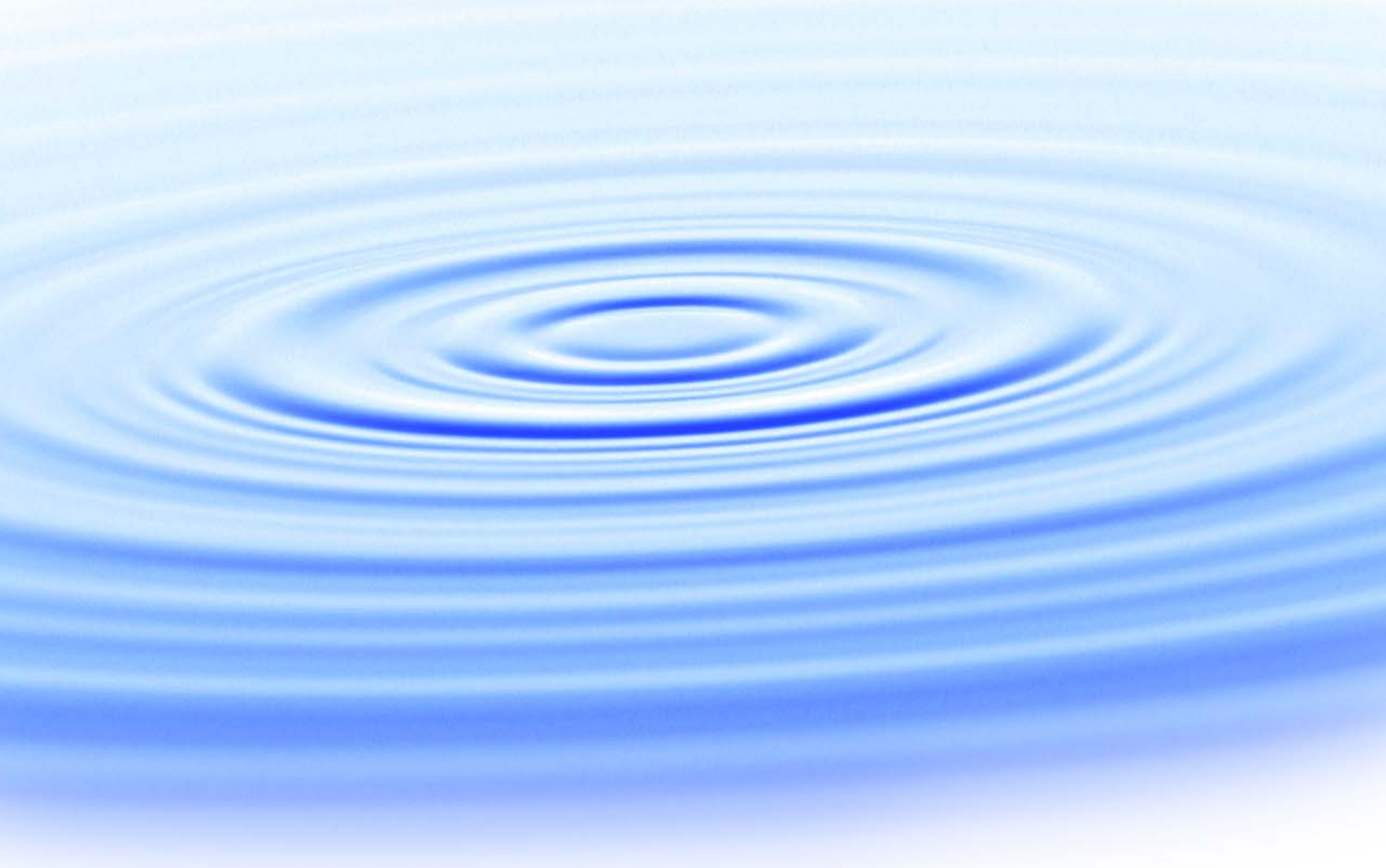
Impingement Mortality and Entrainment (IM&E) Reduction Guidance Document for Existing Seawater Intakes



WateReuse Research Foundation

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About the WateReuse Research Foundation

The mission of the WateReuse Research Foundation is to conduct and promote applied research on the reclamation, recycling, reuse, and desalination of water. The Foundation's research advances the science of water reuse and supports communities across the United States and abroad in their efforts to create new sources of high-quality water through reclamation, recycling, reuse, and desalination while protecting public health and the environment.

The Foundation sponsors research on all aspects of water reuse, including emerging chemical contaminants, microbiological agents, treatment technologies, salinity management and desalination, public perception and acceptance, economics, and marketing. The Foundation's research informs the public of the safety of reclaimed water and provides water professionals with the tools and knowledge to meet their commitment of increasing reliability and quality.

The Foundation's funding partners include the Bureau of Reclamation, the California State Water Resources Control Board, the California Energy Commission, and the California Department of Water Resources. Funding is also provided by the Foundation's subscribers, water and wastewater agencies, and other interested organizations.

Impingement Mortality and Entrainment (IM&E) Reduction Guidance Document for Existing Seawater Intakes

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Abbreviations and Acronyms

ACEC	areas of critical and environmental concern
AEL	adult equivalent loss
AFB	aquatic filter barrier
BACIP	before–after/control–impact paired
BARDP	Bay Area Regional Desalination Project
BPJ	best professional judgment
BTA	best technology available
CCC	California Coastal Commission
CDFG	California Department of Fish and Game
CDP	Carlsbad Desalination Plant
CEQA	California Environmental Quality Act
CFD	computational fluid dynamics
CP&L	Carolina Power and Light
CWA	Clean Water Act
CWIS	cooling water intake structure
CWWS	cylindrical wedgewire screen
DOC	debris organism collection
DWIS	desalination water intake structure
EIA	environmental impact assessment
EIR	environmental impact report
EOEEA	Executive Office of Energy and Environmental Affairs, Massachusetts
EPA	Environmental Protection Agency, United States
EPRI	Electric Power Research Institute
EPS	Encina Power Station
ERP	environmental resource permit
ESA	Endangered Species Act
ETM	empirical transport model
FDEP	Florida Department of Environmental Protection
FFS	Filtrex filter system
FFWCC	Florida Fish and Wildlife Conservation Committee
FGE	fish guidance efficiency
FH	fecundity hindcast
HCD	head capsule depth
I&E	impingement and entrainment
IM	impingement mortality
IM&E	impingement mortality and entrainment
LCP	local coastal program

MBNMS	Monterey Bay National Marine Sanctuary
MIS	modular inclined screen
MLES	Marine Life Exclusion System
MMWD	Marin Municipal Water District
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NYDEC	New York State Department of Environmental Conservation
O&M	operation and maintenance
OPC	Ocean Protection Council, California
ORW	outstanding resource waters
OTC	once-through cooling
RIS	representative important/indicative species
RWQCB	Regional Water Quality Control Board
$SCWD^2$	City of Santa Cruz Water Department and Soquel Creek Water District Desalination Program
SLC	State Lands Commission, California
SONGS	San Onofre Nuclear Generating Station
SWRCB	State Water Resources Control Board
TCEQ	Texas Commission on Environmental Quality
TECO	Tampa Electric Company
TRDP	Taunton River Desalination Plant
TSV	through-screen velocity
TWS	traveling water screen
USFWS	U.S. Fish and Wildlife Service
WBMWD	West Basin Municipal Water District
WIP	Water Intake Protection

Glossary of Terms

Term	Definition
316(b)	Section of the Clean Water Act that requires that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impacts
adult equivalent loss (AEL)	A demographic model that equates the number of fish eggs and larvae lost as a result of intake operation to an equivalent number of adults of the same species
airburst	Passive screen air backwash system, typically associated with wedgewire screens
approach velocity	Average water velocity in a channel upstream of a screen or other obstruction
aquatic filter barrier	A fish protection technology composed of permeable geotextile fabric used as a physical barrier to protect organisms from entrainment. With very low through-fabric velocities, impingement can be all but eliminated. Application as an intake technology is limited by the large surface area and substantial support structures required.
area of production foregone	A demographic model that calculates the area of spawning habitat required to offset the number of eggs and larvae lost as a result of intake operation
barrier net	A fish protection technology composed of netting material to exclude aquatic organisms from an intake withdrawal. Mesh size is variable but typically limited to 0.25-in. bar (0.5-in. stretch) mesh.
bar screen	A stationary bar rack that is automatically cleaned by one or more dedicated power-operated rakes
beach well	An intake well making use of coastal aquifer strata as a filter medium
behavioral system	Intake protection technologies that function on the premise that some species can be repelled from an intake or attracted to a safe location away from the intake by various stimuli: light, sound, electricity, air bubbles, chemicals, velocity direction, turbulence (e.g., ultrasound for repelling herring)
benthic	Of or relating to the bottom of a water body, typically used to describe bottom-dwelling organisms
biofouling	Unwanted biological growth on submerged or water-filled structures such as intake pipes and canals
coarse screen	Screen with mesh greater than approximately 2.5 mm
collection system	Aquatic life protection technologies designed to actively collect impinged organisms from the intake and return them to the source water body (e.g., a modified traveling water screen with fish return system)

diversion system	Aquatic life protection technologies designed to passively divert, collect, and return organisms from the intake to the source water body (e.g., angled screens with bypass)
drum screen	A cylindrical screening device used to remove floatable and suspended solids from water or wastewater
dual-flow screen	A traveling water screen arranged in a channel so that water enters through both the ascending and descending wire mesh panels and exits through the center of the screen
egg	The earliest life stage, which, for many species of fish, is planktonic (free floating, neutrally buoyant); other eggs may be demersal (bottom oriented, negatively buoyant)
entrainment	The passage of small organisms, including the eggs and larvae of fish and shellfish, through the screening structure at an intake
entrapment	The capture of organisms within an intake system between the intake terminus and the screening structure/technology
fecundity hindcast	A demographic model that calculates the number of fecund females required to produce the number of eggs and larvae lost as a result of intake operation
fine-mesh screen	Screen with mesh less than or equal to approximately 2.5 mm.
Gunderboom	Manufacturer of the Aquatic Filter Barrier (also known as Marine Life Exclusion System)
impingement	The retention of fish and other aquatic life on the surface of an intake screen when water velocity prevents escape
larvae	The early life stage of a fish between egg and juvenile
louver screen system	An exclusion device that consists of an array of evenly spaced, vertical slats aligned across a channel at a specified angle and leading to a bypass
modified traveling water screen	A traveling water screen modified to remove impinged fish and return them to the water body
open ocean intake	Reference to intake withdrawing seawater from the water column above the ocean bottom
offshore intake	Reference to the location of the point of water withdrawal relative to the shoreline
passive screen	Intake screening device that does not employ mechanical cleaning
physical barrier	A structure that prevents passage of aquatic organisms; the level of exclusion is determined by the open area and the size of the organism
plankton	Small, passively floating or weakly swimming animal and plant life of a body of water
porous dike	A physical barrier composed of rock or other material that is loosely packed and allows water passage but restricts passage of aquatic organisms
production foregone	A demographic model that calculates the area of spawning habitat required to offset the number of eggs and larvae lost as a result of intake operation

restoration	An action to replace or restore an area to equivalent or previous ecological productivity, usually associated with offsetting adverse environmental impact
Ristroph screen	See modified traveling water screen
shoreline intake	Reference to the point of water withdrawal
subsurface intake	See sub-seabed intake
sub-seabed intake	An intake located below the seabed surface
target species	A subset of aquatic organisms exposed to an intake that are selected for impact assessment
through-screen velocity	The velocity of fluid passing through the open area of a screen
trash screen	A screen placed in a waterway to prevent the passage of large debris, typically consisting of a series of steel bars oriented at an angle slightly less than vertical
traveling water screen	Automatically cleaned screening device employing chain-mounted wire mesh panels to remove floating or suspended solids from a channel of water
velocity cap	The horizontal cap on a vertical, offshore water intake that results in a horizontal inflow, thus reducing fish impingement
wedgewire	General term to describe trapezoidal or V-shaped wire
wedgewire screen	A (usually) cylindrical passive screen constructed of wedgewire

Foreword

The WateReuse Research Foundation, a nonprofit corporation, sponsors research that advances the science of water reclamation, recycling, reuse, and desalination. The Foundation funds projects that meet the water reuse and desalination research needs of water and wastewater agencies and the public. The goal of the Foundation's research is to ensure that water reuse and desalination projects provide high-quality water, protect public health, and improve the environment.

An Operating Plan guides the Foundation's research program. Under the plan, a research agenda of high priority topics is maintained. The agenda is developed in cooperation with the water reuse and desalination communities, including water professionals, academics, and Foundation subscribers. The Foundation's research focuses on a broad range of water reuse research topics including:

- Definition of and addressing emerging contaminants
- Public perceptions of the benefits and risks of water reuse
- Management practices related to indirect potable reuse
- Groundwater recharge and aquifer storage and recovery
- Evaluation and methods for managing salinity and desalination
- Economics and marketing of water reuse

The Operating Plan outlines the role of the Foundation's Research Advisory Committee (RAC), Project Advisory Committees (PACs), and Foundation staff. The RAC sets priorities, recommends projects for funding, and provides advice and recommendations on the Foundation's research agenda and other related efforts. PACs are convened for each project and provide technical review and oversight. The Foundation's RAC and PACs consist of experts in their fields and provide the Foundation with an independent review, which ensures the credibility of the Foundation's research results. The Foundation's Project Managers facilitate the efforts of the RAC and PACs and provide overall management of projects.

This project identifies intake technologies and modifications that have the potential to minimize the impingement mortality and entrainment (IM&E) of marine organisms at existing seawater intake structures. This report provides a detailed literature review of the various intake technologies used throughout the water-use industries (e.g., power plants) as well as the state and federal regulations that govern their operation. It is clear that many intake technologies can be used to retrofit existing intakes. Guidance on the intake modification/intake technology selection process, what to consider (biological performance, engineering practicability, cost, regulatory compliance, etc.), how to minimize risk while maximizing the potential for success, how to estimate the potential biological effectiveness of various intake alternatives, and how to measure reductions in IM&E after a modification has been made are included. In addition, the report comprehensively outlines the engineering considerations and costs of intake modifications. Two case studies provide real life examples of existing intakes that underwent successful modifications to reduce IM&E impacts.

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Executive Summary

Human population projections indicate that the demand for potable water will increase over time. This demand can be responsibly met through a diversified water supply portfolio, a component of which is desalinated water. Therefore, it is important to be mindful of the potential environmental impacts posed by desalination operations and prepare in advance to minimize these impacts. The operation of intake structures designed to supply feed water to the desalination treatment processes creates potential environmental impacts. In particular, the withdrawal of water poses a risk of IM&E of aquatic organisms residing in the source water body. Careful consideration of these potential environmental impacts is also critical because they can significantly affect facility economics by dictating intake type, size, location, and operational requirements as well as the type and magnitude of mitigation required to offset the impacts.

Goal

The goal of this project is to provide guidance on the intake technologies and modifications that have potential for mitigating IM&E of marine organisms at existing seawater intake structures. If existing intakes can be modified for desalination use, the seawater desalination industry can realize reduced capital costs associated with constructing new intakes.

Objectives

The specific objectives of this project are to:

- synthesize the available literature on intake technologies and their ability to reduce IM&E
- present case studies of sites where intakes have been modified to reduce IM&E
- provide guidance on how to evaluate intake technologies for reducing IM&E at existing intakes
- describe the methods for measuring IM&E reductions
- determine the costs associated with modifying intakes
- describe the likely permitting requirements for modifying intakes

Approach

This project began with a comprehensive literature review for papers associated with intake technologies and IM&E. The relevant intake-related regulations were reviewed. Case studies were then selected to demonstrate the reductions in IM&E achieved at real-world sites where intakes were modified. The team provided guidance on the steps to take and issues to consider when modifying various types of intakes. The available methods for measuring IM&E reductions were described based on best professional judgment (BPJ) and with limited input from regulators. In order to generate relative costs for different scenarios under which existing intakes can be modified, the team has developed 10 hypothetical intake modification designs. The designs are conceptual but include adequate detail to estimate relative costs.

Finally, intake permitting processes in the United States were reviewed to determine IM&E-related studies that may be required when considering an intake modification.

Results

Research was conducted to meet the listed objectives and then compiled into this final Guidance Document to be used by WateReuse Research Foundation subscribers. More than 375 references were identified during the literature review that pertains to intake technologies, IM&E, or both. These references were assembled into an annotated bibliography. In addition, all relevant federal and state regulations pertinent to IM&E are presented.

There are various intake technologies that can be used to retrofit existing intakes to reduce IM&E impacts. These technologies can be grouped into four main categories based on their mode of action. These categories include *behavioral systems*, which take advantage of natural behavior patterns to attract or repel fish; *exclusion systems*, which physically block fish passage; *collection systems*, which actively collect fish and return them to a safe release location; and *diversion systems*, which divert fish to a bypass for return to a safe release location. Details are given on the design, state of research and development, engineering and biological considerations, and costs of each technology as well as their potential utility for use at modified seawater intakes for desalination facilities. Table ES.1 provides an overview of the intake technologies that have been used at full-scale intakes for addressing concerns over IM&E; greater detail on each technology is provided in the body of the report.

Table ES.1. Summary of Intake Technologies That Have Been Used for Addressing IM&E

Technology Mode of Action	Technology	Has Been Used for Impingement	Has Been Used for Entrainment
Behavioral	sound	Y	N
	light	Y	N
	air bubble curtain	Y	N
	electric barrier	Y	N
	velocity cap	Y	N
Exclusion	aquatic filter barrier	Y	Y
	barrier net	Y	N
	porous dike	Y	Y
	narrow-slot wedgewire screens	Y	Y
	wide-slot wedgewire screens	Y	N
Collection	modified traveling water screens	Y	Y
	modified rotating drum screens	Y	Y
	Passavant-Geiger multidisc screens	Y	Y
	Hydrolox screens	Y	Y
	Beaudrey water intake protection screens	Y	Y
Diversion	angled bar rack/louver	Y	N
	angled screens	Y	Y

The logic behind the intake selection process comprises sequential steps designed to meet the core tenets of the language in Section 316(b) of the Clean Water Act. These tenets, and the focus of any intake selection process, include the location, design, construction, and capacity of the intake. Because the most likely existing seawater intakes that represent opportunities for desalination project proponents are power plant cooling water intake structures (CWIS), designing to Section 316(b) is the recommended approach. Selection of the best technology available is based on sound engineering and consideration of all applicable biological data.

Two case studies are presented in which power plant CWIS were modified to reduce IM&E. The power plants used as case studies were the Tampa Bay Electric Company's Big Bend Station, which retrofitted its intake with modified traveling water screens (TWS) with 0.5 mm mesh, and Brunswick Steam Electric Power Plant, which retrofitted its intake with a diversion screen with 9.4 mm openings and modified TWS with 1.0 mm mesh.

Estimating the biological efficacy of an intake technology is best done using existing empirical data from the same site, other sites, or other evaluations (e.g., laboratory and pilot-scale studies). In an ideal situation, data are available for each alternative under consideration and each of the numerically dominant species and life stages; however, this is seldom the case. More often, data are available for some species and technologies and lacking for others.

Therefore, the process of estimating potential biological effectiveness of a given alternative involves the use of available data in two ways:

- direct application for those species or life stages that are potentially impinged or entrained at the site under consideration
- extrapolation of the data to other species or life stages for which no data exist

In cases where no data are available, the potential biological efficacy (i.e., exclusion and survival) can be estimated for candidate intake technologies using the morphological and physiological characteristics of the target organisms for protection.

The most direct method for measuring reductions in IM&E is to compare IM&E abundances before and after the modification. Other indirect techniques include using demographic models to extrapolate raw data into an equivalent number of adult fish; comparison of adult fish can yield a measure of effectiveness for the modification.

Costs for intake modifications can vary depending on: (1) the size, location, configuration, and operational status of the existing intake; and (2) the scenario under which the desalination intake is installed. In each scenario, the existing intake was a power plant CWIS. Both shoreline and offshore intake configurations were considered. In addition, the team investigated how the operational status (operational or decommissioned) affected the intake modification design. Cost for the various intake modification scenarios ranged between $2,088,000 and $6,636,000 for a desalination facility with an intake designed to withdraw 100 MGD. The least expensive intake modifications were those completed at CWIS undergoing upgrades to meet 316(b) performance standards; the most expensive were those that required significant structural modification of the existing intake's footprint. The existing intakes that hold the greatest potential for desalination development are decommissioned CWIS with intake capacities sufficient to accommodate desalination water intake structure flows without any major structural modification to the CWIS. When an intake is being considered for modification to meet IM&E performance standards, there are a number of supporting data that may be required. These data may already exist; if they do not, the onus will be on the project proponent to conduct the requisite studies to collect them. The studies may include baseline characterization of the source water body, impingement studies, or entrainment studies.

Application

The use of existing intakes for collecting source seawater for desalination is a viable means of reducing capital costs of desalination project development in the United States. The most critical step is identifying an existing CWIS that can be rededicated for desalination use. There are multiple intake technologies available for modifying intakes to reduce IM&E; depending on the site under consideration, some technologies will clearly have advantages (biological or engineering) over others. This Guidance Document provides a means to evaluate a number of intake modification options, taking into account not solely cost but also biological performance and permitting feasibility to make an informed decision about how to develop a desalination facility using an existing seawater intake.

Chapter 1

Introduction

Human population projections indicate that the demand for potable water will increase over time. This demand can be responsibly met through a diversified water supply portfolio, a component of which is desalinated water. Therefore, it is important to be mindful of the potential environmental impacts posed by desalination operations and prepare in advance to minimize these risks. The operation of intake structures designed to supply feed water to the treatment processes is one of the potential environmental impacts present in the desalination industry. In particular, the withdrawal of water poses a risk of impingement mortality and entrainment (IM&E) of aquatic organisms residing in the source water body. Careful consideration of these potential environmental impacts is also critical because they can significantly affect facility economics by dictating intake type, size, location, and operational requirements as well as the type and magnitude of mitigation required to offset the impacts.

The most significant impacts to aquatic organisms caused by desalination intake structures are broadly categorized into (1) impingement and (2) entrainment. Each represents an interaction between the organisms in the source water body and the screening technology, and each is dependent on organism and screen mesh size. Impingement is the entrapment of larger organisms against the screen mesh by the flow of the withdrawn water. The magnitude of impingement losses for any species from intake operation is a function of the involvement of the species with the intake (number or proportion impinged) and the subsequent mortality of those organisms (referred to as impingement mortality [IM]). Entrainment is the passage of smaller organisms through the screening mesh. The magnitude of entrainment losses for any species from intake operation is a function of the involvement of the species with the intake (number or proportion entrained) and the subsequent mortality of those organisms as they pass through the process equipment (referred to as entrainment mortality). Entrainment mortality in desalination treatment processes is 100%.

A third term, entrapment, is often used when describing impacts associated with offshore intake structures. These structures are typically composed of an offshore pipe riser covered with a velocity cap, a long intake tunnel, and an onshore screening facility. Organisms that pass through the offshore velocity cap and are unable to escape the intake velocity in the tunnel are often referred to as entrapped. They have technically been entrained into the intake system, but their ultimate fate has not yet been determined. Depending on the mesh size of the screens at the onshore screening facility, these organisms can impinge on or entrain through the final screen mesh. Furthermore, unless the onshore screening facility includes a fish return system to transport impinged fish safely back to the source water body, they are considered entrainment mortalities.

Commonly accepted definitions of entrainable and impingeable organisms, as they are used in the United States, are listed here:

<u>Impingeable organism</u>: large enough to be retained by a 9.5 mm mesh screen. This includes larger, actively moving, juvenile and adult organisms.

<u>Entrainable organism</u>: small enough to pass through a 9.5 mm mesh screen. This includes small organisms with limited to no swimming ability. Some of these organisms (e.g., fish eggs) lack the ability to avoid the intake flow regardless of velocity.

1.1 Project Objective

The objective of this project is to identify and document modifications to existing seawater intakes that can reduce the impacts of IM&E. Producing potable water at a reasonable rate is the ultimate goal for the desalination industry. By looking towards existing seawater intake structures for use in the desalination industry, considerable capital cost savings can be realized, resulting in a decrease in produced water costs.

This Guidance Document evaluates all the available technological means for reducing IM&E impacts. In addition, it offers a comprehensive synthesis of literature pertinent to existing intake structures from the desalination industry as well as other water-use industries (e.g., power generation). Case studies demonstrating actual IM&E reductions achieved at intake structures that have undergone modifications are presented. Reviews of intake-related permitting and the methods for reliably measuring reductions achieved after modification are discussed. In addition, details are given on the costs associated with intake modifications. Finally, the reader is offered guidance on how the intake selection process works and what is considered at each step of this process.

As a whole, this Guidance Document is intended to provide the user with all the necessary details to make an informed decision about how to modify an existing intake to meet IM&E performance standards in a cost-effective and efficient manner. In addition, this document builds on previous intake-related work undertaken by the WateReuse Research Foundation (listed herein) in its effort to promote the responsible development of seawater desalination:

- Assessing Seawater Intake Systems for Desalination Plants (WRF, 2011a)
- Desalination Plant Intakes: Impingement and Entrainment Impacts and Solutions White Paper (WRF, 2011b)
- Overview of Desalination Plant Intake Alternatives White Paper (WRF, 2001c)

1.2 Lessons Learned from Existing Desalination Plant Intakes

Seawater desalination is relied upon heavily in many parts of the world for the production of potable water. In some regions, desalinated water constitutes the only reliable source for freshwater supply. The treatment approaches vary globally depending on a number of factors (e.g., energy requirements, fuel prices, feed water quality). Similarly, the feed water intake methods also vary considerably. Each intake approach has the potential to impact marine life through IM&E. Although intake-related impacts are typically considered the greatest desalination-related impacts in the United States, the discharge of brine is typically considered the principal desalination-related impact in other parts of the world. It follows that there are considerable data available relative to IM&E at seawater intakes (primarily in the power generation industry) in the United States but a paucity of such data elsewhere. It is important to note, therefore, that without biological monitoring data, determining the IM&E reduction efficiency of any intake is not possible.

The following section provides a brief overview of general approaches to reducing IM&E at seawater intakes used by existing desalination plants throughout the world. The use of subsurface intakes is not discussed; only screened, open ocean intakes are addressed in this study.

1.2.1 Offshore Capped Intake

Locating an intake's point of withdrawal offshore may confer biological benefits to marine organisms and constitutes a conservative, albeit costly, approach to seawater intake design. Spawning and nursery areas are typically near shore or in marshes and tributaries; however, any offshore structure (anthropogenic or natural) can attract fish and other organisms. In addition, if the offshore intake structure is designed to be a true velocity cap (velocity through the coarse openings between 2 and 3.5 ft/sec), it would act as a behavioral barrier, further minimizing the capture of fish with sufficient swimming ability to avoid the intake flow.

In general, Australian and most other membrane reverse osmosis desalination plants worldwide use offshore capped intakes (Figure 1.1). For the most part, the intakes are all of a similar design. The intake systems are composed of a long tunnel or pipe leading offshore to a riser that is covered with a cap and has a coarse bar screen. Feed water drawn through the tunnel or pipes is screened to a finer level at an onshore screening house. Fine-mesh (e.g., 3 mm mesh at Gold Coast Desalination Plant) screens collect debris and impinged marine organisms. Unless the onshore screens in such an intake system have a fish return system, impinged organisms are likely to be disposed of with the debris (i.e., 100% IM). Organisms smaller than the size of the mesh of the traveling water screens (TWS) will be entrained into the process equipment downstream of the intake and will be lost (i.e., 100% entrainment mortality).

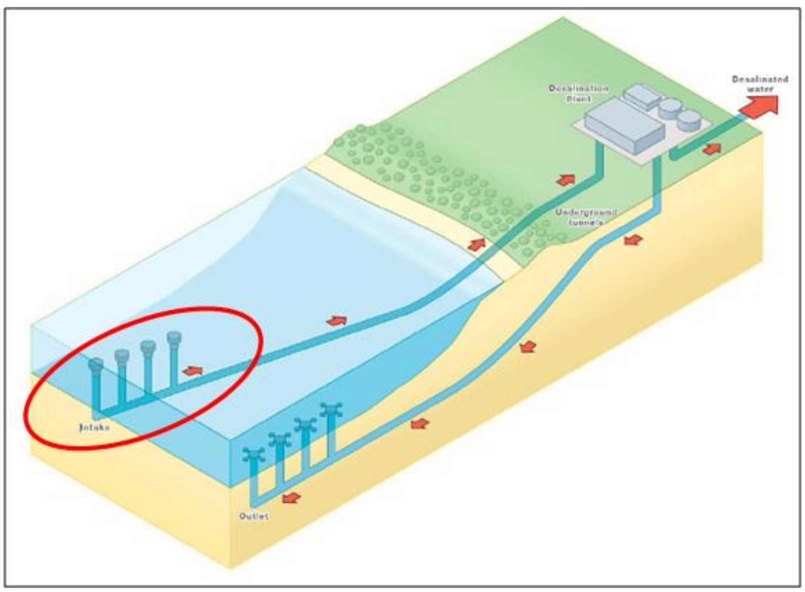


Figure 1.1. Schematic of an offshore velocity cap intake.

Source: Victorian Government Department of Sustainability and Environment, Melbourne, 2008

No data are available on the levels of IM&E at offshore capped intakes of existing desalination plants; it is therefore difficult to verify the biological effectiveness of these types of offshore intake systems. That said, it has been demonstrated in the United States that properly designed velocity caps can significantly reduce IM (see Section 3.1.2.6). In addition, entrainment impacts may also be reduced because the withdrawal point is located away from biologically productive near-shore areas. Locating an intake's withdrawal point offshore and at an appropriate water depth is good environmental practice. In addition, deep offshore intakes typically provide better quality feed water than onshore intakes, which should translate to decreased pretreatment costs.

1.2.2 Shoreline Intake

Another common intake location for desalination plants is at the shoreline (Figure 1.2). For example, some of the large thermal desalination facilities throughout the Middle East have large shoreline intakes to provide the requisite feed water flow. The shoreline intakes often follow conventional designs: a canal or lagoon-type intake basin with a screening house composed of conventional TWS (may be dual-flow, through-flow [Figure 1.2], or center-flow). For the most part, these conventional TWS are not equipped with fish protection features (e.g., fish collection buckets on the screen panels' faces, low pressure spray-wash system, fish collection and return trough); rather, the screenings (fish and debris) are cleared from the screen and disposed of.

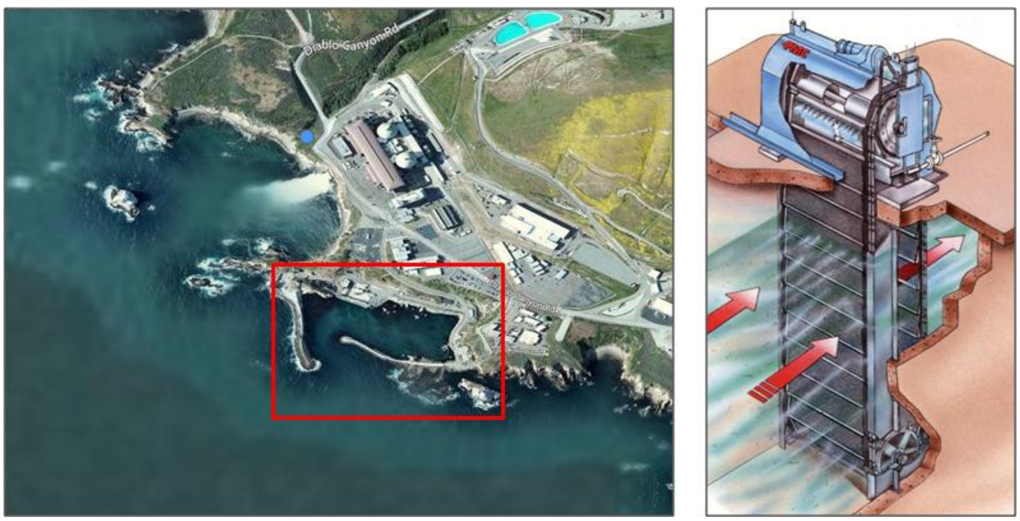


Figure 1.2. Shoreline intake lagoon (L) at the Diablo Canyon Power Plant in CA and (R) conventional traveling water screen.

Sources: (L) www.bingmaps.com; (R) U.S. Filter

Conventional TWS are effective for removal of debris from the source water and preventing the downstream equipment from clogging; however, without fish protection features, conventional TWS do not offer benefits in regard to IM&E impacts. Implementation of conventional TWS without fish protection features would likely not be considered good environmental practice for seawater intake systems in the United States. Other intake technologies are available to meet IM&E reduction goals.

1.2.3 Other Intake Designs

1.2.3.1 Hybrid Intake

In addition to offshore capped intakes and shoreline intakes, there are various other designs utilized by existing desalination plants. For example, at the Thames Gateway Desalination Plant (Beckton Plant) in the United Kingdom, an exclusion technology (cylindrical wedgewire screens [CWWS]) and a behavioral technology (sound) are used in combination to protect aquatic organisms from IM&E (Pankratz, 2009). The CWWS have 3 mm slots and are designed for a through-slot velocity of 0.5 ft/sec. Though no biological efficacy data are currently available, this conservative design should aid in minimizing IM&E. In particular, the 3 mm CWWS are expected to prevent the entrainment of many smaller organisms, and the low through-slot velocity would essentially eliminate impingement of larger organisms. The acoustic deterrence system is expected to provide a benefit to those organisms with both the sensitivity to the sound signal generated and the swimming ability to mount an avoidance response to it. Use of a hybrid intake protection system, such as the one in use at the Beckton Plant, may constitute good environmental practice in cases where a developer can use a broadband (exclusion technology) and a species-specific approach (acoustics) to protect the target species at the intake.

1.2.3.2 Cylindrical Wedgewire Intake

In the United States., the use of offshore CWWS has been investigated. With low through-slot velocities and small screen slot sizes, CWWS have strong potential to minimize IM&E impacts at seawater desalination plant intakes. Currently, there are no existing desalination plant intakes that have data on the effectiveness of CWWS, but there have been a number of recent pilot-scale studies conducted in California that have collected data. Section 3.2.2.5 provides summaries of the recent wedgewire screen effectiveness studies conducted for seawater desalination plants proposed by the Marin Municipal Water District (MMWD), the City of Santa Cruz Water Department and Soquel Creek Water District ($SCWD^2$), and the West Basin Municipal Water District (WBMWD).

1.2.3.3 Co-located Intake

Co-location of desalination facilities and power generation facilities is a common practice throughout the world that provides an economic benefit because both facilities share a common intake. In many cases where seawater reverse osmosis (SWRO) plants are co-located with thermal desalination plants, cooling water from the thermal plant is used as feed water to the SWRO plant, thereby reducing the overall volume of seawater collected from the water body. In the United States, co-located desalination plants are designed to collect warm cooling water from the power plant discharge, which is already pre-screened. In the case of the Tampa Bay desalination plant, a small volume (10 to 15%) of cooler ambient seawater is collected at the existing power plant intake to reduce the temperature of feed water to the desalination plant in the summer when temperatures exceed 95 °F.

If developed as a new combined desalination/power project, a state-of-the-art intake system can be incorporated; however, if a desalination facility is to be co-located at an existing power generation facility, careful consideration must be given to the design and operation of the existing intake. In many cases, a simple retrofit of the TWS may be an effective approach for modifying an existing intake to reduce IM&E. If the existing intake uses conventional TWS without fish protection features, it may be possible to replace the screens with TWS that do have fish protection features without making major modifications to the civil structures. As would be expected, if tangible reductions in IM&E can be made through screen replacement rather than major intake reconstruction, it would be considered both good environmental and engineering practice.

1.2.4 Intake Survey Results from WateReuse Research Foundation Study

The WateReuse Research Foundation (2011a) conducted a survey to summarize the experiences of utilities in ocean intake planning, design, and implementation. The survey amassed responses from 24 utility managers. Of the screening technologies described in the survey, 67% of respondents stated they prefer vertical TWS, and 52% stated they prefer velocity caps (more than one technology could be selected by respondents). Respondents were also asked whether they had conducted or intended to conduct an IM&E study. Nearly all of the installed or operating plants responded that they planned to conduct such studies. The reported duration of the IM&E studies ranged from 15 to 39 months.

Chapter 2

Literature Review

There are numerous publications, reports, and conference papers on the intake technologies used to minimize IM&E of organisms at large industrial water intakes. Much of this information has been obtained from once-through cooled, steam electric, power generation.facilities. To a lesser degree, the hydroelectric power industry has also evaluated intake technologies used to protect organisms from IM&E. A review of the literature available, therefore, includes a search for relevant material in multiple water-use industries.

A comprehensive literature search was performed. The literature search focused primarily on U.S. intakes, though international facilities (e.g., Australian) were also included when appropriate. The search began by developing a list of keywords (Table 2.1).

Table 2.1. Keywords for Literature Search

316(b)	environmentally friendly intake	mercury lights
air bubble curtains	Filtrex candles	MIS
angled bar racks	fine-mesh screens	modular inclined screen
angled barriers	fish pumps	once-through screens
angled louvers	flat-panel wedgewire	Passavant-Geiger screens
angled rotary drum screens	Fletcher modified screen	porous dikes
angled screens	flow velocity enhancement system	Ristroph
aquatic filter barrier	Geiger screens	rotary drum screens
barrier nets	guidance walls	seawater intake
Beaudrey screens	hybrid behavioral barriers	sills
Beaudrey Water Intake Protection screen	Hydrolox screens	skimmer walls
center-flow screens	impingement	sound
cooling water intake structure	inclined plane screens	stationary screens
cylindrical wedgewire	infiltration intakes	strobe lights
drum screens	infrasound	traveling water screens
dual-flow screens	intake	turbulence
Eicher screens	intake modification	ultrasound
electric barriers	intake structure	velocity cap
entrainment	louvers	velocity induced guidance
entrapment	marine life exclusion system	wedgewire screens

A comprehensive group of abstract databases, journals, and libraries was developed (Table 2.2). These sources were searched using the keywords listed in Table 2.1.

Table 2.2. Literature Sources Searched

Source	**Description**
Alden in-house library	More than 7,000 references on fish protection and industrial water intakes
Abstract Databases	
Aquatic Sciences and Fisheries Abstracts	Materials from 1965 to present in the field of aquatic sciences and fisheries, including social, economic, and legal aspects
Commonwealth Agricultural Bureau (CAB) abstracts	Materials from 1910 to present in the field of applied life sciences and agriculture
Agricola	Materials from 1970 to present in the fields of agriculture, plant and animal sciences, forestry, entomology, soil and water resources, agricultural economics and engineering, alternative farming, and nutrition
Zoological Record Plus	Materials from 1864 to present in the fields of zoology and animal science
Web of Science	Materials from 1900 to present in the fields of arts and humanities, social sciences, and science
Civil Engineering Database	Provided by the American Society of Civil Engineers (ASCE) with material published by ASCE related to a large variety of engineering topics from 1970 to present
Google Scholar	Scholarly materials from various disciplines
Journals	
Desalination	Dedicated to communicating the latest developments in desalination and advanced water purification
International Desalination Association Journal on Desalination and Water Reuse	Includes peer-reviewed articles on the technical and scientific aspects of desalination
Journal of Water Reuse and Desalination	Publishes refereed review articles, theoretical and experimental research papers, new findings, and issues of unplanned and planned reuse
International Journal of Nuclear Desalination	Develops, disseminates, and exchanges scientific, technical, and economic knowledge relative to the use of nuclear energy for the production and social use of freshwater

As applicable literature was identified, the full reference was entered into the bibliography. Every effort was made to obtain the original paper, although in some cases only a reference or abstract was available. For each entry, a brief annotation was provided describing the content of the paper. The full citation and the annotation were entered into an Excel-based annotated bibliography. Columns in the annotated bibliography provide the facility name, source water body, type of intake technology, and type of study (e.g., lab-, pilot-, or full-scale).

The literature review produced approximately 375 references related to intake protection technologies employed at industrial water intakes. The majority of these references are related to CWIS used at steam electric power plants. The annotated bibliography also includes literature related to other types of industrial water intakes (e.g., hydroelectric power plants) in cases in which the intake technology discussed could be applied to seawater desalination intakes. For example, louvers are a popular technology to guide fish downstream at hydroelectric power plants, but they can also be used at steam electric power plants. Such is the case at the San Onofre Nuclear Generating Station (SONGS) that draws cooling water from the Pacific Ocean and has an onshore intake structure that incorporates louvers to guide fish to a bypass system. Therefore, in cases where literature presents information on the biological performance and design criteria of an intake technology that is applicable to desalination, the reference was included.

The results of the literature review are presented in two forms: (1) an annotated bibliography (on attached CD) and (2) as part of Chapter 3. Some of the literature included in the annotated bibliography provides information on the biological and/or engineering performance of the intake technology, which represents a critical aspect of an intake modification. Greater detail on the individual intake technologies represented in the annotated bibliography is provided in Chapter 3.

2.1 Annotated Bibliography

Results of the literature review were tabulated in an annotated bibliography, which was created in Microsoft Excel and can be sorted by literature reference, facility name, source water body for the intake, and intake technology. Each bibliographic entry includes a brief annotation to describe the contents of the work. The annotated bibliography is provided on an attached CD.

2.2 Federal and State Intake Regulations Relative to IM&E

There are a number of regulatory and resource agencies that are involved in regulating the impacts of seawater intakes on marine organisms. However, there is no federal directive in the United States that directly regulates the operation of stand-alone desalination intake structures; the regulation occurs predominantly at the state level. Therefore, the level of environmental protection afforded aquatic organisms can vary by state. These variations in the regulatory landscape contribute substantially to project uncertainty and make selecting, designing, and constructing a seawater desalination intake difficult for developers. In addition, when considering the modification of an existing intake (versus constructing a stand-alone intake) for use in a desalination project, the permitting and regulatory requirements may become even more diffuse depending on how the existing intake is currently being used (e.g., if it is supplying cooling water to a power plant). The following sections provide a critical overview of the pertinent federal and state regulations that could apply to the environmental impacts associated with the operation of seawater intakes for desalination. In most cases, only general guidance is available on acceptable levels of IM&E, particularly at the state level.

Table 2.3. Federal Regulations Associated with the Impacts of Seawater Intakes on Marine Organisms

Regulatory Agency	Potential Regulatory Permit, Authorization, or Approval	Permit/Approval	Comment
U.S. Army Corps of Engineers	Section 404 Clean Water Act Nationwide or Individual Permit	Required for discharges of dredged or fill material into waters of the United States.	Would apply if intake modification requires any dredging or filling work or "work or structures" in navigable waters; e.g., an existing shoreline intake being modified to an offshore wedgewire screen intake.
	Section 10 Rivers and Harbors Act Individual Permit	Required for building any pipelines, piers, wharfs, or other in-water structures in navigable waters.	
National Oceanic and Atmospheric Administration/National Marine Fisheries Service	Section 7 Consultation Under the Endangered Species Act	Required for any federal permitting agency that may adversely affect federally listed marine species or designated critical habitat.	A Section 7 consultation would be required for any intake modification that would potentially affect endangered species.
	Section 305(b) Consultation Under the Magnuson-Stevens Fishery Conservation and Management Act (also known as the Sustainable Fisheries Act)	Required for any federal or state approval that may adversely affect designated essential fish habitat.	
	Marine Mammal Protection Act	Required to protect all marine mammals from any source of take (direct or indirect).	
U.S. Fish and Wildlife Service	Section 7 Consultation Under the Endangered Species Act	Required for any federal permitting agency that may adversely affect federally listed species or designated critical habitat.	A Section 7 consultation would be required for any intake modification that would potentially affect endangered species.

U.S. Environmental Protection Agency (EPA)	Clean Water Act, Section 316(b)	Required for ensuring compliance of intake with federal performance standards. Designed to minimize adverse environmental impacts to marine life.	Although Section 316(b) is a federal regulation, it is implemented at the state level, typically through the National Pollutant Discharge Elimination System permitting process.
	National Environmental Policy Act (NEPA)	Required to ensure that federally funded actions with potential to affect the environment undergo a comprehensive environmental review process.	Although EPA has a role in reviewing all NEPA documents, the lead federal agency is selected based on the nature of the action undertaken.
U.S. Coast Guard (USCG)	Approval for structures in navigable waters	Required to ensure that intake components/structures in navigable waters do not pose risks to navigation.	USCG approvals would be more important for intake modifications that move components of the intake system offshore. The intent is to ensure that the offshore structures are clearly marked, maintain sufficient submergence at all water levels, and can be indicated on nautical charts.

2.2.1 Federal Regulations

Table 2.3 lists the federal regulations associated, directly or indirectly, with the impacts of seawater intakes on marine organisms. Although some of the federal regulations are not directly applicable to the seawater desalination industry, they have been or are likely to be applied at a state level and are therefore included in this review.

2.2.1.1 Clean Water Act Section 316(b)

Because many desalination facilities have been or will be proposed to be co-located with existing power plants, power plant intake regulations may therefore be applied to the desalination facility as well. CWIS at power plants fall under the federal Clean Water Act (CWA) which is administered by the U.S. Environmental Protection Agency (EPA). Section 316(b) of the CWA requires that the location, design, construction, and capacity of a CWIS reflect the "best technology available" (BTA) for minimizing adverse environmental impacts. In 2004, rulemaking by the EPA established new guidelines for the implementation of Section 316(b), known as the Rule, that required all CWIS to meet national performance standards relative to IM and in some cases entrainment (EPA, 2004a). The rulemaking was parsed into several phases: Phase I covered new power-generating facilities, Phase II covered existing power-generating facilities, and Phase III covered new offshore oil and gas extraction facilities that can withdraw 2 MGD or more of cooling water and withdraw at least 25% of the water exclusively for cooling. The Rule laid out benchmark performance standards for the reduction of IM&E.

The Phase II Rule covering existing power plants was remanded in January 2007 after a lawsuit by Riverkeeper, Inc., and temporary authority was given to states to use best professional judgment (BPJ) in issuing permits in the absence of a federal directive. During the litigation, two important components of 316(b) were found to be invalid: the use of restoration to mitigate IM&E impacts and the consideration of cost in determining BTA.

A new Rule is forthcoming from the EPA on November 4, 2013. Desalination intakes that are proposed to be co-located with power plant CWIS are likely to be held to the 316(b) performance standards set forth in this future Rule if such intakes operate in a stand-alone mode. If the desalination plant intake draws feed water from the power plant discharge, no additional IM&E impacts are expected to be imposed.

In cases where a desalination intake is not co-located with a power plant CWIS, it follows that some states will likely adopt the performance standards put forth in the new Rule, but others may not. Provisions of the federal 316(b) regulations are implemented at a state level through the issuance of a National Pollutant Discharge Elimination System (NPDES) permit. With some exceptions, desalination intakes designed to meet the future 316(b) performance standards should also be compliant with state regulatory requirements.

The proposed 316(b) Rule (as it currently stands) sets forth specific performance criteria for existing power plant intakes. At the time of this report, existing CWIS drawing greater than 2 MGD will be required to meet either:

- a 0.5 ft/sec through-screen velocity (TSV) criterion or
- limit IM to no more than 12% annually or 31% monthly (refers to the percentage of impinged fish that are killed; assumes that operator collects and holds impinged fish to determine latent mortality)

Because of site-specificity, entrainment of early life stages (eggs and larvae) will be reviewed on a case-by-case basis. Whether entrainment will be a concern will depend on the location of the intake. Some freshwater intakes may be exempted because they are not located in important spawning or nursery areas, but seawater (marine and estuarine) intakes will likely have to address regulatory concerns over entrainment. The features of the case-by-case entrainment standard will vary.

In addition, the proposed Rule indicates that facilities with offshore intakes or open channels or canals must provide a means of egress for entrapped fish. The following definition for entrapment is provided in the proposed Rule:

> *Entrapment means the condition where impingeable fish and shellfish lack the means to escape the cooling water intake system. Entrapment includes but is not limited to: organisms caught in the bucket of a traveling screen and unable to reach a fish return; organisms caught in the forebay of a cooling water intake system without any means of being returned to the source water body without experiencing mortality; or cooling water intake systems where the velocities in the intake pipes or in any channels leading to the forebay prevent organisms from being able to return to the source water body through the intake pipe or channel.* (EPA, 2011)

The means of egress in most cases will be a modified TWS designed to collect impinged fish and return them to the source water body. Greater resolution will be available on the implications of a new Rule to desalination intakes after it is finalized by the EPA in 2013.

2.2.1.2 Endangered Species Act

The Endangered Species Act (ESA) provides protection to threatened and endangered (federally listed) species of animals and plants. The ESA ensures that any federally authorized action has been reviewed for its potential to adversely impact any federally listed species or its critically designated habitat. The ESA is implemented at a federal level through the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service (National Marine Fisheries Service [NMFS]). Typically, the means of implementation of the ESA is through consultation with one of the resource agencies mentioned previously.

Seawater intakes for desalination will need to satisfy the requirements of the ESA. In the case of West Coast ocean desalinations sites, salmon are likely to be the ESA species of greatest concern to resource agencies. In the case of estuarine desalination facilities located in the San Joaquin/Sacramento River Bay Delta, the ESA species likely to be of greatest concern would include Pacific salmon and delta smelt (URS, 2003); however, Sacramento splittail and longfin smelt are also species of concern, though they are not federally listed at this time. The requisite consultation process entails engaging the federal agency with jurisdiction over the fisheries resource under consideration and presenting information to document whether the operation of the intake is likely to adversely impact protected species and to what degree. NMFS has jurisdiction over marine and anadromous species, whereas USFWS has jurisdiction over freshwater species; therefore, seawater desalination facilities are not likely to consult with the USFWS, only NMFS, in regards to marine species.

2.2.1.3 Marine Mammal Protection Act

The Marine Mammal Protection Act was passed in 1972 to protect all marine mammals from any source of take (direct or indirect). Therefore, depending on the location and design of the intake, there may also be concerns with impacts to protected marine mammals (Cooley, 2006). For example, the California sea lion would be afforded protection under the act, and provisions would have to be made to preclude its involvement with a seawater intake system. In fact, NMFS directed coastal power plants with histories of pinniped "takes" to apply for Incidental Take Permits, though NMFS has not since acted on those applications.

2.2.1.4 National Environmental Policy Act

The National Environmental Policy Act (NEPA) is a federal act with an established protocol for assessing the potential impacts to the environment from any federally funded activity (CADWR, 2008). Therefore, if a desalination facility receives federal funding in any form, it may be subject to a NEPA review. The act established within EPA the Council on Environmental Quality (CEQ). CEQ oversees NEPA and performs the following duties:

- gathering information on the conditions and trends in environmental quality
- evaluating federal programs in light of the goals established in Title I of the act
- developing and promoting national policies to improve environmental quality
- conducting studies, surveys, research, and analyses relating to ecosystems and environmental quality

Analyses of the potential environmental impacts under NEPA take the form of categorical exclusions, environmental assessments, and environmental impact statements. The intake-related issues that are likely to be part of a NEPA review are not likely to be different from the issues that would come under scrutiny during a 316(b)-type review. Therefore, the potential for a NEPA review does not pose an incremental regulatory effort beyond that which would already exist.

2.2.2 State Regulations

Intake-related regulations for desalination vary greatly from state to state throughout the United States. The following section provides an overview of the relative regulations for the states in which most of the seawater desalination progress has been made.

2.2.2.1 California

There are many state agencies in California that are involved with permitting of desalination intakes. The principal agencies involved with coastal or aquatic permits are the California Coastal Commission (CCC), which oversees implementation of the California Coast Act, Regional Water Quality Control Boards (RWQCB) and State Water Resources Control Board

(SWRCB), which oversee implementation of the California Water Code, and the State Lands Commission (SLC), which controls land use along the coast.

Porter-Cologne Act

The Porter-Cologne Act was enacted to:

> *…preserve, enhance, and restore the quality of the State's water resources. The Act established the State Water Resources Control Board and nine Regional Water Quality Control Boards as the principal state agencies with the responsibility for controlling water quality in California. Under the Act, water quality policy is established, water quality standards are enforced for both surface and ground water, and the discharges of pollutants from point and non-point sources are regulated. The Act authorizes the State Control Board to establish water quality principles and guidelines for long range resource planning including ground water and surface water management programs and control and use of recycled water.* (DOE, 2012)

Section 13142.5(b) of the Porter-Cologne Act contains language pertinent to desalination intakes. It requires that:

> *For each new or expanded coastal power plant or other industrial installation using seawater for cooling, heating, or industrial processing, the best available site, design, technology, and mitigation measures feasible shall be used to minimize the intake and mortality of all forms of marine life.* (SWRCB, 2013)

Therefore, seawater intakes (new or modified) for desalination would be regulated under this section of the act. The act further stipulates that "Independent baseline studies of the existing marine system should be conducted in the area that could be affected. (SWRCB, 2013)" Therefore, the expectation of preconstruction baseline data suggests that postconstruction IM&E monitoring will also be required. To that end, the IM&E monitoring requirements that are likely to be part of 316(b)-type compliance through the SWRCB should not differ greatly from what would be required by Section 13142.5(b) of the Porter-Cologne Act.

California Environmental Quality Act

The California Environmental Quality Act (CEQA) is a policy that establishes a protocol for assessing the potential impacts of development on the environment and determining the feasibility of avoiding these impacts. These assessments typically take the form of an environmental impact report (EIR) or environmental impact assessment (EIA; CCC, 2004; CADWR, 2008). During the preparation of an EIR or EIA, the potential impacts of the intake will have to be addressed as well as the alternatives to minimize the impacts. The lead agency in the CEQA review process will be designated based on the location and function of the facility. It has the responsibility of determining which environmental impact documents are required. No clear intake standards are described in this policy, though a comprehensive review of the potential impacts of the intake would certainly be part of any EIR under CEQA.

Monterey Bay National Marine Sanctuary

NOAA has issued guidelines for desalination plants in the Monterey Bay National Marine Sanctuary (MBNMS and NOAA, 2010). The guidelines do not amount to regulatory standards, but they do offer guidance on IM&E at the intakes. Although this document focuses on projects that would be constructed in the sanctuary, the guidelines provide a detailed description of what may be required for assessing and monitoring desalination intake impacts as part of the CEQA or NEPA review process. Relative to IM&E, MBNMS and NOAA (2010) state that developers should include the following in a project application:

- first investigate the feasibility of subsurface intakes (e.g., infiltration galleries, beach wells)
- if not feasible, investigate the feasibility of using an existing pipeline (presumably an abandoned one that would fulfill the intake requirements of the facility under consideration)
- if a new screened ocean intake is to be built, efforts must include:
- avoiding sensitive areas when selecting its location
- selecting the most appropriate screening mesh type
- including provisions to keep intake velocities low (e.g., larger intake ports, multiple intake ports)
- estimating IM&E based on available data for the area
- For unavoidable impacts to essential fish habitat and the species that use it, mitigation will have to be implemented.
- For co-located desalination plants, the developer will have to assess the impacts of the intake system as a stand-alone desalination structure in the event that the power plant is decommissioned

MBNMS and NOAA (2010) offer guidelines on the monitoring of intake impacts as well. They suggest that a postconstruction monitoring program should focus on developing a statistically acceptable baseline, monitor IM&E of marine organisms, and monitor any mitigation that may be part of the project. They suggest a monitoring period of no less than three years and state that the following studies should be part of intake monitoring for project applications:

- preconstruction biological analysis with consideration of seasonal variability of marine organisms in the affected area and control site to include ecological indices (e.g., species richness and abundance), along with evaluation of IM&E impacts
- operational monitoring of quantities (biomass and species) of marine organisms entrained and impinged, if applicable
- postconstruction biological analysis to compare to baseline
- mitigation plan including monitoring methodologies and success criteria

California Coastal Act

The California Coast Act was created to protect California's coastline. Whereas explicit permits would be required for activities associated with modification of an existing intake or construction of a new intake, the act does not have specific permit requirements that address IM&E. Rather, the CCC (2004) indicated that the coastal development permit process would likely include a review of potential environmental impacts for consistency with act policies. Policies in the act that are most applicable to IM&E at intakes are described in Sections 30230 and 30231, which discuss the maintenance of healthy marine resources and biological productivity. As stated by the CCC (2004), the following studies are likely to be required as a result of the California Coastal Act review process:

- feasibility of a subsurface intake design (e.g., infiltration gallery, beach wells), which may include bathymetric, geotechnical, and sediment transport investigations
- if a subsurface intake is not feasible, the project proponent would have to evaluate the feasibility of artificial cover (sand, gravel, cobble) at the screened ocean intake point.
- if a subsurface intake is not feasible, the following investigations for a screened ocean intake may be required:
- identify the best location to minimize impacts and what the entrainment impacts are likely to be there through an entrainment study or review of recent, local entrainment data
- engineering evaluations to determine:
    - that intake velocity is equal to or less than 0.5 ft/sec
    - if a velocity cap is appropriate
    - which screening technology is BTA
    - what type of mitigation approach will be viable for impacts that cannot be avoided

According to the CCC (2004), California's Desalination Task Force indicated that "…the siting of a new desalination facility, which utilizes any new or existing open water feed water intakes, will require a current assessment of entrainment and impingement impacts as part of the environmental review and permitting process."

