16-7
Laboratory/Hatchery Facility, Illinois Department of Natural Resources.....	16-15
Laboratory Study - Kinetrics .....	16-17
<b>17 OTHER FISH PROTECTION TECHNOLOGIES.....</b>	<b>17-1</b>
Introduction .....	17-1
Inclined Plane Screen .....	17-1
Filtrex Candles .....	17-1
Case Studies – Field Applications .....	17-2
Taunton River, Dighton, MA .....	17-2
Case Studies – Laboratory .....	17-5
Alden Research Laboratory .....	17-5
Guidance Walls .....	17-12
Turbulence .....	17-12
Electrical Barriers.....	17-13
Case Studies – Laboratory Evaluation .....	17-14
<b>18 SPECIES / TECHNOLOGY CROSS REFERENCE TABLE.....</b>	<b>18-1</b>
<b>19 REFERENCES.....</b>	<b>19-1</b>