The act also established local coastal programs (LCP), which allow local governments to oversee coastal development in their communities. After approval of an LCP by the CCC, development is monitored locally to allow for better conservation and use of coastal resources. Because the LCP oversees the location, type, and scale of new or changed uses of land and water, an intake modification is something that would undergo a review for consistency with the LCP in which it is proposed.

A coastal development permit is issued by the CCC. During a permit review, the CCC would require IM&E data (CCC, 2004) to quantify the impacts. In addition, the review process will require the developer to differentiate between the impacts of a co-located desalination facility operating in tandem with a power plant and a desalination facility operating as a stand-alone facility when the power plant is offline or decommissioned. Consideration of this "worst case" would likely be part of the comprehensive CEQA review and therefore would be addressed in an EIR.

State Water Resources Control Board and Regional Water Quality Control Boards

The SWRCB and RWQCB are responsible for issuing NPDES permits for desalination projects. Through the NPDES permitting process, either of the referenced state agencies can implement 316(b) provisions in regards to intake performance (Kelley, 2011). In the absence of a 316(b) Rule, the SWRCB has implemented a once-through cooling (OTC) policy that establishes two compliance alternatives, each of which may be applied to seawater desalination intakes in California. The key OTC policy provisions are as follows:

- Track 1: Existing intakes must be modified to reduce the flow rate by at least 93% and have a TSV of 0.5 ft/sec or less.
- Track 2: If Track 1 is not feasible (cannot include a consideration of cost), the operator must demonstrate a comparable level of IM&E reduction to what would be achieved in Track 1.
- For impingement mortality, this could be demonstrated through:
    - monthly verification of TSV of 0.5 ft/sec or less
    - impingement monitoring studies verifying that the reduction is at least 90% of that which would be achieved in Track 1
- For entrainment, this could be demonstrated through:
    - reductions in flow of 93%
    - entrainment monitoring studies verifying that the entrainment reduction is at least 90% of that which would be achieved in Track 1

In addition, the OTC policy dictates that, in the interim, large organism exclusion devices must be installed at offshore intakes with bar spacing of 9 in. or less and implement mitigation measures for unavoidable IM&E impacts.

In addition to implementing 316(b) regulations through the NPDES permit process, the SWRCB and RWQCB are also charged with ensuring consistency with the Porter-Cologne Act (described previously).

California Department of Fish and Game

California Department of Fish and Game (CDFG) has jurisdiction over state-listed species through the California ESA. CDFG would join the federal Section 7 consultation and provide input on the state-listed species that are of special concern. Under the Fish and Wildlife Coordination Act, the CDFG would also consult with federal resource agencies, such as USFWS, charged with protecting marine resources from loss or damage.

State Lands Commission

The California SLC is charged with overseeing development in coastal waters. Although a modified intake may require a modified lease agreement, there are no stipulations regarding the performance of the intake for minimizing IM&E.

Desalination Policy Currently Under Development

California is currently developing a state desalination policy through an amendment to the California Ocean Plan (SWRCB, 2012). The amendment will focus on addressing both intake- and discharge-related impacts and is anticipated to be complete by late 2013. The state anticipates that the amendment will have three primary focuses (SWRCB, 2011):

- a narrative objective for salinity
- limits on IM&E from desalination intakes
- an implementation policy

The limits to IM&E are important because they affect the ways in which existing intakes would have to be modified. The SWRCB has assembled an expert panel to aid in the development of intake-related guidelines. It will be very important to scrutinize the final amendments to the desalination policy to understand what the numerical IM&E requirements may be for desalination in California.

In addition to the efforts of the SWRCB, the California Ocean Protection Council (OPC) has issued a draft strategic plan that indicates that it will work collaboratively with the SWRCB in developing California's desalination policy (i.e., amendment to the California Ocean Plan). In particular, the OPC will be evaluating the potential for developing a desalination policy with IM&E goals that are consistent with the SWRCB's OTC policy finalized in 2010 (OPC, 2011).

2.2.2.2 Texas

In 2002, Texas launched its Seawater Desalination Initiative to develop a water supply through seawater desalination. Texas does not currently have any seawater desalination facilities in operation; however, the Texas Water Development Board has made efforts to demonstrate its potential. After initial feasibility studies, two pilot projects were performed; one in the Brownsville Ship Channel, completed by the Brownsville Public Utilities Board, and one on South Padre Island, by the Laguna Madre Water District. Each of these projects has been proposed for expansion into demonstration projects of 2.5 MGD (Brownsville) and 1 MGD (South Padre Island).

In anticipation of a complex regulatory process for demonstration and commercial-scale desalination projects, the board authorized the preparation of a scoping document (NRS, 2011) to help determine the environmental permitting process. This project, termed the "Texas Desal Project," identified 26 permits (state and federal) that would likely be required for implementation of a demonstration-scale desalination facility in the Brownsville ship channel. An appendix to this scoping document (NRS, 2011), titled "Draft Seawater Desalination Permitting Report," was included to outline the permits and compliance strategies likely to be required for demonstration- and full-scale desalination facilities. Of the 26 permits identified, none establish numerical IM&E standards. Although the appendix does not include specific information on IM&E reduction requirements, it does indicate that IM&E studies are likely to be required to identify the species and quantities of marine life potentially impacted by the intake.

Texas Commission on Environmental Quality

The Texas Commission on Environmental Quality (TCEQ) would likely be the lead agency if any applications were filed for a full-scale desalination facility. To date, the TCEQ has not developed any desalination intake regulations (Miramontes, TCEQ, personal communication, 2011), and it appears that IM&E standards will be developed on a case-by-case basis.

Texas Parks and Wildlife Department

The Texas Parks and Wildlife Department has jurisdiction over state-listed species and would join the federal Section 7 ESA consultation process to provide input on the state-listed species that are of special concern. Under the Fish and Wildlife Coordination Act, the Texas Parks and Wildlife Department would also consult with federal resource agencies, such as USFWS, charged with protecting marine resources from loss or damage (NRS, 2010).

2.2.2.3 Florida

Florida has the nation's first large seawater desalination plant, Tampa Bay Seawater Desalination Plant, co-located at the Big Bend Power Station in Tampa Bay. As the first large-scale desalination facility, it has already gone through the permitting process and provides a template of the state regulations likely to be applied to a desalination facility. However, because this desalination facility is co-located at a power plant and draws its feed water from the power plant's discharge stream, there were no explicit intake permitting requirements relative to IM&E. Rather, the special conditions of the revised NPDES permit required the implementation of a hydrobiological monitoring program of the plant discharge area. The monitoring program focused on impacts to water quality and biological resources (PBS&J, 2010; Owen, 2011).

Florida Department of Environmental Protection

The Florida Department of Environmental Protection (FDEP) is the state agency charged with implementing Section 316(b) regulations through the NPDES permit process. In the event that an intake would need to be modified, the NPDES permit would need to be revised to reflect the new use. The FDEP encourages the co-location of desalination facilities at power plants in order to reduce potential environmental impacts through the use of existing infrastructure.

Florida Fish and Wildlife Conservation Committee

The Florida Fish and Wildlife Conservation Committee (FFWCC) would coordinate with the FDEP on potential impacts of desalination intakes on marine resources (Younos, 2005). Therefore, IM&E standards and reduction requirements would be developed collaboratively between the FDEP and FFWCC. To date, however, no numerical standards exist describing the reductions in IM&E that would be required at a modified intake.

Environmental Resource Permit

An environmental resource permit (ERP) would be necessary to ensure that there are no adverse impacts to either the land or aquatic environment as a result of a desalination facility's operations. As such, the FDEP would be responsible for implementing 316(b) standards during the NPDES permit process to ensure compliance with the ERP (Malcolm Pirnie, 2011). See Section 2.2.1.1 for details on the IM&E reduction targets for the draft 316(b) Rule.

2.2.2.4 Massachusetts

The Executive Office of Energy and Environmental Affairs (EOEEA) has developed a draft policy regarding desalination facilities (EOEEA, 2007). The policy is intended to be used by all state regulatory agencies to aid in the coordination of the permitting process. Although the guidelines contained in the policy are available for developers, they do not constitute hard and fast regulatory requirements and are therefore subject to change based on site-specific considerations. The following is the general intent of the draft policy:

- The state upholds that "…under certain conditions desalinized water can be used as a potential source of water supply."
- The policy is designed to:
- ensure sound resource management in regards to water
- "…protect aquatic resources and their ecological integrity" (EOEEA, 2007)
- "…provide greater predictability of process and permitting requirements" (EOEEA, 2007)

The draft policy is composed of the following general principles:

- minimize potable water use and maximize water supply alternatives
- assess all other viable sources
- minimize environmental impacts
- encourage co-location of desalination plants with power or wastewater treatment plants
- consider regionalization of desalination facilities
- plan for growth

The policy further states that, in an effort to minimize intake impacts, the preference is for subsurface intakes in "…open, well-circulated waters, marine waters." (EOEEA, 2007) In addition, intakes should be located away from estuaries, areas of critical and environmental concern (ACEC), outstanding resource waters (ORW), fish passage corridors, and areas of fish and shellfish spawning and nursery habitat. The policy clearly indicates that intakes proposed within any of these areas will be held to very high performance standards in an effort to protect the resources; however, there are no specific performance standards in the state regulations (Callaghan, 2008).

In a more recent document, the EOEEA (2008) outlined the performance criteria and data collection that would likely be required for any desalination intakes and discharges. Although the document is only for informational purposes, it provides details on regulatory expectations relative to intake siting and impact monitoring.

Intake Siting

Relative to the siting of intakes, the EOEEA agencies may request maps of the resource areas depicting the potential intake locations under consideration. Once a location is selected, at least one year of baseline biological monitoring will be required. The preferred locations for intakes (and discharges) are outside of biologically productive areas such as estuaries, ACEC, ORW, fish passage corridors, and productive fish and shellfish habitat. If the intake is located outside of these areas, agencies will consider less stringent monitoring requirements.

Intake Operation

Relative to intake operation, the EOEEA agencies prefer subsurface intakes with an effective through-media intake velocity of zero. Where a subsurface intake is shown to be infeasible, the screened intake should be designed for the "…lowest approach/through-media velocity technologically achievable (~ 0.01–0.02 ft/sec or less) at all tides. (EOEEA, 2008)" in order to minimize IM&E. This is an intake velocity comparable to the design intake velocity of an aquatic filter barrier (AFB).

Intake Technologies for Minimizing IM&E

EOEEA agencies expect that subsurface intakes and AFB intakes will meet the intent of this policy and that wedgewire intakes will not:

> *It is expected that the substratum intake and filter fabric barrier control technologies outlined below can meet the desired environmental protocols of this policy (for e.g. see 1. A. II. "Intake Operation"). Currently, wedgewire screen technology does not meet all the protocols and therefore is not preferred.* (EOEEA, 2008)

If a subsurface intake is feasible, the preference is for horizontal directional drilling to minimize impacts. If a subsurface intake is infeasible, AFB is preferred over screens constructed of metal. If an AFB is infeasible, a CWWS meeting the following criteria is preferred over other technologies:

- slot size ≤0.5 mm
- located above the river, embayment, or ocean bottom to protect benthic organisms
- located in an area with sufficient sweeping flows or having a "passive fish return system to remove impinged organisms" (EOEEA, 2008)

Other intake technologies may be acceptable if they can be shown to have comparable or better biological performance.

Biological Monitoring

EOEEA agencies request one year of baseline monitoring prior to facility construction. In most cases, these requirements apply to both the intake and discharge. Table 2.4 summarizes the baseline biological monitoring requirements associated with the intake. In addition to these requirements for fish monitoring, surveys would also be required for shellfish and benthic invertebrates at the proposed intake (and discharge) location.

Table 2.4. Baseline Monitoring Requirements for Ambient Fish Populations Relative to Desalination Intakes in MA

	Ichthyoplankton monitoring			Juvenile/Adult monitoring			Benthic fish monitoring		
	Inside sensitive areas	Outside sensitive areas	Subsurface Intake	Inside sensitive areas	Outside sensitive areas	Subsurface Intake	Inside sensitive areas	Outside sensitive areas	Subsurface Intake
Mar 15 - Nov 15	3/week	1/week		2/week	1/week		2/month		none
Nov 16 - Feb 28	2/week	2/month		2/month	1/month				

Note: Requirements vary based on the location of the intake and whether a subsurface intake can be used (EOEEA, 2008).

Table 2.5. Long-Term Monitoring Requirements for Ambient Fish Populations Relative to Desalination Intakes in MA

	Ichthyoplankton monitoring			Juvenile/Adult monitoring			Benthic fish monitoring		
	Inside sensitive areas	Outside sensitive areas	Subsurface Intake	Inside sensitive areas	Outside sensitive areas	Subsurface Intake	Inside sensitive areas	Outside sensitive areas	Subsurface Intake
Mar 1 - Nov 15	3/week	reduced or eliminated		2/week	reduced or eliminated		2/month		reduced or eliminated
Nov 16 - Feb 28	2/week			2/month					

Note: Requirements vary based on the location of the intake and whether a subsurface intake can be used (EOEEA, 2008).

Table 2.6. Intake Monitoring Requirements (IM&E) Relative to Desalination Intakes in MA

	Entrainment monitoring		Impingement monitoring	
	Screened intake	Subsurface intake	Screened intake	Subsurface intake
Mar 1 - Nov 15	3/week	reduced or eliminated	3/week	reduced or eliminated
Nov 16 - Feb 28	2/week		2/week	

Note: Requirements vary based on the location of the intake and whether a subsurface intake can be used (EOEEA, 2008).

Long-Term Monitoring

EOEEA agencies also outline the long-term monitoring requirements for ambient populations after a desalination intake becomes operational (Table 2.5).

Intake Monitoring

EOEEA agencies also outline the intake monitoring requirements for impinged and entrained organisms at the intake (Table 2.6). No mention is made of holding impinged organisms to determine survival.

Massachusetts Environmental Policy Act

The Massachusetts Environmental Policy Act is implemented by the EOEEA and its intent is to ensure:

> *…that state agencies study the environmental consequences of their actions, including permitting and financial assistance. It also requires them to take all feasible measures to avoid, minimize, and mitigate damage to the environment.* (EOEEA, 2012)

The act is enforced by the EOEEA through input from multiple state agencies, including the Department of Environmental Protection, Office of Coastal Zone Management, Department of Fish and Game (Division of Marine Fisheries), and Department of Conservation and Recreation. Each of these agencies is likely to have input on the potential permitting requirements relative to intake performance for reducing IM&E.

2.2.2.5 New York

New York has no regulatory guidelines explicit to desalination intakes; rather, state agencies typically apply policies developed for CWIS for municipal water intakes and other industrial water withdrawals.

New York State Department of Environmental Conservation

The New York State Department of Environmental Conservation (NYSDEC) is the principal agency involved in the regulation of water intakes. NYSDEC oversees the environmental review process known as the State Environmental Quality Review. It issued a policy on the cooling water intake requirements for power plants (NYSDEC, 2011). This policy describes how the state evaluates the impacts caused by water intake structures. Furthermore, it indicates what reductions in IM&E are required for minimizing adverse environmental impacts. Though explicitly developed for CWIS, the policy has been and likely will be applied to any desalination developments.

The policy establishes closed-cycle cooling (or its equivalent) as the BTA for minimizing IM&E impacts at CWIS; however, because desalination facilities do not draw water for cooling purposes, they would likely have to achieve a comparable performance standard using a different intake technology. This means that the intake technology selected would have to provide "*…reductions in impingement mortality and entrainment from calculation baseline that are 90 percent or greater of that which would be achieved by a wet closed-cycle cooling system.*"

“Calculation baseline” is defined as

> *…an estimate of impingement mortality and entrainment that would occur at a facility CWIS assuming that: the cooling water system has been designed as a once-through system; the opening of the cooling water intake structure is located at, and the face of the standard 3/8-inch mesh conventional traveling screen is oriented parallel to, the shoreline near the surface of the source water body and is operated at the full rated capacity 24 hours a day, 365 days a year. This is the baseline of adverse environmental impact to be used in estimating reductions in impingement mortality and entrainment resulting from operating a closed-cycle cooling system.* (NYSDEC, 2011)

Therefore, a desalination facility would have to reduce IM&E by 90% of what could be achieved with closed-cycle cooling. Because closed-cycle cooling provides a reduction in flow between 93 and 98%, the reduction in entrainment of passive early life stages of organisms should be equivalent to the flow reduction (i.e., 93 to 98%). Achieving 90% of the 93 to 98% reduction that could be achieved with closed-cycle cooling would equate to an entrainment reduction of 84 to 88% from the calculation baseline. IM&E data from power plants indicate a weak and insignificant relationship between flow rate and impingement rates (Nieder, 2010; Loar et al., 1978); therefore, expecting a similar reduction in impingement is debatable.

Chapter 3

Identification of Key Intake Modification Technologies

There are various intake technologies that can be retrofitted at existing intakes to reduce IM&E impacts. These technologies can be grouped into four main categories based on their mode of action: *behavioral systems*, which take advantage of natural behavior patterns to attract or repel fish; *exclusion systems*, which physically block fish passage; *collection systems*, which actively collect fish and return them to a safe release location; and *diversion systems*, which divert fish to a bypass for return to a safe release location. The following subsections present a review of the various intake technologies in each of the four categories including:

- a description of the technologies in each general grouping
- a review of the research (biological and engineering performance) that has been conducted with each to date
- each technology's state of development
- a review of the engineering considerations when using each technology as a retrofit at an existing CWIS
- information on the costs of each technology (where available and typically only the capital costs, not operational costs because those are very site specific)
- some conclusions about each technology's general applicability as a modification technology for minimizing IM&E

Table 3.1 provides a summary of the intake technologies reviewed in this chapter.

Table 3.1. Summary of Key Intake Modification Technologies

Technology Mode of Action	Technology	Development (scale)	Used in a Marine or Estuarine Environment?	Reduces I?	Reduces E?	Considerations
Behavioral	sound	lab, pilot, and full	Y	Y	N	Application is site- and species-specific. *Alosa* spp. (herring) are the only species that demonstrate a consistent response to sound.
	light	lab, pilot, and full	Y	Y	N	Application is site- and species-specific. *Alosa* spp. (herring) are the only species that demonstrate a consistent response to light.
	turbulence	experimental	N	Y	N	Actively induced turbulence is considered experimental and would require additional evaluation.
	air bubbles	lab, pilot, and full	Y	Y	N	May be difficult to maintain an air bubble curtain in a turbulent marine environment. Holds potential when combined with other behavioral technologies.
	electric barrier	lab, pilot, and full	N	Y	N	The high conductivity of seawater would preclude its use at a marine intake.
	velocity cap	lab and full	Y	Y	N[1]	A velocity cap is a very good technology for consideration at a seawater intake. They have been shown to significantly reduce impingement and are generally inexpensive to retrofit on an existing offshore intake.

Technology Mode of Action	Technology	Development (scale)	Used in a Marine or Estuarine Environment?	Reduces I?	Reduces E?	Considerations
Exclusion	aquatic filter barrier (AFB)	lab, pilot, and full	Y	Y	Y	May be applicable in calm estuarine locations but not in turbulent marine environments. AFB uses very low flow rates, so there are practical limitations to withdrawal rates.
	barrier net	lab, pilot, and full	Y	Y	N[2]	May be appropriate at estuarine sites that are protected from the open ocean.
	conventional traveling water screens	full	Y	N	N	Does not offer fish protection.
	narrow-slot wedgewire screens	lab, pilot, and full	Y	Y	Y	Wedgewire screens are a very good technology to consider for IM&E protection at seawater intakes. Site-specific pilot-scale testing may be required to select the best anti-biofouling materials for construction and identify the best locations in relation to ambient currents.
	wide-slot wedgewire screens				N[3]	
	Filtrex filter system	lab and pilot	Y	Y	Y	This technology is still considered experimental. It has been used at one desalination intake. Further refinement of cleaning mechanisms may be necessary.
	porous dike	lab, pilot, and full	Y	Y	Y	The fate of the organisms that are prevented from being entrained is unknown. Some portion of the organisms that have limited or no motility may be lost within the internal structure of the dike.

Technology Mode of Action	Technology	Development (scale)	Used in a Marine or Estuarine Environment?	Reduces I?	Reduces E?	Considerations
Collection	modified traveling water screens (TWS)	lab, pilot, and full	Y	Y	Y[4]	Modified TWS are very good technologies to consider for IM&E protection at seawater intakes. Traveling screens modified for fish protection are a commercially available and well-accepted technology for minimizing adverse environmental impacts and constitute a very good technology to consider for modifying existing seawater intakes. Modified rotating drum screens are commonly used in Europe but not in the United States.
	modified rotating drum screens					
	Passavant-Geiger multidisc screens					
	Hydrolox screens					
	Beaudrey Water Intake Protection (WIP) screens					
Diversion	angled bar rack/louver	lab, pilot, and full	Y	Y	N	Not a good candidate for retrofit because of the civil/structural modifications likely required at an existing intake. A transport system would be required to return diverted organisms back to a safe release location.
	modular inclined screens (MIS)/Eicher screens	lab and pilot[5]	N	Y	N[6]	Not a good candidate for retrofit because of the civil/structural modifications likely required at an existing intake. No data on the performance of the technology at full-scale seawater intakes.
	angled screens	lab, pilot, and full	N	Y	Y[7]	

Notes: 1=In cases where the point of withdrawal is moved from onshore to offshore, there may be some reduction in entrainment associated with moving the location of the intake. 2=Depending upon mesh size, some reduction in entrainment of small juvenile fish may occur. 3=There may be some reduction associated with moving the point of withdrawal. In addition, low through-slot velocity and ambient hydraulic conditions may reduce total entrainment.4=Ability to prevent entrainment will be dependent upon the mesh size selected, the site-specific size distribution of the eggs and larvae, the screen's tolerances relative to side seals, boot seals, and gaps between baskets, and hydraulic conditions. Survival of entrainable-sized organisms impinged on the fine mesh will depend upon the species life stage and physiological condition of the organisms. 5= Eicher screens have been used at full scale in hydroelectric applications. 6=Some reduction in entrainment may occur as a result of the narrow-slot wedgewire used (MIS are typically designed with 2.0 mm wedgewire). However, there have been no studies undertaken to measure biological effectiveness of earlier life stages of fish at the high velocities under which these screens are designed to operate. 7=The degree of entrainment reduction will be dependent upon the slot- or mesh-size selected. E=entrainment; I=impingement

3.1 Behavioral Technologies

3.1.1 General Description

Behavioral systems function on the premise that some fish species can be repelled or attracted by various stimuli. Behavioral barriers that have received research focus over the years include sound, light, turbulence, air bubbles, electricity, chemicals, and flow velocity. In particular, sound, strobe lights, and air bubble curtains have been shown to effectively repel particular species of fish. Critical to the effectiveness of behavioral barriers is the target organism's ability to mount a directional response to the stimulus. As such, these technologies are only effective with later life stages of fish (i.e., juveniles and adults) because early life stages (i.e., eggs and most larvae) may have little to no ability to overcome the hydraulic influence of the withdrawn flow regardless of whether they can sense the behavioral stimulus. Therefore, behavioral barriers alone or in combination cannot be considered as alternatives that will effectively address entrainment of early life stages of organisms at seawater intakes. Behavioral barriers may be appropriate for minimizing the impingement of juveniles and adults that have been shown to be sensitive to behavioral stimuli.

In addition to the effectiveness of behavioral barriers as a function of species and life stage, there are practical engineering constraints as well. For example, strobe lights function optimally in water with low turbidity; as turbidity increases, the effective range of the light emitted decreases. As such, engineering design considerations as well as the overall cost of the technology must be included in any evaluation.

3.1.2 List of Behavioral Technologies

3.1.2.1 Sound

There are two components to sound propagation through water: particle displacement and sound pressure. Particle displacement, the to-and-fro movement (on the order of nanometers) of water molecules, is a vector quantity, whereas sound pressure, the oscillatory change in pressure above and below hydrostatic pressure, is a scalar quantity acting in all directions (Feist and Anderson, 1991).

<u>Description of Technology</u>

Underwater sound has been evaluated as a fish deterrent for application at water intakes for more than 40 years. Three types of sound systems have been extensively evaluated: (1) ultrasonic (>80 kHz), which is high frequency sound near or beyond the upper end of human hearing; (2) sonic (100 Hz to 5 kHz), which is audible to humans; and (3) infrasonic (<100 Hz), which is too low for humans to hear but can be felt as vibrations.

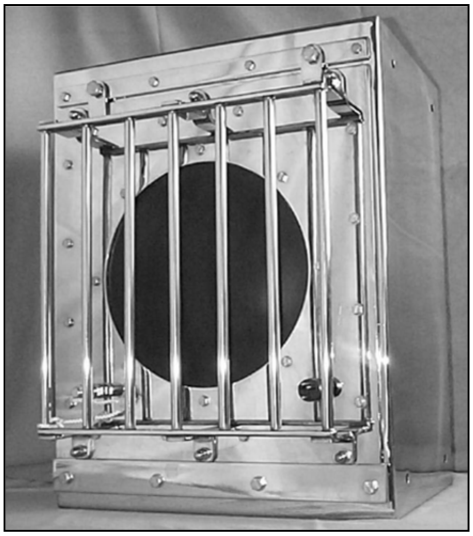


Figure 3.1. Sound projector that operates in the sonic range from Fish Guidance Systems, Ltd.
Source: Turnpenny et al., 2008

Brief Review of Research

The most successful applications of sound have involved the use of ultrasonic signals (>100 kHz) to repel species of the genus *Alosa* (e.g., alewife, blueback herring, and American shad juveniles; Nestler et al., 1992; Ross et al., 1993, 1996). The strong response of Alosids has been attributed to specialized hearing abilities that are only found in this genus of fish.

There is no evidence that any species other than those in the genus *Alosa* can hear frequencies above about 4 to 5 kHz. Consequently, lower frequency sonic signals (typically between 100 Hz and 1 kHz) have been evaluated as a deterrent to anadromous salmonids and estuarine and riverine fishes (Electric Power Research Institute [EPRI], 1998; Goetz et al., 2001; Maes et al., 2004; PSEG, 2005). Results from these studies have been mixed, but generally sonic systems are not considered a viable technology for repelling most fish species at water intakes in the United States. Conversely, a sonic system developed by Fish Guidance Systems, Ltd. (FGS), 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).

There is some evidence that infrasound may be effective for repelling some species. In the near field, fish response to sound is more related to particle motion than acoustic pressure (Kalmijn, 1988). The particle motion component of infrasound is the primary deterrent in the near field and what fish most likely sense (and respond to) when exposed to infrasonic signals. 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 a small diversion channel. Later field tests in the United States produced mixed results with anadromous salmon, and it was concluded that infrasound did not hold good potential for repelling fish at water intakes. Conversely, research in Belgium has indicated that there may be potential for repelling some freshwater species (particularly cyprinids) with infrasound at cooling water intakes (Sonny et al., 2006). In addition to the mixed results of biological studies, the effective range of infrasound (10 to 30 ft) may be an issue at some power plants where velocities may be too high for fish to respond before being impinged. Additional testing with other species and at other sites is needed before infrasonic generators can be seriously considered for application at cooling water intakes.

There have been many studies evaluating the effectiveness of sound as a behavioral deterrent. These studies have evaluated the full sound spectrum (i.e., infrasonic, sonic, and ultrasonic), and the results were very species-specific. If impingement is dominated by a species that has a proven response to sound (e.g., *Alosa* spp.), then sound may be a viable option for reducing impingement at an existing intake; however, sound, like other behavioral barriers, would not reduce entrainment of early life stages that have little or no swimming ability.

An example of a sound system application at a CWIS is the high frequency sound system used as a behavioral barrier at the James A. Fitzpatrick Nuclear Power Plant on Lake Ontario in Oswego, NY (Dunning et al., 1992; Ross et al., 1993, 1996; Dunning, 1997). It has an offshore intake and onshore TWS. Approximately 80% of the fish that are impinged are alewife. Based on pilot-scale studies showing that alewife exhibited a strong avoidance response to ultrasonic sound, a permanent full-scale ultrasonic deterrent system was installed at the plant. Post-installation monitoring has demonstrated that impingement of alewife has been reduced by approximately 85%. This behavioral barrier was approved as the BTA by NYSDEC.

The Thames Gateway Desalination Plant (Beckton Plant) in the United Kingdom uses a hybrid intake system with acoustic deterrence (sound) and physical exclusion (CWWS) in combination to protect aquatic organisms from IM&E (Pankratz, 2009). The CWWS have 3 mm slots and are designed for a through-slot velocity of 0.5 ft/sec. No biological data are available on the performance of this hybrid system; however, it is important to note that the acoustic deterrent system will not protect organisms with limited swimming ability from being entrained.

State of Development

Sound as a fish protection technology is well developed. Off-the-shelf systems are available from vendors such as FGS. As described previously, sound has undergone lab-, pilot-, and full-scale application with variable results. Sound deterrent systems, particularly the signal frequencies and sound pressure level components, would have to be designed with a target species in mind; therefore, additional biological design would be required to put a system into operation.

Engineering Considerations

For the optimized performance of a behavioral sound system, it is important to have a strong understanding of the ambient sound (noise) in the water body. Understanding the ambient noise in the system helps determine whether the generated sound signal will be detectable by the target organisms. Because of the nature of sound propagation, careful consideration must also be given to the location of the sound transducers to maximize the ensonified area of the water column before the effects of the water boundaries (water surface or sea bed) impact the sound wave. Sound systems must also be adequately protected against biofouling growth and debris in the water column, particularly in cases where ambient velocity is high (USBR, 2006).

The structural adequacy of the mounting structure as well as the means of mounting must be considered prior to installation. A relatively complex system of electronic controls is required to operate and automate the system. The controls must be in a protected, dry location and in close proximity to the installation location, complicating the application of sound at offshore intakes.

Costs

A review of several installations indicated that a typical range of costs would be on the order of $300 to $700/cfs. These values include the equipment, materials, and labor required for installation as well as operational equipment such as transducers, frequency generators, amplifiers, cables, and raceways. The cost will vary somewhat depending on the installation location and layout as well as the specific application.

Conclusion

Sound as a behavioral barrier is not likely to be an effective technology for modifying an existing seawater intake because it is very species specific and has only been proven to be effective with a very limited number of species. Also, the organism has to have the ability to respond to the stimulus; the sensory component necessary to respond to sound does not develop until later life stages. Perhaps more importantly, because behavioral barriers are only effective on organisms with the ability to swim away from them, they will not reduce entrainment of early life stages (eggs and nonmotile larvae). Finally, resource agencies have become increasingly concerned with sound as an anthropogenic stressor on endangered marine mammals, so this would need to be taken into account for applications in the marine environment.

3.1.2.2 Light

Several types of lights have been evaluated for attracting or repelling fish. Results have varied depending largely on the light source, intensity, species, and water clarity. The majority of tests have been conducted with strobe and mercury lights. Figure 3.2 shows a strobe light and associated controls.

Figure 3.2. Strobe light with associated controls.

Description of Technology

Strobe or flashing light has been intensively evaluated for repelling or guiding fish away from hydroelectric facilities and water intakes (EPRI, 1986b, 1994b, 1998 and in many cases toward bypasses for transport to a safe release location. Early studies with light examined the response of salmonids to both flashing and continuous sources (Brett and MacKinnon, 1953; Craddock, 1956). The results from these studies indicate that a flashing light produced stronger avoidance reaction than continuous light and that the responses varied with species tested, developmental stage (i.e., age or size of fish), and adaptation light level (Feist and Anderson, 1991). More recent studies with salmonids have corroborated these findings (EPRI, 1990; Nemeth and Anderson, 1992).

Mercury lights have been considered primarily as an attractant device that may improve fish passage and protection by drawing fish to bypass entrances or away from intakes. Observed responses to mercury light have varied among species and size classes, with some fish demonstrating avoidance and others attraction. Generally, mercury lights have been evaluated or employed to draw out-migrating salmonid smolts to bypasses at hydroelectric facilities. Use of mercury lights at CWIS has been limited.

Other light sources that have been evaluated as behavioral guidance devices (attraction and repulsion) include incandescent, fluorescent, overhead sodium vapor, and drop lights. In some cases, existing station lighting also has been used in attempts to enhance bypass efficiencies. Most testing conducted to date with these types of lights has been done at hydroelectric facilities with anadromous species such as salmon, clupeids, and eels.

Brief Review of Research

The concept of light as a fish protection technology is based on its potential to elicit an avoidance or attraction response from fish resulting in a change in behavior that prevents involvement of the fish with the intake. Because strobe lights have shown greater potential, much of the available research has focused on them; this brief review focuses on strobe lights as well.

The results of laboratory and cage tests with strobe lights have demonstrated that strong avoidance behaviors can be elicited in several fish species. Successful application of strobe lights in the field has proved difficult, however, with results being confounded by environmental variables such as flow and turbidity. Although research with strobe lights is ongoing, there are relatively few permanent installations at CWIS to date. Results of evaluations at CWIS sites remain somewhat inconclusive. For example, results from field tests at the Milliken Steam Electric Station on Cayuga Lake in New York state have been mixed, with some species and age classes repelled by strobe light and others attracted (Ichthyological Associates, 1994, 1997). The unclear results, confounded by small sample sizes, mean that the strobe light system at this site has not undergone any recent evaluations. Similarly, the strobe light system tested at the Roseton Generating Station on the Hudson River was not effective as a behavioral barrier for all species at all times (EPRI, 1999; Matousek et al., 1988). Strobe lights were also tested at the Pickering Nuclear Generating Station on Lake Ontario with variable results. The effectiveness of the strobe lights ranged considerably based on depth and the direction of fish movement in the water column (Patrick et al., 1988).

State of Development

Lights are currently commercially available from FGS. Additional research is needed to better understand the potential of lights for use on the species common at seawater intakes. Although the potential of strobe lights has been demonstrated at various hydroelectric facilities with salmonid species, further research addressing the potential for use with non-salmonid species is needed to determine their applicability for reducing IM&E at seawater desalination intakes. Typically, pilot studies are required to identify the important engineering (number of lights and location, project hydraulics) and environmental (water turbidity, ambient light conditions) parameters that may influence the success of strobe light systems.

Engineering Considerations

In designing a strobe light array for a specific site, careful consideration must be given to site physical, hydraulic, and environmental characteristics; however, the primary consideration is whether the strobe light has been shown to be effective for repelling the species of concern. Typically, laboratory or field cage tests or small-scale pilot studies are performed to verify fish response and determine optimum parameters for repulsion (e.g., flash rate, intensity, direction of light). Once biological evaluations have determined that light is an effective deterrent, it is appropriate to move to larger-scale applications in which other parameters that might affect performance can be evaluated (e.g., turbidity, flow velocity, bypass configuration). This approach generally has been followed in the many strobe light evaluations conducted to date, as presented in the previous discussion.

The structural adequacy of the mounting structure as well as the means of mounting must be considered prior to installation. A power source and strobe timing system is required to operate and automate the system. The controls should be in a protected and dry location and in close proximity to the installation location.

Costs

Limited information is available with regard to the cost of light arrays because of limited installations. Cost estimates available for a hydroelectric installation indicated that approximately $600/cfs would be required for the installation of a light array approximately 100 ft deep and 500 ft wide. The cost of an installation will be highly dependent upon the levels of turbidity in the water and the type of light. As the quality of the water and light decreases, additional infrastructure is required to overcome the reductions in illumination.

Conclusion

Light as a behavioral barrier is not likely to be an effective technology for modifying an existing seawater intake because it is very species specific and has had variable results. As with all other behavioral technologies, because it is only effective on organisms with the ability to swim away from it and will not reduce entrainment of early life stages (eggs and nonmotile larvae). Finally, turbidity directly affects the distance that the light field is visible. In highly turbid environments, more lights of higher intensity would be required.

3.1.2.3 Turbulence

Description of Technology

The use of water turbulence to divert or guide fish away from intakes has undergone recent evaluation as a potential behavioral barrier. Turbulence has been used successfully at hydroelectric projects to divert out-migrating salmonids to bypasses, and there may be potential to use turbulence at CWIS and desalination intakes as well. Figure 3.3 illustrates the use of turbulent flow for deterring fish from a particular area.

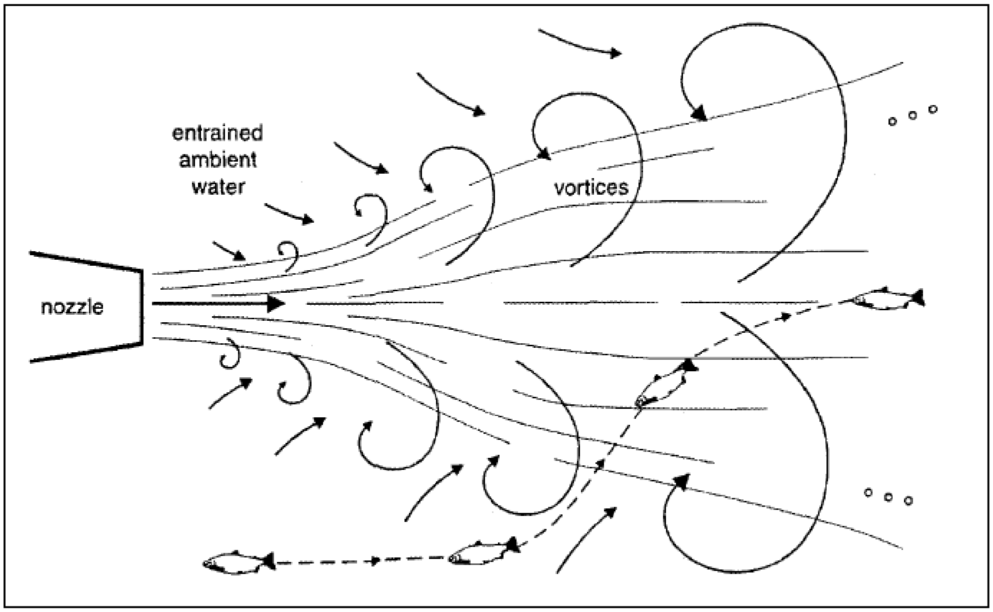


Figure 3.3. Two-dimensional view of turbulent mixing of a hydraulic jet into a standing or slowly moving fluid.

Source: Coutant, 2001

The induction of turbulent flows can be achieved either actively or passively. Active induction involves the generation of turbulence through the use of technologies such as submerged water jets (Figure 3.3) or propellers. As such, active induction requires the input of energy. Passive induction makes use of natural velocities to generate turbulence by placing structures (e.g., submerged vanes and berms, pilings, concrete cylinders) in strategic locations in the existing flow field. An ancillary benefit of using turbulence may be the passive diversion of debris from the intake.

Brief Review of Research

Induced turbulence as a behavioral device is currently considered experimental, having only been evaluated in the field at hydroelectric sites with salmonids (Truebe and Truebe, 1997, 1998; Darland et al., 2001). No field trials have been conducted to date with marine species, nor have any trials been conducted at large seawater intakes.

State of Development

As stated previously, induced turbulence is considered experimental because it has undergone few evaluations with a limited number of species. The potential for inducing shear-related stress associated with high pressure jets has not yet been fully investigated, though research with angled bar racks and louver arrays (passive turbulence) indicate the potential for turbulence to successfully guide fish to bypasses (EPRI, 2001). Current theoretical designs of turbulence guidance systems (e.g., Flow Velocity Enhancement System)attempt to create a trail of turbulent flow to guide fish along. The use of current computer modeling programs such as computational fluid dynamics (CFD) could facilitate the development and design of turbulent flows for fish guidance.

Engineering Considerations

The approach taken to induce flows would depend on the site-specific flow characteristics of the water body being considered. If the flows maintain a relatively high velocity, a passive turbulence induction device may be used, whereas if relatively low velocity flows are present, an active induction device would be necessary.

When considering an active induction device, the potential for high shear forces must be evaluated to determine whether the shear forces created would impact fish survival. For both active and passive installations, a CFD analysis is strongly recommended because of the complexity of the fluid dynamics issues. The placement of the jet should consider the ambient conditions and the radius of impact.

Costs

No cost data are currently available for actively induced turbulence technologies because they are at a relatively early development stage and there are no known installations. Cost data for louvers can be found in Section 3.4.2.1.

Conclusion

Turbulence as a behavioral barrier is not likely to be an effective technology for modifying an existing seawater intake. Actively induced turbulence is considered experimental and would require an evaluation of the potential effects of shear on the target species; therefore, a pilot-scale test would be required prior to a full-scale installation. Passively induced turbulence technologies may be appropriate based on the design of the existing intake, although if major civil modifications are required to fit them in, they would likely be more expensive than other intake technology options. Passively induced devices will not be effective for entrainment reduction; however, actively induced devices would be potentially effective on all life stages.

3.1.2.4 Air Bubble Curtain

Description of Technology

Air bubble curtains are created by pumping air through a bottom-mounted diffuser to create a continuous, dense curtain of bubbles. The objective of an air bubble curtain is to deter rather than attract fish. The air bubbles create stimuli that can be visual, auditory, tactile, or some combination of each depending on ambient lighting, ambient sound, and location relative to the fish. Figure 3.4 shows an air bubble curtain that was investigated in the laboratory for deterring movement of fish upstream.

Figure 3.4. Laboratory evaluation of the ability of an air bubble curtain to prevent the movement of fish.

The success of air bubble curtains at all water intakes has been variable but generally poor and appears to be affected by such factors as species, temperature, light intensity, water velocity, and orientation within the water body. Air bubble curtains have been shown to increase the effectiveness of some hybrid behavioral barriers (e.g., sound, light, and air bubbles).

Brief Review of Research

The most extensive investigations of air bubble curtains have been conducted at steam electric stations to block the passage of fish into CWIS. For example, an air bubble curtain was shown to be ineffective in reducing impingement of white perch (*Morone americana*), striped bass (*Morone saxatilis*), and clupeids at the Indian Point Generating Station on the Hudson River (Vanderwalker, 1967). Similarly, at the Commonwealth Edison Company Quad-Cities Generating Station located on the Mississippi River, an air bubble curtain was found to be ineffective in reducing fish impingement (primarily gizzard shad [*Dorosoma cepedianum*]) when placed across the entrance to the intake canal (Latvaitis, 1976). At the Prairie Island Nuclear Generating Plant on the Mississippi River, small decreases in impingement were achieved for crappie (*Pomoxis* spp.) and freshwater drum (*Aplodinotus grunniens*) when an air curtain was placed across the intake canal; however, the number of individuals of other species (carp [*Cyprinus carpio*], silver chub [*Hybopsis storeriana*], and white bass [*Morone chrysops*]) entering the canal actually increased (Grotbeck, 1975).

At the Monroe Power Plant on Lake Erie, an air bubble curtain was installed across the mouth of the intake canal in 1972, creating a continuous wall of bubbles from bottom to surface. On the basis of daily fish counts made with the system either on or off, it was concluded that an air bubble curtain was ineffective in preventing yellow perch, walleye, gizzard shad, drum, alewife, or smelt from entering the intake canal (Detroit Edison, 1975). An air bubble curtain was investigated as a means to exclude alewives from the Milwaukee River near its confluence with the Menominee River in Wisconsin (Kupfer and Gordon, 1966). Data indicated that the air bubble curtain was somewhat successful in stopping the alewives from migrating up the Milwaukee River; however, the effectiveness could not be quantified. Stewart (1982) was successful in confining roundfish in sea cages with the use of an air bubble curtain. Studies in Canada have also shown that an air bubble curtain can be effective in excluding fish from passage (70–98% exclusion under artificial, low-level light conditions; Patrick, 1982).

When used in conjunction with sound, the device appears to have potential for reducing fish passage under various conditions of turbidity. For example, the combination of an air bubble curtain with sound was shown to hold potential for diverting salmon smolts (Welton et al., 2002).

The effectiveness of air bubble curtains may be highly species specific, however, because some species have actually been attracted to the device. Variables that appear to influence performance of the device include water velocity, turbidity, and illumination, which appears to be a key factor influencing effectiveness.

State of Development

Air bubble curtain systems are available, though there is only one commercial vendor, Fish Guidance Systems, Ltd. It is also possible to custom-design air bubble curtains for specific sites from common components (e.g., piping, diffusers, air compressors). As described previously, the effectiveness of stand-alone air bubble curtains has been shown to be relatively low, although when incorporated into a hybrid behavioral barrier, with sound for instance, the performance can be improved.

Engineering Considerations

Air bubble curtains must be designed to provide a continuous wall of bubbles under all ambient flow conditions without inducing any harmful effects. Based on the area to be protected, the total length of the piping system can be determined. Multiple compressors and piping loops may be required depending on the total length of the system as well as the installation depth. Depending on the magnitude of ambient currents, there is potential for the curtain to be deflected from a vertical position. This potential must be taken into consideration in the system design.

Air bubble curtains can be compromised by high water velocities and may require special design considerations at tidal sites where the flow direction and magnitude change daily. For this reason, it would be very difficult to design an effective air bubble curtain in an open ocean environment. There are also challenges with evenly distributing compressed air to large air bubble curtain installations. Uneven air distribution can reduce the ability to create a uniform, continuous barrier without gaps.

Costs

Air bubble systems can be installed on the order of $2000 per linear foot of piping. Cost items include the cost of an air compressor, piping, and installation. The size and cost of the air compressor will be dependent on the length of pipe in the system. The cost of the system will vary depending on its depth and distance from shore. The longer the piping system, the larger the overall system must be to overcome system losses.

Conclusion

An air bubble curtain as a behavioral barrier is not likely to be an effective technology for modifying an existing seawater intake because of its variable performance. Designing a system for an open ocean environment would be difficult because ambient hydraulic forces (e.g., ocean currents, tidal currents, waves) would frequently compromise the integrity of the system. In addition, as with all other behavioral technologies, because the curtain is only effective on organisms with the ability to swim away from it; it will not reduce entrainment of early life stages (eggs and nonmotile larvae).

3.1.2.5 Electric Barrier

Description of Technology

Electric fields are used to cause an avoidance response in fish. The barrier uses an electric current passing through water. The electrical circuit has two or more metal electrodes submerged in water with a voltage applied between them. Electric current passing between the electrodes through the water medium produces an electric field. When fish are within the field, they become a part of the electrical circuit, with some of the current flowing through their bodies. Electrical current is typically used as a deterrent to keep fish out of certain areas, though there is potential to stun or kill fish depending on the current and fish size. Special considerations with regard to the layout are required if the fish are migrating downstream. Figure 3.5 depicts a conceptual electrical barrier configuration at an industrial water intake.

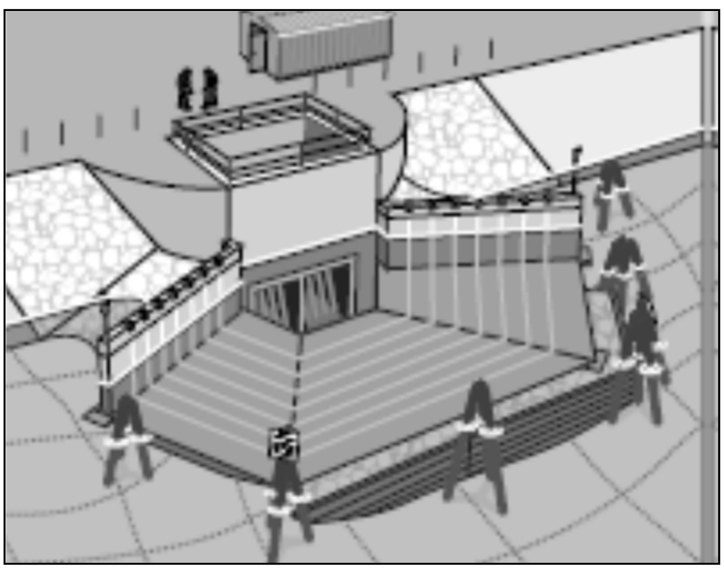


Figure 3.5. Conceptual layout of an electric screen installation at an industrial water intake.
Source: Smith-Root, 2012

Brief Review of Research

Although electrical barriers have been shown to be effective in some cases, their potential for use at CWIS has not yet been fully evaluated. A system was evaluated by Bengeyfield and Smith (1989) at Puntledge Diversion Dam. The system was developed to divert out-migrating coho salmon smolts from a hydropower intake and toward a bypass structure. The strength of the electric field increased in the downstream direction as the barrier was placed at an angle to the intake. The effectiveness of diverting fish from the intake ranged from 2 to 22%. Factors leading to decreased effectiveness likely included unstable flow patterns, incomplete electric fields, and ineffective bypass structures. Personnel at the Wilkins Slough Pumping Plant on the Sacramento River and at the U.S. Bureau of Reclamation have worked with various behavioral technology suppliers in testing experimental acoustical and electrical fish fields for more than 4 years to try to evaluate and develop a more cost-effective barrier than a positive barrier screen (Cramer et al., 1993). Although considerable and valuable data were gathered, these experimental devices did not prove to be as effective as positive barrier screens and, in most cases, are not acceptable as proven fish barriers by fishery resource agencies. An electrical barrier is also currently in use in the Chicago Sanitary and Ship Canal to prevent the passage of Asian carp into Lake Michigan. With three separate systems, this installation probably constitutes the largest electrical barrier installation in the United States. The barrier has performed well. A field investigation revealed that only 1 of 130 test fish passed the barrier (Sparks et al., 2011).

State of Development

Electricity as a fish deterrent is well developed. Electrical barriers are commercially available from vendors such as Smith-Root. Data on the biological efficacy of electrical barriers at seawater intakes do not exist, as they have been applied for the most part at hydroelectric and irrigation projects in freshwater. Applications in which the barrier is operated continuously (versus periodically pulsed) in full seawater would require special design considerations because of the higher current required to maintain a barrier in higher conductivity seawater. Higher electrical currents may also represent a hazard to operators and maintenance personnel.

Engineering Considerations

Electric barriers must be designed to provide a continuous barrier to target organisms. The conductivity of the water in which they will be installed will dictate the electrical current required for repelling organisms. The effectiveness of the electric field depends on site-specific parameters such as flow velocities, conductivity, water temperature, changes in water depth, and sediment transport characteristics, each of which can impact system performance (Smith-Root, 2012).

A full-scale demonstration system to determine its biological efficacy prior to a permanent installation is highly recommended because of uncertainties in effectiveness on a site-specific basis. A demonstration also offers the opportunity to refine the design of the system.

Costs

The costs of electric barriers are on the order of $500 to $800/cfs. They can be affected by factors such as depth and quality of water, distance to the control housing structures, and target species. A watertight housing is required to protect the control system. If an existing structure is available, it can be used in lieu of a new structure. In addition to the initial capital investment, the cost of powering the barrier must be considered.

Conclusion

An electric barrier is not likely to be an effective technology for modifying an existing seawater intake; the high conductivity of seawater would preclude its use at a marine intake.

3.1.2.6 Flow Velocity (Velocity Cap)

Description of Technology

A velocity cap (Figure 3.6) is a behavioral barrier that changes what would otherwise be vertical flow vectors at an uncapped offshore intake riser to horizontal flow vectors. Velocity caps are most often used in conjunction with other intake technologies (e.g., onshore modified TWS with fish protection features) to reliably minimize the impacts of seawater intakes on aquatic life. It has been shown that horizontal flow vectors are more easily sensed and avoided by fishes (Beck et al., 2007; Lifton and Storr, 1978; Weight, 1958).

Most offshore CWIS are fitted with velocity caps. An offshore intake withdrawal point has potential to reduce entrainment impacts because of its location in less productive water; the addition of a velocity cap increases the potential to reduce impacts as it constitutes a behavioral barrier that larger fish can sense and avoid when intake velocities are high enough. This technology does not reduce entrainment of free-floating eggs and larvae, which are unable to distinguish flow characteristics and lack sufficient swimming ability to avoid them.

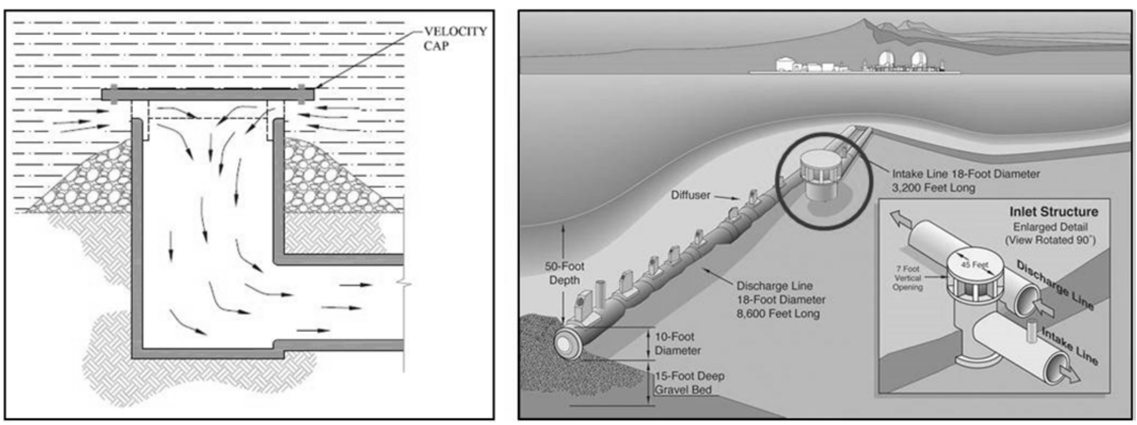


Figure 3.6. Velocity caps. L to R: schematic of a typical velocity cap and the velocity cap used at San Onofre Nuclear Generating Station in CA.

Brief Review of Research

Velocity caps have been evaluated at a number of southern California coastal power plants. For example Pender (1975) determined that the velocity cap at Scattergood Generating Station in Los Angeles reduced impingement of fish by 83%. Early research at the El Segundo Generating Station (Weight, 1958) indicated a reduction in impingement of 95%. Impingement and ambient densities were monitored at the Huntington Beach Generating Station in the late 1970s to early 1980s (Johnson et al., 1980). These data demonstrate an overall reduction in impingement of 82%. Similarly, an investigation was completed at Ormond Beach Generating Station that demonstrated a reduction in impingement of 61% at night and 87% during the daytime (Thomas et al., 1980). A velocity cap effectiveness study at Scattergood Generating Station demonstrated that the velocity cap reduced the number of fish impinged by about 98%, and the biomass of fish impinged was reduced by 95% (MBC et al., 2007a). EPA (2004) reports that the velocity caps at Seabrook Station in New Hampshire have minimized the number of pelagic fish entrapped, with the exception of pollock. The same study also reports that two velocity cap installations in England (Sizewell Power Station and Dungeness Power Station) have reduced impingement by 50 and 62% through the use of velocity caps

State of Development

Velocity caps have been installed at offshore intakes for some time and are used worldwide (e.g., at new seawater desalination intakes in Australia). Although the design of the caps varies globally from simple concrete caps on vertical risers to more dome-shaped metal structures, the design objective remains common—creating horizontal velocity vectors from what would otherwise be vertical vectors. Velocity caps have been shown to be effective in reducing impingement, but they are not effective for reducing entrainment. As such, velocity caps are typically used in conjunction with another screening technology such as TWS.

Engineering Considerations

Although velocity caps are designed to change vertical velocity vectors to horizontal vectors, maintaining minimum horizontal velocities is still critical to success. As a behavioral barrier, the intake velocities created need to be high enough for fish to sense and avoid. Velocity caps in southern California were originally designed with entrance velocities between 2 and 3.5 ft/sec (Weight, 1958). The cap must extend vertically from the sea floor for a minimum distance of 5 ft to reduce the potential for sediment and debris entrainment. Typically, a velocity cap is designed with a series of coarse bars arranged in a vertical orientation around the opening of the cap. These bars act as a very coarsely-spaced trash rack in addition to providing stability to the cap itself. In southern California, the new OTC policy requires bars spaced at no greater than 9 in. apart to prevent entrapment of large organisms (e.g., seals, sea lions, and sea turtles). Typically, the dimensions of the cap are a function of the pipeline size and facility flow rate. Multiple caps and risers can be used for a single intake flow.

Costs

Typically, the cost of the velocity cap is listed with the cost of the offshore conveyance (such as primary distribution pipe or tunnel), resulting in relatively high capital costs on the order of $45,000/cfs. When focusing on the cost of the velocity cap itself, the cost is much lower and on the order of $3000/cfs. Velocity caps are generally constructed of reinforced concrete; however, the use of alternative materials will affect the cost. The depth of water and climatic and locational factors will all influence the cost of installation.

Conclusion

A velocity cap is a very good technology for consideration at a seawater intake. They have been shown to significantly reduce impingement and are generally inexpensive to retrofit on an existing offshore intake. As with all other behavioral technologies, because caps are only effective on organisms with the ability to swim away from them, they will not reduce entrainment of early life stages (eggs and nonmotile larvae). However, there may be a measurable benefit in entrainment reduction because of their location offshore.

3.2 Exclusion Technologies

3.2.1 General Description

Exclusion technologies include systems that passively prevent the passage of organisms based on their size. Potential effectiveness can be determined based on the size distribution of the organisms that may come in contact with the system (i.e., exclusion technologies function on the premise that a screen will physically exclude organisms equal to or greater than its mesh size). Exclusion systems are also typically designed with low intake velocities to minimize the risk of impingement.

3.2.2 List of Exclusion Technologies

3.2.2.1 Aquatic Filter Barrier

Description of Technology

An AFB is an exclusion technology composed of two layers of geotextile material with an air purge system installed between the layers to permit automatic cleaning of accumulated silt and debris (Figure 3.7). This cleaning system can also free impinged fish eggs, larvae, and other organisms with low motility. AFB is designed for an approach velocity of approximately 10 gpm/ft^2. Currently, AFB is considered an experimental technology for addressing IM&E at intakes. There are no full-scale applications in a marine environment.

Brief Review of Research

AFB has proven effective in reducing IM&E of early life stages of fish at some open freshwater intakes. An AFB was installed at the Lovett Generating Station on the Hudson River in 1994. A subsequent 11-year evaluation of the engineering and biological performance of an AFB was conducted. Biological evaluations conducted between 1995 and 2001 compared the entrainment rates of a protected intake to that of an unprotected intake (Figure 3.7). Later biological evaluations conducted between 2004 and 2006 evaluated a full-scale AFB installation at Lovett Station 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 with 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 with 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 an 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.

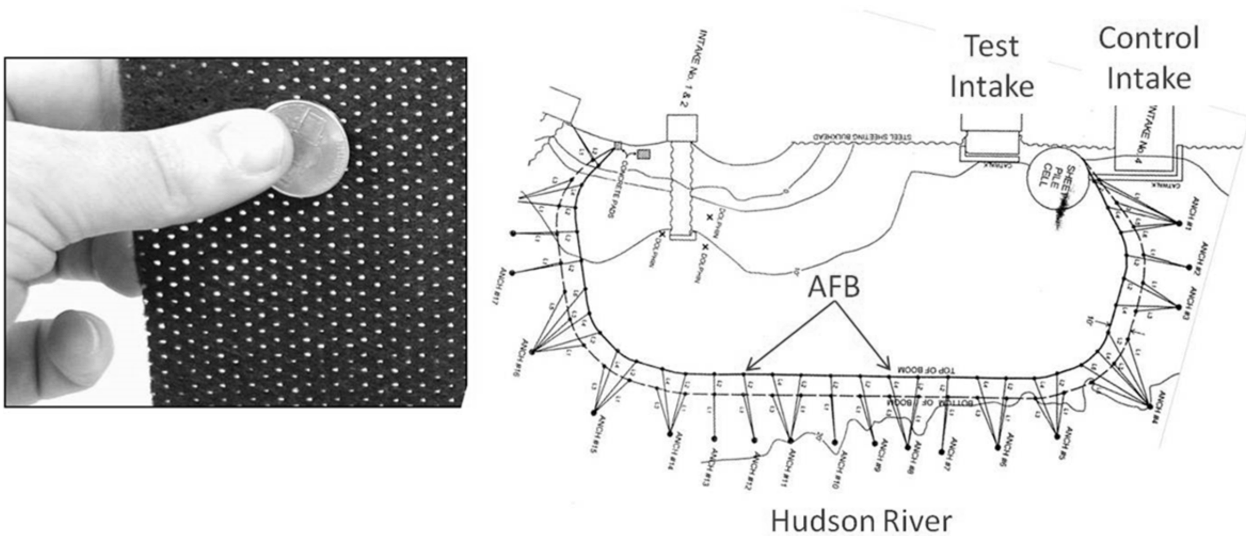


Figure 3.7. Aquatic Filter Barrier. L to R: detailed view of AFB material with perforations and site plan of the AFB deployment at the Lovett Generating Station showing sampling locations for entrainment sampling conducted between 1995 and 1999.

Source: Image modified from LMS, 1998

A full-scale AFB was installed at the Bethlehem Energy Center on the Hudson River just south of Albany in Bethlehem, NY. Because of physical constraints, the AFB was designed to be deployed in a fixed-panel arrangement in front of the CWIS. 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 that were 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 (from 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 Bethlehem Energy Center site.

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, but no data were available for review at the time of this report.

Pilot- and laboratory-scale research has revealed that biofouling on the AFB can decrease the flow capacity of the system (Henderson et al., 2001), impingement of early life stages of American shad on the AFB did not significantly impact survival (Radle, 2001), the AFB is best deployed where ambient sweeping currents are available to carry debris away from the barrier, and neither flow rate nor pore size significantly impact survival; exclusion and survival are very species specific (EPRI, 2004).

State of Development

AFB is commercially available as the Gunderboom Marine Life Exclusion System (MLES). The MLES is undergoing continual development as site-specific criteria dictate. Although the MLES has been installed at some freshwater sites, it has not yet been installed at any marine sites and is therefore considered experimental for this application until data are generated on its performance.

Engineering Considerations

Because of its very low through-mesh design velocity, a large surface area is typically required for an adequate AFB installation. This surface area is typically large enough that potential impacts on navigation and recreation must be considered. In addition, its large surface area and footprint require a substantial support structure. Depending on the AFB size and site conditions, the support structure may consist of either an anchor and float system or a rigid frame with removable panels.

The airburst cleaning system operates most efficiently in an area where there is sufficient sweeping flow to carry away dislodged debris; therefore, careful consideration must be given to the ambient hydraulics at the intake location. Although AFB has been installed and shown to be effective in reducing IM&E of early life stages of fish at some freshwater intakes, there are significant engineering challenges associated with its use in the marine environment. Deployment and maintenance of AFB have been shown to be difficult. Application of this intake technology has been limited to two freshwater installations on the Hudson River, NY. At these sites, the AFB has undergone significant failures due to ambient hydraulic and hydrodynamic forces, excessive debris loading, and ineffective backwashing (LMS, 1996, 1997). It is expected that tidal and wind-driven currents in the ocean may pose significant design obstacles for the support structure.

Cost

The cost of AFB is on the order of $25,000/cfs. It will be influenced by typical and extreme conditions of the installation area and the associated infrastructure requirements. In addition, the required cleaning mechanism will depend on the typical types of debris encountered at the intake.

Conclusion

AFB is not likely to be an effective technology for modifying an existing seawater intake. Although the biological potential of the technology to reduce IM&E is high, the practical aspects associated with its installation are likely insurmountable in a marine environment. First, large intake flow rates will require very large AFBs to accommodate the design capacity of the facility at the very low through-screen flow rate for which the technology is designed. Second, mounting and keeping the AFB in good operating condition will be very difficult in the open ocean environment.

3.2.2.2 Barrier Net

Description of Technology

A barrier net is an exclusion technology that functions in a similar manner to AFB. Barrier nets have larger mesh sizes than AFB and may be effective for minimizing IM, but finer-mesh barrier nets are still considered experimental and therefore cannot be considered for reductions in entrainment. Similar to AFB, they are easily fouled by silt and algae and would require labor-intensive cleaning. As with AFB, there are engineering challenges associated with the design and maintenance of a barrier net support structure in an open ocean environment.

Brief Review of Research

Barrier nets are a widely used intake protection technology at hydroelectric sites for excluding juvenile and adult fish from plant intakes. There are multiple installations in freshwater bodies that function effectively for minimizing IM&E, although to date there are no data on barrier nets used in a fully marine environment. A few exceptions are the barrier nets at the Chalk Point Generating Station on the Patuxent River in MD and the Bowline Generating Station on the Hudson River in NY, though each of these is an estuarine intake drawing water that is substantially lower in salinity than full seawater.

The net at the Chalk Point Generating Station was originally designed to minimize impacts associated with seasonal influxes of blue crab but also serves to reduce impingement of fish at the TWS downstream. The barrier net system is composed of two separate nets: a coarser-mesh (1.25 in. [32 mm] stretch mesh) outside net and a finer-mesh (0.75 in. [20 mm] stretch mesh) inner net (Figure 3.8). Each net is supported by pilings driven into the estuary bed. The barrier net system has been shown to be effective for minimizing impingement of blue crabs and fishes on the TWS. As reported by Bailey (2005), impingement of dominant species (fish and blue crabs) was reduced by 82 to 98% after installation of the barrier net system. Typical operation and maintenance (O&M) concerns at Chalk Point focus on net biofouling, debris maintenance (leaves and jellyfish), and the prevention of ice damage during winter months.

Figure 3.8. Barrier net mesh (L) and barrier net system (R) at Chalk Point Generating Station on the Patuxent River, MD.

Source: Courtesy of Dave Bailey

The net at Bowline Generating Station was designed to reduce impingement of commercially and ecologically important species (mostly white perch and striped bass) in the Hudson River. The net is composed of 0.15 to 0.2 in. (38 to 51 mm) mesh arranged in a V shape in front of the intake. It is deployed seasonally when the target fish are present in the river. Monitoring indicated that impingement of the target species was reduced by 91% (Hutchinson and Matousek, 1988). A finer-mesh net (3 mm) was evaluated in 1993 to determine whether entrainment of larger larvae could be reduced; however, the study ended when the screen suffered a debris-related collapse associated with suspended silt and algae (LMS, 1994).

State of Development

Barrier nets have been used extensively at freshwater hydroelectric intakes and shown to be biologically effective at reducing impacts to fish. Barrier nets are commercially available from various vendors and in various materials (nylon, polypropylene, polyethylene, and polyester), mesh sizes, and installation types. Some vendors include Pacific Netting Products, Redden Marine, and Memphis Net and Twine.

With a regulatory push towards protecting early life stages of fish, some facilities may evaluate the feasibility of fine-mesh barrier nets; however, debris-related clogging may present a significant challenge in terms of O&M, and fine-mesh barrier nets are currently considered experimental for this application.

Engineering Considerations

There are several biological and engineering design considerations that are important to the effective application of barrier nets at most types of water intakes. Biological considerations include the behavior, swimming capabilities, and seasonal occurrences of target species and life stages (i.e., size). Behavior and swimming capabilities will influence the location of barrier nets with respect to where fish are located in a water body (e.g., shoreline areas, near the surface or bottom) and at what approach velocities they are capable of avoiding IM&E. Turbidity levels and diurnal patterns in fish presence may also affect net effectiveness through changes in visibility associated with suspended particles and ambient light levels. The sizes of fish to be protected and estimated debris loading at the site are the most important considerations in net design. These critical parameters are used to determine the net size that will result in adequate fish protection and ensure a design that can withstand the expected hydraulic forces at a given site. It is critical that the integrity of a net (i.e., its condition and location) be maintained for it to be an effective fish barrier. Net section failures or large gaps can result in significant reductions in protection.

Engineering design considerations important to developing an effective barrier net include:

- mesh size
- net material
- net size (depth and length)
- debris loading and biofouling
- local hydraulic conditions
- bottom topography and sediment composition

The mesh size should be selected based on both biological and engineering considerations, including the size of fish targeted for protection and potential problems related to biofouling and debris loading. Net material influences the integrity of the net over time and may affect the potential for impingement or gilling depending on its rigidity. The overall size of a net is an important consideration in selecting the best support system (floats and anchors, piles, or rigid structure). Debris loading and hydraulic conditions must be fully understood to develop a net design that will maintain its integrity under all environmental and hydraulic conditions expected during deployment. Ambient hydraulics are arguably the greatest limitation in the use of barrier nets at fully marine intakes; accounting for hydraulic forces in an open ocean environment will result in a large supporting structure with an intensive debris cleaning program to maintain the net in good working order.

Costs

Table 3.2 presents costs of some barrier net installations. Unless noted otherwise in the table, these costs were derived from freshwater installations.

Table 3.2. Summary of Barrier Net Installation Capacity and Cost

Project Name	**Flow Capacity (cfs)**	**Capital Cost (2012 USD unless otherwise noted)**
Arkansas Nuclear Plant	1323	$30,000
Baker River	4100	$750,000
Banks Lake	7910	$29,725 (1978)
Chalk Point (estuarine)	1060	$97,000 (1981)
Hayward Hydroelectric Project	180	$6700
Highline	2000	$92,500
J. P. Pulliam	805	$612,000 (1981)
Laskin	223	$170,000
Ludington Pumped Storage Project	66,000	$1,700,000
Pine Hydro	640	$3000

Source: EPRI, 2006

Conclusion

A barrier net may be an effective technology for modifying certain existing seawater intakes. In particular, it may be possible to retrofit a barrier net at an estuarine site that is protected from the open ocean because it would be sheltered from the strong hydrodynamic forces in the marine environment (e.g., waves and currents). At fully marine sites, barrier nets have the same limitations described in the AFB section: they would require substantial support structures and very aggressive cleaning schedules to be kept in good operating condition. Furthermore, fine-mesh barrier nets are considered experimental for addressing entrainment and likely to experience even greater issues with debris and fouling. Therefore, depending on site-specific characteristics, barrier nets may be appropriate for addressing impingement concerns, but not entrainment.

3.2.2.3 Porous Dike

Description of Technology

Rock structures such as porous dikes, rock cribs, or leaking dams, which allow water to pass while preventing passage of juvenile and adult fish, have been shown to be effective on an experimental basis and at a few water intakes. Results of laboratory- and small-scale pilot studies have indicated that these dikes might be effective in preventing passage of juvenile and adult fish by eliciting a behavioral avoidance response; however, entrainable organisms with limited swimming ability will generally be trapped in the porous medium or entrained into the pump flow. Figure 3.9 shows porous dikes used at existing intakes.

Brief Review of Research

The effectiveness of porous dike and leaky dam systems in minimizing IM&E at power plant intakes was assessed from monitoring studies conducted by the Wisconsin Electric Power Company (Michaud, 1981). The results of this study indicated that, for several species of adult and larval fish, the IM&E rates of the porous dike and leaky dam structures were lower than the rates at nearby onshore intake structures. The accuracy of these results was limited by the variable densities of Lake Michigan ichthyoplankton populations.

We Energies recently built a porous dike system at Port Washington Generating Station on Lake Michigan during repowering. A 2-year biological (IM&E monitoring) and operational performance evaluation study commenced in January 2009 and was completed in December 2010. Impingement rates after the installation of the porous dike were 92 to 99% lower than pre-installation levels (Lee, 2011). Similarly, egg entrainment was reduced by around 96%. Total larval entrainment increased, but this was driven by the invasive round goby, which constituted more than 70% of larval entrainment after the dike was installed as compared to about 25% of preconstruction larval entrainment (Lee, 2011).

Field and laboratory studies using marine fish species also indicated that a rock porous dike is a barrier to juveniles and adults and may be a physical or behavioral barrier to larval fish (Ketschke, 1981). Most species of juvenile and adult fish showed at least partial entrainment avoidance in the laboratory flume and showed little or no attraction to the gabion, although mummichog and cunner were strongly attracted to the gabion. The cunner took up residence in the gabion but were not actually entrained.

Figure 3.9. Existing porous dikes used at industrial intakes. Clockwise from top L: We Energies' Port Washington Generating Station on Lake Michigan; Kudankulam Nuclear Power Plant; Gran Canaria desalination plant.

Sources: Courtesy of David Lee, We Energies (Port Washington and Kudankulam) and Google Earth (Gran Canaria)

In the field (Brayton Point Station, Narragansett Bay, MA), naturally occurring ichthyoplankton were sampled by pumps from locations upstream and downstream of the dike to determine differences in larval fish abundance related to each of the gabion types. If the downstream densities were lower than the upstream densities, it was assumed that avoidance, filtration, or cropping had occurred. In addition to naturally occurring ichthyoplankton, groups of seven finfish species (*n*=2000+) were fin-clipped and impounded upstream of the gabions for periods of 24 to 48 hours. The numbers of fish caught by seining downstream of the gabions were counted as entrained.

Significant differences between upstream and downstream larval densities were seen for bay anchovy and winter flounder (*Pseudopleuronectes americanus*). Field test data for larval anchovy and other larval species with 7.6 cm (3 in.) stone gabions were not available. With the 20.3 cm (8 in.) stones, the density of bay anchovy was reduced by 94 to 99%, and that of winter flounder was reduced by 23 to 87%. The differences in flounder density became larger and more significant as the season progressed. Similar results were obtained for winter flounder with 7.6 cm (3 in.) stones, except that the differences in density were not noticeable until later in the season. Entrainment avoidance was 100% for all juvenile and adult finfish species.

Consumers Power Company sponsored a laboratory investigation in 1972 to determine the practicality of a rock barrier permeable dike as a fish barrier (Bell et al., 1974). Fish of various species and sizes were placed upstream under velocity conditions approximating their normal cruising speeds (range: 0.04 to 0.09 m/s). Eleven tests were performed in the flume with rainbow trout (2.8 to 5.8 cm), Chinook salmon (7.1 to 8.1 cm), bluegill (3.0 cm), largemouth bass (4.14 cm), bullheads (5.1 cm), and stickleback (*n*=1, no length data).

Rainbow trout moved into and through the dike after 96 hours in one test. In another test, the bluegill, bass, and bullheads placed below the rock barrier did not penetrate it upstream in a period of 24 hours. In two tests with young rainbow trout and one with the warm water fish illuminating either the downstream or upstream face of the barrier appeared to have little or no effect on the effectiveness of stopping fish at the rock barrier.

As expected, a few of the fish were trapped in the rock barrier. Rainbow trout stayed in the area upstream of the rock barrier when they reached a size at which they did not penetrate the barrier. The barrier was effective when the critical head depth range was exceeded. Observations showed that the fish were usually entrained through the barrier during the dark hours when it is normal for them to seek the protection of a river bank.

Porous dikes have also seen some international use at seawater intakes. The desalination plant in Gran Canaria, Spain, uses a porous dike , as does the Kudankulam Nuclear Power Plant in India (Figure 3.9).

State of Development

Full-scale application of this technology has been installed at We Energies' Port Washington Generating Station on Lake Michigan. Although no full-scale applications are known to exist in marine environments, there is no reason to assume that such installations would not be possible.

Engineering Considerations

There are several important design considerations for porous dikes, including operational velocities and stability. To ensure adequate flow through the body of a porous dike, the structure is heavily engineered using specially selected fill and armor stones. The result is very low velocities through the rock voids, on the order of 0.2 ft/sec. This low velocity along with the small size of the rock voids will allow for the passage of water through the media while preventing passage of juvenile and adult fish. It is important to understand that, because of the low velocities, these structures will typically require significant footprints and would prevent access to a large area in front of the DWIS. As there is currently no method for cleaning the interior of a porous dike, it is not recommended for environments with high debris or silt loading because of the potential for plugging.

In addition to operational criteria, the porous dike must be constructed to withstand its aquatic environment. Similar to a jetty, the structure must have a sufficient footprint and armament to be partially submerged and endure both regular and extreme storm surges.

Costs

The cost of a porous dike will be approximately $4000/cfs. The costs will be influenced by the installation location and the availability of local construction materials. In addition, the levels and type of debris, sedimentation, and severity of the marine environment will all influence the final costs.

Conclusions

Porous dikes have been shown to be effective on an experimental basis and at a limited number of water intakes. Although potentially effective in preventing passage of juvenile and adult fish, the protection from entrainment afforded to passive life stages is substantially less.

3.2.2.4 Conventional Traveling Water Screen

Description of Technology

Conventional TWS (i.e., those without fish protection features) are standard features at most large industrial water intakes (Figure 3.10). The primary function of such screens is to prevent the ingress of debris that has potential to clog downstream equipment (e.g., condensers). The ability of traveling screens to act as a physical barrier to fish without resulting in impingement is dependent on many site-specific factors such as the size of the fish, flow velocity, location of screens, and presence of escape routes. Generally, without the addition of fish protection features such as fish-collecting buckets, a low pressure spray wash system, and a fish return trough, these types of screens are only useful for providing a physical barrier to those organisms capable of swimming away from it. If the through-mesh velocity exceeds an organism’s swimming ability, it will impinge and be lost.

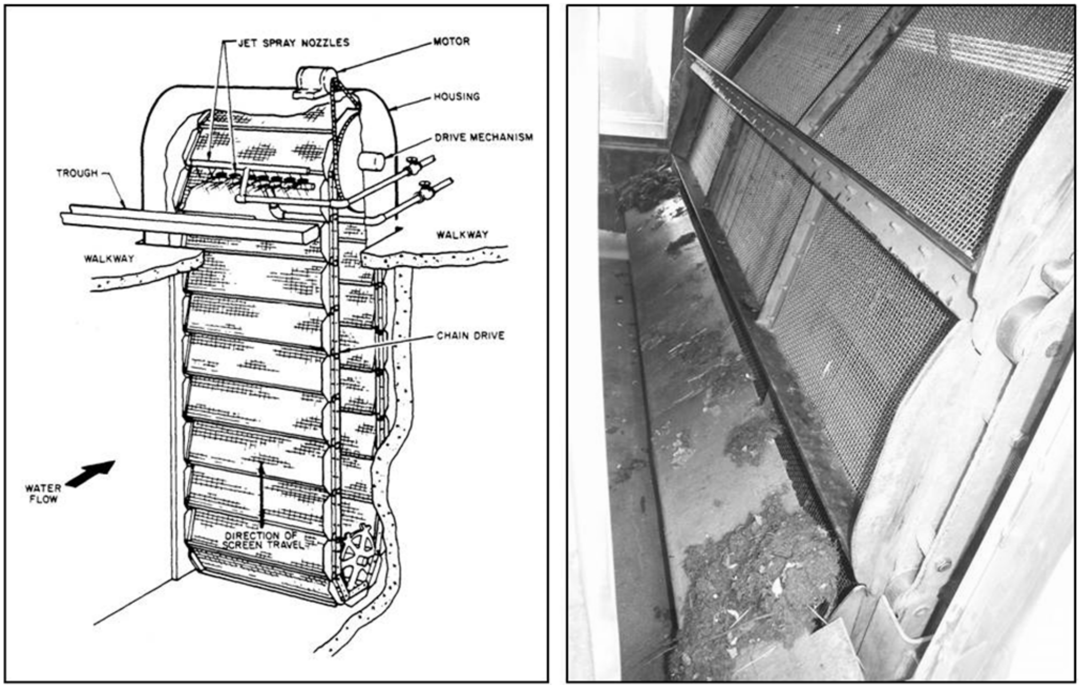


Figure 3.10. Conventional (unmodified) traveling water screen: L to R: schematic from EPRI and image of the descending side of a conventional traveling water screen.

Source: EPRI, 1986a

Conventional TWS are included in this discussion simply because they are the primary intake screening technologies present at existing CWIS in the United States. No further review of this intake technology is included, as it does not constitute a viable technology to reduce IM&E at intakes. See Section 3.3.2.1 for a description of modified TWS that are capable of providing protection against IM&E at intakes.

3.2.2.5 Cylindrical Wedgewire Screen

<u>Description of Technology</u>

CWWS are designed to reduce entrainment by physically excluding organisms from the withdrawn flow. CWWS are also designed to reduce impingement of organisms by providing low TSV (0.5 ft/sec or less). The TSV is the rate at which water is drawn through the screen (measured perpendicular to the screen surface). With a low TSV, impingement is widely considered to be a nonissue. Biological effectiveness is enhanced with the presence of a sweeping flow past the screens to transport debris and nonmotile early life stages with weak swimming abilities away from the intake. CWWS utilize wire that is V- or wedge-shaped in cross-section. The wire is welded to a framing system to form a slotted screening element (Figure 3.11). In order to minimize IM&E, CWWS are typically designed with the following details in mind:

- Screen slot size must be sufficiently small to physically exclude the smallest life stage to be protected.
- TSV should be low.
- Relatively high velocity ambient sweeping currents are preferred to carry organisms and debris around and away from the screen.

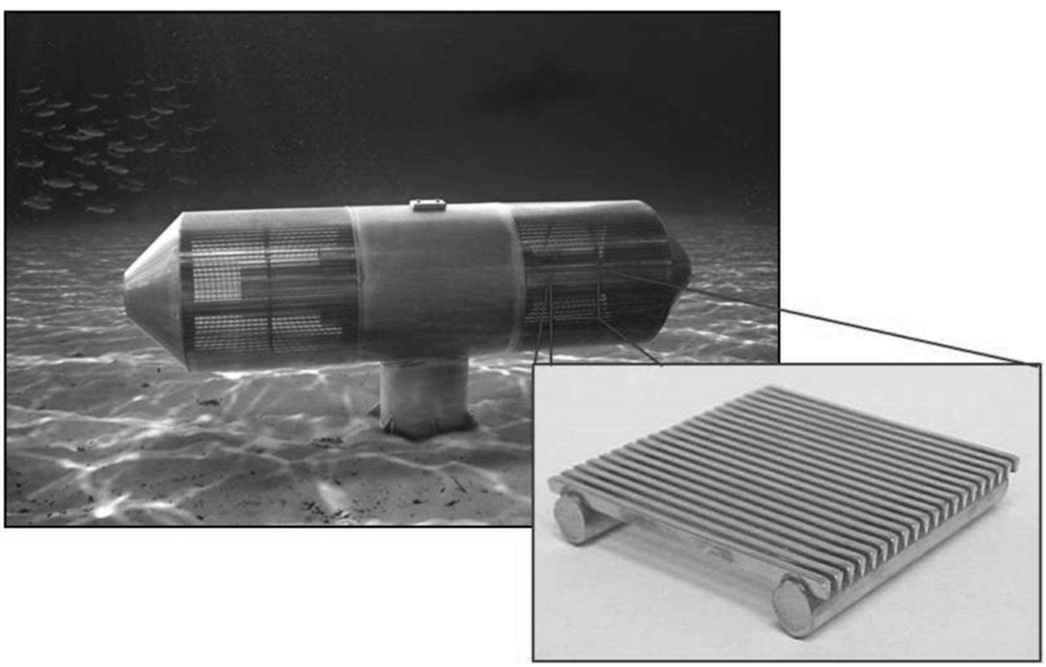


Figure 3.11. Cylindrical wedgewire screen, showing detail of V-shaped wedgewire.
Source: Courtesy of Johnson Screens

These screens have been biologically effective in preventing IM&E of fish and have not caused unusual maintenance problems. The potential for clogging and biofouling remains a major concern in a marine environment, so careful consideration needs to be given to the materials used and the cleaning mechanism and process. Given the proper conditions, CWWS can incorporate an automatic air backwash cleaning system, which makes them more easily cleaned than other exclusion technologies such as fixed screens and barrier nets. Alternatively, screens are available with internal and external fixed brushes and rotating screen drums that provide continual or periodic cleaning of the screening material. Therefore, CWWS have a cleaning advantage over other exclusion technologies.

Brief Review of Research

CWWS are used in the power generation industry to minimize IM&E and meet 316(b) regulations; subsequently, there has been substantial research on their potential to minimize IM&E. In addition, CWWS have also been part of many recent pilot-scale studies at proposed desalination facilities. For instance, pilot studies have been completed or are in progress for the following proposed seawater desalination facilities: WBMWD, SCWD[2], and MMWD. These studies focus on both biological effectiveness and engineering feasibility. The following section provides a summary of the research that has been conducted on CWWS.

Full-Scale Studies

A number of studies have evaluated the performance (biological or engineering) of full-scale CWWS installations. Ehrler and Raifsnider (1999) evaluated the effectiveness of a 1 mm CWWS used to withdraw makeup water for the closed-cycle cooling system at the Logan Generating Plant on the Delaware River, NJ. The results indicated that the screens provided greater than expected protection of the target species (striped bass larvae) against entrainment. Proportional withdrawal of striped bass larvae was estimated to be 0.03% of the total population, though the results of the 1995 evaluation demonstrated that only 0.003% was withdrawn. Cumbie and Banks (1997) evaluated a 2 mm CWWS used to withdraw makeup water for the closed-cycle cooling system for the Cope Station power plant on the South Fork Edisto River, SC. Though no biological effectiveness data were given, the hydraulic zone of influence for the screen operating at a maximum TSV of 0.5 ft/sec was determined to be relatively small: approximately 8% of the stream width. Veneziale (1991) reported on the design of a 6.4 mm CWWS intake installed to address IM&E concerns at the existing TWS at the Eddystone Generating Station on the Delaware River, PA. The 16 CWWS were installed on a sheet pile bulkhead and have not experienced any major maintenance or cleaning issues.

Impingement was also stated to have been reduced from 3 million fish in a 20-month period to none. No results were available on entrainment. Veneziale (1991) also reported that the cost of the 16-screen array was approximately $4.1 million at the time of installation. Johnson and Ettema (1988) described the 10 mm CWWS used to withdraw makeup water for the closed-cycle cooling system for the Jeffrey Energy Center on the Kansas River, KS. Although the paper does not present biological effectiveness data, the authors concluded that the intake system was functioning as designed. An evaluation of the wedgewire intake system at the Charles Point Resource Recovery Facility on the Hudson River in New York state was conducted in the mid-1980s (EA Science and Technology, 1986). This study was unique in that it included impingement sampling off the screens through the utilization of a vacuum collection system. The authors did not report reductions in IM&E achieved with the CWWS; rather, the study focused on the species and life stage composition and the seasonality of the entrained and impinged organisms.

Pilot-Scale Studies

Other research has focused on the evaluation of pilot-scale CWWS. Weisberg et al. (1987) conducted a field evaluation of CWWS (1, 2, and 3 mm) in the Chalk Point Generating Station intake canal. The results demonstrated that exclusion was influenced not only by the size of organisms, but also by hydrodynamics, particularly because not all fish small enough to be entrained were always entrained. The biological efficacy of the screens was reported as a reduction in entrainment over an open port. The authors concluded that the entrainment of larger larvae was regularly reduced by 80% over the open port and 90% over the ambient densities of larvae in the canal. Browne (1997) conducted a field evaluation of CWWS (1, 2, and 3 mm) from a floating facility at the Oyster Creek Generating Station on Barnegat Bay in New Jersey. The researchers concluded that the air backwashing feature functioned well in keeping the screens free of debris and that the screens constructed of metals with higher copper contents had the lowest amount of biofouling. Too few organisms were collected in entrainment samples to draw significant conclusions about the biological performance of the screen, although the authors pointed out that fewer fish were entrained through the 1 mm screen than the 2 mm screen or the open port, and that those entrained through the 1 mm screen were generally smaller. Impingement was negligible. Lifton (1979) conducted a similar evaluation of 1 and 2 mm CWWS on the St. John's River, FL. The data indicated no significant difference in entrainment between the 1 and 2 mm screens. Sixty-five percent of the time, the screened intakes entrained at least 50% fewer organisms. Gulvas and Zeitoun (1979) evaluated entrainment through pilot-scale CWWS (2 and 9.5 mm) in Lake Michigan. The results indicated that entrainment densities were much lower than ambient densities of larvae and no significant differences were seen in entrainment among either screen of the open pipe (control). No fish were impinged on the screens. In addition, EPRI (2005, 2006) completed a comprehensive field evaluation of the exclusion efficiency of 0.5 and 1.0 mm CWWS in three different water bodies (ocean, estuarine, and freshwater). The results indicate that 0.5 and 1.0 mm wedgewire screens can effectively exclude eggs and larvae at TSV of 0.5 and 1.0 ft/sec.

California Desalination Pilot-Scale Studies

There have been four recent pilot-scale studies conducted (one of which is not yet completed) in California evaluating the use of wedgewire at proposed seawater desalination facilities:

- MMWD: tested 2.4 mm (3/32 in.) CWWS
- SCWD^2: tested a 2.0 mm CWWS
- WBMWD: currently testing 1.0 and 2.0 mm CWWS
- Bay Area Regional Desalination Project (BARDP): tested 2.4 mm (3/32 in.) flat-panel wedgewire screen

Marin Municipal Water District

The objective of this pilot study was to determine the potential entrainment impacts of a proposed desalination facility to be located in northern San Francisco Bay. The pilot-scale CWWS had 2.4 mm slots and drew water from about 2000 ft offshore at a TSV of 0.3 ft/sec. Entrainment sampling was conducted at the pilot plant intake, and source water sampling was conducted at near-field stations in northern San Francisco Bay.

Results indicated that Pacific herring dominated the entrainment samples, composing about 98% of the total entrainment. Empirical transport model (ETM) estimates of Pm (probability of mortality due to entrainment) values, based on maximum period of entrainment risk, ranged from 0.02 to 0.06% (Tenera, 2007). The study authors concluded that the risks posed by entrainment resulting from a full-scale desalination facility (30 MGD) would be low to ambient populations of fish.

City of Santa Cruz Water Department & Soquel Creek Water District ($SCWD^2$) Desalination Program

The objectives of the $SCWD^2$ Desalination Program were to establish a baseline characterization of larval fish and invertebrate populations in the source water body, estimate the biological efficacy of a CWWS intake, and model the potential impacts on local populations caused by the loss of entrained organisms (Tenera, 2010a).

The intake study also included: (1) an investigation of the potential for impinging larvae on the operating CWWS (via video); (2) a dye release study to visualize fluid flow near the CWWS; and (3) a corrosion and biofouling study of screen materials.

Results of the screen efficacy tests of the 2.0 mm slot screen with intake flows of approximately 0.33 ft/sec demonstrated a reduction in entrainment as a function of slot size and size of organisms. The study also demonstrated the effective elimination of impingement. The total estimated annual entrainment of ichthyoplankton was reduced by nearly 20% based on the results of the screened versus unscreened tests. The test results also indicate that, although the screens effect a positive reduction in entrainment of larvae of some fishes occurring in the near-shore area of Santa Cruz, the reduction is not significant compared to entrainment of an unscreened intake. The study authors stated that an abundance of small larvae with heads smaller than the 2 mm slot size of the screen may have affected the results.

The results of biofouling tests using test coupons of stainless steel, titanium, and Z-alloy confirmed that Z-alloy was the most highly resistant of all the materials to the settlement and growth of biofouling organisms. The results of the dye release study indicate that local ambient velocities were sufficient to keep the screen clean and minimize the risk of impingement to fish.

West Basin Municipal Water District

WBMWD began a pilot-scale evaluation of CWWS in March 2011. Sample collection is ongoing, and data that have been available publicly are preliminary (Tenera, 2011a, 2011b, 2011c). WBMWD is evaluating 1.0 and 2.0 mm CWWS at the former Redondo Beach Generating Station discharge from Plant 1. The screens have been installed on the terminus of the pipeline on the intake riser and are designed for a TSV of 0.5 ft/sec. In addition, WBMWD is conducting an evaluation of a subsurface infiltration bed intake to estimate its potential to reduce entrainment, although very few organisms have been collected to date.

Bay Area Regional Desalination Project

The studies were designed to specifically address the following questions:

- What are the species composition and abundance of larval fishes and fish eggs entrained by the BARDP pilot plant?
- What are the local species composition and abundance of entrainable larval fishes and fish eggs in the Mallard Slough source water?
- What are the potential impacts of entrainment losses on larval fish and fish eggs from operation of a BARDP full-scale feed water intake system?

ETM estimates were not calculated for any of the entrained fishes because they were not found in the collected source water samples, or source water samples were not collected because of a lack of permission to collect during the sensitive fish period (January through June). In addition, no fish eggs were collected in entrainment or source water samples during the entire study. Consequently, proportional entrainment (PE) estimates could not be calculated (Tenera, 2010b).

Laboratory Studies

Hanson et al. (1978) demonstrated that preserved striped bass eggs measuring 2.0 to 3.0 mm (0.08–0.12 in.) in diameter were either entrained or impinged on a 1.0 mm (0.04 in.) slot screen. The tests were conducted in a cylindrical flume where different species and life stages of fish were exposed to screens with different slot sizes and orientations at various channel and slot velocities. Most of these tests were conducted in the static mode (i.e., flow only into the screen), and the fish were contained in close proximity to the screen. The authors assumed that these are worst-case conditions because of constant exposure and lack of bypass currents to lessen IM&E. This assumption was proven valid in dynamic mode tests where fish–screen interaction was nonexistent

Additional experiments by Hanson et al. (1978) examined the ability of wedgewire screens to protect striped bass larvae between 4 and 20 days of age (5.2–9.2 mm). Using a 1.0 mm (0.04 in.) slot screen at slot velocities from 0.13 to 0.5 ft/sec, groups of larvae were placed in the test facility on a daily basis and exposed to the screen in each test until all were entrained. As the larvae grew, they were increasingly capable of avoiding entrainment, and the intake velocity was gradually increased over the study period until all were eventually entrained. Although all larvae were eventually entrained, avoidance behavior was observed in all tests.

Laboratory evaluations of narrow-slot CWWS conducted by EPRI (2003) revealed that there are relationships among the various factors that affect IM&E of aquatic organisms. In general, (1) impingement decreased with increases in slot size; (2) entrainment increased with increases in slot size; (3) IM&E increased with increases in TSV; and (4) IM&E decreased with increases in channel velocity. EPRI (2003) identified several biological factors, including size and swimming ability of the test organisms, that affect screen efficacy.

Beal Lake is a historical backwater on the Lower Colorado River that is being developed as a protected habitat for native Lower Colorado River fishes. As a part of the U.S. Bureau of Reclamation's ongoing commitment to compliance with the terms of the ESA, major improvements were made to this backwater to make it suitable for native fishes. A 0.6 mm wedgewire screen was considered to exclude nonnative species from entering the lake. A hydraulic flume was used to determine the effectiveness of the screen system at excluding all life stages of nonnative fishes. Three size classes of eggs and larvae were selected for testing, representing three size classes of nonnative species found in the Lower Colorado River drainage. Gizzard shad (*Dorosoma cepedianum*) were used to represent the smallest size class of fish eggs

(<1 mm diameter) and larvae (<5 mm in length). Fathead minnow (*Pimephales promelas*) were used to represent the medium-size class of eggs (1–2 mm diameter), and smallmouth bass (*Micropterus dolomieu*) were used to represent the medium-size class of larvae (5–10 mm in length). The largest size class of eggs (>2 mm diameter) and larvae (>10 mm in length) were represented by blue catfish (*Ictalurus furcatus*). A screen having the same flow characteristics and slot width (0.6 mm) as the screens installed at Beal Lake was mounted in the hydraulic flume. Entrainment was tested under three slot velocities (0.10, 0.21, and 0.42 ft/sec), and all tests were conducted with static flow conditions in the flume (i.e., the only flow was through the screens). Of the three size classes tested, only eggs and larvae from the smallest size class passed through the wedgewire screen (NAI, 2007a).

A laboratory study was conducted in 2010 to estimate parameters of an avoidance/exclusion model that addressed three distinct mechanisms by which CWWS can reduce entrainment: hydraulic bypass, avoidance, and mechanical exclusion. CWWS with slot widths of 2, 3, 6, and 9 mm were tested at flume velocities of 0.08, 0.15, and 0.30 m/sec (0.25, 0.5, and 1.0 ft/sec) with TSV of 0.08 and 0.15 m/sec (0.25 and 0.5 ft/sec). Tests were conducted by releasing neutrally buoyant beads, fish eggs of approximately 1 and 3 mm diameter, and fish larvae with robust (Atlantic tomcod, striped bass) and slender (white sucker) body forms at a location of known high probability of entrainment immediately upstream of the test screen. The length, body depth, and number of the test subjects carried past, entrained through, or excluded and retained on the CWWS were recorded. Avoidance was typically higher during the day, for the smaller slot sizes, for the lower TSV, and at higher ratios of flume/slot velocity. Exclusion of live larvae was reduced as slot velocity increased on 2 mm CWWS. Exclusion of white sucker eggs (3.3-mm-diameter) by 2 mm CWWS was nearly 100% at either TSV, but was somewhat lower (70–95%) with 3 mm CWWS. The probability of being swept off, if excluded, was higher for the white sucker eggs than for fish larvae and for the low slot velocity (0.08 m/sec [0.25 ft/sec]) and increased with increasing flume velocity. The 2010 laboratory study confirmed that avoidance occurs and that the expected avoidance capability increases exponentially with length (NAI, 2011a).

The laboratory studies were repeated in 2011. The first objective was to supplement the testing conducted in 2010 by repeating the 2010 test procedure for ambient velocities of 0.5, 1.0, 1.5, and 2.0 ft/sec. Objective 2 of the 2011 laboratory study further refined the means of estimating the efficacy of the T-72 (72 in. diameter screens in a T configuration) CWWS screens that are proposed for implementation at the Indian Point Energy Center. This objective was to be accomplished by (1) conducting additional laboratory flume studies in 2011, (2) conducting CFD modeling in support of the flume studies, and (3) integrating the new information from 2011 with the studies done in 2010. Efficacy of CWWS appears to be related to the ambient velocity flowing past the screens through two complementary effects. Because efficacy, the probability that an organism encountering the screen will not be entrained, is the combination of hydraulic bypass, avoidance, and potentially exclusion for larger organisms, combining these three mechanisms generally resulted in an increase in efficacy as ambient velocity increased. The 2011 studies, using data obtained from the T-12 and T-18 screens, found the length of the screen did not affect efficacy. Larval length was an important factor in determining avoidance capability and therefore also overall efficacy of the screens (NAI, 2011b).

State of Development

CWWS are one of the most widely applied submerged screen concepts and consist of fully submerged screen modules placed at the intake end of a pumped or gravity diversion conduit (USBR, 2006). The screens are readily available and manufactured by several notable screening companies including U.S. Filter, Johnson, Hendrick, and Intake Screens, Inc.

Engineering Considerations

The potential for clogging and biofouling is a concern in a fully marine environment, so careful consideration needs to be given to the cleaning mechanism and process. Previous evaluations have indicated that optimizing the ratio of ambient current velocity to TSV has the potential to improve the biological effectiveness of CWWS, with larger ratios providing the highest levels of protection (Hanson et al., 1978; EPRI, 2003). This suggests that the location of the screens in a seawater application would have to be optimized in relation to prevailing currents. If an airburst system is desired, it is important to keep in mind that the effective limit on the distance compressed air can be delivered is about 300 ft.

The screens should be installed with minimum clearance above and below the screen equal to its diameter. The underside clearance is provided to avoid blockage of water flow that is due to siltation or debris accumulation, whereas the top cover is provided to reduce any entrainment of air into the system. In areas where climatic conditions may result in severe temperatures, provisions for the prevention of frazil ice formation on the screens should be considered.

Consideration of CWWS should include in situ pilot-scale studies to determine potential biological effectiveness and identify the ability to control clogging and fouling in a way that does not impact station operation (EPRI, 2007a; Smith and Ferguson, 1979). Where O&M requirements can be met, narrow-slot CWWS have good potential to reduce both the impingement of juveniles and adults and the entrainment of early life stages of fish.

Costs

The cost of a wedgewire installation is on the order of $31,000/cfs. Costs may vary depending upon the type of cleaning system required (air backwash or brushes) as well as the need to consider frazil ice and biological growth. The costs associated with a bulkhead installation will vary from those of a distribution pipe. The conditions of installation, such as depth of water and channel substrate, will impact the level of effort required during installation.

Conclusion

A cylindrical wedgewire installation is likely to be a very effective technology for modifying an existing seawater intake. Wedgewire has undergone extensive biological evaluation and been shown to substantially reduce IM&E. Furthermore, these screens have not experienced unusual maintenance problems; pilot studies are helpful for selecting the best anti-biofouling materials for construction and identifying the best locations in relation to ambient currents.

Figure 3.12. Filtrex filter candle elements.

3.2.2.6 Filtrex Filter System

Description of Technology

The Filtrex Filter System (FFS) is composed of racks of "candles" through which river water is withdrawn (Figure 3.12). The pore size (0.04 mm) of the Filtrex candles is sufficiently small to prevent entrainment of all ichthyoplankton and other small organisms. The low through-pore velocity (0.2 ft/sec) will prevent impingement of juvenile fish and should minimize impingement of fish eggs and larvae.

Brief Review of Research

The FFS has undergone limited biological evaluation. It was tested at Alden in a laboratory flume to examine egg and larval impingement rates and survival of impinged organisms (Alden, 2007). Tests were conducted with alewife and blueback herring (collectively referred to as river herring) and American shad. The results of the laboratory study indicated that American shad and river herring eggs and post–yolk sac larvae could experience low impingement rates (≤15%) at a full-scale desalination facility intake. However, impingement of alewife yolk-sac larvae was high (58%). A pilot-scale field study was also conducted at the TRDP (NAI, 2007b). The control density of impinged eggs was 9 per 100 m^3 of water; none were recorded as impinged on the FFS. The density of impinged larvae on the FFS was 16 per 100 m^3 of water versus 297 per 100 m^3 of water in the control. The study authors concluded that the low through-pore velocity and relatively high ambient velocities in the river resulted in very low impingement rates.

State of Development

The FFS is a new intake technology. To date, it has only been tested at the TRDP and in the lab. It is commercially available but would require substantial site-specific engineering to ensure that the system can be kept clean. Ongoing in situ testing to improve the cleaning efficacy continues.

Engineering Considerations

An FFS is composed of multiple intake modules on a common header pipe. It consists of filter elements approximately 5 in. long, 1.5 in. in diameter, and made of plastic wafers stacked and fastened together with a central spring. Grooves between stacked wafers provide filtration of 40 µm (0.04 mm), and the flow capacity of each candle is approximately 5 gpm at a head loss of 1.5 ft. Filter elements are assembled on tube sheets 2 ft by 2 ft and separated by 3 ft spacing rods. A total of 48 filter elements are arranged on each tube sheet, and two tube sheets with spacer rods is considered an intake module.

Cleaning of the filter candles is conducted by a backwash that separates the stacked wafers, removing debris. There is potential for debris to become entangled in the module; therefore, the location in the source water body and method of cleaning (e.g., air or water backwash) must be evaluated closely when considering an FFS. In addition, the header pipe should be designed for a velocity of 6 to 10 ft/sec to reduce the potential of biofouling.

Costs

Because this technology has not yet been implemented at full-scale, no costs are available at this time.

Conclusion

The FFS may have potential for modifying an existing intake. Although the very small pore size would result in virtual elimination of entrainment, a substantial footprint is required because of the designed low through-pore velocity. Furthermore, because it has only undergone one pilot-scale test at one site, more data with a variety of species would be useful for determining its applicability to other species. In addition, the FFS would have to be evaluated for its susceptibility to biofouling at seawater sites. Given its limited field testing, it is presently considered an experimental technology for seawater intake applications, pending further evaluation.

3.3 Collection Technologies

3.3.1 General Description

Collection systems are designed to either actively or passively collect organisms or direct them to a bypass. Their potential effectiveness can be determined in much the same way as discussed previously for exclusion systems; however, because the organisms are being collected, it is necessary to know how well they survive the collection and return process. Therefore, whereas the potential efficacy of exclusion systems can be determined based on the size of the organisms in relation to the size of the mesh, the potential efficacy of collection systems also has to take into account injury and mortality that may be imparted by the systems.

The modified TWS is one of the most popular collection technologies used at CWIS in the power industry. These screens represent an improvement over conventional TWS in that they have been modified to include fish-lifting buckets and low pressure spray wash and are run continuously to minimize impingement duration and maximize survival. Furthermore, over the years, the design of the fish-lifting bucket has been optimized to produce internal hydraulics that are conducive to transporting fish gently. These screens have biological and engineering advantages over other intake technologies.

Four alternatives currently exist for traveling screens with fish protection features. Ristroph TWS (Ristroph), Geiger Multidisc™ Screening System (Geiger), Beaudrey Water Intake Protection screens (WIP), and Hydrolox™ screens (Hydrolox) are all engineered to reduce IM&E. Ristroph traveling screens currently have the most biological data available. Limited biological data exist for the Geiger, WIP, and Hydrolox screens; however, these designs should provide comparable biological efficacy.

3.3.2 List of Collection Technologies

3.3.2.1 Modified Traveling Water Screens

Description of Technology

Modified TWS, commonly referred to as Ristroph screens, are very similar to conventional TWS except that they incorporate modifications that improve survival of impinged fish (Figure 3.13). The modifications include fish-lifting buckets that collect impinged fish on the upstream screen face while the screen rotates towards the surface, a low pressure spray wash system to gently rinse impinged fish from the bucket into a fish return system, a high- pressure spray wash system to remove any remaining debris from the screen face, and a fish return system to return impinged fish to the source water body a safe distance from the intake.

There are several variations to modified TWS: through-flow, dual-flow, and center-flow. Drum screens function the same way as the modified TWS and can be considered equivalent conceptually. The most common variation is the through-flow screen, in which the screen is perpendicular to the flow. Dual-flow and center-flow screens differ in that the screen is parallel to the flow. In the dual-flow screen, water flows around each side of the screen, then through the mesh, and exits out the center of the screen. In a center-flow screen, the water enters through the center of the screen, flows through the mesh, and exits on each side of the screen.

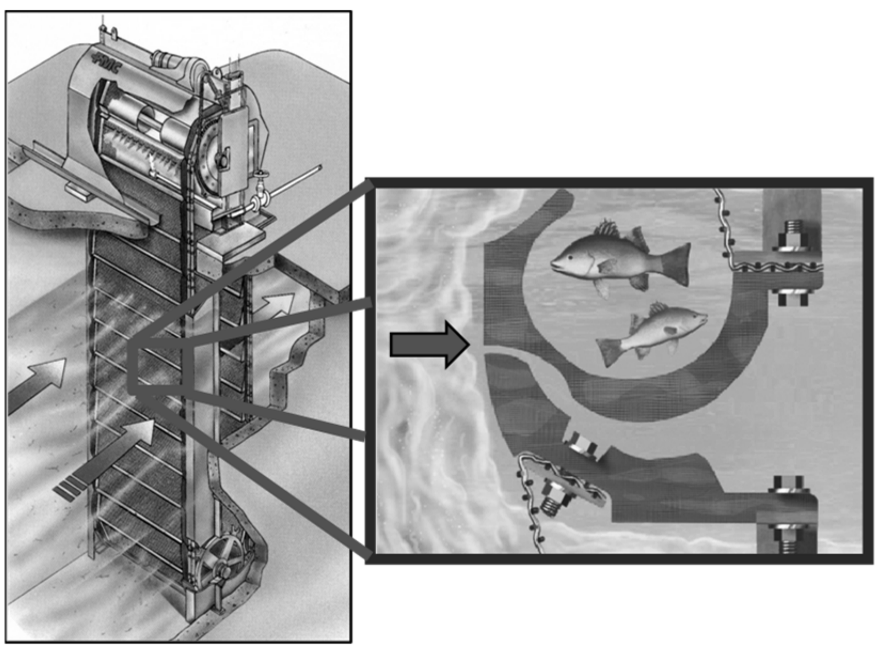


Figure 3.13. Modified traveling water screen (through-flow) with fish-lifting buckets.
Source: Courtesy of Siemens

Brief Review of Research

The state-of-the-art modified Ristroph screen design was developed through extensive laboratory and field experimentation. A series of studies conducted by Fletcher (1990) indicated that substantial injury associated with traveling screens was due to repeated buffeting of fish inside the lifting buckets as a result of undesirable hydraulic conditions. To eliminate these conditions, a number of alternative bucket configurations were developed to create a sheltered area in which fish could safely reside during screen rotation. After several attempts, a bucket configuration was developed that achieved the desired conditions (Envirex, 1996). In 1995, Public Service Gas and Electric (PSEG) performed a biological evaluation of the improved screening system installed at the Salem Generating Station in the Delaware River (PSEG, 1999; Ronafalvy, 1999). The results indicate that, with the modified TWS with 6.4 by 12.7 mm mesh, losses of weakfish (a target species for protection) were reduced by 51% (Ronafalvy, 1999).

Laboratory evaluations by EPRI (2006) looked at the mortality, injury, and scale loss rates of 10 species of freshwater fish impinged and recovered with a modified traveling screen. Mortality rates did not exceed 5% for any species and velocity tested (0.3, 0.6, and 0.9 m/s). Other modified screen designs, including a rotary disc screen (Geiger) and extruded polymer screens (Hydrolox) have shown similarly high survival rates in the laboratory and field (EPRI, 2007b; ASA, 2008).

In addition to the fish handling provisions noted previously, TWS 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 water body. For many species and early life stages, mesh sizes of 0.5 to 1.0 mm are required for effective screening. 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 not experienced unusual clogging or cleaning problems. Biological data indicate that survival is highly species- and life stage–specific. Species such as bay anchovy (*Anchoa mitchilli*) and *Alosa* spp. have shown low survival, whereas other species, such as striped bass (*Morone saxatilis*), white perch (*Morone americana*), yellow perch (*Perca flavescens*), and invertebrates (crabs and shrimp), show moderate to high survival.

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. 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 as well as nontarget species. Pilot-scale studies at the site of potential application may also be recommended if available data are limited.

In addition to field studies, fine-mesh screen survival data are available from extensive laboratory studies (Taft et al., 1981; ESEERCO, 1981; Stone & Webster, , 1980). In these studies, larval life stages of striped bass, winter flounder, alewife, yellow perch, walleye (*Sander vitreus*), channel catfish (*Ictalurus punctatus*), and bluegill (*Lepomis macrochirus*) were impinged on a 0.5 mm screen mesh at velocities ranging from 0.15 to 0.91 m/sec (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.

The primary concern with fine-mesh TWS is that they function by impinging early life stages that would otherwise be entrained through coarse-mesh (typically 9.5 mm) screens. Depending on species and life stage, mortality from impingement can exceed entrainment mortality. In order for fine-mesh screens to offer a meaningful benefit in protecting fish, impingement survival of target species and life stages must be substantially greater than survival through the circulating water system. When considering application at a desalination facility, any entrained organisms would be considered lost to the system.

State of Development

These technologies are considered mature and are commercially available. Vendors include Siemens, U.S. Filter, Beaudrey, Geiger, and Hydrolox. Modified through-flow and dual-flow screens have been used extensively in the United States. There has been only one U.S. installation of a center-flow screen; however, they are used in Europe. Drum screens are not used at generating station intakes in the United States.

Engineering Considerations

All three screen types (through-flow, dual-flow, and center-flow) can be modified to allow a front wash process or a front and back wash process. Regardless of the location (front or back), the low pressure spray wash should be used prior to the high pressure spray wash to reduce fish mortality. A dual-flow screen retrofit would be limited to a screen width roughly half that of an existing conventional traveling screen. That is, an existing 10 ft wide conventional screen could be replaced with a 4 to 5 ft wide dual-flow screen. The multidisc, WIP, and dual-flow screens eliminate, and the Hydrolox screen virtually eliminates, debris carryover. More detail on these screens is given later.

Modification of an existing conventional TWS intake with modified TWS would likely require relatively few changes to the existing civil structures (i.e., new screens should fit within the existing bays of the intake). Consideration needs to be given to the mesh size, which will be determined by the size of the organisms targeted for exclusion. Smaller mesh screening will require additional screens to provide the same flow at the same intake velocity. If the screens are to run continuously, consideration should be given to the potential for increased barnacle growth because the screen will no longer be exposed to air for very long. It is also important to consider the design and location of the fish return system to return collected organisms to the source water body.

Costs

A comparison of actual quotes for modified TWS results in an average cost of $300,000 and a range from $120,000 to $600,000. Although actual costs will vary among stations because of height, width, and shipping costs, the relative screen costs are valid. Additional costs should be considered, including those associated with installation, electrical systems, and civil modifications. The cost associated with installing modified TWS is estimated to be on the order of $18,000/cfs.

Conclusion

Modified TWS are a commercially available and well-accepted technology for minimizing adverse environmental impacts and a very good technology to consider for modifying existing seawater intakes. Survival of impinged organisms is species- and life stage–specific, but high survival of impinged organisms is possible. Modified TWS may reduce entrainment of some life stages, although exclusion will be dependent on fish size. Survival of impinged early life stages is generally poor.

3.3.2.2 Modified Rotating Drum Screens

Description of Technology

A drum screen is a horizontally oriented, screened cylinder that rotates to collect and rinse organisms and debris from the screen face. Although drum screens are not commonly used in the United States, they are prevalent at seawater intakes elsewhere. For example, most of the large Australian desalination plants use drum screens for screening of debris. The Melbourne and Sydney plants use large-diameter, double-entry drum screens, and the Gold Coast Desalination Plant uses a small-diameter, single-entry drum screen, all of which are equipped with woven wire mesh screens with 3 mm openings. The screens are located at onshore pump stations at the discharge end of a tunnel that extends out into the sea at least 300 m.

Some drum screens use a debris organism collection (DOC) system (also called "Scoop-a-Fish"), which is a system that uses a vacuum driven by a fish-friendly pump to remove fish and debris from the drum screen and return them to the source water body by a fish return system (Figure 3.14). The DOC system is located below the water level and set close to the drum screen. The number of pumps needed is dictated by the width of the drum screen. As the drum rotates upward toward the water surface, the pumping system has a fixed intake covering a section of the drum screen that vacuums debris off the screen. After passing through the pump, flow, debris, and fish are conveyed through a piping system and discharged to a location where the debris and fish will not become re-entrained into the system.

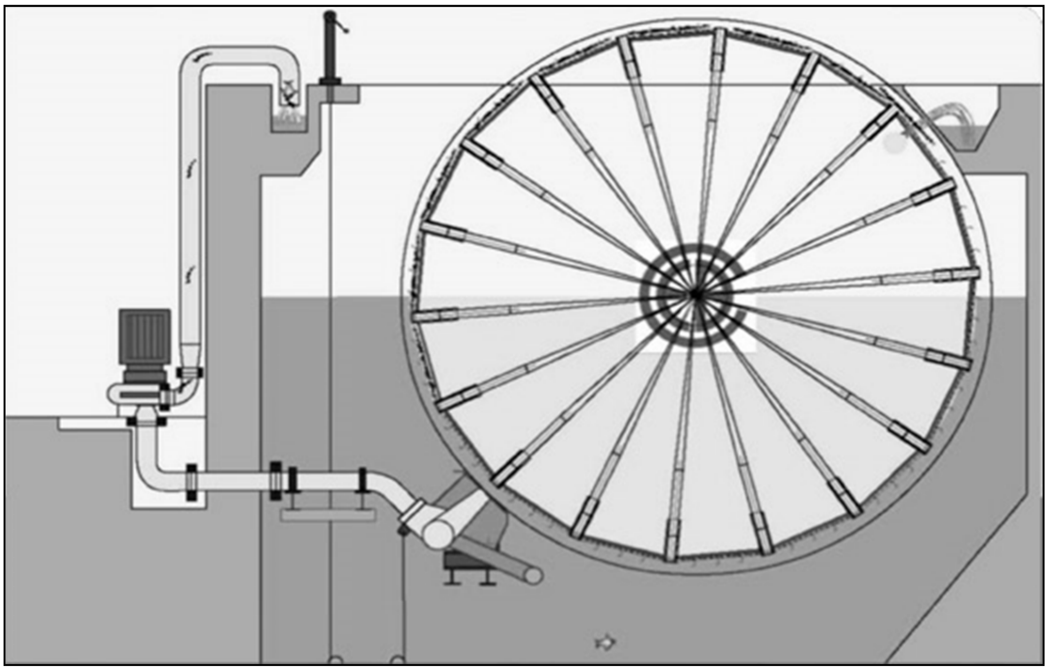


Figure 3.14. Modified rotating drum screen with submerged Scoop-a-Fish pump for removing impinged organisms.
Source: Courtesy of Beaudrey

<u>*Brief Review of Research*</u>

Very limited research has been conducted on modified rotating drum screens. Although they are used frequently in other countries, in the United States they have been used primarily at irrigation and hydroelectric projects to exclude fish. The Gold Coast Desalination Plant is the only existing desalination plant that has published any data on the biological efficacy of these intakes (Gordon et al., 2011), and the data were limited to the weight of marine organisms impinged on the 3 mm screen during several test periods. The weight of fish removed from the screen did not exceed 20 kg in one month during any of the test periods.

The Beaudrey WIP screen (described in a later section) is essentially the same concept (underwater vacuum removal of impinged fish) as a drum screen and has performed well in biological evaluations. Results showed that fish impinged and recovered from the WIP screen exhibited high survival. In fact, survival rates of impinged fish showed no significant differences from control fish, indicating that screen contact and collection added no additional mortality.

State of Development

Rotating drum screens are a mature technology, although rotating drum screens modified for fish protection are still considered experimental in terms of biological performance, principally because of a lack of biological efficacy data. Beaudrey is the principal vendor of modified rotating drum screens and has patented the Scoop-a-Fish technology. Though the debris-handling capabilities of these screens are good, there are no biological data (other than the data generated in the evaluation of the Beaudrey WIP screen) from which to determine their ability to reliably reduce IM&E.

Engineering Considerations

For an existing CWIS that utilizes drum screens, upgrading the system to the Scoop-a-Fish technology should be considered. If the site does not currently have drum screens in place, the existing civil structures will have to be removed and new ones constructed. The size of drum screens are likely to make the cost of the required civil structures prohibitive.

The pumps associated with the modified drum screen must be designed with fish-friendly features such as low rpm and minimum blades. Once removed from the screen by the pumps, the ensuing piping must be designed to have gradual changes in elevation and pressure for fish protection. In addition, the area at which the pump removes the fish must consist of smooth surfaces and transitions to minimize fish injury.

Costs

Costs are not currently available for the Scoop-a-Fish technology.

Conclusion

If an existing intake utilizes drum screens, the installation of fish-friendly pumps on the existing screens may be a practical alternative for reducing impacts. Drum screens are not used at existing seawater intakes in the United States, and there are no biological efficacy data to support projected reductions in aquatic losses. Therefore, a modified rotating drum screen is not likely to be an effective technology for modifying an existing seawater intake.

3.3.2.3 Passavant-Geiger Multi-Disc™ Screens

Description of Technology

Multidisc screens are a variation on conventional TWS. In a conventional modified traveling screen, only the ascending side of the screen removes fish and debris from the raw water. By contrast, the total submerged screening area (the descending and ascending mesh panels as well as mesh panels in the lower guiding section) of multidisc screens filter raw water (Figure 3.15). Fish and debris are retained on the mesh panels and carried upward in a bucket as the screen band travels through the water column to the discharge position above deck. Debris and fish are washed off the screen by spray wash headers into a collecting and transfer trough. A low pressure wash is used first to clear the ascending panels of aquatic organisms, and a high pressure spray wash is used to remove debris as the panels descend. As both the ascending and descending side of the screen are on the same plane (the upstream side) of the system, carryover is eliminated.

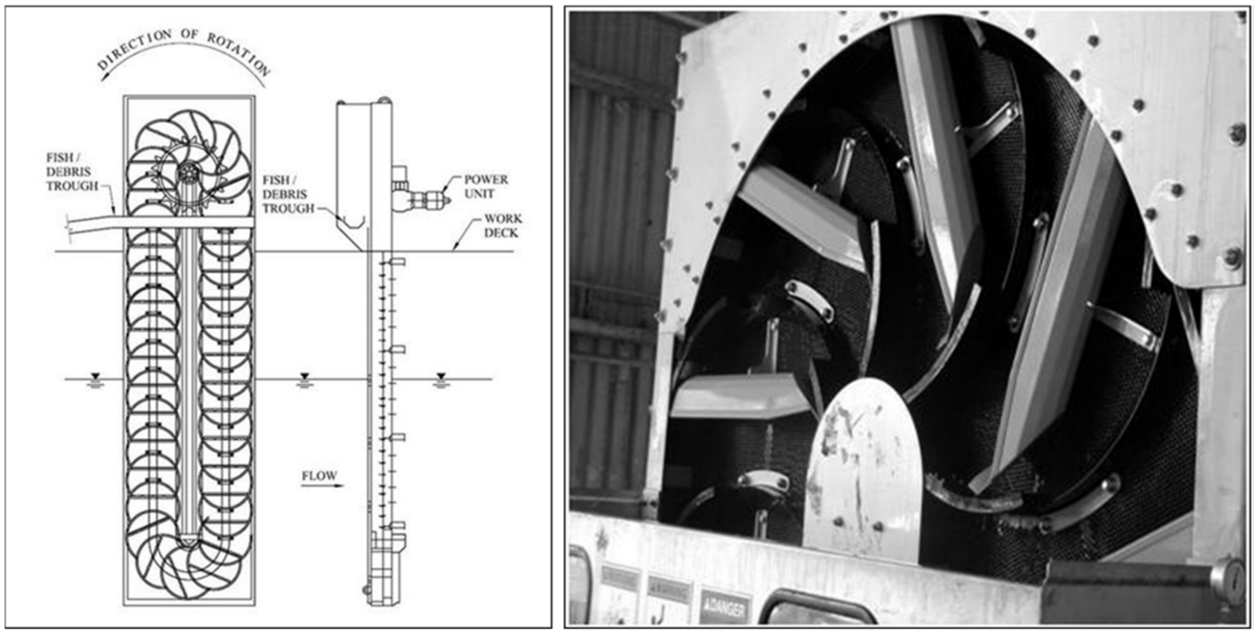


Figure 3.15. Passavant-Geiger Multidisc Screen.
Source: Courtesy of Passavant-Geiger

Brief Review of Research

A multidisc screen (3/8 in. drilled plastic) with fish protection features was tested at the Potomac River Generation Station in 2005 through 2006 (EPRI, 2007b). Injury and survival of fish exposed to the impingement and collection process were evaluated. During the evaluation, the screen was rotated continuously, and wash water was diverted to a fish collection system. Approximately 94% of the impinged fish were associated with two storm events. The reduced water quality during these events likely compromised survival results. That is, the environmental conditions at the study site, outside the control of the facility or the screens, influenced the observed survival. Overall, however, mortality was comparable to results for other traveling screen studies.

EPRI is currently funding a study to evaluate juvenile and adult fish survival in the laboratory with the multidisc screen. Methods used will be similar to those used previously (EPRI, 2006) to evaluate modified Ristroph traveling screens. The objective is to develop mortality, injury, and scale loss rates that can be directly compared to those developed for modified traveling screens in the absence of environmental factors that could obscure similarities in screen survival.

The multidisc screen was also one of three screens included in a multiple-year laboratory study of finer mesh (<3/8 in. [9.5 mm]) screens (EPRI, 2008, 2009b, 2010). The impingement survival results demonstrated that the multidisc screens performed comparably with the modified Ristroph screen when considering early life stages of fish (3 to 44 mm; mean of 15.9 mm).

State of Development

The multidisc screen is considered a mature technology. It is available commercially from Passavant-Geiger and has been shown to have comparable biological performance to other modified TWS technologies.

Engineering Considerations

The main components of the multidisc screen are the sickle-shaped mesh panels, one central chain guideway integrated in the supporting structure, one revolving chain, and one lower guide. The multidisc screens have a 10 ft wide limitation and eliminate debris carryover. Multidisc screens can be made of a drilled plastic material and can rotate up to 60 ft/min. It would have the same engineering considerations as the through-flow modified TWS described previously.

Costs

The cost for multidisc screens is comparable to the cost of other similarly sized modified TWS.

Conclusion

The multidisc screen is an effective technology for modifying an existing seawater intake to minimize adverse environmental impacts. Its biological performance is comparable to other modified TWS, but it has the added advantage of preventing debris carryover. Depending on the screen mesh size selected, however, its biological efficacy is substantially reduced for early life stages (i.e., eggs and larvae), as is the case for any modified TWS.

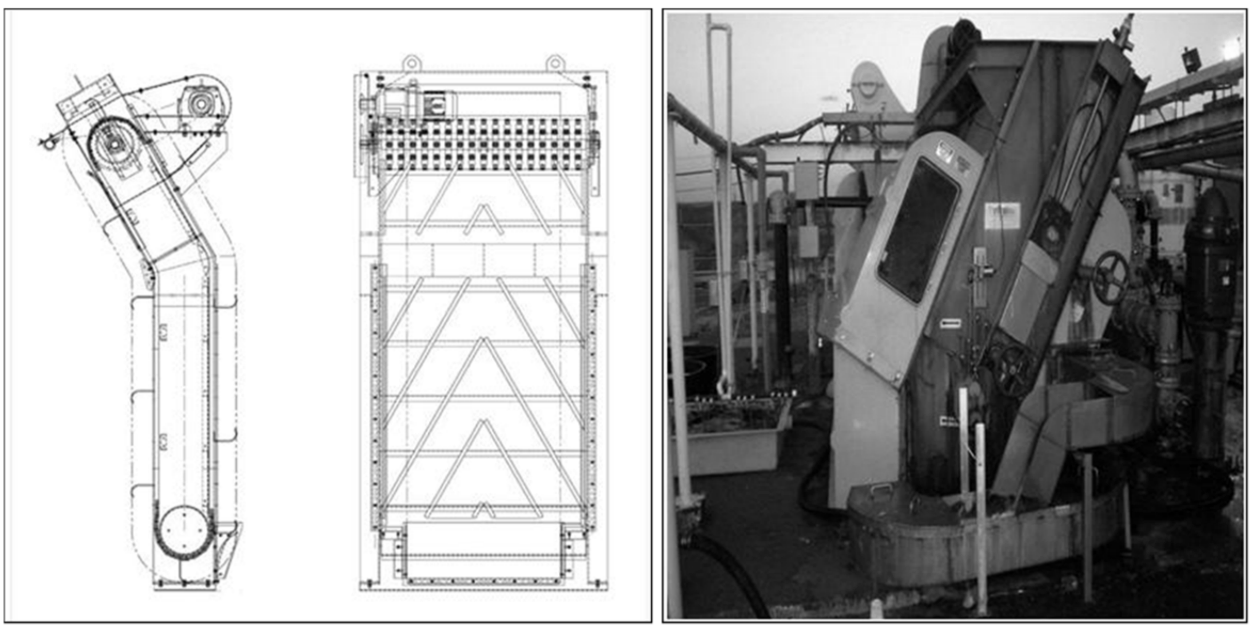


Figure 3.16. Hydrolox screen.
Source: Courtesy of Hydrolox, Inc.

3.3.2.4 Hydrolox Screens

Description of Technology

Hydrolox Inc. has developed a polymer-based traveling screen (Hydrolox screen) with fish handling features. This screen's operation is similar to conventional traveling screens with a few significant differences. The screen material and sprockets are made of a polymer, which results in a lighter weight screen compared to standard TWS, similar to the logic used by Fletcher (1990) in developing the lighter weight "composite" screen baskets. In addition, the top sprocket of the screen is offset from the bottom sprocket, allowing gravity to assist in removal of debris and fish, reducing the potential for debris carryover (Figure 3.16).

Brief Review of Research

These screens have been evaluated in both laboratory and field settings. Alden worked with Hydrolox to develop its fish bucket to ensure a level of turbulence comparable to that found with the Fletcher design. In the laboratory, the mortality, injury, and scale-loss rates of five species of freshwater fish impinged and recovered with a Hydrolox screen were evaluated and found to be generally low (Alden, 2006). One Hydrolox screen with fish protection features was installed and tested at National Grid's Barrett Station on Long Island in New York state (ASA, 2008). The results demonstrated that survival of fish impinged on the Hydrolox screen was near the upper bound of estimates for most species reported in other studies and consistently equal to or greater than that found on the other modified traveling screen at the station (ASA, 2008).

State of Development

Hydrolox screens are commercially available and have been used at industrial water intakes in the United States. They are considered a mature technology and have been shown to have comparable biological performance to other modified TWS technologies.

Engineering Considerations

The Hydrolox screen is very light compared to other TWS. Low O&M has been reported, and concerns over the durability of the polymer materials have been addressed subsequent to pilot-scale field evaluations. The Hydrolox screen has a debris-handling advantage over other modified TWS as it virtually eliminates debris carryover.

Costs

The cost for Hydrolox screens is similar to that of other similarly sized modified TWS.

Conclusion

The Hydrolox screen is an effective technology for modifying an existing seawater intake to minimize adverse environmental impacts. Its biological performance is comparable to other modified TWS, but, as with the Geiger multidisc screen, it has the added advantage of minimizing the risk of debris carryover. Depending on the screen mesh size selected, however, the biological efficacy is substantially reduced for early life stages (i.e., eggs and larvae), as is the case for any modified TWS.

3.3.2.5 Beaudrey Water Intake Protection Screens

Description of Technology

The Beaudrey WIP screen is the most recent variation of a modified TWS. These screens incorporate large filter disks divided into several pie-shaped wedges that rotate on a center axle (Figure 3.17). Each disk rotates perpendicularly to the net intake flow, eliminating any potential for debris carryover. As the disk rotates, each screen wedge passes under a stationary suction scoop mounted over one section of the filter disk. Fish and debris impinged on the screen are vacuumed off as the screen rotates under this section. A fish-friendly pump, designed to handle fragile materials, is used to transport impinged organisms and debris to a return trough. Organisms removed from the screen are continuously submerged, which may reduce or eliminate some of the stresses (e.g., air exposure) associated with handling and return to the water body.

Brief Review of Research

A WIP screen was tested at Omaha Public Power's North Omaha Station (Bigbee et al., 2010; EPRI, 2009a). Fish collected off the screen were held for 48 hours to assess post-impingement survival. Results demonstrated that fish impinged and recovered from the WIP screen exhibited high survival. In fact, survival rates of impinged fish showed no significant differences from control fish, indicating that screen contact and collection added no additional mortality.

State of Development

This is considered a mature technology, albeit with minimal biological data available. The WIP screen is available commercially from Beaudrey. There are currently no full-scale installations of WIP screens at seawater intakes.

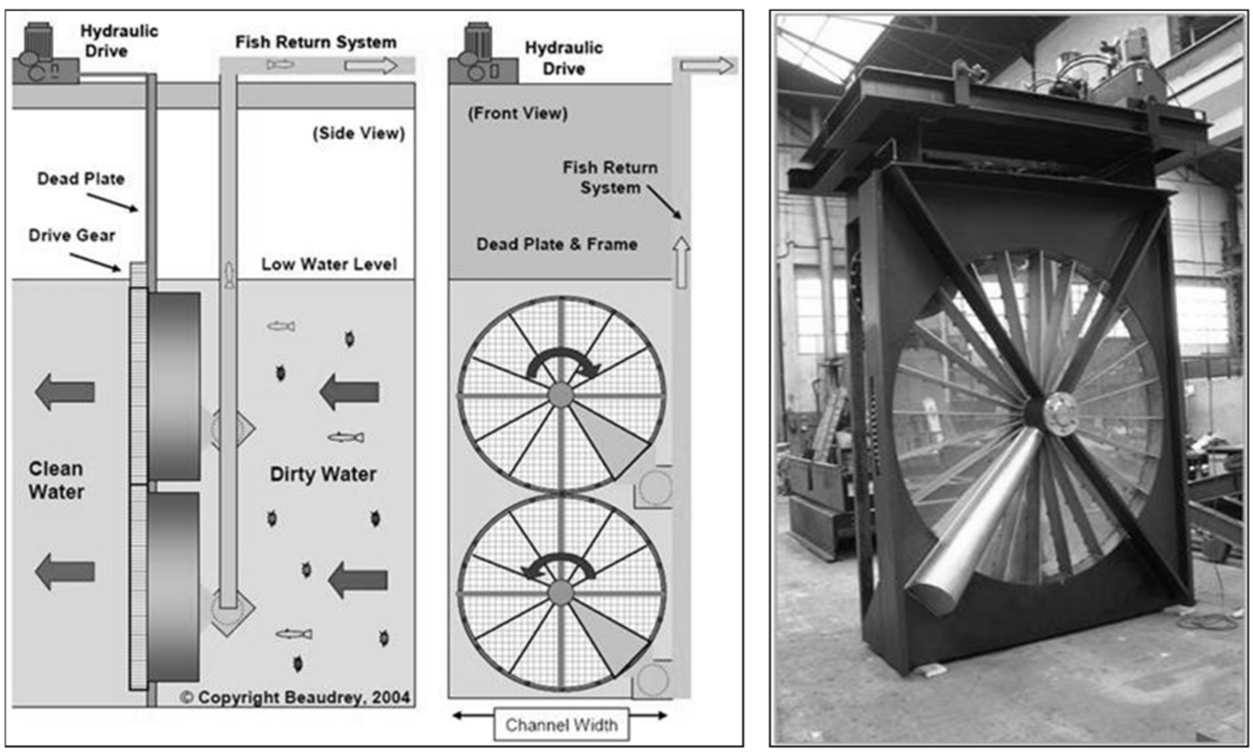


Figure 3.17. Beaudrey WIP screen.
Source: Courtesy of Beaudrey

Engineering Considerations

The WIP screen is designed to fit within existing screen bays, making retrofits straightforward. The design of the screen support structures gives the WIP screen the lowest percent open area of all modified TWS. Because the WIP screen uses a pump to collect and transport impinged organisms, the fish return pipe can be used where local conditions preclude the use of a gravity flow return. Consideration must be given to the design and length of the return pipe.

Costs

The cost for WIP screens is similar to that of other similarly sized modified TWS.

Conclusion

The WIP screen is an effective technology for modifying an existing seawater intake to minimize adverse environmental impacts. Because there have been no full-scale installations to date, biological efficacy data are sparse. Pilot-scale studies are recommended to determine the screen effectiveness for the species of concern at any given site. Depending on the screen mesh size selected, however, the biological efficacy is substantially reduced for early life stages (i.e., eggs and larvae), as is the case for any modified TWS.

3.4 Diversion Technologies

3.4.1 General Description

Fish diversion systems operate by directing fish and other organisms to a bypass that returns them to the receiving waters. This bypass can be either gravity or pump fed depending on the specific technology and site characteristics. The potential effectiveness of diversion systems is based on the diversion efficiency as well as the survival of organisms through the return system. Therefore, diversion systems must take into account injury and mortality that may be imparted by the return system in estimation of system effectiveness.

3.4.2 List of Diversion Technologies

3.4.2.1 Angled Bar Rack/Louver

Description of Technology

Angled bar racks and louvers consist of an array of evenly spaced vertical slats aligned across a channel at a specified angle, leading to a bypass. Louver slats are oriented 90° to the flow, whereas angled rack slats are angled 90° to the rack frame, and their orientation to the flow will be dependent upon the angle of the entire rack structure (Figure 3.18).

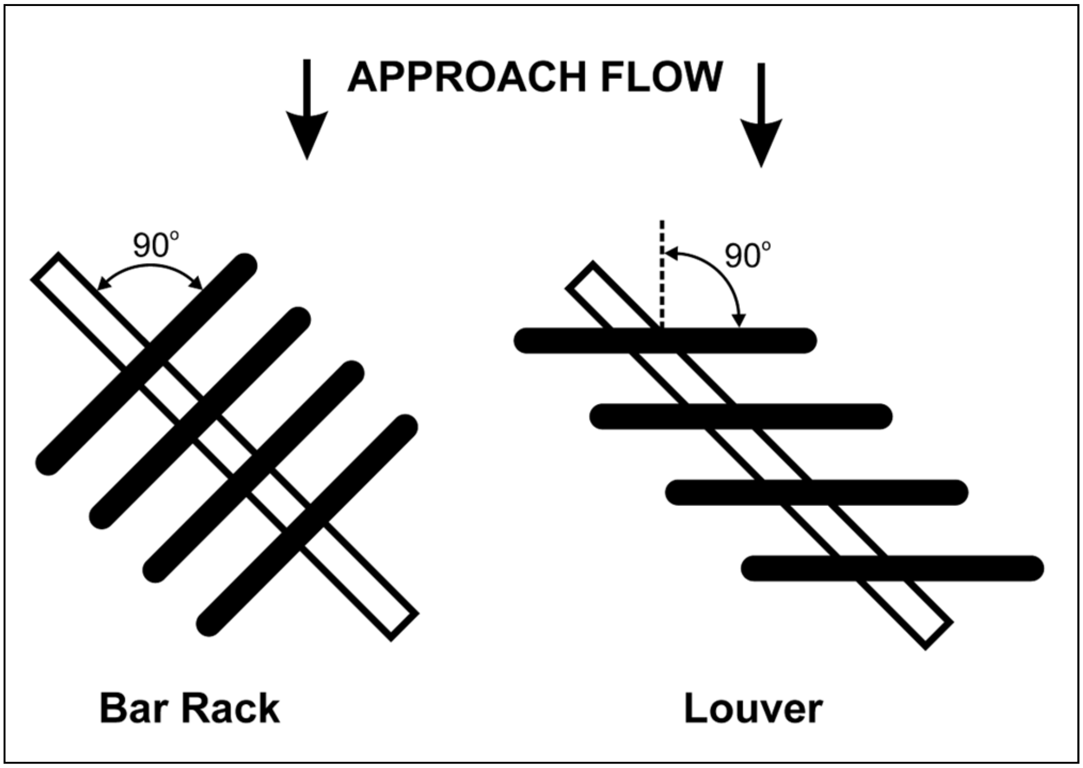


Figure 3.18. Orientation of angled bar racks and louver slats: structures depicted are angled at 45° to the approach flow.

Source: EPRI, 2001

Brief Review of Research

Though typically classified as a diversion technology, the mode of action in the guidance of fish along these structures is believed to be behaviorally based. Using their lateral line sensory system, fish swimming along angled bar racks and louvers detect flow disturbances (turbulence) created by the slats and actively avoid the structure while moving downstream with the flow towards a bypass.

Results of angled bar rack and louver studies to date have been variable by species and site; however, numerous studies have demonstrated that diversion efficiency of louvers can be on the order of 80 to 95% for a wide array of species and design and operational conditions (EPRI, 1986a, 1998, 2001). Louver systems have been used at one CWIS and applied successfully at several hydroelectric and irrigation facilities in the Northwest and Northeast. Schuler (1973) tested various louver configurations with 18 species of fish, including northern anchovy, queenfish, white croaker, walleye, surfperch, and shiner perch, in a test flume at Southern California Edison's Redondo Beach Station. This flume study led to the development and installation of an angled traveling screen/louver system at SONGS (Schuler and Larson, 1975). Other laboratory studies conducted for potential CWIS application on the East Coast showed reasonably high diversion efficiencies with striped bass, white perch, and Atlantic tomcod (Taft and Mussalli, 1978). Studies of louver facilities at hydroelectric and irrigation facilities on both coasts have shown that salmonid and clupeid species were successfully diverted to bypasses. In all studies, louver effectiveness has been shown to be species-, life stage–, and site-specific and depends extensively on the swimming capabilities and behavior of target species, the angle and orientation of the louver array, approach and bypass velocities, and localized hydraulic conditions.

Although louvers may be considered for potential CWIS application, given the limited data available for this application to date, further studies with species of importance at CWIS are needed to define the full potential of this technology. Overall, tests conducted at a 15° angle to the flow produced the highest fish guidance efficiencies (FGE) for the species that were evaluated with more than one angle. The next highest guidance rates were observed with the 45° arrays, and the lowest guidance rates of all the arrays evaluated occurred with the 90° bar rack. When all test conditions are considered, the lowest FGE were observed when there was no structure in the flume (i.e., control condition), indicating that all of the guidance array configurations evaluated produced some level of diversion to the bypass greater than what might result from random distribution of fish in the flume (EPRI, 2001).

State of Development

Angled bar racks or louvers used at hydroelectric intakes and limited steam electric facility intakes have been shown to be biologically effective at reducing impacts to fish. Each technology is available commercially from screen vendors such as Hydrothane and Hydro Component Systems. Angled bar racks or louvers have been used at only one CWIS, however, so biological performance data for this application are limited.

Engineering Considerations

Hydraulic studies have identified problems within a power canal and louver bypass system. The studies confirmed the existence of poor guidance conditions near the center of the array and at the bypass entrance, as well as the existence of reverse flow conditions and large vortex eddies. The size of the structure will be directly proportional to the flow rate. Debris handling capabilities could be an issue and will in all likelihood require TWS in addition to the louvers. In the confined space of an existing intake's footprint, a fish-friendly removal pump will be required. A significant support structure is required to support both angled bar racks and louver systems.

Costs

The cost of bar racks and louvers is on the order of $10,000/cfs. Factors that may influence the cost include the rack spacing, angle relative to the flow at which the rack is set, anticipated debris loading, fabrication material, and required support structures. In general, a louver will likely be more expensive than an angled bar rack. This is because the fabrication associated with the louver is slightly more complex than that of the angled bar rack. Bar racks are common features of any water withdrawal facility and readily available.

Conclusion

To be effective, an angled bar rack or louver system must be installed in a flowing water situation with sufficient velocity to affect fish behavior and also have a place or mechanism to bypass fish. Although possible conceptually, this technology is not considered practicable for modification of an existing seawater intake, principally because of the large footprint of the civil structural modifications required to fit it in.

3.4.2.2 High Velocity Screens

High velocity screens include both the modular inclined screen (MIS) and the Eicher screen. To date, there has been limited application of these types of screens at CWIS, but the Eicher screen has been used successfully at several hydroelectric power plants.

Description of Technology

The MIS was developed and tested in the 1990s (EPRI, 1994b, 1996; Alden and Stone & Webster, 1996) with the intention of protecting 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 (10–20°) to the flow, and a bypass for directing and diverting fish to a transport pipe or other bypass system (Figure 3.19). The module is completely enclosed and designed to operate at relatively high water velocities ranging from 0.6 to 3.0 m/sec (2.0 to 10.0 ft/sec), depending on the species and life stage to be protected. The screen is designed to pivot at a predetermined screen differential, allowing the flow to backwash debris from the screen.

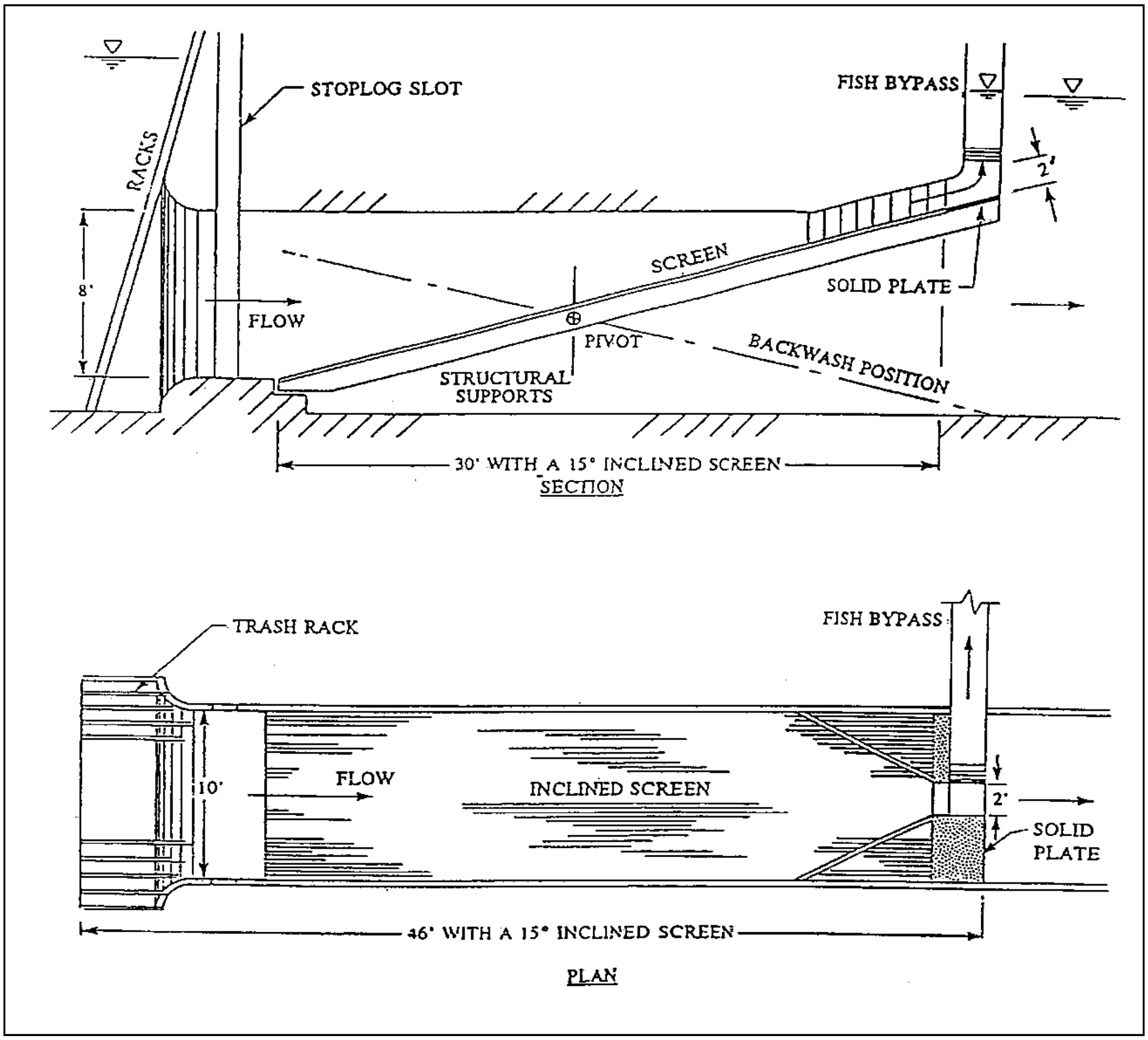


Figure 3.19. Modular inclined screen.
Source: Taft et al., 1997

An Eicher screen is a passive-pressure screen designed for application at hydroelectric facilities with penstocks (Figure 3.20). The concept was patented in the United States by George Eicher. Although the technology is not directly applicable to desalination or cooling water intakes, the biological information is pertinent to high velocity fish diversion screens in general (particularly the MIS). The Eicher screen consists of an inclined elliptical plane center mounted on an axle fitted inside a circular section of pipe. The center mount is designed to allow for pivoting of the plane. Should the screen become lodged with debris, it is pivoted so the flow back flushes the screen, removing the debris.

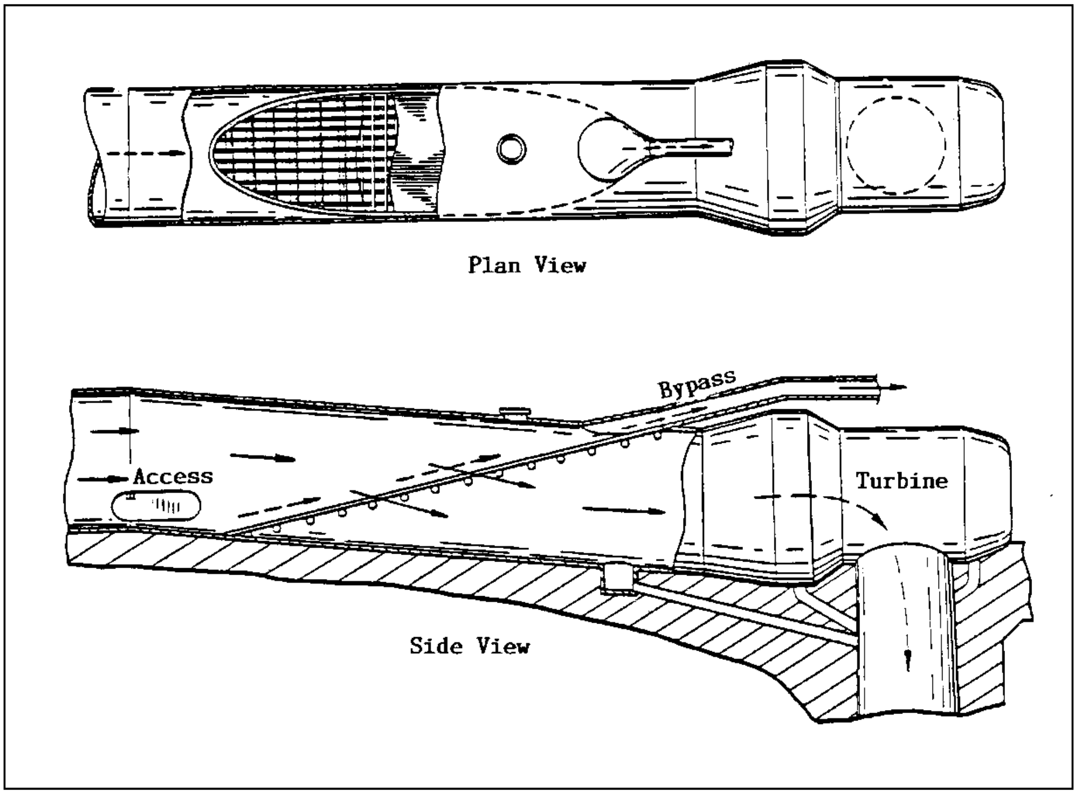


Figure 3.20. Plan and section of an Eicher screen.
Source: EPRI, 1999

Brief Review of Research

Based on good laboratory results, a pilot-scale evaluation of the MIS (with 2.0 mm slot width) was conducted at Niagara Mohawk Power Corporation's Green Island Hydroelectric Project on the Hudson River near Troy, NY (EPRI, 1996; Alden and Stone & Webster, 1996). The results obtained in this field evaluation were similar to those obtained in laboratory studies. Golden shiners and rainbow trout showed diversion and survival rates approaching 100% under most test conditions. For blueback herring, diversion efficiencies and extended survival values obtained were similar to laboratory results. In both cases, there was a relationship between diversion and survival and test velocity. Higher velocities resulted in lower diversion and survival rates. Additional studies at Green Island in 1996 showed high diversion efficiencies and low latent mortality of largemouth and smallmouth bass, yellow perch, and bluegill (EPRI, 1996).

State of Development

To date, the MIS has undergone extensive evaluation in the laboratory and at a prototype field site; however, it has yet to be used on a permanent basis to protect fish at water intakes. On the basis of both laboratory testing and a field evaluation, it has been demonstrated that this screen is an effective fish diversion device that has the potential for protecting fish at water intakes. Given the large number of species evaluated that cover a wide range of swimming capabilities and body shapes, it is reasonable to assume that juvenile and adult life stages of many species may be diverted and survive within the range of net passage survivals observed in the laboratory and field studies. To date, no large-scale installations have been completed; these are needed prior to determining the final effectiveness of this technology for desalination purposes.

The MIS is not a commercially available product; the module will likely have to be custom-designed for the project under consideration.

Engineering Considerations

Functionally, the MIS and Eicher screens are similar in that they consist of an inclined and permeable plane allowing flow to pass through while diverting organisms to a bypass structure. As flow approaches the MIS in an absolute vector, one component will continue upward across the face of the screen while another will fall through the screen, continuing to the plant. The angle at which the screen is set relative to the direction of flow and the water velocity are critical parameters in designing a biologically effective system. It is important to have a bypass facility included with any plans for using high velocity screens, as the organisms diverted by the screen must ultimately be returned to the source water body. The MIS would likely require substantial civil modifications to an existing intake for incorporation.

Costs

Actual costs associated with high velocity screens are not available because none have been permanently installed. It is estimated that the cost associated with an MIS installation is on the order of $5000/cfs. These costs are based on a series of conceptual desktop studies that have been completed for various CWIS.

Conclusion

An MIS or Eicher screen is not likely to be an effective technology for modifying an existing seawater intake. Although the diversion efficiency and survival of fish have been high in previous studies, there are no data on the performance of the technology at full-scale seawater intakes. Pilot-scale studies would be required to evaluate its performance with the species of concern at a given site. The potential biological efficacy for entrainment reduction has not been determined.

3.4.2.3 Angled Screens

Description of Technology

Angled fish diversion screens leading to bypass and return pipelines (Figure 3.21) have been extensively investigated and are commonly used for guiding salmonids in the Pacific Northwest. A wide variety of other species have been shown to guide effectively on screens given suitable hydraulic conditions. Flat panel wedgewire screens are the most commonly used in an angled screen array, but traveling screens or angled drum screens have also been used at cooling water intakes. In order to be biologically effective, angled screens require uniform flow conditions, a fairly constant approach velocity, and a low TSV.

Figure 3.21. Angled screen diversion system at White River.

Brief Review of Research

A variety of species have been shown to guide effectively on screens given suitable hydraulic conditions. Angled screen diversion efficiency varies by species but has generally been relatively high for the many species evaluated (LMS, 1985, 1992; Davis et al., 1988). Survival following diversion and pumping (to return fish to the source water body, as required) has been more variable. Overall survival rates of relatively fragile species following diversion may be less than 70%. Hardier species should exhibit survival rates approaching 100% (LMS, 1985, 1992; Davis et al., 1988).

Angled diversion screens leading with bypass and return pipelines are being used extensively for guiding salmonids in the Pacific Northwest (Neitzel et al., 1991). These screens are mostly of the rotary drum or vertical flat panel (nonmoving) types. Like other angled screens, suitable hydraulic conditions at the screen face and a safe bypass system are required for the screens to effectively protect fish from IM&E and return them to the source water body (Pearce and Lee, 1991).

State of Development

Angled screen systems have been installed and biologically evaluated at a number of water intakes on a prototype and full-scale basis. These screens are primarily being used with anadromous species (e.g., salmonids) in freshwater river applications. Therefore, data addressing the effectiveness of this technology with non-anadromous marine species are important. These data are being generated in laboratory evaluations using potamodromous species in a fish treadmill at the University of California, Davis. By simulating a fish screen of indeterminate length, the design of the treadmill has allowed the testing of fish behavior, impingement, and survival in complex flow fields (approach and sweeping velocities) similar to those experienced at many CWIS (Swanson et al., 2005; Danley et al., 2002). Pilot-scale studies would be required for applications in seawater, as there is a paucity of data for marine species.

Engineering Considerations

When considering an angled screen diversion, engineering considerations should focus on maintaining a consistent velocity profile approaching the screens. Hydraulic modeling will allow for refinement of the civil works to optimize flow profiles; however, maintaining the screens in a clean condition will be critical to the biological performance, as it will influence the screen velocities.

McMillen and Smith (1996) present a review of available cleaning systems for use with angled vertical, flat panel fish screens leading to a bypass. Most angled screen facilities incorporate a profile wire (or wedgewire) screen design composed of individual bars that results in a smooth upstream face. The smooth surface allows sweeping currents to transport debris to the bypass, reducing debris loadings. Screens with vertical bar orientations require specially designed screen cleaning systems to match the orientation of the screen panels. Typically, the most effective screen cleaning system for vertical orientations has been mechanical (brush) screen cleaners and water backwash systems. Water backwash systems can be considered at sites where high velocities exist, space is limited, or distinct debris such as ice or weeds is a concern. The backwash is created with high pressure water jets, so jet orientation is an important design consideration. For most sites, the overall site hydraulics will be important in providing a sweeping mechanism for fish and debris once they have been cleared from the face of the screen.

Costs

The cost associated with an angled screen diversion will be dependent upon the type of screen utilized, site characteristics, fisheries criteria, and facility size. Some cost data were available for review, and ultimately the unit cost ranged from about $700 to $4000/cfs, illustrating the high variability in cost. Typically, the unit cost will decrease with the size of the structure (USBR, 2006).

Conclusions

Angled screens are not likely to be an effective technology for modifying an existing seawater intake. Although the diversion efficiency and survival of adults and juveniles have been high in previous studies, there are no data on the performance of the technology at full-scale seawater intakes. Pilot-scale studies would be required to evaluate their performance with the species of concern at a given seawater site. In some cases, a fish-friendly pump may be necessary to return fish to a safe release location. In such cases, the potential for fish injury or mortality should be factored into the screen's biological performance. Finally, angled screens are not likely to be practicable for modification of an existing seawater intake, principally because of the large footprint of the civil structural modifications required to fit them in.

Chapter 4

Recommendations for Improving Existing Intake Structures

Developing standard guidelines to modify existing intakes can aid in minimizing the efforts associated with developing a seawater desalination facility. A discussion of issues to consider when assessing use of an existing intake (either active or abandoned) follows.

Use of an existing intake is an attractive alternative because of the existing structure(s) and ostensibly a permitted water withdrawal/discharge under 316(a) and (b) for a steam generating station. The volume of circulating water associated with an operating OTC facility also provides a cost-effective means (i.e., dilution) for brine disposal. An example of this approach is provided in Section 8.1. Similarly, use of an existing abandoned discharge structure has appeal because of reduced permitting (related to new construction) and capital costs and potential reduction in aquatic impacts.

The key considerations for intake selection are captured in the heart of 316(b), which requires "…the location, design, construction, and capacity of a CWIS reflect the 'best technology available' for minimizing adverse environmental impacts..." The fact that desalination facilities, by design, are located on marine or estuarine water bodies requires that developers consider technologies designed to protect all life stages of aquatic organisms. Following is a general discussion of each of these considerations in relation to all life stages: entrainable-sized eggs and larvae up to impingeable-sized juveniles and adults.

- *Location.* A locational benefit is typically accepted when considering 316(b) for an intake located offshore. Spawning and nursery areas are typically near shore or in marshes and tributaries; however, any offshore structure (anthropogenic or natural) can attract fish and other organisms.

- *Design and construction.* Technologies that are designed to protect fish and other aquatic organisms are discussed in Section 3. Some are eliminated from consideration when early life stages are involved. For example, eggs and larvae have little or no mobility, so diversion systems are not effective. Also, sensory organs typically do not develop until later life stages, which eliminates or minimizes effects of behavioral systems. When considering entrainment reduction technologies, this narrows the alternative technologies to exclusion (e.g., CWWS) or collection systems (e.g., modified TWS) with finer-mesh (e.g., down to 2.0 mm) screening material. Whether entrainment will be a concern will depend on the location of the intake; seawater (marine and estuarine) intakes will have to address regulatory concerns over entrainment. Construction concerns are minimized when tunnel or boring techniques are used rather than cut-and-cover; however, any construction activities can be affected by the presence of marine mammals (e.g., manatees) or fish spawning periods (e.g., salmon).

- *Capacity* is synonymous with volume. In relation to 316(b), EPA considers adverse environmental impact to be directly proportional to the volume of water withdrawn. Unfortunately, marine/estuarine water withdrawal is often considered as having an adverse impact regardless of capacity, rendering the consideration of capacity moot.

One overarching consideration under 316(b) is the belief that a TSV of 0.5 ft/sec will be protective of aquatic organisms. This tenet applies to each of the components but is only valid for organisms that have the ability to avoid the structure (i.e., not passive early life stages).

When considering existing intake structures at active or decommissioned power plants, the size of the CWIS should be more than adequate for the proposed desalination facility. Active sites will be regulated under 316(b), and the concern will be associated with any additional volume required and its effect on the CWIS design characteristics, for example, TSV.

The previous discussion provides background when considering an existing CWIS or discharge structure for a desalination facility intake. The following discussions focus on existing facilities and the engineering and biological processes involved with the intake technology selection process.

4.1 Considerations for Potential Existing Intakes

There are several basic components of any potential established structure being considered as the intake location for a DWIS that need to be assessed. These include location (i.e., offshore vs. shoreline and shallow vs. deep), existing screening technology, existing velocity, and system capacity (i.e., excess structure from decommissioned units) and are discussed herein.

The group of existing seawater intakes that presents the greatest opportunity to desalination developers is power plant CWIS; however, other industrial water intakes or outfalls may also provide the basic infrastructure needed to repurpose them for use as DWIS. The following sections provide some general guidance on the items that would have to be considered when modifying either to reduce IM&E impacts.

4.1.1 CWIS

4.1.1.1 Offshore CWIS

An offshore CWIS will in all likelihood have a velocity cap and wide-spaced bars to exclude large debris; however, it will not be screened to exclude early life stages of aquatic organisms. If an exclusion technology is considered for retrofit, it would be wise to size it to meet the 0.5 ft/sec TSV criterion for 316(b), as it will meet EPA’s proposed IM reduction criterion regardless of the mesh size selected. The problem with adding fine mesh (e.g., ≤0.5 mm) is the ability to keep it clean from marine biofouling or debris accumulation. Also, the use of an air backwash system with CWWS is limited by the size of the compressor needed to provide the volume of air for distances greater than 300 ft. For an air backwash system to be considered, a substantial structure would be required to house the compressor(s) and support the screens (see Section 3.2.2.5).

An abandoned offshore municipal outfall by definition would not have been designed for fish exclusion and will have no screens. Regardless, any intake will likely require some manual (i.e., diver) maintenance and cleaning. In addition, tunnels associated with offshore structures are subject to severe macrofouling issues. At operating steam electric stations, this issue can be controlled with a thermal back flush (for macrofouling) or chlorine injection (for microfouling). Both techniques can have substantial adverse impacts on entrained aquatic organisms during the action. The quantity and type of biofouling will dictate the duration of treatment and quantity of chemical required. This treatment plan must then be compared to the timing of exposure at the intake of the aquatic organisms to be protected. Finally, if retrofit of exclusion devices is considered for protection of aquatic organisms, thought must be given to how to handle the macrofouling waste (e.g., shells, growth) dislodged during treatment.

4.1.1.2 Shoreline CWIS

A shoreline CWIS will have to comply with the same 316(b) requirements discussed previously. When considering the modification of a CWIS for use as a DWIS, the state of operation of the CWIS needs to be considered. There are several scenarios that could exist:

- It is an operating facility with all pumps and screens functioning.
- It is an operating facility with some unit retirements, resulting in some decommissioned screens/pumps.
- It is a decommissioned facility with no screens or pumps operating.

A key consideration in any condition is whether the pumps are in a common bay drawing through all screens or each pump draws through a separate screen. The existence of a common pump bay allows for flow reduction through the screens with pump flow elimination (on/off) or reduction (with variable frequency drivers) and resultant reduction in TSV. In the absence of a common pump bay, the effect of any deviation in flow is limited to one screen. A common pump bay provides the most flexibility in relation to additional volume for the desalination facility by spreading the additional volume withdrawn across multiple screens, affecting TSV. A common pump bay at an operating CWIS with decommissioned pumps and screens is an ideal situation. This scenario would allow the replacement of an existing decommissioned pump with one or more sized for the desalination facility. If the CWIS already meets the 0.5 ft/sec TSV compliance alternative, the only consideration would be the effect, if any, of additional flow from the desalination facility on the TSV. The major concern with this approach is how to assure effective distribution of flow among the screens to comply with the 0.5-ft/sec TSV criterion. Depending on the screen/pump bay design, some structural modifications may be required downstream of the screens.

Depending on the facility, either the existing conventional TWS will have to be upgraded to modified TWS or the CWIS footprint expanded to meet the 0.5 ft/sec TSV criterion for IM compliance. In the first case, it is assumed that existing TWS would be retrofitted with screens with fish protection features and a fish return line added. Again, the only consideration would be the possible effect of additional flow from the desalination facility on fish survival. Alternatively, if the facility expands the CWIS to meet the 0.5 ft/sec TSV criterion, the expansion can be sized to accommodate the additional flow required for the desalination facility.

Finally, if the site is a decommissioned generating facility with no screens or pumps operating, it would have to be developed with 316(b) issues in mind, and savings would only accrue for the established civil structure(s). Each of these intake modification scenarios is discussed in more detail in Section 5.

4.1.2 Municipal Outfall

An abandoned municipal outfall has appeal because of reduced permitting (related to new construction), capital costs, and aquatic impacts. Typically, the outfall would be located outside productive near-shore areas, which is a biological benefit; however, an abandoned municipal outfall will have no screens or structure. In all likelihood, addition of some screening system would be required. Consequently, reduced permitting will not be realized, and reduction in construction costs will be only afforded for use of the existing pipe or tunnel. All concerns discussed previously for an offshore CWIS apply to a municipal outfall. Unless there are multiple outfall lines available, the brine discharge plan must include co-discharge with another industrial effluent (wastewater or power plant cooling water). If the brine is to be discharged directly offshore through a diffuser, construction of such a brine discharge system would trigger new construction, related permits, and concerns for aquatic impacts.

4.2 Technology Selection Process

This section outlines a process for conducting an evaluation of screening technologies for use at desalination facilities in a consistent manner. The process is suitable for application to both new and existing intakes.

The overall technology evaluation process involves three basic tasks:

- compilation and review of available baseline data and information
- screening of alternatives based purely on their general technical feasibility and potential for biological effectiveness
- detailed evaluation of technologies that remain feasible after screening

In the first step of the screening process, available information is used to narrow down the list of options from a suite of possible technologies to a smaller number of options. The technologies selected during the initial analysis should be practicable to install and operate and also have the potential to reduce losses of the types of aquatic organisms anticipated at the site.

The second step in the technology evaluation process is to perform a detailed, site-specific analysis to identify important engineering, biological, and cost factors associated with each alternative identified in the preliminary evaluation. In this step, all pertinent information is assembled to provide a basis for making an informed decision on which alternative best satisfies the environmental regulatory requirements of a facility.

4.2.1 Review of Available Information

Specific information necessary to conduct an assessment of intake technologies includes:

- specific facility layout
- design features and environmental factors that may affect evaluation of intake technologies
- aquatic organisms (species and life stages) that occur near the proposed intake

These factors provide the background information needed to conduct a site-specific evaluation of different intake technologies. The water intake system must be designed and operated consistently with the needs of the primary source water user and key components of the desalination system. Thus, a review and understanding of the primary water user's overall facility design and operational parameters are critical to any evaluation of alternative intake technologies. This will help to identify constraints that may affect application of alternative technologies at a specific facility. Some of the existing design and operational factors that might influence the engineering practicability and biological effectiveness of a specific intake alternative include:

- location of the intake with respect to other structures
- withdrawal and discharge rates
- availability of flow (base and peaking)
- type of intake (shoreline, offshore, canal)
- pump inlet configuration and sizes (bell mouths, elbows, inlet expansions)
- detailed intake drawings (plan, section)
- configuration (ice/debris curtains, trash racks, isolation stop logs and gates, TWS, circulating water pumps, service water pumps, deicing features)

- construction materials (concrete, steel sheet pile)
- type, size, and condition of existing screening technologies
- mode of screen operation (continuous or intermittent)
- existing fish protection features
- debris and fish handling return system (layout, discharge location)
- design water levels
- design head loss

In addition to the physical features of the intake, it is important to consider the effect of any given alternative under evaluation on velocity and flow patterns at the site and the effect of head losses through any alternative technology. This is a vital step to prevent any changes to the intake from impacting the primary water user's operations.

Environmental and hydrologic factors can influence the engineering practicability of installing and operating fish protection technologies. These factors should be assessed to identify conditions that may preclude the use of a technology. Environmental and hydrologic factors of importance include:

- water level variations (tides and storm events)
- variations in flow direction and magnitude during tidal or hydrologic changes
- currents and flow patterns near the intake
- sediment conditions (suspended and bed load)
- debris loading
- icing conditions (frazil, sheet, and pack ice)

If specific information on these factors is not available to determine whether a given alternative technology is appropriate for a facility, field studies may be required to complete the evaluation.

4.2.1.1 Biological Data

The evaluation of alternative technologies should also make use of all available site-specific biological data, including those developed during any previous studies undertaken by the primary water user to satisfy regulatory requirements. Because the evaluation process eventually leads to estimation of potential biological effectiveness at the species or life stage level, it is critical to identify some representative subset of the aquatic species potentially affected by the intake, often referred to as representative important/indicative species (RIS). Typically, these species are selected on the basis of, among other things, their commercial or recreational value, importance to the food chain, and status as rare or endangered. Original guidance language offered in 316(b) indicated that adverse impacts were those that "may interfere with the maintenance or establishment of optimum yields to sport or commercial fish or shellfish, decrease populations of endangered organisms, and seriously disrupt sensitive ecosystems." (EPA, 1976). Furthermore, the EPA offered a definition for what it termed "critical aquatic organisms":

> *those species which would be involved with the intake structure and are: (1) Representative, in terms of their biological requirements, of a balanced, indigenous community of fish, shellfish, and wildlife; (2) commercially or recreationally valuable (e.g. among the top ten species landed—by dollar value); (3) threatened or endangered; (4) critical to the structure and function of the ecological system (e.g. habitat formers); (5) potentially capable of becoming localized nuisance*

species; (6) necessary, in the food chain, for the well-being of species determined in 1–4; (7) one of 1–6 and have high potential susceptibility to entrapment-impingement and/or entrainment; and (8) critical aquatic organisms based on 1–7, are suggested by the applicant, and are approved by the appropriate regulatory agencies. (EPA, 1977)

Data on the presence, abundance, and variability of RIS are critical to the initial review process for selecting the appropriate intake technology.

4.2.2 Preliminary Screening

The baseline information is used to preliminarily screen all available intake alternatives to determine which technology offers the greatest potential for practical application. The primary questions to be addressed during the preliminary screening are the following:

- Is the technology available or does it require further engineering development?
- Has the biological effectiveness of the technology been proven (albeit not necessarily the species and life stages of interest at the facility under review)?
- Does the technology have engineering or biological advantages over the other technologies evaluated?

During the preliminary screening, cost should not be a consideration. The selection of technologies for further consideration is based on their biological effectiveness and potential for implementation.

4.2.2.1 Assessment of Potential Biological Effectiveness

The preliminary phase of the evaluation process is used to determine if a technology has been evaluated in some manner with aquatic organisms and whether it has been demonstrated to be biologically effective with at least one species. The level of biological certainty associated with each technology can be broken down into four categories:

- not previously evaluated
- previously evaluated, but not in full-scale application
- previously used, but not with RIS life stages of concern at the facility under review
- previously used with one or more of the relevant life stages of RIS or comparable species

Naturally, it would be desirable to have all technologies fall into the last category. Often, this is not the case, and BPJ is used to determine if a technology merits further review. A detailed example of how biological efficacy is estimated for selected species and technologies is presented in Section 5.

Generally, a technology is deemed to have proven biological effectiveness if test data (preferably from full-scale application) document that it was effective for one or more of the targeted species when used at other sites.

4.2.2.2 Assessment of Engineering Practicability

In the second part of the preliminary screening, the remaining alternatives are evaluated to determine if they are practicable to install and operate at the site under review. Technologies are considered on a number of engineering grounds, including:

- practicable to install at other sites having similar layouts

- practicable to install or operate in a similar water body
- impact on other water users (navigation, recreation)
- operable over the expected range of intake flows and water depths
- sufficient area available for installation and operation in a manner that maximizes biological effectiveness
- potential for maintaining in acceptable operating condition under environmental conditions at the site (corrosion, biofouling, debris loading, siltation).

A technology is judged as available if there is sufficient information to address these engineering considerations. When information about a technology is lacking, BPJ is used to determine if it merits further review.

4.2.2.3 Comparative Assessment of Advantages and Disadvantages

During the final part of the preliminary screening process, the relative advantages and disadvantages of the alternatives remaining after the biological and engineering analyses have been completed are discussed. The purpose of the comparative assessment is to ensure that only the best technologies, in terms of biological performance and engineering feasibility, are carried forward into the detailed evaluation. For example, an intake technology that has been proven effective at reducing losses for many species 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. From an engineering perspective, one technology may hold an advantage over another if the civil and structural requirements for its installation are substantially fewer.

Site-specific conditions that could impact the effectiveness of each alternative are also taken into consideration. Some examples include:

- Turbidity or background noise could affect one behavioral barrier more than another.
- Heavy debris loads would favor a technology with automatic screen cleaning features.
- Ambient currents could make supporting one technology more difficult than another.

These examples demonstrate the way in which the biological and engineering advantages and disadvantages of the technologies are identified and weighed against one another as part of the selection process. As with the other steps in the preliminary selection process, there are many uncertainties associated with determining the advantages and disadvantages of each alternative. This comparison should be conducted by experts using BPJ.

4.2.3 Detailed Evaluation of Intake Alternatives

The detailed evaluation process involves a site-specific analysis to identify important biological, engineering, and cost factors associated with each alternative identified during the preliminary screening. The detailed evaluation process includes three parts:

- consideration of site-specific design, installation, and O&M
- estimated biological effectiveness
- development of construction and O&M costs, including replacement power

Most of the same kinds of questions addressed generally during the preliminary screening process come into play during the detailed evaluation, but the level of evaluation will be far more detailed, and costs will now be included. Although the evaluation will rely on available site-specific information whenever possible, it also may be necessary in some cases to collect additional data.

Existing intakes may already be equipped with fish protection technologies or have applied other measures to meet required regulations. These existing technologies should be included as part of the detailed technology evaluation.

4.2.3.1 Site-Specific Design, Construction, and O&M Analysis

The first part of the detailed evaluation process involves: (1) the development of site-specific design, construction, and operating criteria; and (2) preparation of conceptual layouts (plans and sections) used to evaluate each alternative to determine whether it will satisfy those criteria. When the design includes sharing an intake with an existing facility, knowledgeable plant operating personnel should be involved in this part of the process to identify, obtain, or verify site characteristics that may affect intake operations.

Design and Operating Analysis

A description of the intake design features with drawings showing the basic dimensions of the structures for each concept considered should be included as part of the detailed evaluation. These features can remain somewhat flexible in the conceptual design phase until a preferred technology or other measures for meeting regulatory requirements have been identified and approved. When modifying an existing intake, the proposed designs should account for features of the existing intake that may represent a constraint on the potential for practicable or effective application of a given technology or measure.

Design criteria are developed for each intake alternative to define site-specific features and concerns necessary for successful application and operation. If specific information on these factors is not available, field studies may be required to fill data gaps. Many of these factors are the same as those used in the preliminary evaluation but are evaluated in greater depth. Environmental and hydrological factors used in the design include those listed previously in the preliminary evaluation section.

The existing intake design and operational features have an obvious role in the identification and location of alternative intakes. The following data on the existing intake are needed to undertake the evaluation process:

- design flow rate (circulating water, service water, other withdrawals)
- design velocities (approaching the intake, approaching the screens, through-screen)
- design water levels (maximum high, mean high and low, and minimum low)
- location (offshore, submerged, shoreline, canal)
- configuration (screens, barriers, curtain walls, gates, pumps)
- number and width of bays (trash racks and TWS)
- invert and deck elevations
- intake materials (concrete, steel sheet pile)
- screen materials (carbon steel, stainless steel, coating, paint)
- screening size (width, height, bar spacing, mesh size, open area)
- screen cleaning (debris removal, debris return location, disposal)
- pump inlet configuration and sizes (bell mouths, elbows, inlet expansions)

Construction Analysis

Appropriate construction techniques for the various intake alternatives must be reflected in the evaluation process. For many intakes, the supporting civil works required for installation of the technology can be more extensive than construction of the intake technology itself. Some alternatives, such as a shoreline intake with flush-mounted TWS, have to be constructed "in the dry" using earth or sheet pile cofferdams. Other alternatives, such as submerged velocity caps or CWWS, can be installed "in the wet" using barge-mounted cranes and divers.

Subsurface conditions are an important factor affecting the construction methods used for installation of an alternative technology at a site. The types of material below grade and on river bottoms generally determine excavation and shoring methods required for installation of foundations for the structures. The subsurface materials also dictate the method for anchoring structures to prevent sliding, overturning, and flotation. This can have a profound impact on the level of effort and construction costs of an intake technology. In some cases, subsurface conditions must be considered in selecting the location for installation of a fish protection technology.

Access for construction equipment is another factor that should be included in the detailed evaluation. Shoreline areas near power plants and other industry may be heavily developed or may not have available access roads. For offshore intakes (and some shoreline intakes), access to the construction site will typically be provided through the use of barge-mounted cranes and other equipment.

The construction season available for installing intakes is another important factor in the evaluation of alternatives. Work on the water may be limited by weather conditions. If protected species occur seasonally in the construction area, work can be delayed. Obviously, more complex structures with more extensive cofferdams will typically have longer construction durations than a simple intake modification that does not require a significant amount of civil work.

Plant outages required to complete installation of an intake alternative at an existing plant are an important consideration in the evaluation of alternatives. Construction methods and sequencing should be identified in the conceptual design to minimize the impacts on existing plant operations during construction. Double shifts and overtime should be used to reduce the downtime for operating units.

O&M Analysis

O&M requirements of various types of intakes are important factors in evaluating alternative designs. Operating parameters include the electric power (kWh) necessary to operate specific equipment (such as trash rakes, TWS, or screen wash pumps) and the labor (hours) needed to inspect, operate, and maintain the equipment in an acceptable condition for effective fish protection. Maintenance parameters that have to be considered include labor (hours) and components (spare parts) that are needed on hand for the performance of routine equipment maintenance.

The effective open area and flow patterns associated with alternative technologies, along with additional piping required to convey flow from a new technology or intake, can affect system head losses and water levels at the pumps. System components must be sized to minimize head losses and maintain adequate suction head on the pumps. At existing CWIS, lower water levels in the pump bay resulting from an alternative technology could reduce pressures in the cooling water system, thereby reducing plant capacity. Therefore, all alternative intakes must provide at least the minimum water level at the pumps that would be acceptable for existing operations. Lost power costs, if any, should be included in the estimated cost of the alternative.

Clogging by debris, sediment, and ice can reduce flow through an intake structure, increase head losses in the system, and increase hydrostatic forces on the intake. If clogging is serious, a structure can become plugged and unable to convey an adequate amount of water. Therefore, debris characterization and clogging potential are important considerations in the evaluation of any intake alternative. Furthermore, clogging of screens results in higher TSV (by a reduction in open area), which can negatively impact biological performance of the screening technology.

Finally, the review of potential O&M issues must identify impacts of routine activities on existing operations. Most maintenance activities can be accomplished without impacting operations or performed during scheduled plant outages; however, some technologies may require portions of the intake to be shut down on a more frequent basis. For example, cessation of water withdrawal would be required for inspection of an underwater, hybrid light/air bubble curtain by divers in high velocity zones. The technology evaluation report should clearly identify the impacts of O&M activities on plant operations and capacity.

4.2.3.2 Biological Effectiveness Analysis

The next step in the detailed evaluation process is to develop estimates of the potential biological effectiveness of each alternative technology selected for review. Chapter 5 contains a detailed review of the methods used for estimating biological efficacy of candidate technologies during the detailed evaluation process.

4.2.3.3 Cost Analysis

The next step in the evaluation process is to develop order-of-magnitude project costs for the candidate alternatives. Order-of-magnitude cost estimates are based on conceptual designs of project components necessary for installation and operation of an intake technology. Quantity takeoffs for the major components of the conceptual design, as well as historical data taken from other projects, form the basis for the estimates.

The costs for each alternative can be broken into two discrete cost components: design phase and construction phase. In addition, O&M costs should be considered prior to making final decisions regarding a technology.

Design Phase

Design phase costs include labor and expenses for engineering services to prepare drawings, specifications, and design documents. These costs are typically identified as indirect costs in an estimate and taken as a percentage (e.g., 10%) of the direct costs (defined herein) for each alternative.

Construction Phase

Construction phase costs include material and labor expenses required for all project features.

- direct costs for material and labor required for construction of all project features
- Distributable costs for site non-manual supervision, temporary facilities, equipment rental, and support services incurred by contractors during construction. These costs typically range between 50 and 100% of the labor portion of the direct costs for each alternative. Distributable costs may be included in the unit rates for the direct costs or identified as a separate line item.

- Allowance for in determinants to cover uncertainties in design and construction at this conceptual level of technology development; an allowance for in determinants is a judgment factor, which is added to allow for unknowns in the data used in developing the estimates. The allowance for in determinants is typically taken as a percentage (e.g., 10%) of the combined direct, distributable, indirect, and company costs of each alternative technology.
- Contingency factor to account for possible additional costs, which might develop but cannot be predetermined (e.g., labor difficulties, delivery delays, weather). The contingency factor is typically taken as a percentage (e.g., 25%) of the combined direct, distributable, indirect, owner, and allowance for indeterminate costs of each concept.

O&M

Costs for normal operation and routine maintenance of the structures and equipment associated with a modified intake should be considered in developing a valid comparison of different technologies. Operating costs, including labor, materials, and power, are important to understand. Maintenance costs should reflect labor and materials needed to keep the structures and equipment operating to meet the intended design functions.

Labor requirements that should be identified for evaluating alternative intakes include the following typical activities:

- inspecting, operating, cleaning and maintaining a technology
- inspecting and maintaining mechanical equipment associated with a technology (screen wash pumps, air compressors)
- inspecting and maintaining ancillary equipment associated with a technology (fish returns, new structures)
- routine maintenance and replacement of components at the end of their useful service life (strobe lights, sound generators, screens, pumps)

In addition, the material and equipment replacement costs for these activities and the power (kWh) required to operate the equipment should be included in the evaluation. The power required to operate alternative technologies will vary widely among technologies and be influenced by site-specific factors. Note that this level of detail with regard to O&M was not included in the estimates in Chapter 6.

It is also important to consider the O&M costs of the desalination facility; these costs are a function of the intake design and configuration. For example, an offshore submerged intake often produces a better feed water quality than a near-shore surface intake, as the water is typically characterized by lower and less variable amounts of organic carbon, suspended solids, nutrients, and microorganisms, and thus by a lower fouling potential. This considerably reduces the pretreatment requirements in the engineered pretreatment system downstream of the intake (reducing both capital and operation costs), cleaning requirements, and replacement of components (e.g., reverse osmosis membranes). An intake with a higher initial capital cost may pay off in terms of total costs saved; therefore, the cost evaluation should not be restricted to the intakes but should take into account benefits for the whole desalination plant.

Other Costs

All project costs cannot necessarily be quantified during the conceptual development of alternatives. The following items are difficult to estimate based on conceptual designs but are included to obtain a total capital cost estimate:

- performing additional field studies that may be required, including effectiveness studies, hydroacoustic surveys, net sampling, soil sampling, and wetlands delineation prior to installation of an intake technology
- disposal of any hazardous materials that may be encountered during excavation and dredging activities
- permitting
- evaluation of the effectiveness of an intake technology after installation

4.2.4 Comparison of Alternatives

Once the conceptual design, potential biological effectiveness, and cost of each alternative technology have been identified, they can be uniformly compared to determine the best technology for a given location. This comparison is typically done in one of two ways, a benefit–cost analysis or evaluation of the incremental differences between biological efficacy and costs.

In a benefit–cost analysis, the biological efficacy of each technology is used to estimate the benefits versus losses. The underlying assumption is that the fish saved from IM&E are a benefit, whereas those fish killed by IM&E are a loss. A second assumption of the benefit–cost analysis is that the value of the saved or lost fish can be monetized. In order to monetize the benefit or loss, the organisms must be converted to a common metric such as equivalent adults (numbers or pounds) lost, biomass lost, or production foregone (see Chapter 7 for greater detail on the metrics used for determining biological losses). The selection of the correct metric depends on the abundance and commercial or recreational importance of each species. In addition, the local permitting agencies may have a preference for a particular method. Whatever metric is used, the overall goal is to convert numbers of organisms entrained and impinged for each alternative under consideration (including the base case) into a number or weight on which a dollar value can be placed. Once a value has been assigned, a benefit–cost analysis is performed by comparing the dollar benefit of each alternative to its cost.

Evaluating the incremental benefit of each alternative is similar to the benefit–cost analysis in that it compares the biological efficacy with the costs of each alternative. This approach is more qualitative and does not rely on converting the biological efficacy to a dollar amount. Different alternatives are evaluated by comparing the incremental change in biological efficacy with incremental change in costs. For example, Alternative A may reduce impingement by an estimated 95% at a cost of $10 million, and Alternative B may reduce impingement by an estimated 80% but only cost $1 million. The incremental benefit method asks the question; “Is the additional 15% reduction in impingement worth $9 million?” Although demographic models can help define the value of the impingement reduction in terms of adult fish, the selection of an intake alternative using this method also relies on the BPJ of the evaluator to determine if the increase in costs is wholly proportionate to the benefit.

Chapter 5

Estimating Biological Efficacy

Chapter 4 described the use of biological efficacy data to narrow down the available technological options to those with a reasonable expectation of reducing environmental impacts associated with IM&E. This chapter presents a process for developing more detailed biological efficacy estimates. For the purposes of illustration, the process is applied to several technology options:

- modify conventional TWS (9.5 mm) with CWWS (9.5 mm)
- modify conventional TWS (9.5 mm) with CWWS (2.0 mm)
- modify conventional TWS (9.5 mm) with modified TWS (9.5 mm)
- modify conventional TWS (9.5 mm) with modified TWS (2.0 mm)

As stated in Chapter 4, selection of the RIS is an important early step. For the following discussion, we have selected several species commonly impinged and entrained in different regions of the country (West, Northeastern, Mid-Atlantic, Southern, and Gulf coasts). The species selected were identified by the EPRI as commonly impinged and entrained at the greatest number of facilities responding to an industry survey (EPRI, 2011).

It is important to recognize that the site-specific intake design and operating characteristics and the morphological and physiological characteristics of the organisms involved at the intake will impact the efficacy of a technology. In other words, a technology's biological efficacy may be quite different from one facility to the next. For this reason, we emphasize the process for estimating biological efficacy over attempts to develop a single performance estimate for each technology and potential RIS.

5.1 General Approach

Estimates of biological efficacy are derived from existing site data or available data from other sites or other evaluations (e.g., laboratory- and pilot-scale studies). Ideally, data are available for each alternative under consideration and each of the numerically dominant species or RIS and life stages; however, this is seldom the case. More often, data are available for some species and technologies and lacking for others. Therefore, the process of estimating potential biological effectiveness of a given alternative involves the use of available data in two ways:

- direct application for those species and life stages that are potentially impinged or entrained at the site under consideration
- extrapolation of the data to other species and life stages for which no data exist

Direct application is relatively straightforward. For each alternative, the available data are reviewed, and a best estimate of potential effectiveness is derived. In many cases, a range of effectiveness values is available for a given species or life stage and technology. A difference in species-specific survival is indicative of the individual species' relative hardiness. It has been well documented that species such as American shad, other shad and herrings, and bay anchovy (all of which are abundant species in impingement samples in different water bodies) are relatively fragile. That is, they lose their mucous coating and scales and bruise easily, making them more susceptible to stress and mortality. Species such as mullet and flat fishes (e.g., flounders and hogchokers) are not as easily injured or stressed and tend to be considered relatively hardy.

The reason for differences in effectiveness estimates across study sites is understood, but the ability to select the best estimate of effectiveness from a range of values in the available data is more complicated, particularly when the range is large. Consideration should be given to the conditions under which the study was conducted and the quality of the study design and resulting data. Environmental conditions, such as water temperature, and operational conditions, such as spray wash pressures and screen rotation speeds, can affect survival estimates. Finally, the number of organisms evaluated is a key factor. That is, survival estimates based on substantial numbers of individuals of a given species are likely more accurate than studies where only a few individuals of that species were observed.

When the range of reported effectiveness is large (≥50%), the accuracy of the estimate selected will be less certain. The process of selecting a best estimate involves a review of all data and the identification of those data that are most representative of the site under review. With the larger range of reported values, the uncertainty surrounding the estimate will be greater. In this case, the evaluator must assess the available data and use BPJ to develop a best estimate of potential effectiveness. Whenever possible, the uncertainty in the estimate should be described either quantitatively or qualitatively. Uncertainty in an estimate used in the comparative evaluation of different alternatives could potentially influence the selection of one technology over another.

The degree of uncertainty around an estimated effectiveness value is even greater in cases where there are no data available for one or more of the RIS life stages under consideration. Several approaches can be taken in such cases. For technologies that involve handling or other possible sources of physical contact that might injure or kill fish (e.g., collection screens, bypasses, pumps), one approach is to evaluate effectiveness data (e.g., survival) for closely related species, genera, or families with similar physiological characteristics.

A second approach is to group species and life stages into categories reflecting their relative hardiness. Effectiveness values based on survival of similar species or other species and life stages in the same hardiness category for which data do exist can then be assigned. Generally, sufficient information is available on the relative hardiness of enough fish species that species for which technology effectiveness data are not available can be broadly grouped into one of three categories (low, intermediate, and high survival potential). They can then be assigned a best estimate based on professional judgment.

As a worst case, the evaluation may determine that there are insufficient data of any kind to develop a best estimate of potential biological effectiveness of a technology. New or experimental technologies could fall into this category. In such cases, some type of laboratory- or pilot-scale field study will be needed to obtain the data necessary to predict effectiveness. Such studies have been common in the past and have advanced the state of the art in fish protection.

Another consideration in the development of biological efficacy estimates is the mode of action of the technology being considered. The example technologies described here are exclusion technologies (CWWS of different slot widths) and collection and transfer technologies (modified traveling screens of different mesh sizes).

For exclusion technologies (CWWS), the key factor is organism size in relation to the mesh size or slot width. Data on biological efficacy of CWWS from lab-, field-, or full-scale applications are often lacking for many RIS. In such cases, exclusion can be estimated using the head capsule depth (HCD; the widest noncompressible portion of the larval body). When head capsules are larger than the nominal opening size of the screening material, a larva will not be entrained. With larvae, the orientation of the organism at the time of contact with the screen will influence the likelihood of being entrained.

For collection and transfer technologies (modified traveling screens), the effectiveness is measured in two ways: retention and survival. In addition to the physical exclusion of organisms described previously, collection and transfer technologies handle the organisms during the transfer process back to the source water body. This handling may impart some additional stress to the organisms, such as injuries, scale loss, or mortality. With modified traveling screens, the second measurement of effectiveness is the survival of the different life stages that would be retained on the screens. In the case of fine-mesh modified traveling screens, this may include eggs, larvae, and early juvenile life stages that would be entrained through coarser meshes typically used at intakes (e.g., 3/8 in. or 1/4 x 1/2 in.) The survival of impinged organisms is dependent upon their biology (life stage, relative hardiness) and the screen operating characteristics (rotation speed, spray wash pressure).

5.2 Specific Approach

The process for developing biological efficacy estimates with the selected technologies is presented in the following sections. The species selected for illustrative purposes are presented in Table 5.1. All the species selected were among the top five most commonly impinged or entrained species within different estuarine or coastal regions of the United States (EPRI, 2011). All the estimates contained herein are purely for illustrative purposes. As new data become available or a subset of these data are selected that best represent the site-specific conditions at the facility considering using fish protection technologies, these estimates can be better refined to reflect the actual biological performance that could be expected.

5.2.1 Coarse-Slot Wedgewire Screens

Coarse-slot CWWS (9.5 mm) are an exclusion technology. CWWS protect fish through a combination of physical exclusion and a low TSV (see Section 3.2.2.5 for more on CWWS). Visual observations of CWWS indicate that impingement is virtually eliminated for healthy juvenile and adult fish. As such, one can safely assume 100% reduction in impingement for all species in these life stages.

Because of their slot size, 9.5 mm CWWS do not physically exclude eggs, larvae, or early juvenile fishes. That said, the very low TSV (typically 0.5 ft/sec) allows early life stages with sufficient motility (e.g., late larval stages or early juveniles) the ability to swim away from the screens. In addition, there can also be a locational benefit when moving the point of withdrawal from an onshore location, which may be near nursery or spawning grounds, to an offshore location, provided the offshore location is in an area of low fish density. Quantifying the potential reduction in entrainment that could occur as a result of using coarse-slot CWWS in very difficult to estimate *a priori*. Typically, coarse-slot CWWS are assumed to have no benefit to entrainable-sized larvae.

Table 5.1. Species Selected To Illustrate the Process of Estimating Biological Efficacy

Region	Family	Common Name	Scientific Name
West Coast	Sciaenidae	queenfish	*Seriphus politus*
	Engraulidae	northern anchovy	*Engraulis mordax*
	Atherinopsidae	topsmelt	*Atherinops affinis*
Northeastern coastal	Clupeidae	Atlantic menhaden	*Brevoortia tyrannus*
	Atherinopsidae	Atlantic silverside	*Menidia menidia*
	Pleuronectidae	winter flounder	*Pseudopleuronectes americanus*
	Portunidae	blue crab	*Callinectes sapidus*
	Sciaenidae	weakfish	*Cynoscion regalis*
Mid-Atlantic coastal	Moronidae	white perch	*Morone americana*
	Portunidae	blue crab	*Callinectes sapidus*
	Centrarchidae	bluegill	*Lepomis macrochirus*
	Sciaenidae	Atlantic croaker	*Micropogonias undulatus*
Southern coastal and Gulf	Penaeidae	white shrimp	*Litopenaeus schmitti*
	Portunidae	blue crab	*Callinectes sapidus*
	Penaeidae	pink shrimp	*Farfantepenaeus brasiliensis*
	Engraulidae	bay anchovy	*Anchoa mitchilli*
	Achiridae	hogchoker	*Trinectes maculatus*

5.2.2 Narrow-Slot Wedgewire Screens

With early life stages, TSV and ambient velocity (also referred to as channel or approach velocity) can have considerable effects on IM&E of fish exposed to CWWS. IM&E have been positively correlated with slot velocity and inversely related to ambient velocity (Hanson et al., 1978; Heuer and Tomljanovich, 1978). The interaction between these two velocity parameters is also important, with available data suggesting that the ratio of ambient to slot velocity should be maximized for effective exclusion of aquatic organisms (Hanson et al., 1978). In laboratory studies (EPRI, 2003), it was demonstrated that as this ratio of ambient velocity to slot velocity increases, IM&E rates decrease.

Empirical observation of exclusion is the best measurement of performance; however, there have been few empirical studies to determine the entrainment rates through narrow-slot CWWS, and there are substantial gaps in the database for several species. In the absence of empirical data, physical exclusion for a given slot size can be predicted theoretically using the body depth of the organisms being protected.

Smith et al. (1968) found that the maximum cross-sectional diameter of the organism must be greater than the mesh diagonal if it is to be fully retained. Bell (1973) noted that fish are generally prevented from entrainment by the size of the bony part of the head and developed relationships of fish length to expected exclusion by meshes of different sizes. Bell cautioned that the relationships he developed were based on a small number of organisms. Turnpenny (1981) further developed Bell's approach by expanding the number of species and size ranges examined. Turnpenny developed a relationship from physical measurements of length and depth of preserved fish and a series of empirical observations on square mesh screens. Turnpenny used these relationships to develop a Fineness Ratio, which offered more flexibility and accuracy than the approach used by Bell (1973). Similar approaches have been used by other researchers (Vannucci, 1968; Lenarz, 1972; Colton et al., 1980; Schneeberger and Jude, 1981; Martin Marietta Environmental Systems, 1984; PSEG, 2002).

Given the limited data set, the predicted exclusion that can be achieved with a slot size can be estimated by the body depth of an organism. Estimates of exclusion of organisms with a given slot size can be developed from the physical dimensions of the organism. Because larval fish are soft bodied and can be compressed, the largest noncompressible portion of the body (head capsule) was used to predict exclusion. Exclusion is species specific because there is substantial variation in the morphometric characteristics among species. Therefore, species-specific estimates were generated for selected RIS in the following section.

The relationship between HCD to body length can be developed in two ways. First, when available, actual measurements of fish can be used. For example, the Salem Generating Station on the Delaware River developed body length to HCD regressions for several species (PSEG, 2002) using measurements taken from preserved specimens representing all size classes of larvae. These types of relationships can also be developed from other data sources: primary scale drawings from available taxonomic keys (e.g., Wang and Kernehan, 1979; Moser, 1996; Auer, 1982), journal articles (e.g., Ditty et al., 2005), and online resources (e.g., fishbase.org). These regressions can then be used to interpolate HCD for fish of given lengths on a species-by-species basis (for sample regressions, see Table 5.2). The estimated entrainment (the inverse of retention) of RIS selected in Table 5.1 is presented in Figure 5.1 by geographic region. A similar approach of using body depth can be used with invertebrate species, such as blue crab and Penaeid shrimp.

The next step in the process is to use the regression equations to estimate exclusion by integration under a normal curve. The lengths of fish entrained at a given site will have a major impact on the retention potential of a wedgewire screen. If larvae length distribution for a given species tends to be smaller at one facility, then retention will be lower there than at a second facility using CWWS with the same size slot and the same species but with a length distribution for that species that tends to be larger. Therefore, the final step in estimating exclusion requires applying the length-specific efficacy estimates to the site-specific length frequency distribution at a given site. If no length data are available, then estimates can be generated assuming that the length frequency distribution is distributed equally along the length ranges described in the literature for a given species or life stage.

Table 5.2. Species-Specific Regression Equations (with Associated R^2 Values) Used to Estimate Head Capsule Depth Based on Larval Lengths for Selected RIS

Family	Common Name	Scientific Name	Regression Equation	R^2 Value	Source
Sciaenidae	queenfish	*Seriphus politus*	depth=-0.0569+(0.212*length)	0.942	MBC et al., 2010
Engraulidae	northern anchovy	*Engraulis mordax*	depth=-0.0151+(0.0845*length)	0.908	MBC et al., 2010
Atherinopsidae	topsmelt	*Atherinops affinis*	HCD=-0.1572939+0.1361715 length	0.921	scale drawings
Clupeidae	Atlantic menhaden	*Brevoortia tyrannus*	ln HCD=-2.588+1.051 length+(length-3.285) (0.645(SIGN(length-3.285))	0.315	PSEG, 2002
Atherinopsidae	Atlantic silverside	*Menidia menidia*	ln HCD=-2.490+1.134 length+(Length-2.625)(0.121(SIGN(length-2.625))	0.966	PSEG, 2002
Pleuronectidae	winter flounder	*Pseudopleuronectes americanus*	HCD=0.1777*length)+0.0473	0.692	EPRI, 2005
Sciaenidae	weakfish	*Cynoscion regalis*	ln HCD=-1.180+0.925length+(length-2.305) (-0.047(SIGN(length-2.305))	0.970	PSEG, 2002
Moronidae	white perch	*Morone americana*	ln HCD=-1.937+1.094length+(length-2.720) (-0.144(SIGN(length-2.720))	0.964	PSEG, 2002
Centrarchidae	bluegill	*Lepomis macrochirus*	HCD=-0.4324962+0.2164779 length	0.969	scale drawings
Sciaenidae	Atlantic croaker	*Micropogonias undulates*	ln HCD=-1.427+0.979length+(length-2.726) (-0.174(SIGN(length-2.727))	0.982	PSEG, 2002
Engraulidae	bay anchovy	*Anchoa mitchilli*	ln HCD=-3.004+1.217length+(length-2.498) (0.523(SIGN(length-2.498))	0.953	PSEG, 2002
Achiridae	hogchoker	*Trinectes maculatus*	HCD=-0.4075561+0.3870033 length	0.914	scale drawings

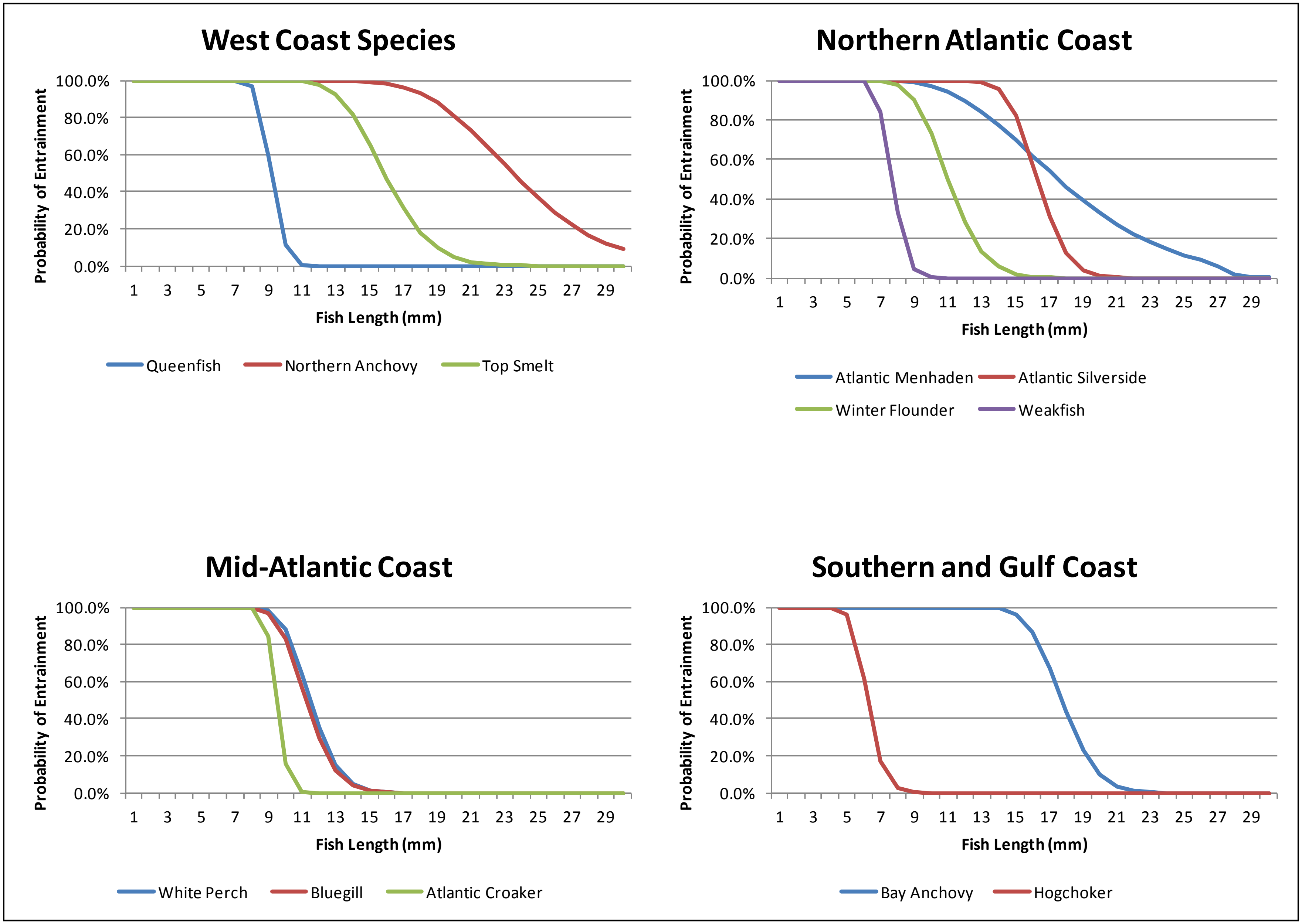


Figure 5.1. Estimated entrainment of larvae through 2.0 mm slot width for selected RIS.

5.2.3 Coarse-Mesh Modified TWS

There are several variations on the concept of coarse-mesh modified TWS (see Section 3.3.2). All modified TWS collect organisms (along with debris) from the raw water as it enters the facility. Once collected, fish are transferred into a return trough and returned to the source water body by gravity or through a fish-friendly pump. Coarse-mesh modified TWS do not reduce entrainment.

For juvenile and adult fish, species-specific post-impingement survival estimates were developed for modified TWS with several of the RIS previously identified. Biological estimates were derived from available data from other sites with modified traveling screens or other evaluations (e.g., laboratory- and pilot-scale studies). Data were gleaned from published papers in peer-reviewed journals and corporate-sponsored efficacy reports (gray literature) and limited to juvenile or adult fish. The data were further limited to studies that (1) were conducted at facilities with modified Ristroph or other screen designs with fish-friendly modifications, (2) were conducted at facilities with the more sophisticated bucket designs developed in the 1980s, and (3) held organisms for at least 24 hours post-impingement to assess the latent survival rate. In some cases, surrogate species were selected because no or limited data were available for a specified RIS (e.g., West Coast species).

Post-impingement survival of juvenile and adult fish from fine-mesh screens is assumed to be similar to what has been observed with other modified TWS designs regardless of mesh size. That is, survival of a 45-mm juvenile from a fine-mesh screen should not be different than survival from a coarse-mesh screen. Estimates of juvenile and adult post-impingement survival are presented in Table 5.3.

5.2.4 Fine-Mesh Modified TWS

There have been few empirical studies to determine the length-specific size of organisms entraining through fine mesh. The majority of these studies has looked at towed ichthyoplankton nets and may not well represent what would be observed at a fine-mesh TWS. Therefore, the estimates of entrainment developed for CWWS previously can be used with fine-mesh TWS.

The second component of effectiveness is the survival of the eggs, larvae, and early juveniles that were previously entrained but would now be retained on the fine-mesh TWS. The survival of impinged organisms is dependent on their biology (life stage, relative hardiness) and the screen operating characteristics (rotation speed, spray wash pressure).

Survival estimates were derived from available data from other sites with modified TWS or other evaluations (e.g., laboratory- and pilot-scale studies). Data on the efficacy of fine-mesh TWS with fish eggs and larvae are limited, and estimates are often based on only a few data points. In such cases, data can be expanded to include other members of the same genus. The underlying assumption is that fish in the same genus have similar morphology and hardiness. There were several cases for which no other data within the same genus were available. In such cases, the database was further expanded to include members of the same family. Estimated larval survival is presented in Table 5.4. Estimating larval survival is extremely difficult given the limited amount of data available upon which to draw. As such, these estimates are very crude, and laboratory- or pilot-scale testing should be undertaken before full-scale implementation to determine potential biological benefit of this technology. Estimates of impingement survival of juvenile and adult fish would be the same as those presented in Table 5.3.

Table 5.3. Estimated Percentage of Post-Impingement Survival with the 2.0- and 9.5 mm TWS Options

Region	Common Name	Surrogate	N	Range	Weighted Mean	Normal Approximation (±95% CI) Lower	Upper
West Coast	queenfish	Atlantic croaker	40,624	49.5–99.0%	77.0%	76.6%	77.5%
	northern anchovy	bay anchovy	21,435	0.0–94.0%	32.1%	31.5%	32.8%
	topsmelt	Atlantic silverside	1290	0.0–99.1%	85.7%	83.8%	87.7%
Northeastern Coastal	winter flounder	not used	383	0.0–97.2%	96.9%	95.0%	98.7%
	blue crab	not used	59,743	85.4–100.0%	96.7%	96.5%	96.8%
	weakfish	not used	33,131	39.1–100.0%	59.7%	59.2%	60.2%
	white perch	not used	38,228	30.0–100.0%	83.6%	83.3%	84.0%
	blue crab	not used	59,743	85.4–100.0%	96.7%	96.5%	96.8%
Mid-Atlantic Coastal	bluegill	*Lepomis* sp.	2011	54.0–100.0%	95.9%	95.0%	96.8%
	gizzard shad	not used	5323	0.4–100.0%	81.0%	80.0%	82.1%
	Atlantic croaker	not used	40,624	49.5–99.0%	76.1%	76.6%	77.5%
	white shrimp	Penaeid shrimp	3076	33.3–100.0%	90.6%	89.6%	91.7%
	blue crab	not used	59,743	85.4–100.0%	96.7%	96.5%	96.8%
Southern Coastal and Gulf	pink shrimp	Penaeid shrimp	3076	33.3–100.0%	90.6%	89.6%	91.7%
	bay anchovy	not used	21,435	0.0–93.8%	32.1%	31.5%	32.8%
	hogchoker	not used	8032	83.7–100.0%	94.2%	93.7%	94.7%

Table 5.4. Estimated Survival of Impinged Larvae on Fine-Mesh TWS

Common Name	Scientific Name	BPJ Larval Survival Estimate
Queenfish	*Seriphus politus*	20%
Northern anchovy	*Engraulis mordax*	0%
Topsmelt	*Atherinops affinis*	20%
Atlantic menhaden	*Brevoortia tyrannus*	1%
Atlantic silverside	*Menidia menidia*	23%
Winter flounder	*Pseudopleuronectes americanus*	9%
Weakfish	*Cynoscion regalis*	14%
White perch	*Morone americana*	23%
Bluegill	*Lepomis macrochirus*	80%
Gizzard shad	*Dorosoma cepedianum*	0%
Atlantic croaker	*Micropogonias undulatus*	21%
Bay anchovy	*Anchoa mitchilli*	0%
Hogchoker	*Trinectes maculatus*	46%

Note: BPJ=best professional judgment

Chapter 6

Cost Considerations for Intake Modifications

To gain a better understanding of the costs associated with retrofitting an existing CWIS to serve as a DWIS, a series of case studies were completed. The case studies took hypothetical CWIS designs through the intake modification process to determine the costs associated with various approaches. The scenarios developed included:

- installing additional desalination capacity during a 316(b) upgrade of an operating CWIS
- rehabilitating a decommissioned CWIS for use as a DWIS

These scenarios were further parsed to evaluate how each of the following three variables affected cost:

- intake configuration (shoreline versus offshore intake configurations)
- whether the existing intake footprint required expansion
- intake modification technologies (TWS and CWWS)

The matrix of intake modification scenarios is presented in Figure 6.1.

This chapter is organized to first take the reader through the development process for the intake modification scenarios that were selected for presentation (Sections 6.1.1 and 6.1.2). Next is a description of the intake technologies selected to complete the intake modification designs and some logic supporting how they may meet proposed 316(b) performance standards (Section 6.1.3). Finally, the remainder of this chapter presents 10 intake modification scenarios. Each of the 10 scenarios includes conceptual-level drawings to help visualize the modification, a textual description of the modification from an engineering perspective, an estimated cost for the intake modification, and a conclusion about the feasibility of each design and the relative value of the existing intake to a desalination developer given the costs for modification. The intake modification scenarios presented are organized logically from those that would be considered as having the highest potential for effective and efficient implementation to those with the lowest potential (Figure 6.1). Determination of which intake modification scenarios have the greatest or least potential are not based solely on cost; other considerations include the impacts of construction on the environment, feasibility of permitting, and feasibility of sharing an intake with an operating power plant.

For consistency in the presentation of the intake modification scenarios, the objective of each design was considered, i.e., whether the design will meet IM standards, entrainment standards, or both. The proposed 316(b) Rule offers clear guidance on how to meet IM standards (see Section 2.2.1.1.1), whereas there is no clear guidance on entrainment. The proposed Rule indicates that because of site specificity, entrainment of smaller life stages will be reviewed on a case-by-case basis. Therefore, for illustrative purposes and consistency in this Guidance Document designs have been chosen that that will achieve the proposed 316(b) performance standard for IM by meeting the 0.5 ft/sec TSV criterion. It is important to note, however, that entrainment is likely to be a concern at intakes in oceans or estuaries.

The intake modification scenarios presented were developed for illustrative purposes only and should not be construed as recommendations to meet either regulatory or financial criteria. Modification of any existing intake requires a detailed review of costs, biological effectiveness, and ability to meet regulatory goals, each of which will vary greatly depending on the particular site under consideration. The intake modification scenarios presented herein are intended to be used as guidance to illustrate how to evaluate potential existing intakes for use as DWIS. As guidance, therefore, some scenarios are included that are clearly not feasible from a cost perspective. It is as valuable for the reader of this document to understand why an option is not practicable as it is to understand why another option is practicable.

The typical approach of co-location was not presented as a scenario because co-location does not require modification *per se* of an existing intake. Instead, it is an approach that makes a concerted effort to utilize existing infrastructure as a cost-saving measure by drawing water from the discharge of a power plant (i.e., no separate DWIS is required). In cases where the power plant may be forced to retrofit to closed-cycle cooling or is decommissioned, the desalination facility would have to modify the intake to meet IM&E standards; this case is presented in the scenarios in Section 6.3.

6.1 Scenario Development

6.1.1 Existing Intake Location/Configuration

Intake modification scenarios were developed based on identifying the most prevalent existing CWIS conditions. The EPRI Entrainment and Impingement Data Base (EPRI, 2002) as well as Alden's internal CWIS data sets were reviewed to determine the most common configurations for existing CWIS. This included a review of intake location, general layout, flow rates, and velocities.

The review indicated that approximately 55% of intake structures are located on the shoreline, 25% are located offshore, and the remaining 20% are atypical arrangements such as long intake canals. Flow rates varied from approximately 70 to 1400 MGD for offshore facilities and from about 30 to 3500 MGD for shoreline facilities. The typical shoreline facility layout included a forebay, screen bays, and a common plenum leading to pumps. Offshore facilities were found to typically withdraw through an offshore velocity cap leading to a primary conveyance pipe that distributes flow to a shoreline forebay housing screen bays that lead to a common plenum.

Based on these findings, shoreline and offshore intake configurations were selected for the development of the intake modification costs because they represent the predominant CWIS configurations. Intake modification scenarios and costs were developed for both intake configurations (Figure 6.1).

6.1.2 Status of Existing CWIS (Operational or Decommissioned)

The next step was to consider the status of the existing CWIS that would be modified. The CWIS could either be in operation or decommissioned. A CWIS in operation may be required to undergo an intake modification of its own to meet 316(b) performance standards. This intake modification presents an opportunity to add additional capacity to supply a DWIS. Intake modification scenarios and costs were developed for operational CWIS undergoing 316(b) upgrades to which additional DWIS capacity could be added (Section 6.4).

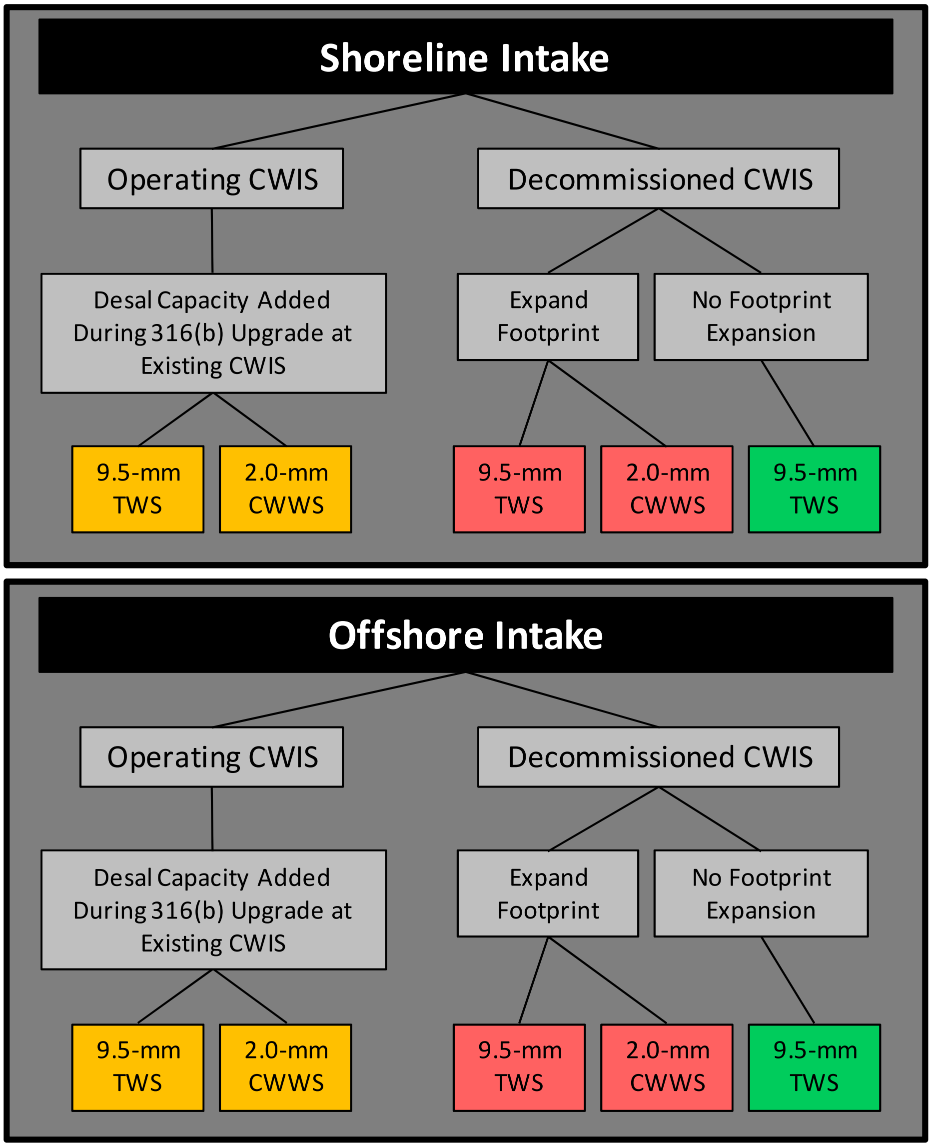


Figure 6,1. Intake modification scenarios selected for development of cost considerations.

Note: The potential for cost-effective implementation as an approach to modification is coded by color: green=high; yellow=moderate; and red=low.

If the existing CWIS was decommissioned, the decommissioned CWIS capacity could either be large enough to provide the flow required for the desalination facility or too small. If too small, the intake footprint would have to be expanded to accommodate the DWIS flow and still meet the 0.5 ft/sec TSV criterion. If the existing CWIS capacity was large enough to accommodate the flow required for the desalination facility, no major structural expansion would be required to meet the 0.5 ft/sec TSV criterion. Intake modification scenarios and costs were developed for decommissioned CWIS that would require an expansion (Section 6.5) and those that would not (Section 6.3).

6.1.3 Technologies Selected for Intake Modifications

For the purposes of this cost evaluation, the assumption was that the existing CWIS being modified had conventional TWS with 9.5 mm mesh and no fish protection features (e.g., fish-collecting buckets, low pressure spray wash, fish return system). Two technologies were selected for modifying these existing intakes:

- 9.5 mm modified TWS with fish protection features
- 2.0 mm CWWS

These two technologies were selected for their proven ability to significantly reduce IM at seawater intakes. Each has been proven to be biologically effective for reducing IM, and each is a mature technology that is commercially available. Furthermore, each was designed to meet the 0.5 ft/sec TSV criterion to satisfy the proposed 316(b) IM performance standard. In addition, 2.0 mm CWWS were selected not only for their proven ability to reduce IM (essentially eliminated at a TSV of 0.5 ft/sec), but for their ability to reduce entrainment of earlier life stages as well. The level of entrainment reduction possible with CWWS is a function of organism size in relation to the slot width and therefore species specific.

Modified TWS with 9.5 mm mesh will not reduce entrainment of early life stages. If entrainment is a concern at a DWIS, a finer mesh will likely be required. The intake modifications described in the following section, in which 9.5 mm modified TWS were used, were designed to meet the 0.5 ft/sec TSV criterion. This ensures compliance with the IM standard only, not entrainment.

For consistency, modified TWS with 9.5 mm mesh were used in all of the intake modification scenarios developed. It is important to note that given the two compliance paths available to meet 316(b) standards, some existing facilities (e.g., an operating CWIS undergoing an upgrade to meet 316(b) standards) may choose to pursue not the 0.5 ft/sec TSV compliance path but rather the alternative compliance path in which they demonstrate that they are able to meet IM limits of no more than 12% annually or 31% monthly (for more detail on the two compliance options for IM, see Section 2.2.1.1). Such a decision could substantially impact the cost of the intake modifications because achieving a 0.5 ft/sec TSV would not be the driving factor of the intake's design. If TSV is not considered, in many cases there is no need for major intake expansions.

For consistency, CWWS with 2.0 mm slots were used in most of the intake modification scenarios developed. Note that CWWS was not considered for the decommissioned CWIS scenario where a footprint expansion would not be required (Figure 6.1). If the CWIS footprint is sufficient to accommodate the DWIS flow (i.e., the existing space does not require expansion to meet the 0.5 ft/sec TSV criterion), there is no clear benefit to installing CWWS because modified TWS can be installed without civil modifications at a much lower cost.

The matrix of intake modification scenarios is presented in Figure 6.1, and the following summarizes the scenarios developed:

- shoreline intake
- planned upgrade of an existing CWIS to meet 316(b) compliance; DWIS flow added during upgrade
- decommissioned CWIS; the CWIS flow is small compared to the 100 MGD required for DWIS; footprint expansion required
- decommissioned CWIS; CWIS flow large compared to 100 MGD required for DWIS; footprint expansion not required

- offshore intake
- planned upgrade of an existing CWIS to meet 316(b) compliance; DWIS flow added during upgrade
- decommissioned CWIS; CWIS flow is small compared to the 100 MGD required for DWIS; footprint expansion is required
- decommissioned CWIS; CWIS flow is large compared to the 100 MGD required for DWIS; footprint expansion is not required

For more information regarding the potential biological benefits of an offshore intake versus a shoreline intake, see Chapter 4.

6.1.4 Intake Design Assumptions

A target DWIS capacity was determined based on reasonable desalination intake facility flows. For this evaluation, a production water capacity of 50 MGD was chosen with 50% recovery rate; therefore, the total capacity required for the DWIS was 100 MGD. No additional flow was assumed for brine dilution purposes (i.e., brine would be prediluted by another industrial effluent: wastewater or power plant effluent).

In each scenario, the assumption is that the circulating water pumps at the existing CWIS would be removed and the requisite number of desalination feed water pumps would be installed. The costs developed for each scenario do not include the cost of the new pumps for the desalination facility.

For the offshore intake configurations (Sections 6.3.2, 6.4.2, and 6.5.2), we have assumed that the velocity in the conveyance tunnel or pipeline is sufficient to prevent the accumulation of debris or macrofouling organisms on the inside of the pipe. Typically, velocities between 6 and 10 ft/sec should be maintained through the conveyance pipe. Lower velocities may encourage the settlement of fouling organisms and the accumulation of sediment. On the other hand, if the existing velocities are too high, then the added head losses through the pipe need to be addressed to verify that the pumps will have adequate submergence. When the velocity is too low, decreasing the inside diameter of the pipe with slip lining can increase it. If an offshore conveyance pipe requires slip lining to increase velocities, it will substantially impact the cost. Therefore, if considering modification of an offshore intake with a tunnel or pipe, the in-pipe velocities must be taken into consideration during the design process. Note that the costs developed for each offshore scenario do not include any modification of the pipe’s inside diameter. Table 6.1 summarizes the velocities used in the design process. According to EPA (2011), the velocity through the face of a velocity cap is typically 0.5 ft/sec. For the intake designs utilizing a velocity cap, an *approach* velocity of 0.5 ft/sec has been used. Approach velocity is measured some distance upstream of the screen face; the TSV will be higher.

Table 6.1. Summary of Velocity Design Parameters

Component	Design Velocity (ft/sec)
Velocity cap	0.5 (approach)
9.5 mm modified TWS	0.5 (through)
2.0 mm CWWS	0.5 (through)

Notes: CWWS=cylindrical wedgewire screen; TWS=traveling wire screen

Brief descriptions of each existing intake site are given in their respective sections before the modification options are presented.

6.2 Other Considerations When Modifying Existing Intakes

When considering modification of an existing intake, taking sequential steps is recommended in order to reduce the risk and cost associated with the alteration of a civil structure. A brief review is provided in the following section to illustrate the typical risk-reduction studies recommended prior to detailed engineering and implementation of an intake modification.

6.2.1 Feasibility Studies

The first risk-reduction step when modifying an intake is to conduct a feasibility study. Feasibility studies evaluate all the intake technology options available and determine their applicability to the existing intake under consideration. Such a study would evaluate the technical, economic, environmental, and regulatory feasibility of each option. By objectively comparing the alternatives, a determination can be made about which technology is likely to provide the best performance (engineering and biological) at the lowest cost. Other items that can be critical to a desalination feasibility study include the potential to acquire permits for the intake and public perception.

6.2.2 Hydraulic Model Studies

Modification of existing intakes will require hydraulic model studies to optimize the design, minimize head losses, and assure that approach flow conditions to the pumps are acceptable. Important issues hydraulic modeling will address include:

- changes in river hydraulics that may affect navigation
- sediment deposition and scour potential around the structure
- flow distribution through the screens
- head loss
- pump intake performance

Hydraulic model studies can be conducted physically with scaled models or numerically using CFD. Often both approaches are used in tandem to efficiently refine intake designs.

6.2.3 Pilot Studies

Pilot studies are a final risk-reduction step that allows the project proponent to evaluate the performance of an intake design at the actual intake site. Pilot studies are used to develop a feel for the site-specific engineering and biological performance of the intake technology selected. It provides the project proponent an opportunity to refine an intake design based on field-collected data prior to construction. Evaluating performance and making modifications to the design can be cost-prohibitive after installation is complete; pilot studies help identify these issues earlier when time and expense are not as limiting.

6.3 Intake Modification Scenarios—Highest Potential

For a desalination developer interested in using an existing intake for a DWIS, the objective is to identify sites that require the fewest structural changes. This is the case with decommissioned CWIS that have flow capacities greater than that required by the DWIS (scenarios shown in green in Figure 6.1). By identifying sites that can accommodate the DWIS capacity while maintaining the 0.5 ft/sec TSV, the greatest efficiencies can be realized. Not only will the existing intake require fewer structural modifications than others, but the impacts associated with construction will be minimized as well. With reduced construction impacts, permitting the installation may be easier, and disturbance of the source water body is minimized (e.g., minimal impact associated with benthic disturbances, navigation, dredging, coffer damming).

Following are two intake modification examples that would be considered the best-case scenarios for a desalination developer, not simply because of cost but for practicability as well.

6.3.1 Shoreline Decommissioned CWIS, No Footprint Expansion Required

This scenario focuses on a decommissioned shoreline CWIS that can be reused for desalination purposes. Based on the previous design capacity for the CWIS, no footprint expansion is required to meet the 0.5 ft/sec TSV criterion. The modification of this intake will be completed with 9.5 mm through-flow modified TWS because they are readily available, commonly used, and have been proven to be biologically effective. CWWS was not considered for this scenario. Because the footprint is sufficient (i.e., the existing structure does not require expansion to meet the 0.5 ft/sec TSV criterion), the requisite modifications to the intake are limited, and there is no clear benefit to installing CWWS because modified TWS can be installed without civil modifications (i.e., at a lower cost).

The existing shoreline CWIS that is being modified consists of five intake bays, each consisting of two trash racks, two conventional TWS (9.5 mm mesh and no fish protection features), and one circulating water pump. The CWIS is located in an estuary and under tidal influence. Table 6.2 summarizes the pertinent design information associated with both the existing and proposed intake structures.

Table 6.2. Summary of Pertinent Design Parameters—Shoreline Decommissioned CWIS, No Footprint Expansion Required

Existing (previous) CWIS design flow (MGD)	253
Proposed DWIS design flow (MGD)	100
Proposed intake structure capacity (MGD)	100
Existing (previous) TSV (ft/sec)	2.0
Target modified TWS TSV (ft/sec)	0.5

Notes: CWIS=cooling water intake structure; DWIS=desalination water intake structure; TSV=through-screen velocity; TWS=traveling water screen

The footprint of the intake does not require expansion; rather, modifications will be limited to upgrading the conventional TWS to through-flow modified TWS and installing a fish return system. Three of the 10 existing screen bays will have sufficient capacity to accommodate 100 MGD of desalination feed water while maintaining a 0.5 ft/sec TSV. In addition, the remaining seven screen bays will be blocked.

The total hydraulic capacity of the modified intake will be 100 MGD; which is required for the desalination project. Three 8 ft wide through-flow modified TWS with 9.5 mm mesh will be installed in the existing bays. The new through-flow modified TWS will be equipped with fish protection features (low pressure spray wash, collection system, return system) to assure maximum IM reduction. The existing trash racks would remain in the three screen bays being utilized. A conceptual plan of the modified intake is provided in Figure 6.2. A typical through-flow modified TWS is shown in Figure 6.3.

The new screens would be rotated and cleaned continuously, reducing impingement duration. A low pressure fish removal spray wash system and a high pressure debris removal spray wash system are required and included in the costs. Fish and debris removed from the screens will be transported and returned to the source water body away from the intake where the potential for re-impingement is minimized. A fish trough would collect fish removed by the low pressure (~10 psi) spray wash, and a separate debris trough would collect debris removed from the screens by the high pressure (~80 psi) spray wash. Prior to exiting the screenhouse, these two troughs would combine into a single return trough. To reduce the potential for re-impingement, two combined return pipes would be required because of tidal flow reversals. Each return pipe would discharge 100 or 85 ft from the ends of the intake structure based on the direction of the tide. The new return troughs are shown in Figure 6.2.

Conceptual cost estimates were developed based on site-specific information for this modified TWS option. The cost for this intake modification is estimated to be $4,041,000. See Section 6.6 for details on what is included in the cost estimates. Summary costs for all 10 intake modification scenarios are presented in Table 6.8.

Conclusion

This represents the best-case scenario for a desalination developer: locating a decommissioned CWIS with sufficient capacity to accommodate the DWIS flow required without having to make any major structural modifications. In this case, only three through-flow modified TWS with 9.5 mm mesh are required to achieve a TSV of 0.5 ft/sec. In fact, the CWIS is oversized for the DWIS that will replace it, and some of the intake bays can be blocked.

Although the costs are higher than other scenarios (Table 6.8), there is a measure of practicality to using a decommissioned CWIS that is oversized for the DWIS capacity required. Once modified, the desalination facility would be the sole operator of the DWIS; no negotiations would be required with another utility on items such as O&M expenditures as would be the case if the intake were shared with a power plant (Section 6.4). Furthermore, construction impacts would be minimized because the modification work would be completed at a brownfield site. With reduced construction impacts, permitting may be less onerous.

This scenario also best represents the type of intake modification that could be required for desalination facilities that are co-located with power plants and draw feed water from the power plant's effluent. If the power plant is decommissioned or forced to retrofit to closed-cycle cooling, and the desalination facility becomes responsible for the intake flows used, modifications would likely be required to meet IM&E standards. It is important to keep in mind that the design illustrated in Figure 6.2 would address IM performance standards only; other intake modifications (e.g., smaller screen mesh on the modified TWS) may be required to meet entrainment standards if they are being enforced at this site.

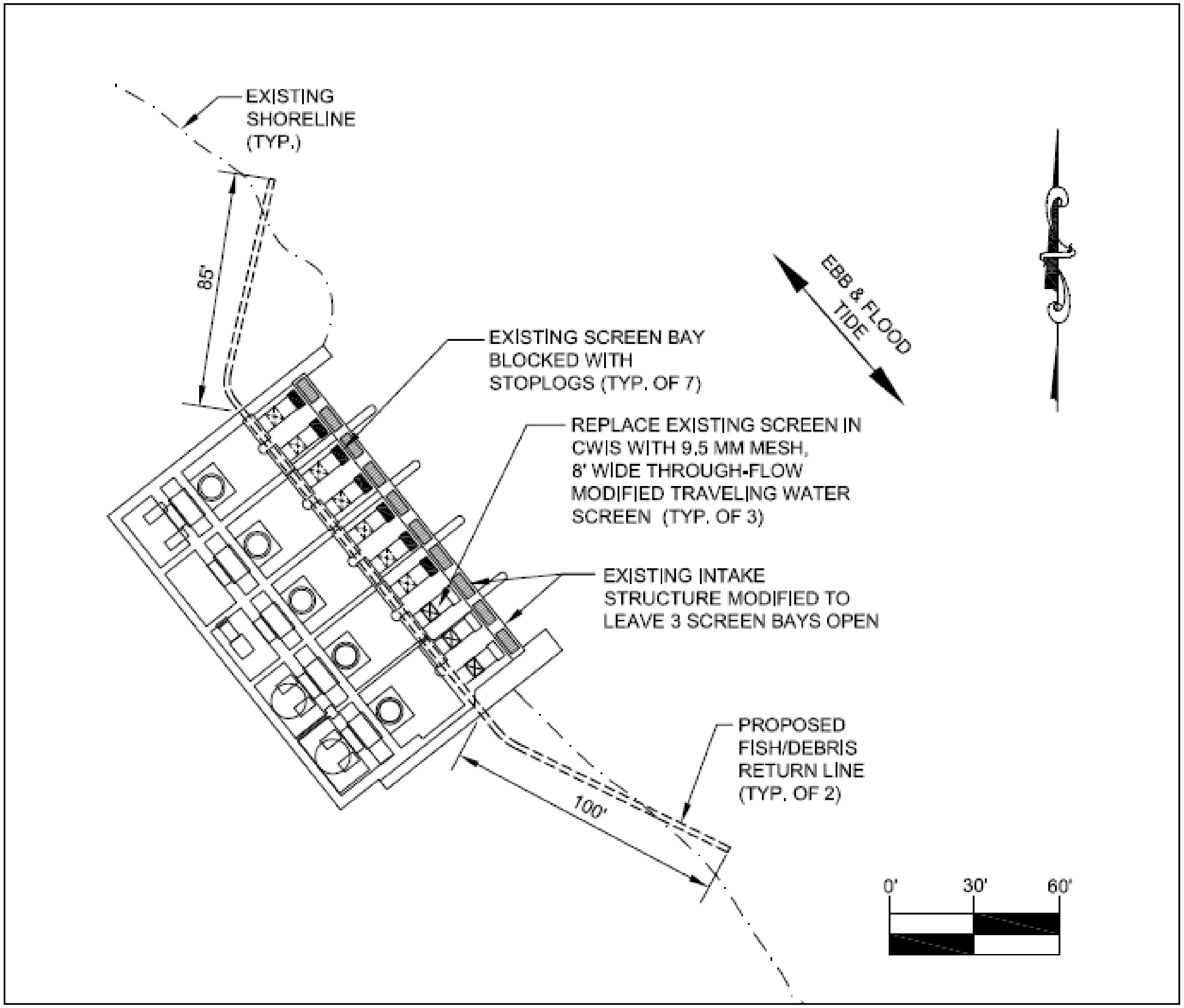


Figure 6.2. Shoreline decommissioned CWIS, no footprint expansion required, modified with 9.5 mm through-flow TWS.

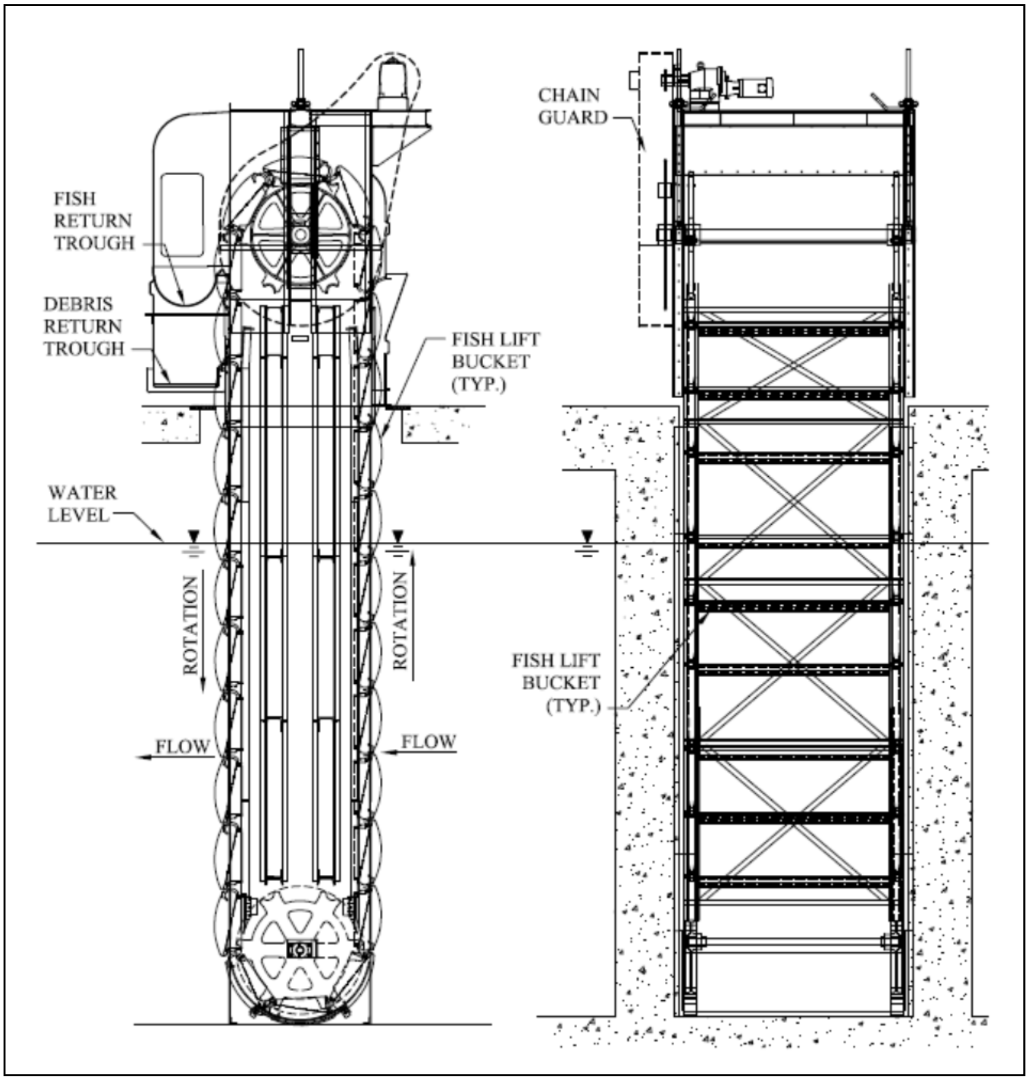


Figure 6.3. Section and elevation views of a typical through-flow modified TWS.
Source: Courtesy of U.S. Filter

6.3.2 Offshore Decommissioned CWIS, No Footprint Expansion Required

This scenario focuses on a decommissioned offshore CWIS that can be reused for desalination purposes. Based on the previous design capacity for the CWIS, no footprint expansion is required to meet the 0.5 ft/sec TSV criterion. As with the shoreline scenario presented in the previous section, the modification of this intake will be completed with 9.5 mm through-flow modified TWS; they are readily available, commonly used, and have been proven to be biologically effective. CWWS was not considered for this scenario. Because the footprint is sufficient (i.e., the existing structure does not require expansion to meet the 0.5 ft/sec TSV criterion), the requisite modifications to the intake are limited, and there is no clear benefit to installing CWWS because modified TWS can be installed without civil modifications (i.e., at a lower cost).

The existing offshore CWIS being modified consists of a single offshore velocity cap and conveyance pipe leading to an onshore screenhouse. The screenhouse has four intake bays, each fitted with a conventional TWS (9.5 mm mesh and no fish protection features) and trash rack. The CWIS is located on the ocean. The two existing bays will have sufficient capacity to accommodate 100 MGD of desalination flow while maintaining 0.5 ft/sec TSV. Table 6.3 summarizes the pertinent design information associated with both the existing and proposed intake structures.

Table 6.3. Summary of Pertinent Design Parameters—Offshore Decommissioned CWIS, No Footprint Expansion Required

Existing (previous) CWIS design flow (MGD)	675
Proposed DWIS design flow (MGD)	100
Proposed intake structure capacity (MGD)	100
Existing (previous) TSV (ft/sec)	1.0
Target modified TWS TSV (ft/sec)	0.5

Notes: CWIS=cooling water intake structure; DWIS=desalination water intake structure; TSV=through-screen velocity; TWS=traveling water screen

The footprint of the intake does not require expansion; rather, modifications will be limited to upgrading the conventional TWS to through-flow modified TWS and installing a fish return system. All four of the existing screen bays will be used to accommodate the 100 MGD of desalination feed water while maintaining a 0.5 ft/sec TSV. No changes will be made to the offshore structures (velocity cap and conveyance pipe).

The total hydraulic capacity of the modified intake will be 100 MGD, which is required for the desalination project. Four 10 ft wide through-flow modified TWS with 9.5 mm mesh will be installed in the existing bays. The new through-flow modified TWS will be equipped with fish protection features (low pressure spray wash, collection system, return system) to assure maximum IM reduction. The existing trash racks would remain in the four screen bays. A conceptual plan of the modified intake is provided in Figure 6.4.

The new screens would be rotated and cleaned continuously, reducing impingement duration. A low pressure fish removal spray wash system and a high pressure debris removal spray wash system are required and included in the costs. Fish and debris removed from the screens will be transported and returned to the source water body away from the intake where the potential for re-impingement is minimized. A fish trough would collect fish removed by the low pressure (~10 psi) spray wash, and a separate debris trough would collect debris removed from the screens by the high pressure (~80 psi) spray wash. Prior to exiting the screenhouse, these two troughs would combine into a single return trough. The return pipe would be approximately 500 ft long and discharge to the ocean. The new return trough is shown in Figure 6.4.

Conceptual cost estimates were developed based on site-specific information for this modified TWS option. The cost for this intake modification is estimated to be $5,161,000. See Section 6.6 for details on what is included in the cost estimates. Summary costs for all 10 intake modification scenarios are presented in Table 6.8.

Conclusions

This represents the best-case scenario for a desalination developer: locating a decommissioned CWIS with sufficient capacity to accommodate the DWIS flow required without having to make any major structural modifications. In this case, only four through-flow modified TWS are required to achieve a TSV of 0.5 ft/sec.

Although the costs are higher than other scenarios (Table 6.8), there is a measure of practicality to using a decommissioned CWIS that is oversized for the DWIS capacity required. Once modified, the desalination facility would be the sole operator of the DWIS; no negotiations would be required with another utility on items such as O&M expenditures as would be the case if the intake were shared with a power plant (Section 6.4). Furthermore, construction impacts would be minimized because the modification work would be completed at a brownfield site. With reduced construction impacts, permitting may be less onerous.

This scenario also best represents the type of intake modification that could be required for desalination facilities that are co-located with power plants and draw feed water from the power plant's effluent. If the power plant is decommissioned or forced to retrofit to closed-cycle cooling and the desalination facility becomes responsible for the intake flows used, modifications would likely be required to meet IM&E standards. It is important to keep in mind that the design illustrated in Figure 6.4 would address IM performance standards only; other intake modifications (e.g., smaller screen mesh on the modified TWS) may be required to meet entrainment standards if they are being enforced at this site.

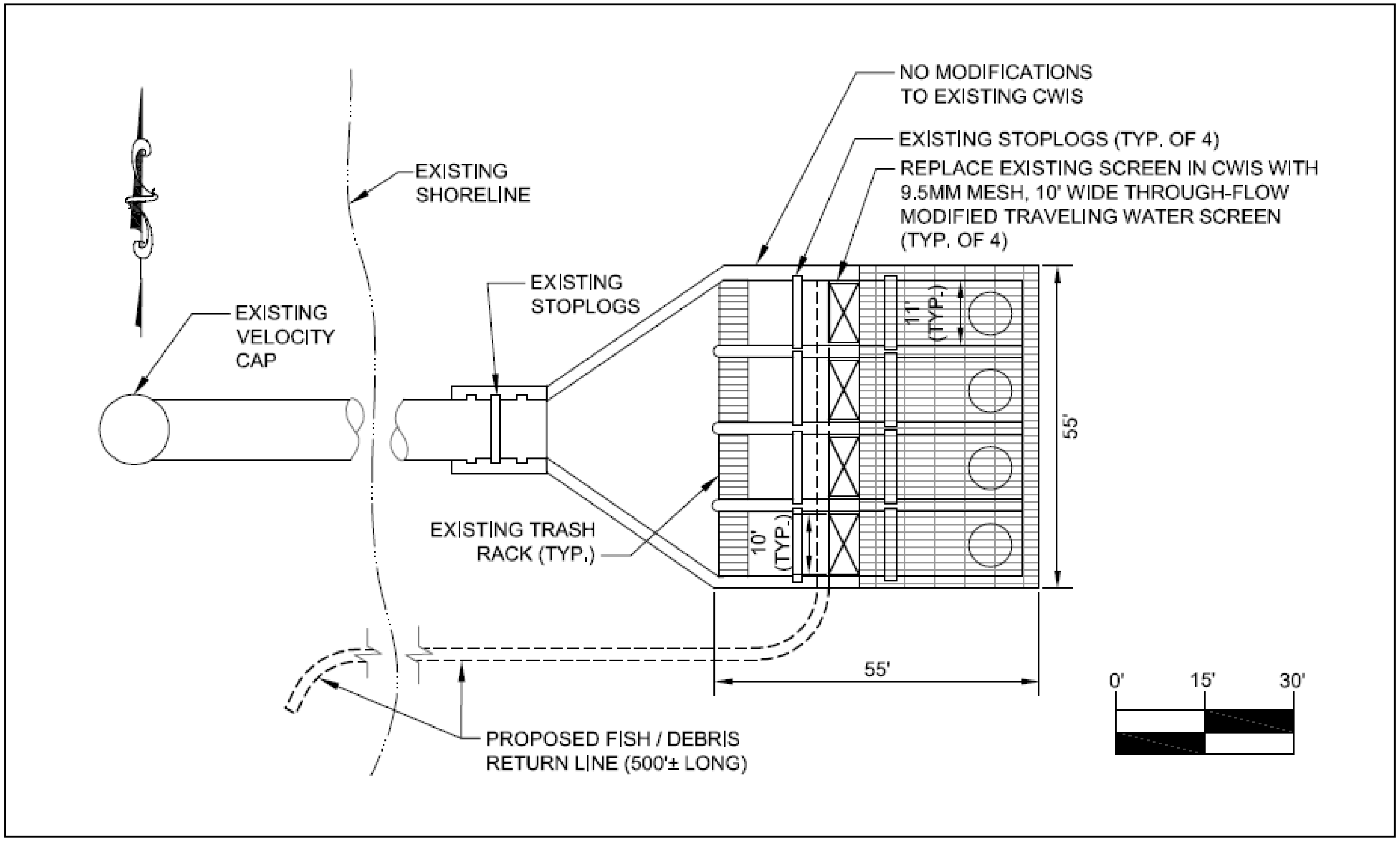


Figure 6.4. Offshore decommissioned CWIS, no footprint expansion required, modified with 9.5 mm through-flow TWS.

6.4 Intake Modifications Scenarios—Moderate Potential

An existing power plant CWIS that holds moderate potential for desalination developers is one that is planning an upgrade to meet 316(b) IM&E performance standards (scenarios shown in orange in Figure 6.1). If, during the intake upgrade process, an agreement can be struck with the power plant, additional intake capacity could be added to provide feed water for a new desalination facility. Relatively speaking, the capacity required for the DWIS is likely to be substantially lower than for the CWIS. For example, the 100 MGD design flow used here for a reasonably sized seawater desalination facility is small compared to a reasonably sized power plant that may draw 500 MGD or more. Because this scenario assumes that the split in the capital costs for the shared modified intake is based on the proportion of flow utilized, the desalination facility in the example would only be responsible for approximately 17% of the capital costs.

The practical limitations, however, may overshadow the cost savings inherent in this intake modification scenario (see relative costs in Table 6.8). First, negotiating an agreement with a power plant to share an intake structure may be a difficult business venture. Second, although a proportional split in costs is assumed based on flow utilized, another agreement must be negotiated to address annual O&M costs. Finally, the feasibility of securing a single permit for two separate industrial processes sharing a single intake would need to be investigated thoroughly.

Following are four intake modification scenarios that would be considered to have moderate potential for a desalination developer.

6.4.1 Shoreline CWIS Undergoing a 316(b) Upgrade, DWIS Capacity Added

This scenario focuses on an existing shoreline CWIS that is required to undertake upgrades to meet 316(b) standards. As the CWIS is undergoing modification and expansion to lower the intake velocities to the 0.5 ft/sec TSV, an incremental increase in the expansion is made to accommodate additional capacity for a DWIS. The design and construction of the modified intake would therefore include an additional 100 MGD for desalination purposes. The modification of this intake will be completed with 9.5 mm dual-flow modified TWS and 2.0 mm CWWS because they are readily available, commonly used, and have been proven to be biologically effective.

The existing shoreline CWIS that is being modified consists of two bays, each with a trash rack, a conventional TWS (9.5 mm mesh and no fish protection features), and a circulating water pump. The CWIS is located in an estuary and under the influence of tidal flux. Table 6.4 summarizes the pertinent design information associated with both the existing and proposed intake structures.

Table 6.4. Summary of Pertinent Design Parameters—Shoreline CWIS Undergoing a 316(b) Upgrade, DWIS Capacity Added

Existing CWIS design flow (MGD)	288
Proposed DWIS design flow (MGD)	100
Proposed combined intake structure capacity (MGD)	388
Existing TSV (ft/sec)	1.4
Target modified TWS TSV (ft/sec)	0.5
Target CWWS TSV (ft/sec)	0.5

Notes: CWIS=cooling water intake structure; CWWS=cylindrical wedgewire screen; DWIS=desalination water intake structure; TSV=through-screen velocity; TWS=traveling water screen

6.4.1.1 Intake Modified with 9.5 mm Modified TWS

This scenario considers a shoreline CWIS with an existing TSV greater than 0.5 ft/sec (Table 6.4). To meet the 0.5 ft/sec TSV criterion, a footprint expansion is required regardless of the desalination project. During the power plant's intake upgrade, additional capacity will be added to the CWIS to accommodate 100 MGD of desalination feed water.

A new screenhouse structure will be installed upstream of the existing CWIS and have a combined total intake flow capacity of 388 MGD (sum of the 288 MGD for the CWIS and 100 MGD of the DWIS). Four 8 ft wide dual-flow modified TWS with 9.5 mm mesh will be installed in the new screenhouse. Dual-flow modified TWS, rather than through-flow, would be used because dual-flow screens provide approximately double the screening area, leading to an intake footprint roughly half the size of a comparable intake constructed of through-flow screens. The new dual-flow modified TWS will be equipped with fish protection features (low pressure spray wash, collection system, return system) to assure maximum IM reduction. Four new trash racks would be installed, one in each intake bay. A conceptual plan of the modified intake is provided in Figure 6.5.

The new screens would be rotated and cleaned continuously, reducing impingement duration. A low pressure fish removal spray wash system and a high pressure debris removal spray wash system are required and included in the costs. Fish and debris removed from the screens will be transported and returned to the source water body away from the intake where the potential for re-impingement is minimized. A fish trough would collect fish removed by the low pressure (~10 psi) spray wash, and a separate debris trough would collect debris removed from the screens by the high pressure (~80 psi) spray wash. Prior to exiting the screenhouse, these two troughs would combine into a single return trough. To reduce the potential for re-impingement, two combined return pipes would be required because of tidal flow reversals. Each return pipe would discharge 120 ft from the ends of the intake structure based on the direction of the tide. The new return troughs are shown in Figure 6.5.

Conceptual cost estimates were developed based on site-specific information for this modified TWS option. The cost for this intake modification is estimated to be $2,096,000. See Section 6.6 for details on what is included in the cost estimates. Summary costs for all 10 intake modification scenarios are presented in Table 6.8.

Conclusion

The majority of the screens depicted in Figure 6.5 are present solely to reduce the TSV of the existing CWIS flow to the 0.5 ft/sec TSV from 1.4 ft/sec (i.e., even if there were no desalination capacity added, the intake would still require a significant expansion). The 100-MGD DWIS flow accounts for a smaller proportion of the overall shared intake flow, and only one of the screens is required for the additional DWIS flow that would be added. Given capital cost savings possible with a shared intake, this represents an attractive option for a desalination facility; however, as discussed previously, there are practical limitations that may overshadow the cost savings of this intake modification scenario.

Limited space is available to expand the intake on land, so this intake extends into the water body. Space on land is usually very scarce at existing power plants. As such, the design presented here is essentially a new intake structure located in front of the existing structure. If the design and construction techniques are planned carefully, the existing intake may be operational during most of the construction. If space were available on land, the existing intake could be expanded by the number of bays required to decrease the TSV to 0.5 ft/sec; however, careful consideration would have to be given to the hydraulic design of the channels approaching the existing pumps to assure uniform flow through all screens (see Section 6.2.2 for more details on hydraulic design). In a case such as this, in which the modification is essentially a new intake structure, dual-flow TWS are preferred because their greater screening area (relative to comparably sized through-flow TWS) reduces the footprint of the intake.

It is also important to consider, however, that an existing power plant may choose to comply with 316(b) through meeting the IM performance standards rather than by undertaking a major intake expansion to decrease TSV. If this is the case, the existing conventional TWS would likely be replaced with modified TWS and a fish return system without making any major structural modifications to the intake. The TSV would not have to be considered because the measure of compliance would be in the survival of impinged fish on the TWS. This compliance option would require an impingement monitoring program in which impinged organisms are collected and held over a period of time to determine survival. If this compliance route is selected by the power plant, the additional flow required by the desalination facility may not require the addition of more modified TWS.

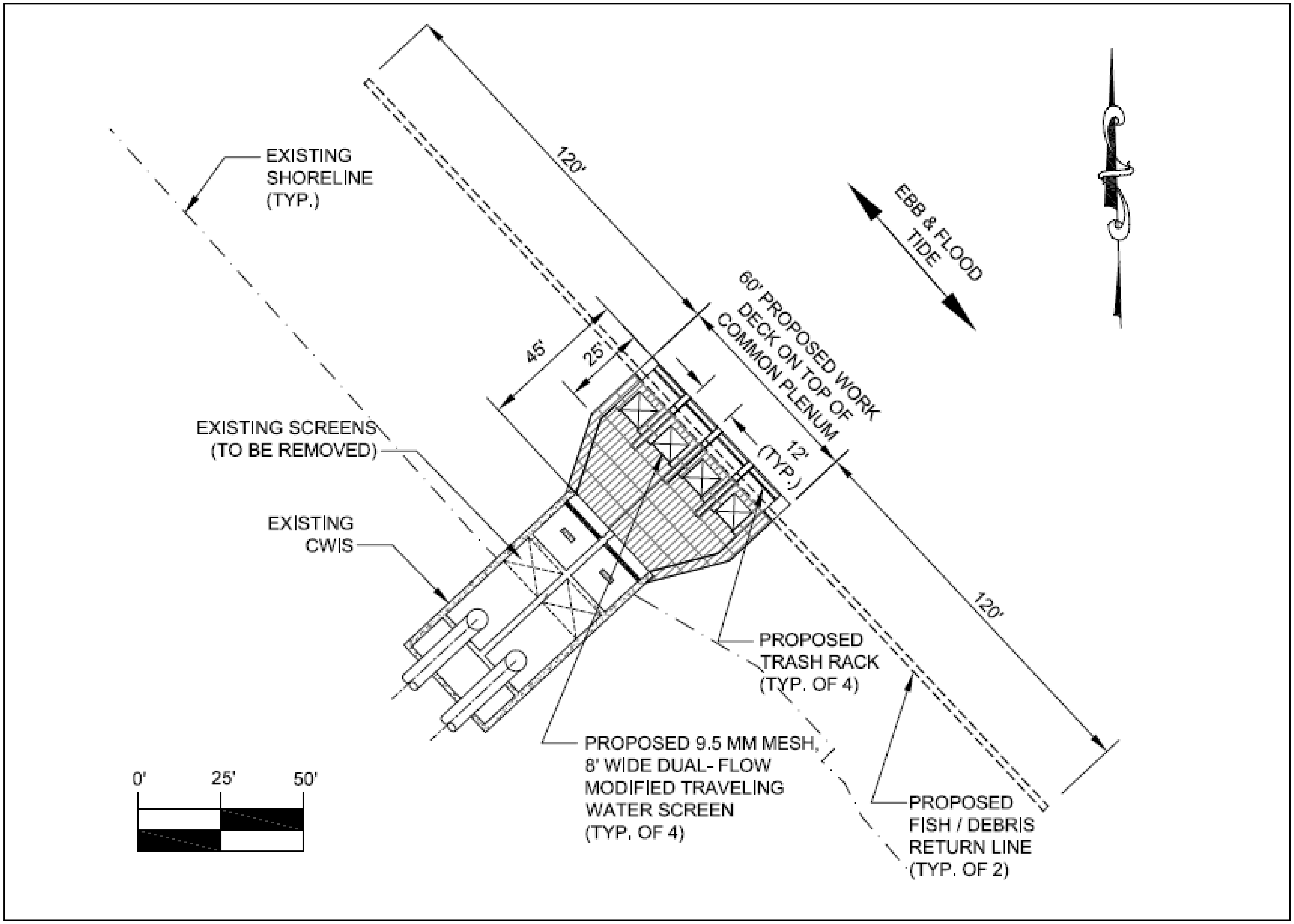


Figure 6.5. Shoreline CWIS undergoing a 316(b) upgrade, DWIS capacity added, modified with 9.5 mm dual-flow TWS.

6.4.1.2 Intake Modified with 2.0 mm CWWS

Following is a description of how the same shoreline CWIS would be modified with 2.0 mm CWWS with a 0.5 ft/sec TSV. Six T-84 (84-in.-diameter) screens with 2.0 mm slot openings would be required to screen the total intake flow (388 MGD). The screen diameter selected was based on the minimum water depth assuming the same bottom invert of the existing intake structure. A new sheet pile bulkhead would be constructed upstream of the existing intake to form a common intake plenum for the water to be conveyed from the CWWS to the pumps. The CWWS would be mounted on two new header pipes that would be connected to the plenum. A conceptual plan of the CWWS layout is provided in Figure 6.6.

Three screens would be installed on each header pipe and extend approximately 50 ft in front of the common plenum, which would be about 35 ft wide by 80 ft long. Emergency bypass gates would be incorporated within the bulkhead wall of the intake plenum to open in the event that the screens are not able to pass the required plant flow to meet thermal requirements. Each screen would be about 7 ft in diameter and T-shaped (Figure 6.7), with an overall length of about 23 ft. The outlet pipe would be 8 ft in diameter and located in the middle of the T section. The bottom of the deployment location is assumed to be at the same level as the bottom of the existing intake structure. If the bottom is different than the assumed elevation, larger or smaller screens would be used for the appropriate water depth. Dolphin piles would be constructed approximately 20 ft in front of the new intake to prevent ships from impacting the structure.

CWWS operate best at locations where there are ambient currents to move debris past the screens. An automated air backwash system has been included in the design to maintain the screens in a clean condition; however, during periods of heavy debris loading, additional manual maintenance may be required. In addition, the screens would require an annual inspection by divers to identify any damage that could affect plant operations and verify effective cleaning by the air backwash system. The screens have been designed with Z-alloy (a copper alloy) to help limit the growth of macro-biofouling organisms (e.g., mussels and barnacles) in order to decrease O&M costs.

Some uncertainties associated with implementing the CWWS option include but are not limited to impacts to navigation, sedimentation, and debris management. Pilot studies are recommended to evaluate these uncertainties prior to detailed design and implementation.

Conceptual cost estimates were developed based on site-specific information for this CWWS option. The cost for this intake modification is estimated to be $2,088,000. See Section 6.6 for details on what is included in the cost estimates. Summary costs for all 10 intake modification scenarios are presented in Table 6.8.

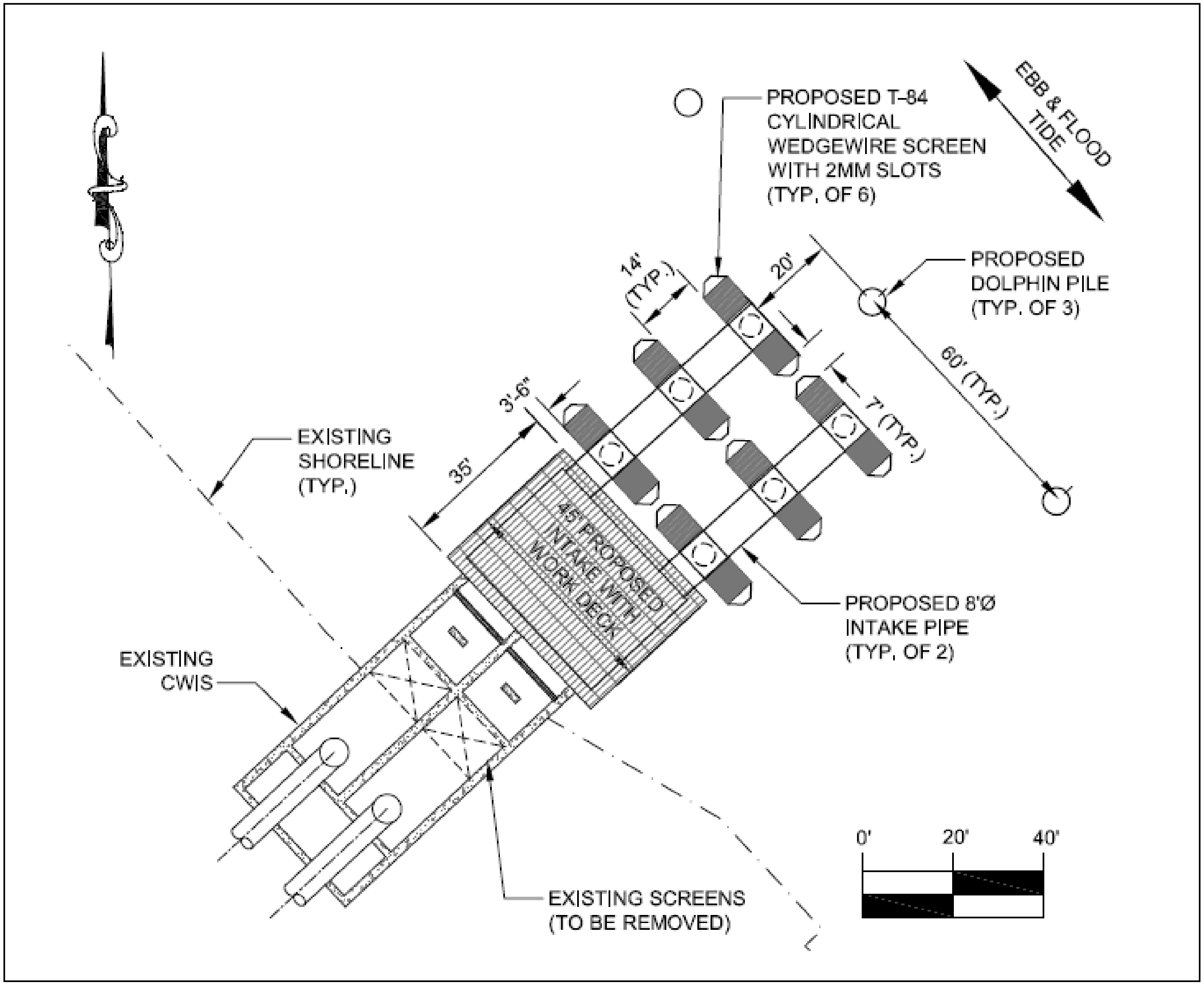


Figure 6.6. Shoreline CWIS undergoing a 316(b) upgrade, DWIS capacity added, modified with 2.0 mm CWWS

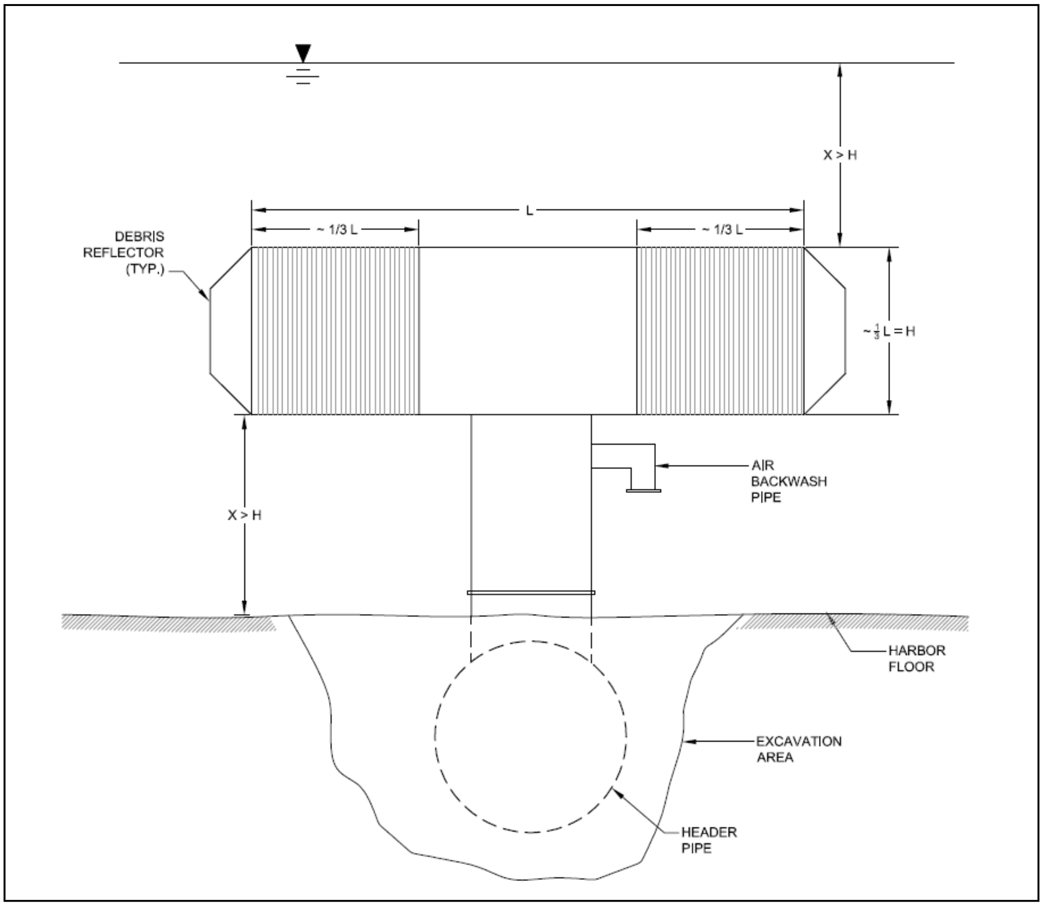


Figure 6.7. Section through a typical CWWS

Conclusion

This intake modification scenario represents a viable approach to meeting IM concerns. When designed to a TSV of 0.5 ft/sec, the CWWS would effectively eliminate IM of juveniles and adults. CWWS with 2.0 mm slots will also likely provide a reduction in entrainment, but the level of reduction is dependent on a number of site- and species-specific factors (see Section 5.2.2).

As with the previous example, the majority of the screens depicted in Figure 6.6 are present solely to reduce the TSV of the existing CWIS flow to the 0.5 ft/sec TSV from 1.4 ft/sec (i.e., even if there were no desalination capacity added, the intake would still require a significant number of CWWS). The 100 MGD DWIS flow accounts for a smaller proportion of the overall shared intake flow, and only one of the screens is required for the additional DWIS flow. Given the capital cost savings possible with a shared intake, this represents an attractive option for a desalination facility; however, as discussed previously, there are practical limitations that may overshadow the cost savings of this intake modification scenario.

Because of the proximity of the CWWS to the shore, an air backwash system should be effective in cleaning the screens. The CWIS used in this example is located on an estuary, so the tidal currents will enhance the effectiveness of the air backwash system, keeping backwashed debris from re-impinging on the screens.

6.4.2 Offshore CWIS Undergoing a 316(b) Upgrade, DWIS Capacity Added

This scenario focuses on an existing offshore CWIS that is required to undertake upgrades to meet 316(b) standards. As the CWIS is undergoing modification and expansion to lower the intake velocities to the 0.5 ft/sec TSV, an incremental increase in the expansion is made to accommodate additional capacity for a DWIS. The design and construction of the modified intake would therefore include an additional 100 MGD for desalination purposes. The modification of this intake will be completed with 9.5 mm dual-flow modified TWS and 2.0 mm CWWS because they are readily available, commonly used, and have been proven to be biologically effective.

The existing offshore CWIS that is being modified consists of a velocity cap located 300 ft offshore. The cap conveys flow through a conveyance pipe to an onshore screenhouse. The screenhouse has four intake bays, each with a trash rack, a conventional TWS (9.5 mm mesh and no fish protection features), and circulating water pump. Table 6.5 summarizes the pertinent design information associated with both the existing and proposed intake structures.

Table 6.5. Summary of Pertinent Design Parameters—Offshore CWIS Undergoing a 316(b) Upgrade, DWIS Capacity Added

Existing CWIS design flow (MGD)	216
Proposed DWIS design flow (MGD)	100
Proposed combined intake structure capacity (MGD)	316
Existing TSV (ft/sec)	1.5
Target modified TWS TSV (ft/sec)	0.5
Target CWWS TSV (ft/sec)	0.5

Notes: CWIS=cooling water intake structure; CWWS=cylindrical wedgewire screen; DWIS=desalination water intake structure; TSV=through-screen velocity; TWS=traveling water screen

6.4.2.1 Intake Modified with 9.5 mm Modified TWS

This scenario considers an offshore CWIS with an existing TSV greater than 0.5 ft/sec (Table 6.5). To meet the 0.5 ft/sec TSV criterion, a footprint expansion is required for the onshore screenhouse regardless of the desalination project. During the power plant's intake upgrade, additional capacity will be added to the CWIS to accommodate 100 MGD of desalination feed water.

A new onshore screenhouse structure will be installed upstream of the existing CWIS and have a combined total intake flow capacity of 316 MGD (sum of the 216 MGD for the CWIS and 100 MGD of the DWIS). No changes will be made to the offshore structures (velocity cap and conveyance pipe). Five 8 ft-wide dual-flow modified TWS with 9.5 mm mesh will be installed in the new screenhouse. Dual-flow modified TWS, rather than through-flow, would be used because dual-flow screens provide approximately double the screening area, leading to an intake footprint roughly half the size of a comparable intake constructed of through-flow screens. The new dual-flow modified TWS will be equipped with fish protection features (low pressure spray wash, collection system, return system) to assure maximum IM reduction. Five new trash racks would be installed, one in each intake bay. A conceptual plan of the modified intake is provided in Figure 6.8.

The new screens would be rotated and cleaned continuously, reducing impingement duration. A low pressure fish removal spray wash system and a high pressure debris removal spray wash system are required and included in the costs. Fish and debris removed from the screens will be transported and returned to the source water body away from the intake where the potential for re-impingement is minimized. A fish trough would collect fish removed by the low pressure (~10 psi) spray wash, and a separate debris trough would collect debris removed from the screens by the high pressure (~80 psi) spray wash. Prior to exiting the screenhouse, these two troughs would combine into a single return trough. The return pipe would be approximately 500 ft long and discharge to the ocean. The new return trough is shown in Figure 6.8.

Conceptual cost estimates were developed based on site-specific information for this modified TWS option. The cost for this intake modification is estimated to be $3,055,000. See Section 6.6 for details on what is included in the cost estimates. Summary costs for all 10 intake modification scenarios are presented in Table 6.8.

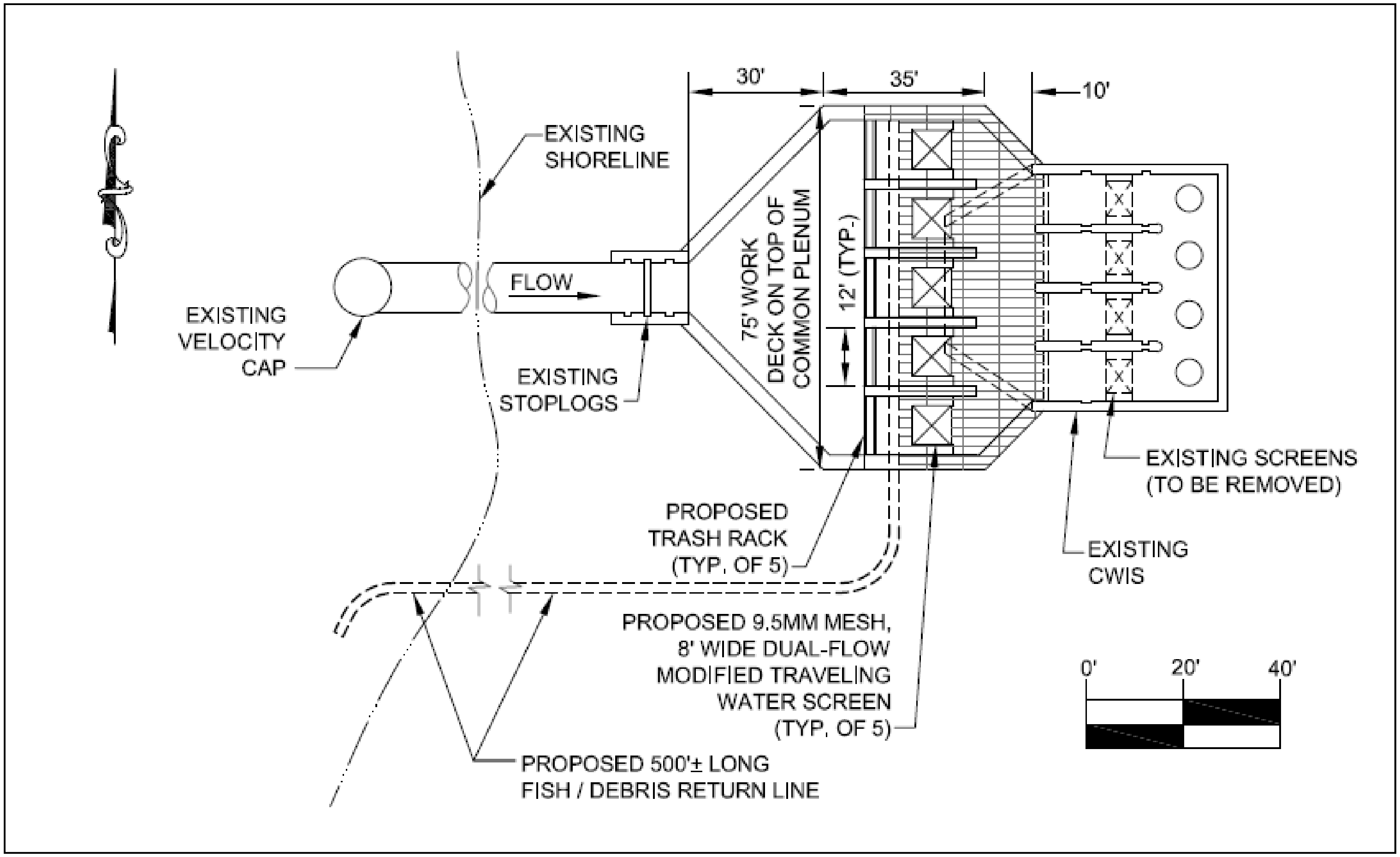


Figure 6.8. Offshore CWIS undergoing a 316(b) upgrade, DWIS capacity added, modified with 9.5 mm dual-flow TWS.

Conclusion

There are practical limitations that may overshadow the cost savings of this intake modification scenario. Principal among the limitations is that available space on land in a highly developed industrial area is scarce, so the extent to which an intake's footprint can be expanded is limited. There are very few power plants that would have this amount of space available on land.

The majority of the screens depicted in Figure 6.8 are present solely to reduce the TSV of the CWIS flow to the 0.5 ft/sec TSV from 1.5 ft/sec (i.e., even if there were no desalination capacity added, the intake would still require a significant expansion). Only one of the screens is required for the additional DWIS flow that would be added. Given the efficiency in adding extra screens to accommodate the DWIS flow, this scenario may be attractive to desalination developers; however, an existing power plant is very unlikely to consider this a viable option for meeting IM&E standards, compared to other alternatives, primarily because of the large onshore footprint.

It is also important to consider that an existing power plant may choose to comply with 316(b) through meeting the IM performance standards rather than by undertaking a major intake expansion to decrease TSV. If this is the case, the existing conventional TWS would likely be replaced with modified TWS and a fish return system without making any major structural modifications to the intake. The TSV would not have to be considered because the measure of compliance would be in the survival of impinged fish on the TWS. This compliance option would require an impingement monitoring program in which impinged organisms are collected and held over a period of time to determine survival. If this compliance route is selected by the power plant, the additional flow required by the desalination facility may not require the addition of more modified TWS.

6.4.2.2 Intake Modified with 2.0 mm CWWS

The following provides a description of how the same shoreline CWIS would be modified with 2.0 mm CWWS with a 0.5 ft/sec TSV.

The existing velocity cap will be removed and an array of CWWS installed in its place. Twenty-one T-48 (48 in. diameter) screens with 2.0 mm slot openings would be required to screen the total flow (316 MGD). The screen diameter was selected to provide sufficient clearance below the screen to prevent sediment entrainment and sufficient depth above the screen to prevent air entrainment and navigational concerns. Other factors that should be considered include the available space and type of cleaning mechanism required. The existing onshore intake components would continue to be used as a common plenum prior to pumping; however, the screens and trash racks would be removed. The CWWS would be mounted on three new header pipes connected to the existing primary conveyance pipe. A conceptual plan of the CWWS layout is provided in Figure 6.9.

Seven CWWS would be installed on each 50 ft long header pipe. Each screen would be about 4 ft in diameter and T-shaped, with an overall length of about 15 ft. The outlet pipe would be 4 ft in diameter and located in the middle of the T section. The bottom of the deployment location is assumed to be at the same level as the bottom of the existing intake structure. If the bottom is different than the assumed elevation, larger or smaller screens can be used for the appropriate water depth. Dolphin piles would be constructed approximately 20 ft in front of the new intake to prevent ships from impacting the structure.

CWWS operate best at locations where there are ambient currents to move debris past the screens. An automated, air backwash system has been included in the design for maintaining the screens in a clean condition; however, during periods of heavy debris loading, additional manual maintenance may be required. In addition, the screens would require an annual inspection by divers to identify any damage that could affect plant operations and verify effective cleaning by the air backwash system. The screens have been designed with Z-alloy (a copper alloy) to help limit the growth of macro-biofouling organisms (e.g., mussels and barnacles) in order to decrease O&M costs.

Some uncertainties associated with implementing the CWWS option include but are not limited to impacts to navigation, sedimentation, and debris management. Pilot studies are recommended to evaluate these uncertainties prior to detailed design and implementation.

Conceptual cost estimates were developed based on site-specific information for this CWWS option. The cost for this intake modification is estimated to be $3,419,000. See Section 6.6 for details on what is included in the cost estimates. Summary costs for all 10 intake modification scenarios are presented in Table 6.8.

Conclusion

This intake modification scenario represents a viable approach to meeting both IM and entrainment concerns. When designed to a TSV of 0.5 ft/sec, the CWWS would effectively eliminate IM. Furthermore, with a slot width of 2.0 mm, many earlier life stages of organisms should be excluded (depending on the species and life stages present). In addition, the offshore location of this intake will provide a benefit because organism densities are typically lower offshore than onshore.

The majority of the screens depicted in Figure 6.9 are present solely to reduce the TSV of the CWIS flow to the 0.5 ft/sec TSV from 1.5 ft/sec (i.e., even if there were no desalination capacity added, the intake would still require a significant number of CWWS). Only seven of the CWWS are required for the additional DWIS flow that would be added. Given the capital cost savings possible with a shared intake, this represents an attractive option for a desalination facility; however, as discussed previously, there are practical limitations that may overshadow the cost savings of this intake modification scenario.

The CWWS array would be within 300 feet from shore, so an air backwash system design should be a feasible method to clean the screens. The tidal currents and wave action should enhance the effectiveness of the cleaning system and keep backwashed debris from re-impinging on the screens. For sites with intakes located further offshore, an air backwash system may not be feasible because of the long air backwash plumbing required. Long air lines require larger airburst systems that may not be practical for every site. An offshore platform to house an air backwash system may be feasible depending on the costs of an onshore system. An offshore structure would significantly increase the cost of this option, if required.

6.5 Intake Modifications Scenarios—Lowest Potential

As a desalination developer interested in using an existing intake for a DWIS, the objective is to identify sites that require the fewest structural changes. Conversely, it is equally important to be able to identify existing intakes that may not be well suited for use as DWIS. This is the case with decommissioned CWIS that have flow capacities less than that required by the DWIS (scenarios shown in red in Figure 6.1). By identifying sites that would require substantial expansions to the footprint to accommodate the DWIS capacity while maintaining the 0.5 ft/sec TSV, prioritizing potential sites will become easier. Intakes that would require substantial structural modification may not provide the cost savings sought and also be more difficult to permit because of increased construction impacts (e.g., to benthic organisms, navigation).

Following are two intake modification scenarios that would be considered the worst-case scenarios for a desalination developer, not simply because of cost but practicability as well.

6.5.1 Shoreline Decommissioned CWIS, Footprint Expansion Required

This scenario considers a decommissioned shoreline CWIS that can be reused for desalination purposes. On the basis of the previous design capacity for the CWIS, the footprint will have to be expanded to meet the 0.5 ft/sec TSV criterion. The modification of this intake will be completed with 9.5 mm dual-flow modified TWS and 2.0 mm CWWS because they are readily available, commonly used, and have been proven to be biologically effective.

The existing shoreline CWIS that is being modified consists of one intake bay, one trash rack, one conventional TWS (9.5 mm mesh and no fish protection features), and one circulating water pump. The CWIS is located in an estuary and under tidal influence. Table 6.6 summarizes the pertinent design information associated with both the existing and proposed intake structures.

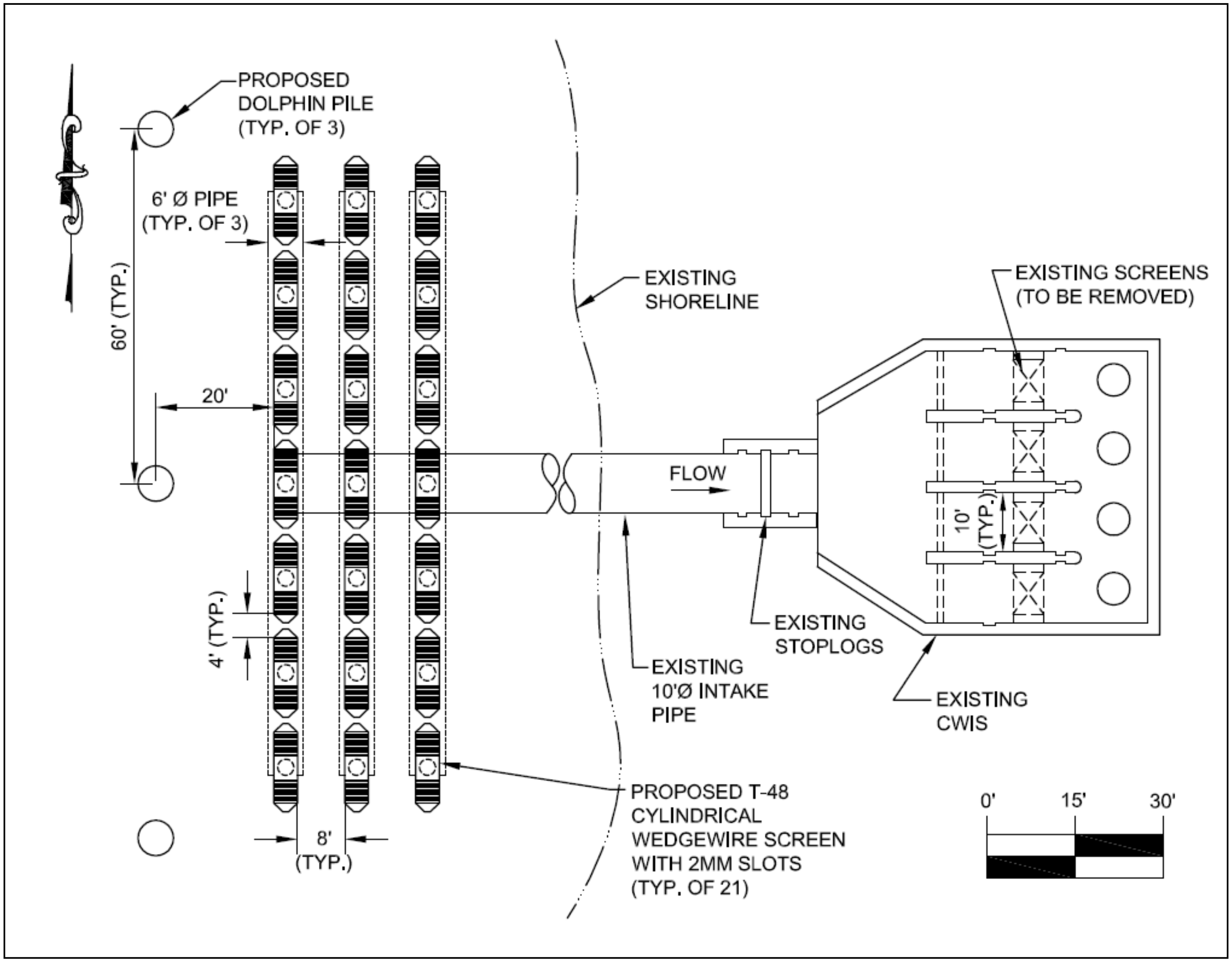


Figure 6.9. Offshore CWIS undergoing a 316(b) upgrade, DWIS capacity added, modified with 2.0 mm CWWS.

Table 6.6. Summary of Pertinent Design Parameters—Shoreline, Decommissioned, Footprint Expansion

Existing (previous) CWIS design flow (MGD)	288
Proposed DWIS design flow (MGD)	100
Proposed intake structure capacity (MGD)	100
Existing (previous) TSV (ft/sec)	1.6
Target modified TWS TSV (ft/sec)	0.5
Target CWWS TSV (ft/sec)	0.5

Notes: CWIS=cooling water intake structure; CWWS=cylindrical wedgewire screen; DWIS=desalination water intake structure; TSV=through-screen velocity; TWS=traveling water screen

6.5.1.1 Intake Modified with Modified 9.5 mm TWS

This scenario considers a decommissioned CWIS being upgraded with fish protection features so it can be reused for desalination purposes. The CWIS consists of one intake bay fitted with a conventional TWS. The one existing bay has insufficient capacity to accommodate the 100 MGD of desalination flow while maintaining 0.5 ft/sec TSV; therefore, expansion of the intake footprint will be required.

To meet the 0.5 ft/sec TSV criteria, a new screenhouse structure for a total desalination design flow of 100 MGD will be installed upstream of the existing intake structure. Two 8 ft-wide dual-flow modified TWS with 9.5 mm mesh would be required to screen the total intake flow. The new screenhouse structure will be approximately 35 ft wide to accommodate these screens and located approximately 45 ft upstream of the existing intake structure. Dual-flow modified TWS, rather than through-flow, would be used because dual-flow screens provide approximately double the screening area, leading to an intake footprint roughly half the size of a comparable intake constructed of through-flow screens. The new dual-flow modified TWS will be equipped with fish protection features (low pressure spray wash, collection system, return system) to assure maximum IM reduction. Two new trash racks would be installed, one in each intake bay. A conceptual plan of the modified intake is provided in Figure 6.10.

The new screens would be rotated and cleaned continuously, reducing impingement duration. A low pressure fish removal spray wash system and a high pressure debris removal spray wash system are required and included in the costs. Fish and debris removed from the screens will be transported and returned to the source water body away from the intake where the potential for re-impingement is minimized. A fish trough would collect fish removed by the low pressure (~10 psi) spray wash, and a separate debris trough would collect debris removed from the screens by the high pressure (~80 psi) spray wash. Prior to exiting the screenhouse, these two troughs would combine into a single return trough. To reduce the potential for re-impingement, two combined return pipes would be required because of tidal flow reversals. Each return pipe would discharge 120 ft from the ends of the intake structure based on the direction of the tide. The new return troughs are shown in Figure 6.10.

Conceptual cost estimates were developed based on site-specific information for this modified TWS option. The cost for this intake modification is estimated to be $5,225,000. See Section 6.6 for details on what is included in the cost estimates. Summary costs for all 10 intake modification scenarios are presented in Table 6.8.

Conclusion

This represents the worst-case scenario for a desalination developer: locating a decommissioned CWIS with insufficient capacity to accommodate the DWIS flow required. Rather, to reach the 0.5 ft/sec TSV criterion, a new intake has to be built upstream of the existing CWIS, substantially reducing the potential for cost-saving efficiencies. This scenario illustrates the importance of doing due diligence in investigating potential existing intake sites. Rather than use this site, a developer may decide to look at designing a new intake from scratch at a different site if none of the existing infrastructure can be reused.

Limited space is available to expand the intake on land, so this intake extends into the water body. As such, it is essentially a new intake structure and will have impacts associated with construction in the water. If space is available on land, it may be possible to expand the footprint on land by the number of bays required to decrease the TSV to 0.5 ft/sec. Careful consideration would have to be given to the hydraulic design of the channels approaching the existing pumps to assure uniform flow through all screens (see Section 6.2.2 for more details on hydraulic design). In a case such as this in which the modification is essentially a new intake structure, dual-flow TWS are preferred because their greater screening area (relative to comparably sized through-flow TWS) reduces the footprint of the intake.

Another question that arises is whether it may be possible to simply replace the existing conventional TWS with modified ones (with a fish return system) without expanding the intake. If the modification included the use of modified dual-flow screens, which can be expensive to retrofit at existing intakes because of required structural modifications, the screening surface area might be sufficient to meet the 0.5 ft/sec criterion. The cost and feasibility of using dual-flow screens within the existing intake channel would have to be investigated carefully to ensure proper flow hydraulics are maintained. In addition, compliance with proposed 316(b) IM standards would have to be achieved by monitoring survival of impinged fish on the TWS. This compliance option would require an impingement monitoring program in which impinged organisms are collected and held over a period of time to determine survival.

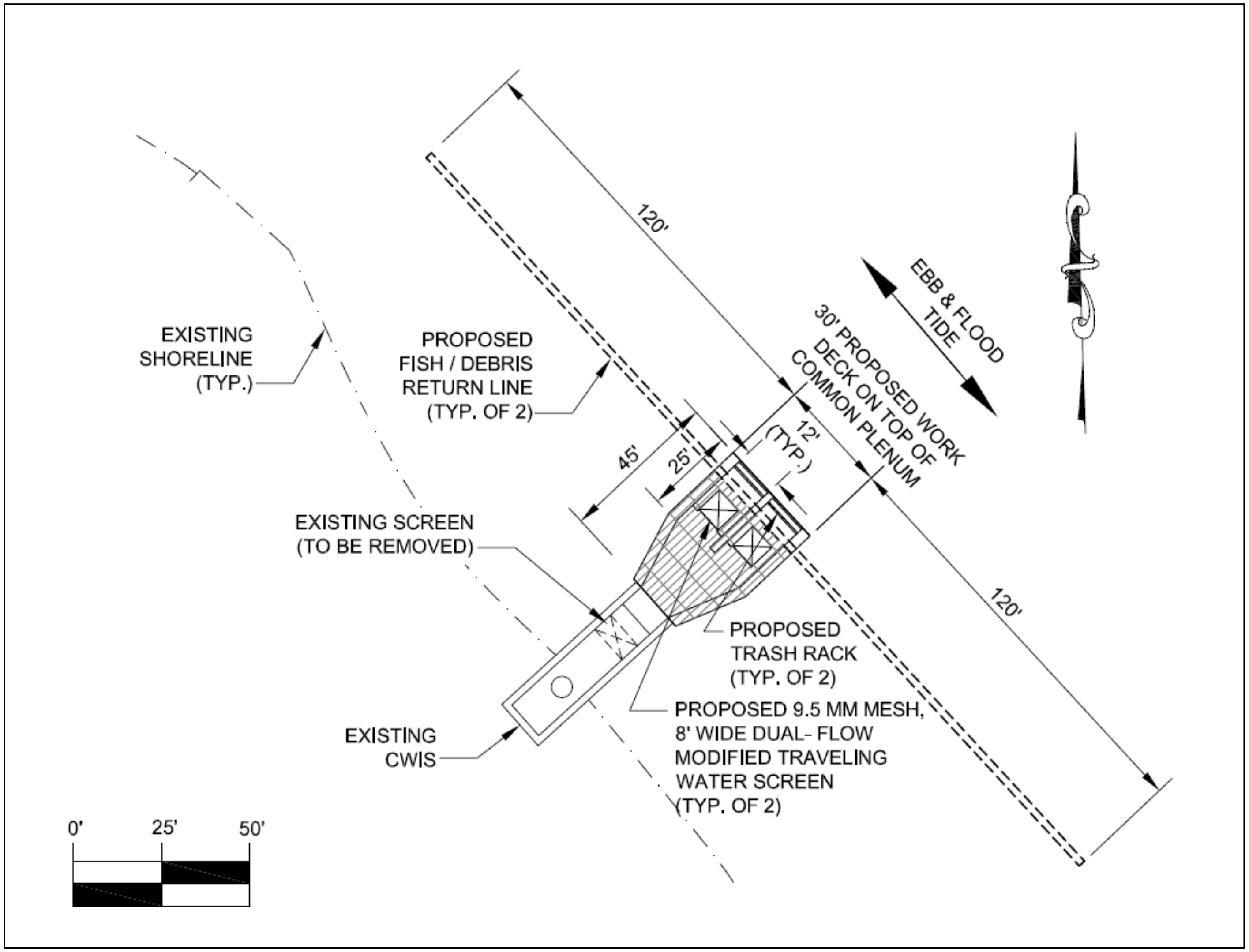


Figure 6.10. Shoreline decommissioned CWIS, footprint expansion required, modified with 9.5 mm through-flow TWS.

6.5.1.2 Intake Modified with 2.0 mm CWWS

Following is a description of how the same shoreline CWIS would be modified with 2.0 mm CWWS with a 0.5 ft/sec TSV. Three T-72 (72-in.-diameter) screens with 2.0 mm slot openings would be required to screen the total intake flow (100 MGD). The screen diameter selected was based on the minimum water depth assuming the same bottom invert of the existing intake structure. A new sheet pile bulkhead would be constructed upstream of the existing intake, forming a common intake plenum for the water to be conveyed from the CWWS to the pumps. The CWWS would be mounted on one new header pipe that would be connected to the plenum. A conceptual plan of the CWWS layout is provided in Figure 6.11.

Three screens would be installed on the header pipe and extend approximately 45 ft in front of the common plenum, which would be approximately 15 ft wide and 25 ft long. Each screen would be about 6 ft in diameter and T-shaped (Figure 6.7), with an overall length of about 20 ft. The outlet pipe would be 6 ft in diameter and located in the middle of the T section. The bottom of the deployment location is assumed to be at the same level as the bottom of the existing intake structure. If the bottom is different than the assumed elevation, larger or smaller screens would be used for the appropriate water depth. Dolphin piles would be constructed approximately 20 ft in front of the new intake to prevent ships from impacting the structure.

CWWS operate best at locations where there are ambient currents to move debris past the screens. An automated air backwash system has been included in the design for maintaining the screens in a clean condition; however, during periods of heavy debris loading, additional manual maintenance may be required. In addition, the screens would require an annual inspection by divers to identify any damage that could affect plant operations and verify effective cleaning by the air backwash system. The screens have been designed with Z-alloy (a copper alloy) to help limit the growth of macro-biofouling organisms (e.g., mussels and barnacles) in order to decrease O&M costs.

Some uncertainties associated with implementing the CWWS option include but are not limited to impacts to navigation, sedimentation, and debris management. Pilot studies are recommended to evaluate these uncertainties prior to detailed design and implementation.

Conceptual cost estimates were developed based on site-specific information for this CWWS option. The cost for this intake modification is estimated to be $4,115,000. See Section 6.6 for details on what is included in the cost estimates. Summary costs for all 10 intake modification scenarios are presented in Table 6.8.

Conclusion

This represents the worst-case scenario for a desalination developer: locating a decommissioned CWIS with insufficient capacity to accommodate the DWIS flow required. To reach the 0.5 ft/sec TSV criterion, a new intake has to be built upstream of the existing CWIS, substantially reducing the potential for cost-saving efficiencies. This scenario illustrates the importance of doing due diligence in investigating potential existing intake sites. Rather than use this site, a developer may decide to look at designing a new intake from scratch at a different site if none of the existing infrastructure can be reused.

Because this intake modification extends into the water body, it will likely have impacts associated with construction in the water. Impact associated with benthic disturbances, navigation, dredging, and coffer damming could complicate permitting.

Essentially, three CWWS would be required to screen the DWIS flow of 100 MGD. Because of the proximity of the CWWS to the shore, an air backwash system should be effective in cleaning the screens.

The CWIS used in this example is located on an estuary, so the tidal currents will enhance the effectiveness of the air backwash system, keeping backwashed debris from re-impinging on the screens.

6.5.2 Offshore Decommissioned CWIS, Footprint Expansion Required

This scenario considers a decommissioned offshore CWIS that can be reused for desalination purposes. Based on the previous design capacity for the CWIS, the footprint will have to be expanded to meet the 0.5 ft/sec TSV criterion. The modification of this intake will be completed with 9.5 mm dual-flow modified TWS and 2.0 mm CWWS because they are readily available, commonly used, and have been proven to be biologically effective.

The existing offshore CWIS that is being modified consists of a velocity cap located 300 ft offshore. The cap conveys flow through a conveyance pipe to an onshore screenhouse. The screenhouse has one intake bay, a trash rack, a conventional TWS (9.5 mm mesh and no fish protection features), and circulating water pump. Table 6.7 summarizes the pertinent design information associated with both the existing and proposed intake structures.

Table 6.7. Summary of Pertinent Design Parameters—Offshore, Decommissioned, Footprint Expansion

Existing (previous) CWIS design flow (MGD)	216
Proposed DWIS design flow (MGD)	100
Proposed intake structure capacity (MGD)	100
Existing (previous) TSV (ft/sec)	1.5
Target modified TWS TSV (ft/sec)	0.5
Target CWWS TSV (ft/sec)	0.5

Notes: CWIS=cooling water intake structure; CWWS=cylindrical wedgewire screen; DWIS=desalination water intake structure; TSV=through-screen velocity; TWS=traveling water screen

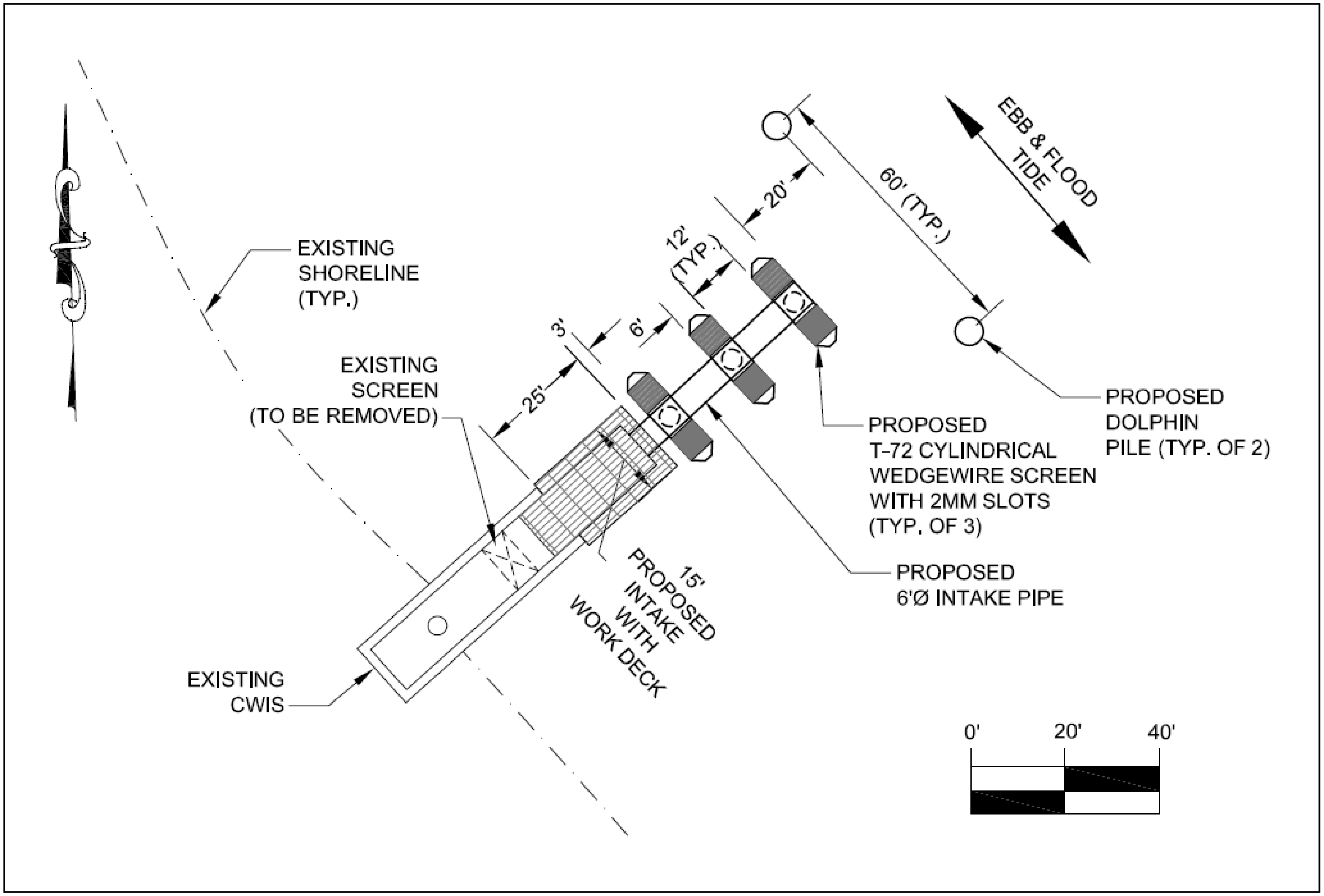


Figure 6.11. Shoreline decommissioned CWIS, footprint expansion required, modified with 2.0 mm CWWS.

6.5.2.1 Intake Modified with Modified 9.5 mm TWS

This scenario considers a decommissioned offshore CWIS with an existing TSV greater than 0.5 ft/sec (Table 6.7). To meet the 0.5 ft/sec TSV criterion, a footprint expansion is required.

The total hydraulic capacity of the modified intake will be 100 MGD, which is required for the desalination project. Two 8 ft-wide dual-flow modified TWS with 9.5 mm mesh will be installed in the two new bays. Dual-flow modified TWS, rather than through-flow, would be used because dual-flow screens provide approximately double the screening area, leading to an intake footprint roughly half the size of a comparable intake constructed of through-flow screens. The new dual-flow modified TWS will be equipped with fish protection features (low pressure spray wash, collection system, return system) to assure maximum IM reduction. The existing trash racks would remain in the four screen bays. A conceptual plan of the modified intake is provided in Figure 6.12.

The new screens would be rotated and cleaned continuously, reducing impingement duration. A low pressure fish removal spray wash system and a high pressure debris removal spray wash system are required and included in the costs. Fish and debris removed from the screens will be transported and returned to the source water body away from the intake where the potential for re-impingement is minimized. A fish trough would collect fish removed by the low pressure (~10 psi) spray wash, and a separate debris trough would collect debris removed from the screens by the high pressure (~80 psi) spray wash. Prior to exiting the screenhouse, these two troughs would combine into a single return trough. The return pipe would be approximately 500 ft long and discharge to the ocean. The new return trough is shown in Figure 6.12.

Conceptual cost estimates were developed based on site-specific information for this modified TWS option. The cost for this intake modification is estimated to be $5,293,000. See Section 6.6 for details on what is included in the cost estimates. Summary costs for all 10 intake modification scenarios are presented in Table 6.8.

Conclusion

This represents the worst-case scenario for a desalination developer: locating a decommissioned CWIS with insufficient capacity to accommodate the DWIS flow required. To reach the 0.5 ft/sec TSV criterion, a new onshore screenhouse has to be built, substantially reducing the potential for cost-saving efficiencies. This scenario illustrates the importance of doing due diligence in investigating potential existing intake sites. Rather than use this site, a developer may decide to look at designing a new intake from scratch at a different site if none of the existing infrastructure can be reused. The location of the existing offshore velocity cap could provide a locational benefit relative to IM&E by maintaining a withdrawal point offshore where there is less biological activity.

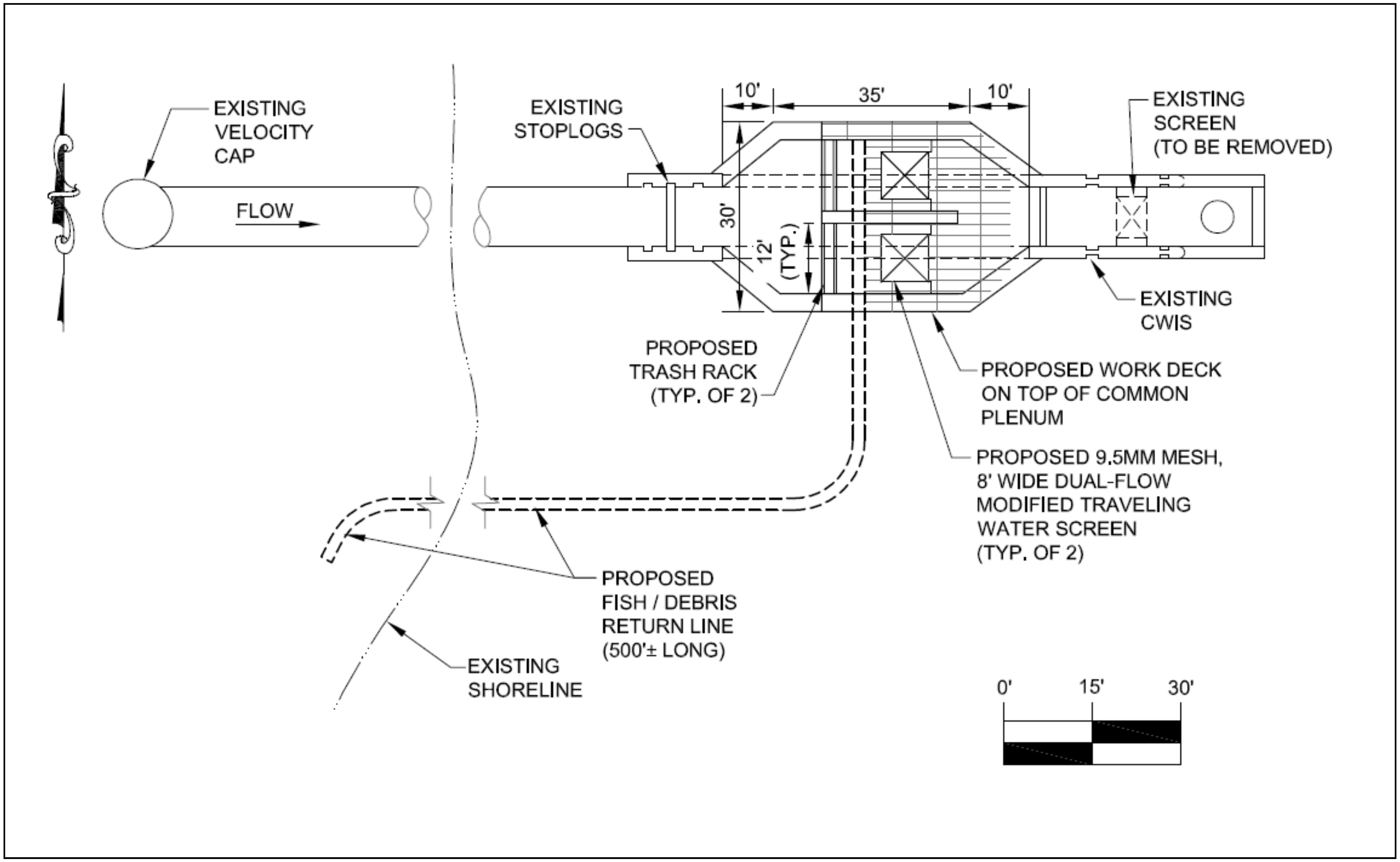


Figure 6.12. Offshore decommissioned CWIS, footprint expansion required, modified with 9.5 mm through-flow TWS.

6.5.2.2 *Intake Modified with 2.0 mm CWWS*

The following is a description of how the same offshore CWIS would be modified with 2.0 mm CWWS with a 0.5 ft/sec TSV.

The existing velocity cap will be removed, and an array of CWWS installed in its place. Seven T-48 (48-in.-diameter) screens with 2.0 mm slot openings would be required to screen the total flow (100 MGD). The screen diameter was selected to provide sufficient clearance below the screen to prevent sediment entrainment and sufficient depth above the screen to prevent air entrainment and navigational concerns. The existing onshore intake components would continue to be used; however, the screens and trash racks would be removed. The CWWS would be mounted on one new header pipe connected to the existing primary conveyance pipe. A conceptual plan of the CWWS layout is provided in Figure 6.13.

The seven CWWS would be installed on one header pipe. Each screen would be about 4 ft in diameter and T-shaped, with an overall length of about 15 ft. The outlet pipe would be 4 ft in diameter and located in the middle of the T section. The bottom of the deployment location is assumed to be at the same level as the bottom of the existing intake structure. If the bottom is different than the assumed elevation, larger or smaller screens can be used for the appropriate water depth. Dolphin piles would be constructed approximately 20 ft in front of the new intake to prevent ships from impacting the structure.

CWWS operate best at locations where there are ambient currents to move debris past the screens. An automated air backwash system has been included in the design for maintaining the screens in a clean condition; however, during periods of heavy debris loading, additional manual maintenance may be required. In addition, the screens would require an annual inspection by divers to identify any damage that could affect plant operations and verify effective cleaning by the air backwash system. The screens have been designed with Z-alloy (a copper alloy) to help limit the growth of macro-biofouling organisms (e.g., mussels and barnacles) in order to decrease O&M costs.

Some uncertainties associated with implementing the CWWS option include but are not limited to impacts to navigation, sedimentation, and debris management. Pilot studies are recommended to evaluate these uncertainties prior to detailed design and implementation.

Conceptual cost estimates were developed based on site-specific information for this CWWS option. The cost for this intake modification is estimated to be $6,636,000. See Section 6.6 for details on what is included in the cost estimates. Summary costs for all 10 intake modification scenarios are presented in Table 6.8.

<u>*Conclusion*</u>

This represents the worst-case scenario for a desalination developer: locating a decommissioned CWIS with insufficient capacity to accommodate the DWIS flow required. This scenario illustrates the importance of doing due diligence in investigating potential existing intake sites. Rather than use this site, a developer may decide to look at designing a new intake from scratch at a different site if none of the existing infrastructure can be reused.

The CWWS array would be within 300 ft from shore, so an air backwash system design should be a feasible method to clean the screens. The tidal currents and wave action should enhance the effectiveness of the cleaning system and keep backwashed debris from re-impinging on the screens. For sites with intakes located further offshore, an air backwash system may not be feasible because of the long air backwash plumbing required. Long air lines require larger airburst systems that may not be practical for every site. An offshore platform to house an air backwash system may be feasible depending on the costs of an onshore system. An offshore structure would significantly increase the cost of this option, if required.

6.6 Costs

Conceptual cost estimates were developed to understand the cost implications associated with using various existing CWIS as DWIS. For the planned 316(b) upgrade scenarios, some costs will be shared between the CWIS and the DWIS. It has been assumed that the distribution of financial responsibility between industries is based on the proportion of flow utilized. For all other scenarios, the project costs are the responsibility of the DWIS only.

Table 6.8. Summary of Costs for Conceptual Intake Modifications

Intake Modification Scenario	Intake Technology Used for Modification	
	Modified TWS	**CWWS**
Shoreline, decommissioned, no expansion	$4,041,000	--
Offshore, decommissioned, no expansion	$5,161,000	--
Shoreline, 316(b) upgrade	$2,096,000	$2,088,000
Offshore, 316(b) upgrade	$3,055,000	$3,419,000
Shoreline, decommissioned, expansion	$5,225,000	$4,115,000
Offshore, decommissioned, expansion	$5,293,000	$6,636,000

Notes: CWWS=cylindrical wedgewire screen; TWS=traveling water screen

A full set of detailed cost estimates was not completed for each project; rather, database information in conjunction with select quantity take-offs were used to estimate the costs associated with each option. It is important to understand that because multiple theoretical projects were used to develop the costs, direct comparisons between the scenarios are not necessarily valid. These costs are intended to provide an order of magnitude cost associated with some of the available retrofit options. When evaluating a potential site, it is important to complete a site-specific, detailed analysis prior to any decision making.

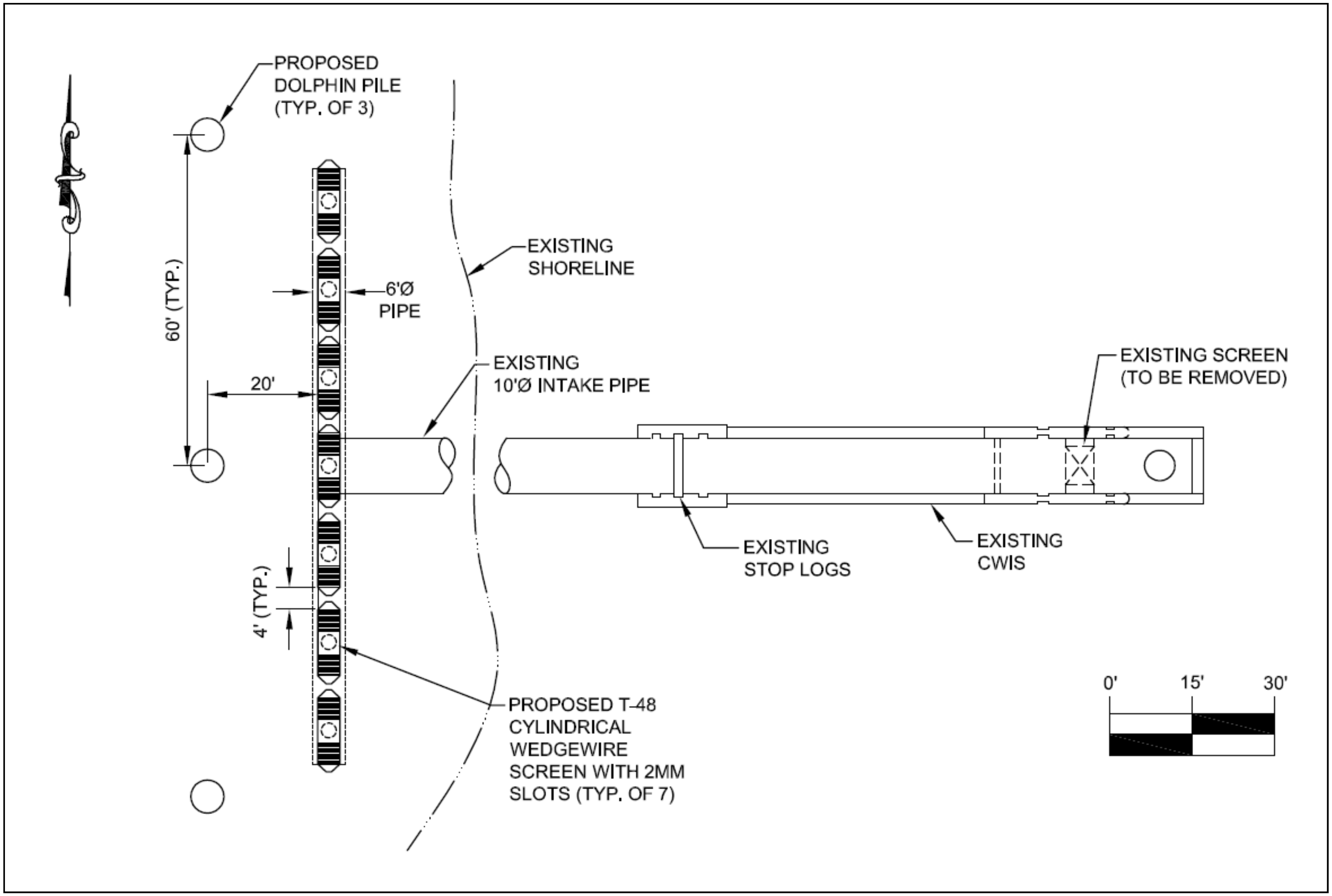


Figure 6.13. Offshore decommissioned CWIS, footprint expansion required, modified with 2.0 mm CWWS.

Generally, the estimated costs are based on the following:

- Present-day prices and fully contracted labor rates as of 2012
- 40 h work week with single-shift operation for construction activities
- Direct costs for material and labor required for construction of all project features. The direct costs also include distributable costs for site nonmanual supervision, temporary facilities, equipment rental, and support services incurred during construction. These costs have been taken as 85% of the labor portion of the direct 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 costs for each alternative.
- Contingency factor to account for possible additional costs that might develop but cannot 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.

The project costs do not include the following items that should be included to obtain total capital cost estimates:

- performing additional laboratory or field studies that may be required, such as hydraulic model studies, biological evaluations of prototype fish protection systems, soil sampling, and wetlands delineation and mitigation
- disposal of any hazardous or nonhazardous materials that may be encountered during excavation and dredging activities
- administration of project contracts and engineering and construction management
- price escalation
- permitting
- hydraulic models
- O&M
- pumps

Chapter 7

Identification of IM&E Reduction Metric Criteria

Typically, IM&E reduction success is measured by comparing pre- and post-modification monitoring data. Biological sampling is conducted prior to intake modification to provide baseline data on the magnitude of IM&E with the existing intake. This sampling may already be conducted as a regulatory requirement, depending on the intake under consideration; however, other metrics may be used to directly (or indirectly) measure the success of an intake modification in reducing IM&E.

There are several potential options for measuring the effectiveness of IM&E reduction technologies. These methods are used extensively throughout the power generation industry and other water-use industries for determining the biological effectiveness and subsequent impact of intake technologies. These methods include, but are not limited to:

- measurement of organisms entrained and impinged before and after intake modification
- conversion of raw numbers of entrained and impinged to adult equivalents (demographic models: adult equivalents lost (AEL) and fecundity hindcasting [FH])
- other modeling techniques (ETM)

7.1 IM&E Abundance

In most cases, the most direct metric by which to measure the effectiveness of an intake modification is through comparing IM&E before and after the modification has been made. That is, the estimated numbers of organisms either (1) excluded (prevented from entraining) or (2) collected and transferred (impinged and returned to source water body). This can be calculated by measuring IM&E before and after installation of a technology or by estimating (modeling) the performance of a technology using available efficacy data.

With essentially all available intake modification technologies, IM&E can be measured before and after installation of the technology to demonstrate the reduction (Table 7.1). The most likely intake technologies to be used in an intake modification scenario are modified TWS and CWWS. Although entrainment can be measured before and after a modification to either technology, the ability and utility of measuring IM can be debated. The EPA has defined a protective intake as one that reduces TSV to 0.5 ft/sec, so it could be argued that IM does not need to be measured after such a modification. Further, in the case of CWWS, the collection of long-term quantitative impingement data with a wedgewire screen in the field is not practical, nor is it necessary because TSV would be so low; however, if required by the regulator, qualitative estimates of impingement on CWWS can be collected using video cameras. IM on modified TWS can be determined through the collection and extended holding of impinged organisms.

Table 7.1. Example of How the Effectiveness of an Intake Modification Can Be Measured by Comparing IM or Entrainment Before and After Modification

	Fish Impingement Mortality or Entrainment
Before Modification	
After Modification	
Effectiveness	60% Reduction

Raw numbers entrained or impinged (abundance) or the weight of those organisms entrained or impinged (biomass) before and after intake modifications could also be scaled to an entrainment or impingement rate, such as the number of larvae entrained per million gallons of water withdrawn or the number of shellfish impinged per day. Scaling to water flow or the number of days can be used to account for differences in operations before and after intake modifications.

During the CWA Section 316(b) Phase II rulemaking process, the EPA performed an economic and benefits analysis to assess the economic impacts and benefits from implementation of the proposed rule (EPA, 2002a). As part of this analysis, EPA extrapolated baseline loss estimates from case study models that applied to all 539 facilities that would be affected by the rule (EPA, 2002b). The extrapolation was done based on flow but also took into consideration water body type (i.e., freshwater, ocean). The advantages and disadvantages of using water flow as a scale of operation are discussed in Section C3-1.6 of EPA (2002a).

7.2 Demographic Models

Demographic models are often used to estimate the impacts of IM&E on the populations of fish as a whole. These models rely on the use of detailed life history data to make projections about how entrainment abundances equate to either adult fish or the fecundity of a spawning female. Demographic models require knowledge of natural mortality rates for each life stage, fecundity, age at maturity, and life span (Steinbeck, 2007). Demographic models and how they can be used to measure a reduction in IM&E are discussed in more detail in the following section.

7.2.1 Adult Equivalents Lost

In some cases, it may be possible to convert the number of fish or shellfish entrained and impinged to the number of adult equivalents (Table 7.2). This would allow a combined analysis of IM&E estimates. One advantage of this approach is that it would simplify comparison of before and after IM&E of multiple age ranges. Results from this analysis could also potentially be converted to biomass (weight). Beyond the assessment of intake modification effectiveness, the estimated AEL could also be compared with recreational and commercial fishery landings. Another benefit of this demographic model is that it provides the ability to put annual larval losses, which can range into the billions for large intakes, into a context that people can more easily envision (numbers of age-1 or adult fishes).

The conversion to adult equivalents takes into account the natural mortality rates experienced by fish and shellfish; therefore, age-specific survival rates are required for this conversion. This approach also requires the assumptions that the affected population is stable and stationary and that age-specific survival rates are constant over time. An example of the AEL approach can be reviewed in MBC et al. (2007b; see results for northern anchovy).

7.2.2 Fecundity Hindcasting

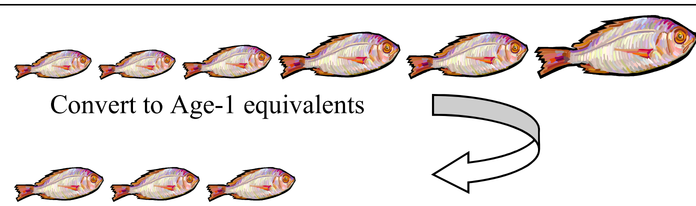
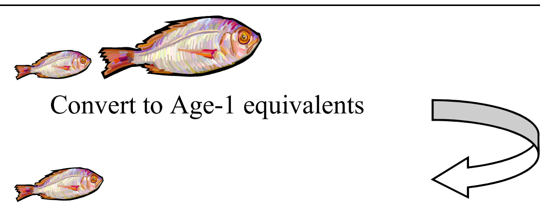
Similar to the conversion to adult equivalents, FH estimates the number of adult females at the age of maturity whose reproductive output has been eliminated by entrainment. This approach requires egg and larval survivorship up to the age of entrainment as well as estimates of fecundity. This approach also requires the assumptions that the affected population is stable and stationary and that fecundity estimates are constant over time. An example of the FH approach can be reviewed in MBC et al. (2007b; see results for northern anchovy).

7.3 Empirical Transport Model

The ETM was proposed by the USFWS to estimate mortality rates caused by power plant cooling water withdrawals. In short, the ETM converts larval losses into the incremental fractional mortality (percent loss by entrainment) on a local source water population. Variations of the original ETM have been used to assess cooling water impacts from coastal power plants in California and the East Coast. A similar approach (determination of the conditional mortality rate) was recently used for the Haverstraw Water Supply Project in New York (HDR, 2008, 2012).

Unlike the conversion to adult equivalents or FH, the ETM requires an additional level of field data to characterize the abundance and composition of source water larval populations. Examples of the ETM approach can be reviewed in MBC et al. (2007b; see results for northern anchovy).

Table 7.2. Example of How the Effectiveness of an Intake Modification Can Be Measured by Comparing Adult Equivalents Lost Before and After Modification

	Fish Impingement Abundance
Before Modification	
After Modification	
Effectiveness	66.6% Reduction

7.4 Before–After/Control–Impact

The Before–After/Control–Impact Paired (BACIP or BACI) approach is, in its simplest form, based on sampling at control and impact sites before and after the onset of a disturbance. For a retrofit of a desalination intake structure, a BACI study design would sample before and after the retrofit, and the sampling would encompass both control and impact sites. In the BACI design, the information of interest is the difference between control and impact samples. The BACI approach was used to determine the effects from SONGS in San Diego County, CA, on the marine environment in the 1970s and 1980s (Murdoch et al., 1989).

One practical problem with simple BACI approaches is the large temporal variance of many populations, which can be overcome by having several simultaneous sampling dates before and after the perturbation in both the control and impact site (paired sampling, or BACIPS). The difference Δ in a parameter value between control and impact sites is assessed on each sampling date. The difference between the average before and after changes (Δ_B-Δ_A) provides an estimate of the magnitude of the environmental impact. Another problem is that the use of only a single control and impact site would be based on the unrealistic assumption that the two sites are identical over time in the absence of the activity. It is therefore necessary to provide for spatial replication. Although it is difficult to have replicated impact sites (i.e., several desalination plants in randomly chosen locations on a coastline), it is important to have multiple control sites. These should adequately represent the biological features of the impact site (Osenberg et al., 1996; Underwood, 1996). For example, adequate temporal and spatial replication following the BACIPS approach was provided in the monitoring programs for the Gold Coast and Sydney desalination plants in Australia (Trousdale and Henderson, 2009; Cannesson et al., 2009; Port et al., 2009).

7.5 Other Considerations

Perhaps more important than the actual method for measuring IM&E reductions is the selection of species to be used in the assessment. For instance, should the assessment consider all species entrained and impinged, or should it focus on a subset of species? The answer to this question could be driven by the availability of sufficient life history information to allow the desired demographic modeling (such as FH or AEL). Application of these methods has been limited in California by the lack of basic life history parameters for many species.

Recent power plant intake assessments have used multiple methods to analyze potential impacts (i.e., FH, AEL, ETM). When possible, use of multiple demographic models (and other assessment methods) allowed entrainment results to be viewed in a greater context. For instance, the ETM results for a particular species could be high (e.g., 35%), indicating a relatively high withdrawal rate from the power plant, whereas AEL results could indicate that the larvae entrained actually only represented a few thousand adults.

State and federal agencies may have guidelines or requirements for screening technologies. NMFS Southwest Region published fish screening criteria for functional designs of downstream migrant fish passage facilities at hydroelectric, irrigation, and other water withdrawal projects (NMFS, 1997). These guidelines were adapted from the NMFS Northwest Region and include specific criteria based on the habitat in the vicinity of the screen structure (i.e., stream, river, canal, lake) and the life stage of the affected species (i.e., fry, fingerling, or longer). Screen placement consideration, approach velocity, sweeping velocity, screen material, structural features, and fish bypass features are all addressed in the document. The Oregon Department of Fish and Wildlife (ODFW) also has fish screening and passage requirements that are largely based on the NMFS Northwest Region guidelines (ODFW, 2006).

In addition to the benefit (reduction) of a particular technology, the cost of constructing and operating a particular technology should also be considered.

7.6 Survey of Regulators' Preferred Approach for Demonstrating IM&E Reductions

An informal survey was administered to regulators in states with the greatest interest in desalination. Recipients of the survey were asked the following:

> Consider an existing seawater intake that would be used for a desalination facility, but would require modification to reduce IM&E. As a regulator, can you please weigh in on which method for measuring a reduction in IM&E would be most useful to you? The list below includes the methods of measuring effectiveness that our project Team has developed. Flow volume reduction and intake velocity metrics were eliminated from further consideration.
>
> - measurement of organisms entrained and impinged before and after intake modification
> - conversion of raw numbers entrained and impinged to adult equivalents (equivalent adult model (EAM)or AEL approach)
> - other modeling techniques (such as FH or ETM) or other study designs (such as BACI).
>
> If you feel another approach would be more useful, feel free to let me know.

Responses were received from only two regulators. One indicated that directly measuring IM&E before and after an intake modification would be the most useful but also indicated that the use of ETM would be helpful as it is often a component of mitigation planning. The other respondent also indicated that direct measurement of IM&E before and after would be best. This respondent also indicated that state policy for regulating IM&E at CWIS has been and would likely be applied at desalination intakes as well.

Chapter 8

Case Studies

8.1 Tampa Electric Company's Big Bend Station

The Tampa Electric Company (TECO) Big Bend Station is located along the eastern shore of Tampa Bay in North Ruskin, FL. The facility currently consists of four coal-fired units producing a combined 1825 megawatts at full generating capacity. Big Bend utilizes an OTC water system with a design cooling water flow of approximately 541.5 cfs (350 MGD) per unit and a station total flow of 2166 cfs (1.4 BGD). The station has two CWIS located at the end of an intake canal, one for Units 1 and 2 and one for Units 3 and 4. A general site plan is provided in Figure 8.1.

8.1.1 Background

TECO was considering the addition of a fourth unit at Big Bend in the late 1970s to early 1980s when it was required to minimize adverse impacts to the aquatic community. Region IV of the EPA and the Florida Department of Environmental Regulation (FDER) expressed concern over the potential losses of organisms from the operation of the station with the additional unit. TECO agreed to evaluate the potential effectiveness of fine-mesh TWS to reduce losses of the selected RIS: bay anchovy, black drum (*Pogonias cromis*), silver perch (*Bairdiella chrysoura*), spotted sea trout (*Cynoscion nebulosus*), scaled sardine (*Harengula jaguana*), tidewater silverside (*Menidia peninsulae*), stone crab (*Menippe mercenaria*), pink shrimp, American oyster (*Crassostrea virginica*), and blue crab. In 1980, an extensive biological evaluation of a full-scale, prototype screen was conducted. The test facility was located in the intake canal immediately upstream of the existing intake screens for Units 1 through 3.

A pilot-scale demonstration of a full-scale prototype fine-mesh (0.5 mm) TWS was conducted in 1980, and the results demonstrated that survival off the screens was high (Taft et al., 1981). Based on these results, TECO committed to installing dual-flow fine-mesh (0.5 mm) TWS at Units 3 and 4. After installation of the fine-mesh screens, their biological efficacy (entrainment reduction and impingement survival) was evaluated (Brueggemeyer et al., 1987). The results of the pilot-scale demonstration and the full-scale installation are discussed in greater detail in the following section.

8.1.2 Intake Description

The following section describes the intake as it currently exists at Big Bend.

The CWIS for Units 1 and 2 is equipped with four dual-flow TWS (Figure 8.2). Each of the screens is 8 ft wide with 9.5 mm mesh. To prevent large debris from impacting the screens, a partial-depth chain-link fence is attached to the face of the CWIS. The coarse-mesh screens are known as "no-well" screens because the pump suction is connected directly to the screen housing (Figure 8.3). Circulating water is withdrawn through four circulating water pumps, two per unit. Each pump is rated for 278.5 cfs (125,000 gpm).

The CWIS for Units 3 and 4 has two sets of screens. Six dual-flow fine-mesh (0.5 mm) TWS are located upstream of four coarse-mesh (9.5 mm) dual-flow screens (Figures 8.2, 8.4, and 8.5). The coarse-mesh TWS were left in place as emergency screening in the event that the fine-mesh TWS get clogged and have to be bypassed. A photograph of the 0.5 mm mesh is shown in Figure 8.6. The mesh material is stainless steel. The fine-mesh screens are equipped with v drives allowing them to be rotated at varying speeds (7–28 ft/min) to minimize differential pressure across the screens. As with the CWIS for Units 1 and 2, a partial-depth chain-link debris barrier is located at the face of the CWIS. Three hydraulic gates are installed between the fine-mesh screens to allow them to be bypassed when not in use or when the head loss across the screens reaches 1.5 ft.

The fine-mesh screens in the Units 3 and 4 CWIS are operated from March 15 through October 15. The screens are rotated continuously during this period. Even with the screens rotating continuously, the bypass gates need to be opened two to three times a season to ensure adequate flow to the units. When the screens are not in use, the bypass gates are opened, and the fine-mesh screens are bypassed and not rotated. The coarse-mesh screens in both CWIS are rotated once per shift. The replacement schedule for both sets of screens is about 25 years. Annual maintenance on the fine-mesh screens amounts to $400,000 to $500,000 per year.

Low pressure and high pressure screen wash pumps take suction from the circulating water pump discharge and provide wash water to the spray nozzle supply headers. Aquatic organisms and debris are collected in a common trough and routed to a screened sump. The sump incorporates a trash basket to facilitate removal of debris. Three Hidrostal pumps take suction from the sump and discharge into one of two 18 in. fiberglass organism return lines. The organism return system is approximately 0.75 mile long and discharges into a natural embayment south of the station discharge canal (Figure 8.1).

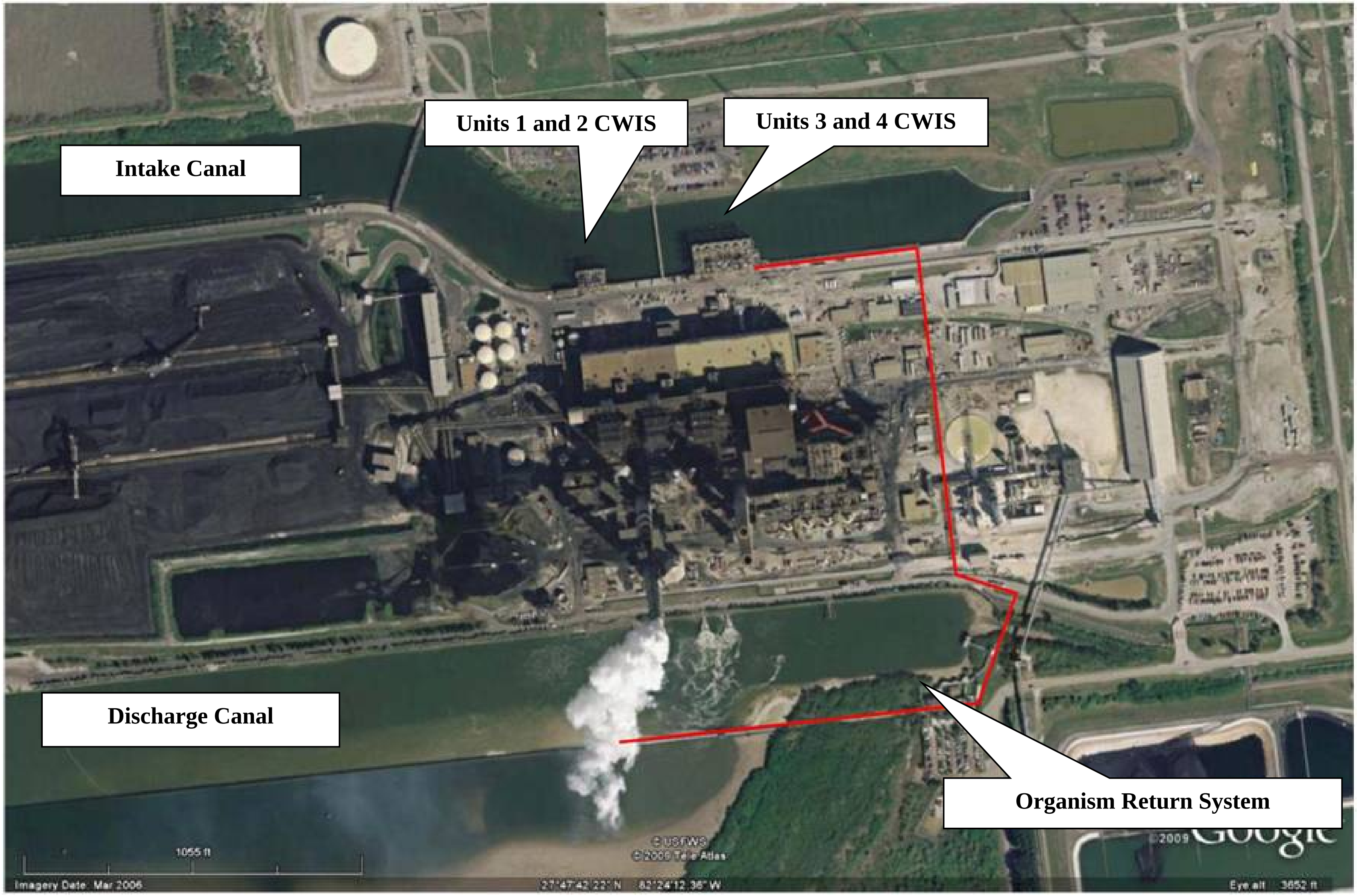


Figure 8.1. General site plan of Big Bend Station.

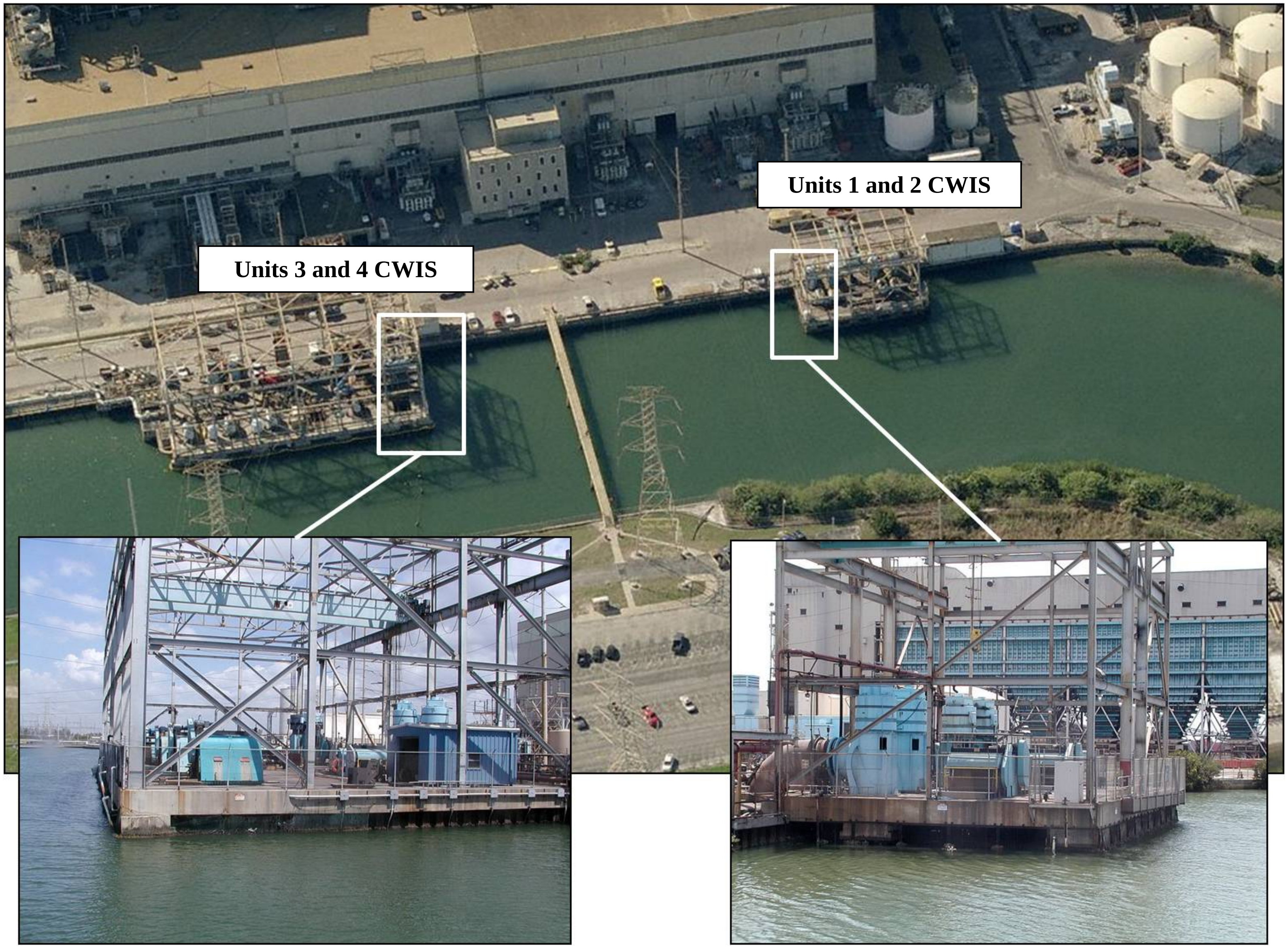
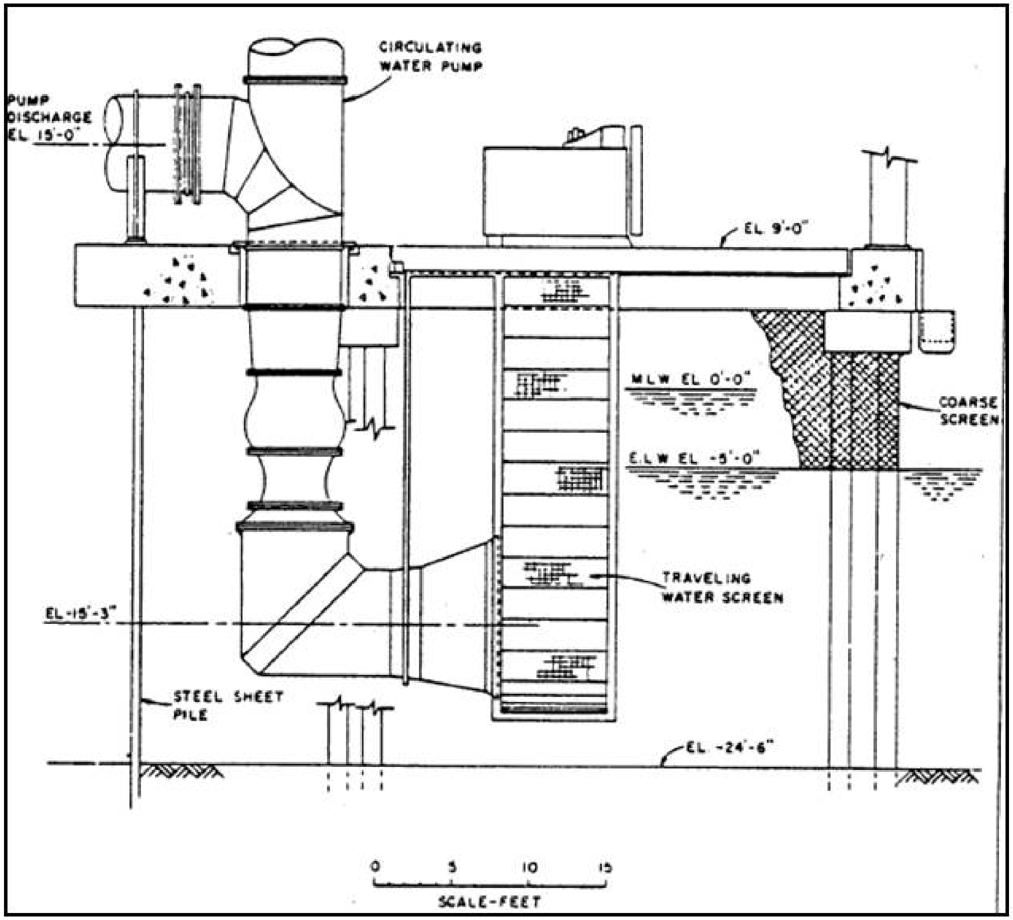


Figure 8.2. Aerial photograph of the two Big Bend CWIS.



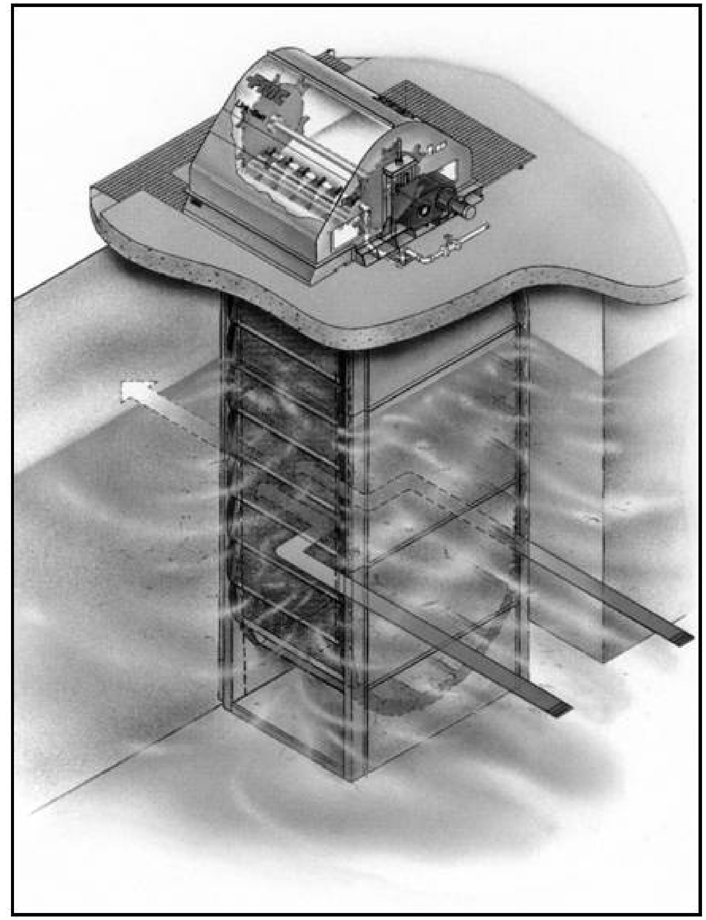


Figure 8.3. No-well dual-flow TWS (L) and typical dual flow TWS (R).

Sources: L: Stone & Webster, 1980; R: courtesy of U.S. Filter

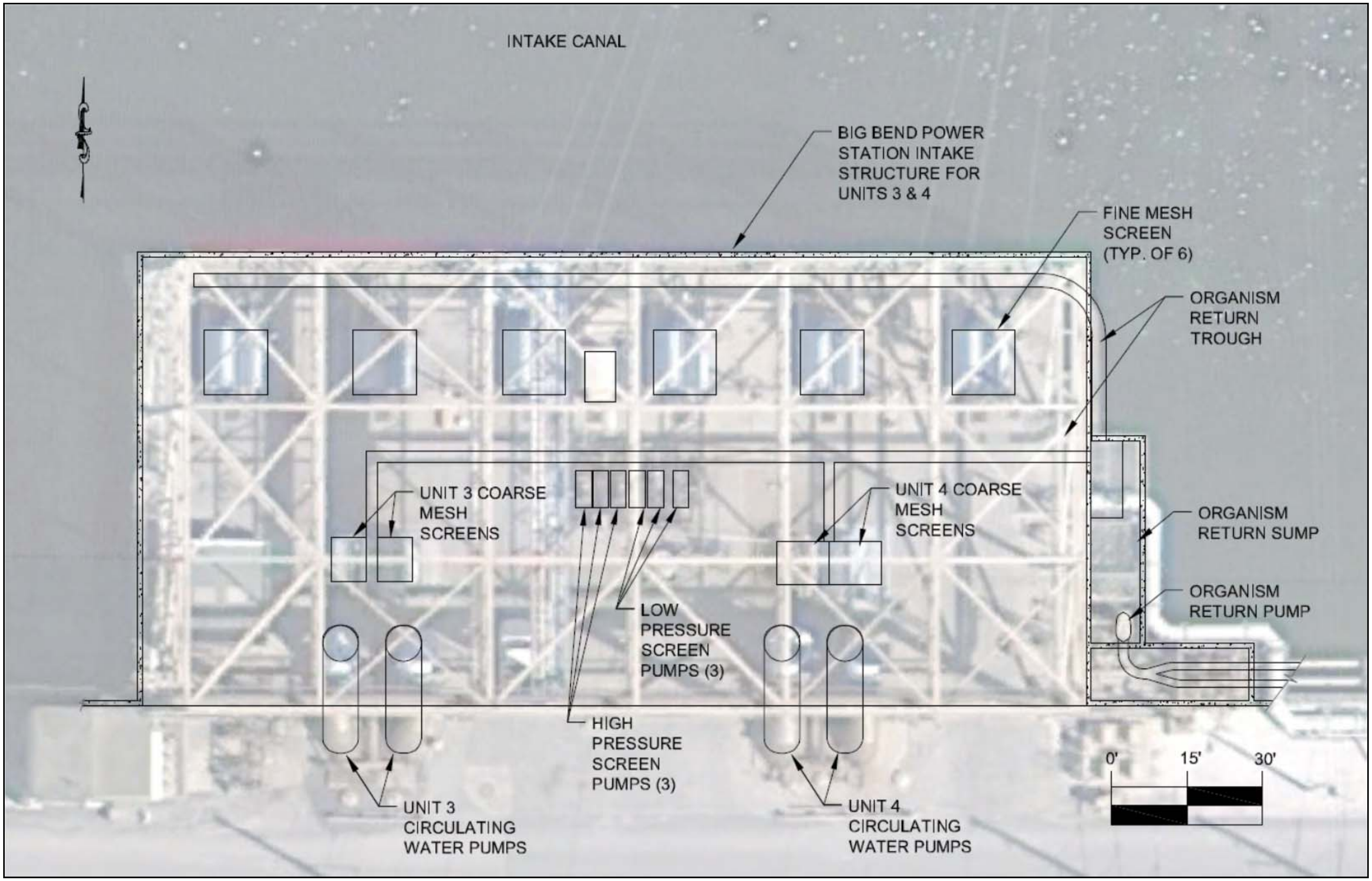


Figure 8.4. CWIS for Units 3 and 4 (plan view).

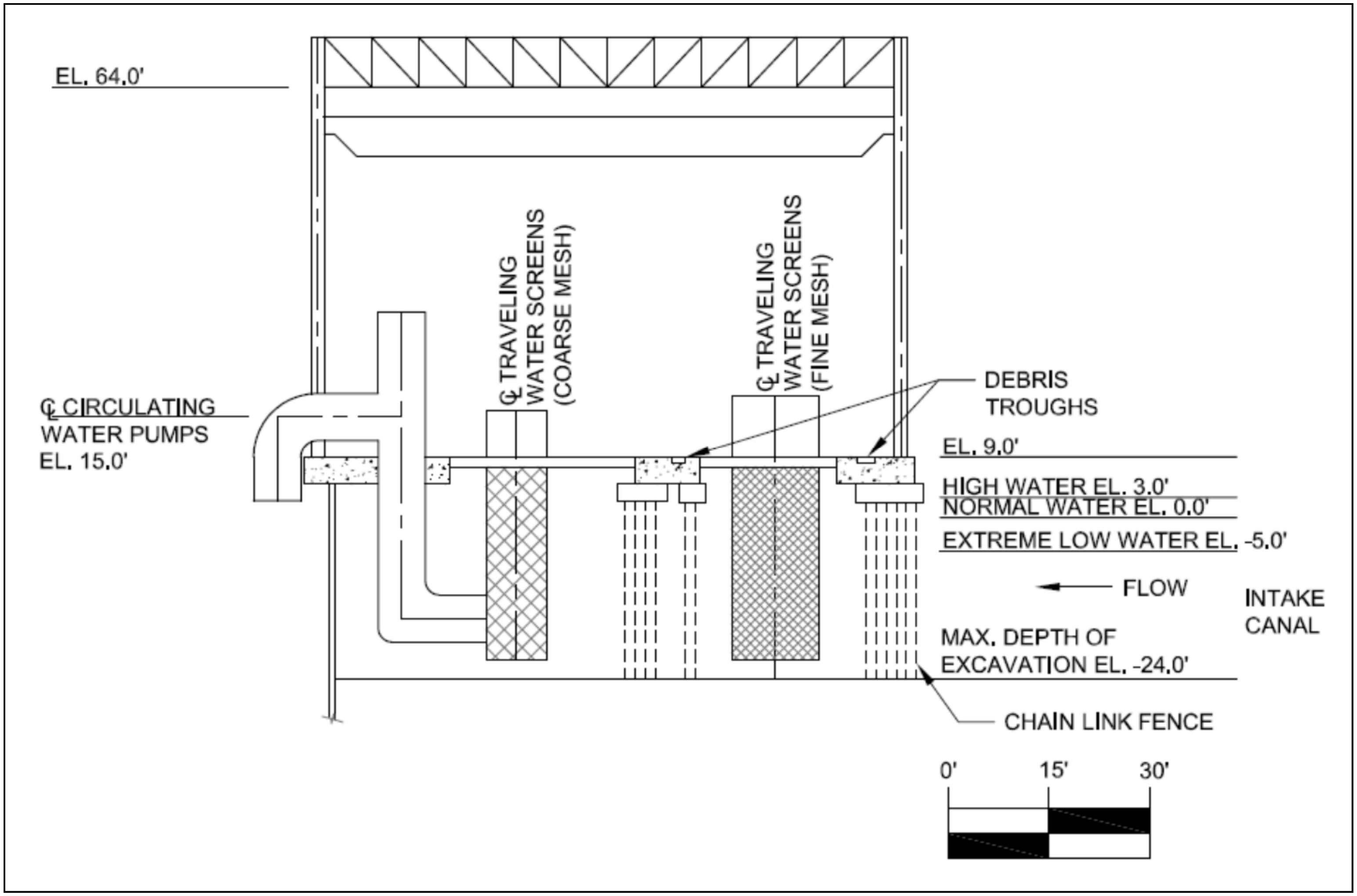


Figure 8.5. CWIS for Units 3 and 4 (section view).

Figure 8.6. Fine-mesh screen panel at Big Bend.

8.1.3 Biological Efficacy

8.1.3.1 Pilot-Scale Demonstration

In 1979, TECO conducted a preliminary desktop analysis of the intake technologies that were available for minimizing intake impacts at its future Unit 4 as an alternative to closed-cycle cooling (Stone & Webster, 1980). The evaluation concluded that fine-mesh traveling screens were the BTA. Therefore, in 1980, TECO conducted a pilot-scale evaluation of a fine-mesh dual flow traveling screen in its intake canal. This pilot-scale prototype demonstration was designed principally to determine the survival of organisms impinged on the fine mesh (Taft et al., 1981). Survival of impinged organisms was compared to that of control organisms collected from the intake canal. Additional field studies were conducted to evaluate the efficiency of the spray wash system in removing impinged organisms and the efficiency of the prototype screen in preventing entrainment (through any system component—screen mesh or sealed areas).

At the time, the station consisted of three generating units with a combined once-through flow rate of 1611 cfs (1.0 BGD). The prototype screen was full-depth and comprised 48 screen baskets that were 0.6 m (2 ft) wide by 0.6 m (2 ft) high with 0.5 mm (0.02 in.) screen mesh. The screen could be rotated at speeds from 2.1 m/min (6.9 ft/m) to 8.5 m/min (27.9 ft/m). A variable speed pump permitted testing at screen approach velocities ranging from 0.15 to 0.31 m/s (0.5–1.0 ft/sec). Organisms were washed from the ascending face of the screens and lifting buckets into a collection trough with a low pressure (10 psi) spray wash. Once in the trough, the organisms flowed by gravity into a primary collection tank from which they were drained into a secondary chamber, which also served as the container in which the organisms were transported to the onsite wet laboratory for sorting and holding. A layout of the prototype test facility is shown in Figure 8.7.

The organism survival study consisted of a series of tests conducted at six combinations of approach velocities (0.15 and 0.31 m/s [0.5 and 1.0 ft/sec]) and screen rotational speeds (2.1, 4.3, and 8.5 m/min [6.9, 14.1, and 27.9 ft/min]). Control organisms were collected from the intake canal using a stationary 505 µm plankton net. All organisms were held for 96 hours following collection to determine latent effects.

Results of testing are presented in Tables 8.1 through 8.4. In general, the highest survival was seen in invertebrates and the lowest in fragile larvae such as bay anchovy (Table 8.2). Latent survival (48 and 96 h) was species- and life stage–specific (Table 8.2). Hatchability and 48-hr survival of eggs were high in nearly every case, but 96-hr survival was lower (Table 8.1). Some species of eggs (*Alosa* spp., scaled sardine, and bay anchovy) experienced low (<50%) initial survival as well (Table 8.1). It was noted by Taft et al. (1981) that the survival of control larvae (i.e., larvae collected directly from the intake canal without interacting with the screen) was low for all but one species (Table 8.2), and that this natural control survival should be considered a component of the measured impingement survival of the test larvae.

In general, the results of this prototype field study indicated that fish eggs survived the impingement and collection process well; fish larvae (both test and control organisms) showed low survival, indicating that natural mortality of larvae is high; invertebrates showed high survival (both test and control organisms); and the independent variables under investigation (approach velocity, screen rotation speed, and water temperature) explained only small proportions of the differences in survival.

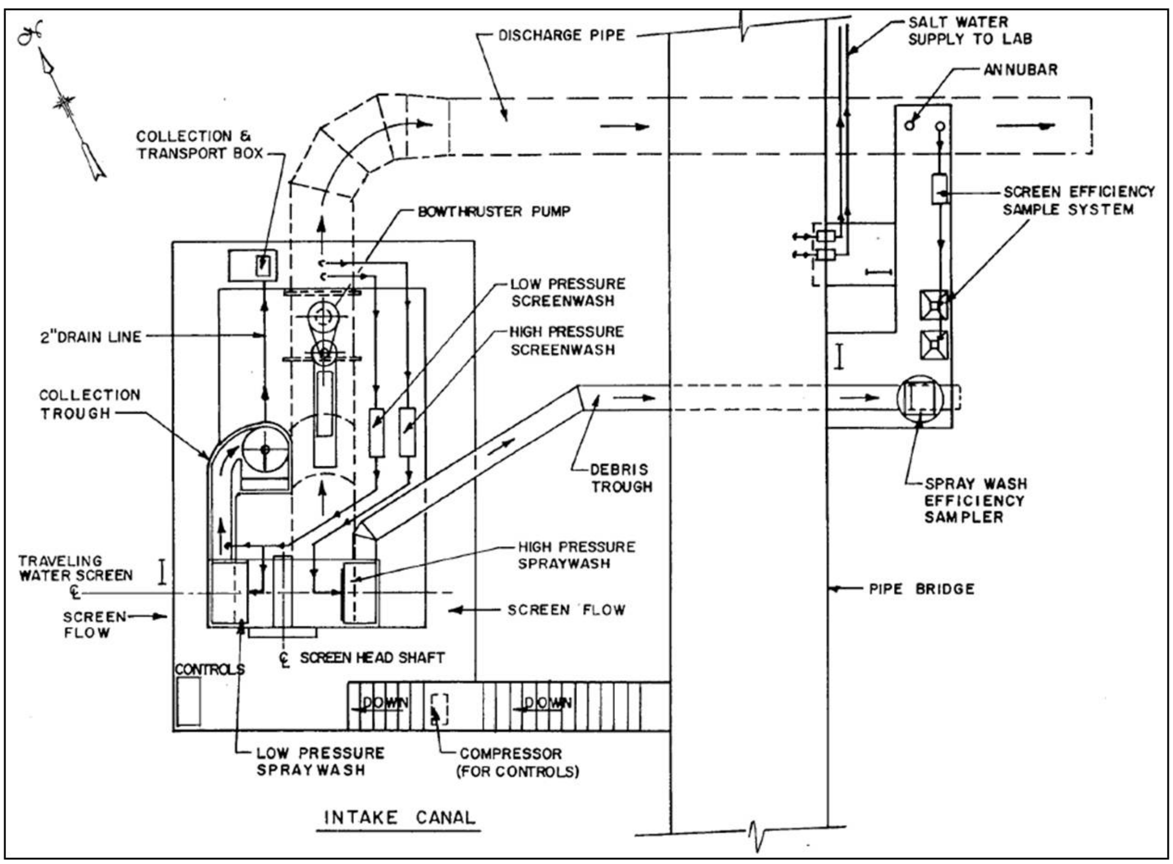


Figure 8.7. Pilot-scale prototype test facility (plan view).

Source: Taft et al., 1981

Table 8.1. Percentage Survival and Hatchability of Fish Eggs During Prototype Fine-Mesh Screen Testing at Big Bend

Fish Eggs								
	Initial Survival (%)		Hatchability (%)		48 Hour Survival (%)		96 Hour Survival (%)	
Taxa	**Test**	**Control**	**Test**	**Control**	**Test**	**Control**	**Test**	**Control**
Sciaenidae	75.3	98.4	94.8	99	84.3	91.3	69.7	82.7
Silver perch	100	100	100	100	99.1	99.4	97.9	97.8
Cynoscion spp.	100	100	100	100	99.4	99.3	89.4	96.9
Menticirrhus spp.	100	100	100	100	99.7	100	88.4	91.5
Black drum	100	--	100	--	82.2	--	85.3	--
Alosa spp.	43.2	85.5	81	89.3	84.4	90.3	62.4	68.6
Scaled sardine	45.8	99.6	92.9	98.5	82.8	92.2	45.9	27.6
Bay anchovy	43.3	85	80	88.6	83.9	90	63.7	72

Source: Taft et al., 1981
Note: --=no eggs of this species were collected

Table 8.2. Percentage Survival (Initial and Extended) of Fish Larvae During Prototype Fine-Mesh Screen Testing at Big Bend

Fish Larvae						
	Initial Survival (%)		48-Hour Survival (%)		96-Hour Survival (%)	
Taxa	**Test**	**Control**	**Test**	**Control**	**Test**	**Control**
Sciaenidae	18.6 (108)	44.4 (6)	10.9 (26)	0.0 (1)	10.1 (26)	0.0 (1)
Silver perch	19.2 (39)	50.0 (2)	--	--	--	--
Cynoscion spp.	15.7 (51)	0.0 (1)	100 (3)	--	100.0 (3)	--
Menticirrhus spp.	0.0 (15)	25.0 (4)	--	--	--	--
Black drum	42.9 (7)	100.0(1)	--	--	--	--
Alosa spp.	1.5 (278)	10.4 (11)	36.4 (11)	0.0 (1)	36.4 (11)	0.0 (1)
Scaled sardine	0.0 (15)	--	--	--	--	--
Bay anchovy	1.5 (274)	11.4 (10)	22.2 (9)	0.0 (1)	22.2 (9)	0.0 (1)

Source: Taft et al., 1981
Notes: Number of observations is given in parentheses; --=no larvae of these species were collected

Table 8.3. Percentage Survival (Initial and Extended) of Decapod Zoea During Prototype Fine-Mesh Screen Testing at Big Bend

Decapod Zoea						
	Initial Survival (%)		**48-Hour Survival (%)**		**96-Hour Survival (%)**	
Taxa	**Test**	**Control**	**Test**	**Control**	**Test**	**Control**
Caridea	94.3	76.7	85	6.8	50	43.8
Upogebia affinis	91.3	75.6	84.1	76.2	42.8	45.4
Brachyura	95.5	65	83.9	55.6	45.9	27.8
Grapsizoea	100	100	95.1	97.9	80.2	92.9
Pinnotheridae	100	100	92.2	93.4	73	72.1
Xanthidae	99.1	--	95.9	95.6	74.9	73.4
Menippe mercenaria	97.9	97.3	91.5	94.9	58.3	61
Paguridae	94.7	100	96.6	100	79.2	33.3

Source: Taft et al., 1981
Note: --=no observations

Table 8.4. Percentage Survival (Initial and Extended) of Decapod Megalops During Prototype Fine-Mesh Screen Testing at Big Bend

Decapod Megalops						
	Initial Survival (%)		**48-Hour Survival (%)**		**96-Hour Survival (%)**	
Taxa	**Test**	**Control**	**Test**	**Control**	**Test**	**Control**
Caridea	100	--	100	--	100	--
Upogebia affinis	100	100	97.7	100	74.3	100
Brachyura	65.1	26.7	71.8	--	15	--
Grapsizoea	100	100	98.1	100	93.1	91.2
Pinnotheridae	100	--	100	--	92.9	--
Xanthidae	100	100	98.3	100	94.2	96.9
Menippe mercenaria	100	--	100	--	100	--
Paguridae	100	--	90	--	80	--

Source: Taft et al., 1981
Note: --=no observations

8.1.3.2 Full-Scale Installation

Survival Study

On the basis of the positive results of the prototype testing described previously, the regulatory agencies determined that Unit 4 could be placed into operation with a once-through condenser cooling system provided that fine-mesh screens were incorporated into the CWIS for Units 3 and 4. Accordingly, six 0.5 mm, no-well, dual-flow TWS were installed at the CWIS for Units 3 and 4 upstream of the four existing coarse-mesh (9.5 mm) dual-flow TWS (Figures 8.2, 8.4, and 8.5). Biological effectiveness studies were later conducted in 1985 to validate the performance of the fine-mesh screens at the CWIS for Units 3 and 4 (Brueggemeyer et al., 1987).

A description of the intake system is provided in Section 8.1.2. Biological sampling was conducted between March and September of 1985 at the Unit 4 fine-mesh screens. Samples were collected from (1) the screen wash return trough; (2) the discharge point of the return system (to account for potential effects of the Hidrostal pumps on survival); and (3) the intake canal upstream of the CWIS (control). Sampling was conducted weekly for 31 weeks (Bruzek and Mahadevan, 1986). During each weekly sampling period, two daytime samples and two nighttime samples were collected from the screen wash and discharge sampling locations and one daytime and nighttime sample each from the control sampling location. All samples were collected with 505-µm plankton nets.

A total of 73,349 eggs, 3460 larvae, and 46,305 invertebrates were collected from the screen wash station; 20,247 eggs, 575 larvae, and 38,465 invertebrates from the return system discharge station; and 22,313 eggs, 462 larvae, and 4086 invertebrates from the control station (Table 8.5). Only two fish taxa (Engraulidae and Sciaenidae) and three invertebrate taxa (Caridea, Xanthidae, and Pinnotheridae) were collected in sufficient numbers for analysis. The results of the full-scale biological evaluation are presented in Tables 8.6 and 8.7.

In general, the survival rates resulting from this full-scale evaluation were comparable to, and in some cases exceeded, those obtained during the prototype study (Table 8.6). Invertebrates experienced the highest survival rates, and fragile Engraulid (bay anchovy) fish larvae experienced the lowest. There was no significant difference in survival rates between organisms collected from the screen wash station and return system discharge sampling station. In addition, when compared to the survival of control organisms, the survival of test organisms was lower for fragile species such as bay anchovy (Engraulidae) eggs.

Table 8.5. Total Number of Organisms Collected from Each of the Three Sampling Stations During the Fine-Mesh Screen Survival Studies at Big Bend

	Number Collected		
Taxa	**Screen Wash**	**Return System Discharge**	**Control**
Fish Eggs			
Clupeidae	219	9	60
Engraulidae	21,899	3522	16,378
Sciaenidae	51,202	16,693	5872
Soleidae	29	23	3
Total	**73,349**	**20,247**	**22,313**
Larvae			
Clupeidae	2	2	-
Engraulidae	1651	271	303
Atherinidae	1	-	3
Sparidae	1	-	-
Sciaenidae	1632	284	95
Bairdiella chrysoura	2	-	-
Cynoscion nebulosus	1	-	-
Cynoscion arenarius	25	11	-
Blenniidae	3	1	12
Gobiidae	107	5	14
Soleidae	35	1	35
Total	**3460**	**575**	**462**
Invertebrates			
Zoea			
Penaeidae	6	2	-
Caridea	1057	458	347
Portunidae	45	7	14
Paguridae	81	21	5
Xanthidae	11,143	7576	671
Pinnotheridae	33,287	29,845	2987
Grapsidae	512	442	37
Megalops			
Xanthiidae	25	5	1
Grapsidae	149	109	24
Total	**46,305**	**38,465**	**4086**

Source: Bruzek and Mahadevan, 1986

Table 8.6. Comparison of Initial Survival During the Fine-Mesh Screen Survival Studies at Big Bend

	Initial Survival (%)		
Taxa	**Screen Wash**	**Return System Discharge**	**Control**
Fish Eggs			
Bay anchovy	48	29	72
Sciaenidae	63	40	72
Fish Larvae			
Bay anchovy	16	58	16
Sciaenidae	61	56	85
Invertebrates			
Caridea	72	70	65
Xanthidae	93	90	88
Pinnotheridae	99	83	77

Source: Brueggemeyer et al., 1987

Table 8.7. Comparison of Fish Egg Hatchability and Extended 48-Hour Survival During Prototype and Fine-Mesh Screen Survival Studies at Big Bend

	Screen Wash	**Return System Discharge**	**Control**
Taxa	Hatchability (%)		
Fish Eggs			
Bay anchovy	74	93	98
Sciaenidae	80	80	90
	Extended 48-Hour Survival (%)		
Fish Larvae			
Bay anchovy	68	65	59
Sciaenidae	63	66	61
Invertebrates			
Caridea	67	66	88
Xanthidae	80	71	85
Pinnotheridae	71	65	74

Source: Brueggemeyer et al., 1987

As part of the evaluation of the fine-mesh screens, an auditing program was established to monitor the conditions of the screens and optimize their screening efficiency. The biggest O&M problem at this site is biofouling (particularly barnacles and mussels). It was found that biweekly manual cleaning of the screens by a two-person crew was effective in preventing damage to the screen mesh and seals.

Screening Efficiency Study

In addition to the impingement survival studies, TECO was interested in evaluating the efficiency of the new fine-mesh screens for excluding organisms from entrainment. To that end, a screening efficiency study was conducted from March through June 1987 after modifications had been made to the screening system and sampling methodology. The modifications were designed to address screens that periodically went out of service for mechanical problems with the screen chains (related to biofouling). When screens went offline, the TSV through the remaining operable screens increased, impacting screening efficiencies. TECO installed new screen seals and implemented a surveillance and preventive maintenance plan.

For the screening efficiency study, pumped samples were collected in front of one dual-flow fine-mesh screen (both ascending and descending sides of the screen) and behind the screen. Sampled water was pumped to 505 μm plankton nets for sample collection.

After modification of the fine-mesh screen, entrainment of abundant species was very low when comparing densities of organisms in front of and behind the screen. Results indicate that entrainment of fish eggs was reduced by between 92 and 97%; fish larvae entrainment was reduced by between 75 and 100%; and entrainment of invertebrates was reduced by 100%.

Table 8.8. Screening Efficiency (Entrainment Reduction) Achieved with Fine-Mesh Screens at Big Bend

Species	Life Stage	Mean Density (#/100 m^3) Upstream of Screen	Mean Density (#/100 m^3) Downstream of Screen	Entrainment Reduction (%)
Scianidae spp.	egg	38,595	1062	97
Anchoa mitchilli	egg	12,860	1071	92
Anchoa mitchilli	larvae	240	27	89
Bairdiella chrysoura	larvae	2	-	100
Cynoscion nebulosus	larvae	1	-	100
Menippe mercenaria	zoea	25	-	100
Penaeus spp.	juvenile	2	-	100
Blenniidae spp.	larvae	30	5	82
Gobiidae spp.	larvae	30	8	75
Gobiesox strumosus	larvae	9	1	88

Source: Brueggemeyer et al., 1987

8.1.4 Conclusions

The fine-mesh TWS at Big Bend were considered to be very successful. They were sufficient, in the view of the EPA and the FDER, for reducing entrainment at the CWIS for Units 3 and 4. In addition, studies at a full-scale installation indicate that the survival of impinged organisms on the fine-mesh screens were comparable to, and in some cases higher than, those achieved during the prototype study; however, the survival of some fragile species and life stages was lower (e.g., bay anchovy). TECO has been operating Big Bend under its NPDES permit successfully since installation of the fine-mesh screens.

8.2 Brunswick Steam Electric Power Plant

Carolina Power and Light's (CP&L, now Progress Energy) Brunswick Steam Electric Power Plant is a nuclear power station located approximately 5.7 miles upstream from the mouth of the Cape Fear River near Southport, NC. The facility consists of two 790-MW units producing a combined 1580 MW at full generating capacity. Units 1 and 2 went online in 1977 and 1975. Brunswick utilizes an OTC water system with a cooling water flow of between 1857 and 2321 cfs (1.2 and 1.5 BGD). The CWIS draws water through a 2.7 mile intake canal. The plant location and a general site plan are provided in Figure 8.8.

8.2.1 Background

CP&L was required by its 1974 NPDES permit to install cooling towers to minimize potential IM&E impacts. Although the OTC intake had been constructed in 1972 and monitoring data indicated that the impact of impinged and entrained organisms on the estuary was minimal, the EPA and the state still required cooling towers. After negotiation, the regulators were willing to accept intake modifications in lieu of cooling towers to reduce IM&E impacts.

Brunswick agreed to the following intake modifications:

- a coarse-mesh diversion structure at the mouth of the intake canal
- fine-mesh screen overlays on a portion of the existing coarse-mesh TWS
- a fish return system
- flow minimization

The species that were targeted in the evaluations of system effectiveness were commercially and recreationally important in the estuary and included some fragile species and some hardier ones. The species of concern included Atlantic menhaden, bay anchovy, striped and white mullet (*Mugil* spp.), spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias undulatus*), weakfish and spotted seatrout (*Cynoscion* spp.), gobies (*Gobiosoma* spp. and *Gobionellus* spp.), southern and summer flounder (*Paralichthys* spp.), white, pink, and brown shrimp (*Penaeus* spp.), blue crab, and portunid crab megalops (Portunidae).

Once the circulating water pumps were operational, CP&L began baseline IM&E sampling at the TWS in the mid-1970s. Despite CP&L's conclusion that the IM&E at the TWS intake did not adversely impact the estuary, the EPA and state reaffirmed their requirement for intake modifications to reduce intake impacts. In 1978, CP&L constructed and then tested (in 1979) a prototype diversion structure with 13 mm (0.5 in.) mesh panels at the mouth of the intake canal (Hogarth and Nichols, 1981). Baseline impingement sampling was conducted in 1977 and 1978 to monitor the effectiveness of the diversion structure in reducing impingement. The full-scale diversion structure was constructed in 1979 and rebuilt in 1982 with a more robust foundation and finer mesh (9.4 mm) panels.

Two of the four existing coarse-mesh (9.4 mm) TWS were modified in 1983 by overlaying fine-mesh (1.0 mm) screening on the existing mesh and adding fish-lifting buckets and a fish return system. There are four screens per unit and a total of two units. Since 1987, three of the four screens for each unit have been retrofitted with 1.0 mm mesh.

In addition to studies designed to evaluate the effectiveness of the intake modifications, in 1979 CP&L initiated a long-term monitoring program that collected samples from the river to determine if the Brunswick intake was exerting a measurable impact on ambient populations of organisms (CP&L, 1985).

8.2.2 Intake Description

The following section describes the intake as it currently exists at Brunswick.

The CWIS at Brunswick comprises a stationary diversion structure located at the mouth of the intake canal in the river, a TWS structure at the end of the intake canal, and a fish return system. The diversion structure is a stationary, V-shaped screen composed of 9.4 mm copper and nickel mesh panels (Figure 8.9). The V shape was chosen to aid in the sweeping of debris from the screen face during ebb and flood tides. The base of the original diversion structure experienced some scour, leading to the loss of some screening panels. When reconstructed in 1982, the structure's foundation was modified to prevent any issues with scour. In addition, the system was designed with redundant screen panels to allow in-place cleaning of fouled panels without the need to stop water withdrawal.

At the end of the intake canal, there are four through-flow TWS, one with 9.4 mm mesh and three that have been retrofitted with 1 mm fine mesh. The fine-mesh screens have fish protection features including fish-lifting buckets and a low pressure spray wash system to rinse fish into a return flume (Figure 8.10). The external spray wash system is located on the ascending, front side of the screen; a high pressure spray wash system is located above it to remove debris. Impinged organisms rinsed from the screen are washed into the fish return flume and carried by gravity to the return pond approximately 4000 ft from the intake (Figures 8.8 and 8.11). Organisms reaching the return pond eventually exit to the adjacent creek through the weir.

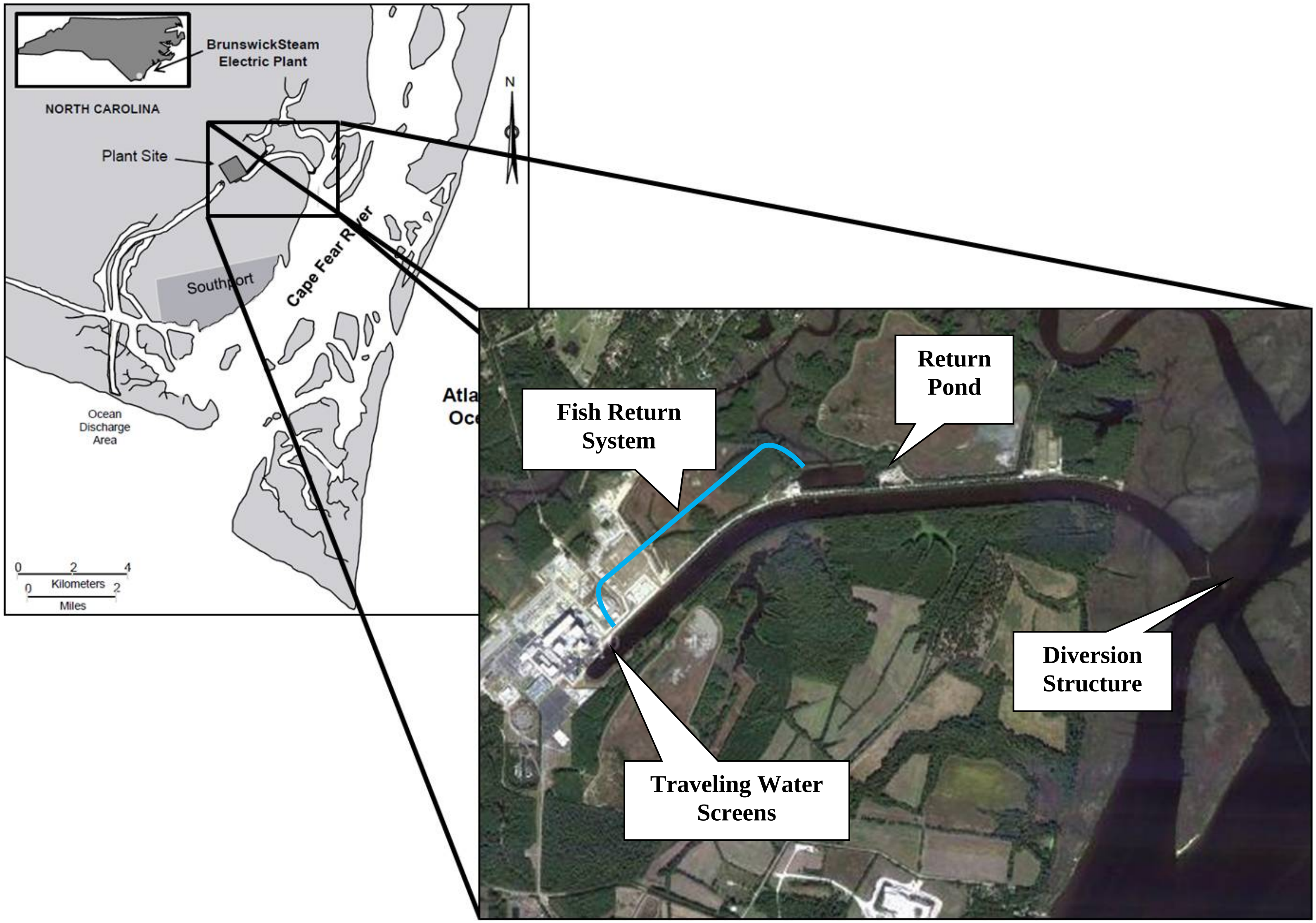


Figure 8.8. General location and site plan of Brunswick .

Sources: top L: Thompson, 2011; bottom R: Bing maps

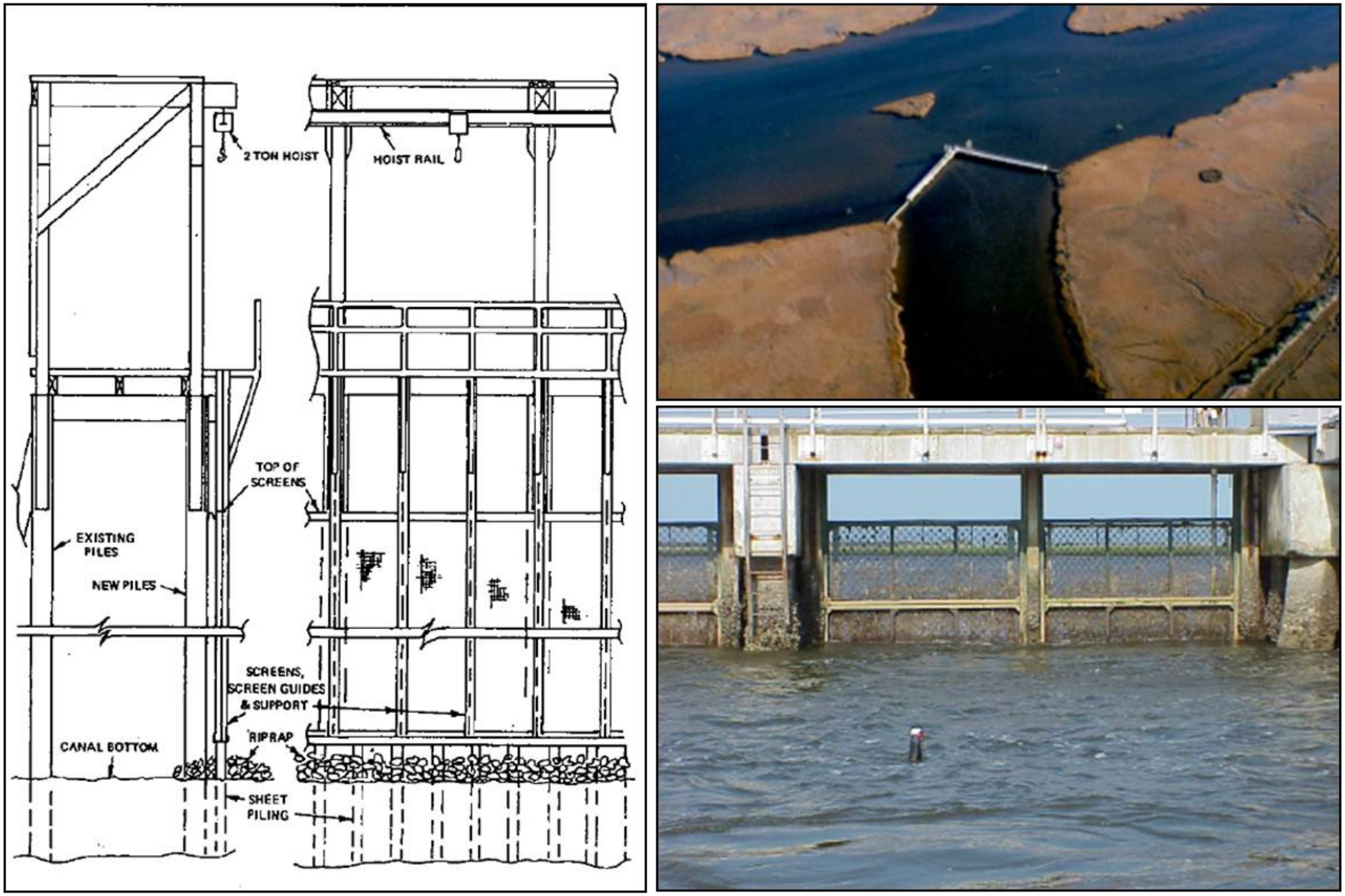


Figure 8.9. Diversion structure at the mouth of the Brunswick intake canal.

Sources: L: Hogarth and Nichols, 1981; R: Thompson, 2011

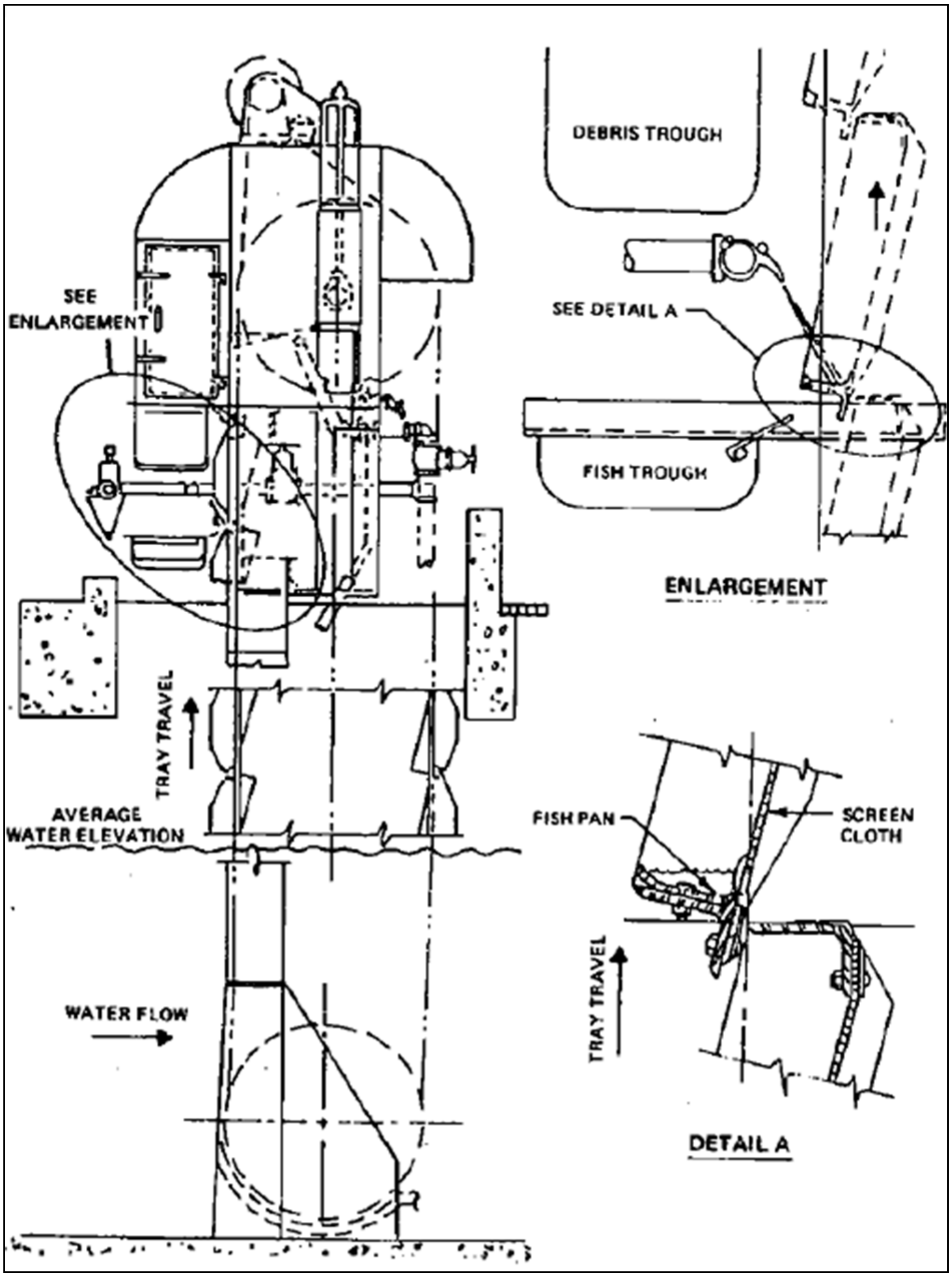


Figure 8.10. Cross-section of fine-mesh screens used at Brunswick showing detail of the fish-friendly features such as fish-lifting buckets and low pressure spray wash system.

Source: Hogarth and Nichols, 1981

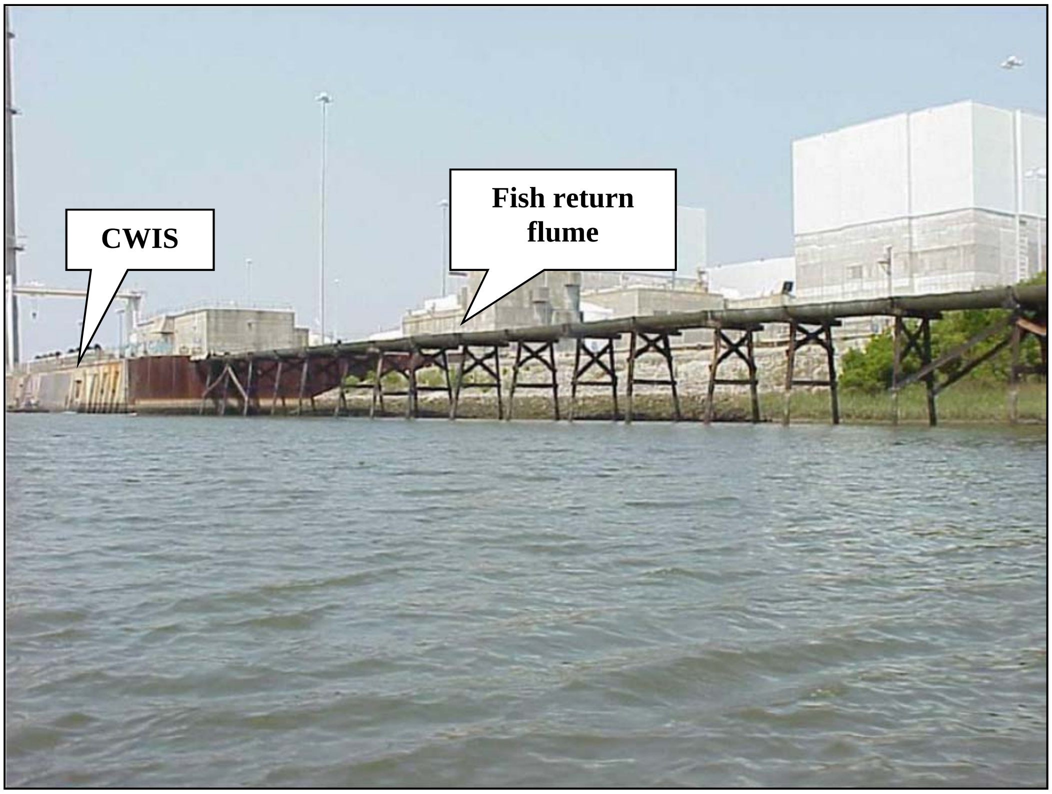


Figure 8.11. CWIS and elevated fish return flume.
Source: Thompson, 2011

8.2.3 Biological Efficacy

The intake modifications at Brunswick have undergone multiple years of effectiveness testing. These tests have focused on:

- effectiveness of the diversion structure in decreasing impingement of larger organisms
- effectiveness of the fine-mesh TWS in decreasing entrainment of smaller organisms
- survival of impinged organisms on the fine-mesh TWS

The following subsections describe the three different components of effectiveness in greater detail.

8.2.3.1 Diversion Structure

The diversion structure underwent evaluation by comparing the numbers, biomass, and sizes of organisms impinged before and after installation. Trawl and gill net sampling stations were also set up inside and outside the diversion structure as another evaluation method.

As shown in Table 8.9, the diversion structure reduced the total number of organisms impinged on the TWS by 43% when compared to the number impinged before the diversion structure was installed. The diversion structure reduced the total biomass impinged by 72%.

Table 8.9. Mean Density and Mean Biomass of Selected Species Impinged at Brunswick, 1977–1985

	Density (#/million m^3)			Biomass (kg/million m^3)		
Taxa	**1977–1981**	**1982–1985**	**Percentage Reduction**	**1977–1981**	**1982–1985**	**Percentage Reduction**
Atlantic menhaden	5481	395	93	38.8	3.4	91
Bay anchovy	1788	4261	+138	2.5	3.7	+48
Spot	362	103	72	3.7	1	73
Croaker	199	127	36	1	0.7	30
Blue crab	351	251	28	4.5	3.6	20
Total organisms collected	**10,538**	**5971**	**43**	**60.6**	**17.3**	**72**

Source: Thompson, 2000
Note: The period between 1977 and 1981 was before the installation of the diversion screen, and the period between 1982 and 1985 was after.

8.2.3.2 Fine-Mesh TWS

Entrainment Reduction

The effectiveness of the fine-mesh screens at Brunswick was initially evaluated by comparing the entrainment densities between two units operating concurrently or operating the same unit with and without the fine-mesh overlays. Later studies compared larval entrainment through the screen to impingement on the screen during the same time period.

Table 8.10 presents data from the initial evaluations of fine-mesh screening at Brunswick (Hogarth and Nichols, 1981). For these studies, entrainment samples were collected from the discharge of one unit that had fine-mesh overlays and another unit that did not. The results indicate that the fine-mesh screening reduced entrainment of all species combined by 89% over the coarse-mesh screens.

When including entrainment sampling during periods when a single screen was sequentially tested with and without the fine-mesh screening, the total reduction in entrainment was 82% (CP&L, 1985). In addition, the reductions in entrainment for each of the predominant species were 58% for spot, 69% for bay anchovy, 70% for gobies, and 88% for croaker.

Data from the later studies that evaluated entrainment reductions based on a comparison of entrained versus impinged larvae are given in Table 8.11. As shown, the entrainment reduction ranged monthly between 14 and 81%.

Table 8.10. Comparison of Entrainment Between Fine-Mesh Screens and Original Coarse-Mesh Screens

		Density entrained (#/1000m^3)		
Time (day/night)	**Tidal Stage**	**Fine-Mesh (1.0 mm)**	**Coarse-Mesh (9.4 mm)**	**Percentage Reduction**
D	MO	240.0	1497.9	84
N	HS	693.3	13,200.0	95
N	MO	347.8	1328.8	74
D	MI	782.6	6569.2	88
D	LS	267.9	1373.4	80
D	MI	89.3	1851.8	95
D	HS	922.6	7464.2	88
N	MO	684.5	8713.1	92
N	LS	119.0	1546.2	92
N	MI	654.7	1400.8	53
D	MO	416.7	3533.1	88
Total		**5218.4**	**48,478.5**	**89**

Source: Hogarth and Nichols, 1981
Note: Samples were collected at the discharge. D=day; N=night; MO=mid-outgoing; MI=mid-incoming; LS=low slack; HS=high slack

Table 8.11. Percentage Entrainment Reduction Provided by Fine-Mesh Screens by Month at Brunswick During 1990

Month	*Gobiosoma* spp.	Portunid megalops	*Panaeus* spp.	*Anchoa* spp.	Spot	Croaker	Atlantic Menhaden	All Organisms
Jan	-	-	-	100	24	51	100	**46**
Feb	-	100	100	100	42	65	100	**60**
Mar	-	79	62	55	24	22	76	**27**
Apr	100	67	65	29	53	18	100	**28**
May	7	4	75	26	100	100	-	**22**
Jun	11	73	76	65	-	-	-	**44**
Jul	56	94	95	70	-	-	-	**78**
Aug	3	19	21	25	-	-	-	**14**
Sep	30	59	38	26	-	-	-	**37**
Oct	-	81	81	100	-	-	-	**81**
Nov	22	91	85	100	-	59	-	**80**
Dec	100	64	100	80	-	47	-	**59**

Source: Thompson, 2000
Notes: Entrainment reduction was calculated as (Total Impinged/Total Entrained+Total Impinged) x 100. --=no data were collected

Impingement Survival

Impingement survival is an important measure of the modified intake system's capacity to return viable impinged fish back to the Cape Fear River estuary. Initial impingement survival studies were conducted with an unmodified system that lacked the basic fish-friendly components and therefore did not accurately assess survival with a full-scale screening and fish return system. Subsequent testing was conducted after the full modification was completed in 1984. During this sampling, impinged organisms were collected and held for 96 hours to assess latent mortality. The screen was rotated at two speeds to determine the effect of impingement duration on survival. The results of the 1984 to 1987 impingement survival sampling are given in Table 8.12.

Survival was both species- and life stage–specific (Table 8.12). The highest survival (96%) was exhibited by the invertebrates, particularly blue crabs. The lowest survival (0%) was exhibited by bay anchovy and Atlantic menhaden. Survival rates were higher at the faster screen rotation speed for all species except Atlantic croaker juveniles and adults.

Table 8.12. Survival of Selected Impinged Organisms at Brunswick from 1984–1987

	Larvae		**Juveniles and Adults**	
Taxa	**Slow Screen Rotation (2.5 ft/min)**	**Fast Screen Rotation (6.6 ft/min)**	**Slow Screen Rotation (2.5 ft/min)**	**Fast Screen Rotation (6.6 ft/min)**
Atlantic menhaden	0	3	ND	16
Bay anchovy	<1	1	1	5
Mugil spp.	7	70	ND	92
Spot	9	29	57	60
Atlantic croaker	14	34	53	45
Cynoscion spp.	ND	13	ND	35
Gobionellus spp.	ND	15	ND	ND
Paralichthys spp.	ND	93	ND	71
Penaeus spp.	75	96	87	94
Blue crab	86	87	92	96

Source: Thompson, 2000, 2011
Note: ND=no data were collected

Engineering Evaluations

In addition to the biological evaluations for the fine-mesh screens, CP&L also conducted initial engineering evaluations to better understand the potential performance of the screens. These studies were designed to determine issues associated with differential pressure across the screen mesh, durability, and cleaning requirements. The results of these evaluations indicated that the fine-mesh screening did not present a cleaning problem; the spray wash system performed well to clean the screen panel. In addition, the screen mesh proved to be durable and capable of withstanding continuous backwashing.

8.2.4 Conclusions

The intake modifications at Brunswick were considered to be very successful at meeting the goals of reducing IM&E. The impingement of larger organisms was dramatically reduced (43% reduction in density and 72% reduction in biomass) through the use of the diversion structure (9.4 mm mesh). The entrainment of smaller life stages was reduced by 89% with the 1.0 mm screens when compared to the existing 9.4 mm TWS. Impingement survival was variable, with more fragile species exhibiting lower survival than hardier species.

When the results were compared to the sampling data from the source water body, CP&L concluded that operation of the modified intake system does not result in any measurable impact on the Cape Fear Estuary.

Chapter 9

Navigating the Intake Permitting Process

Successfully navigating the seawater intake permitting process can be time consuming and expensive. Furthermore, modification of an existing intake may be an even more contentious issue with an even less clearly defined permitting path. To the extent possible, this chapter provides a generic protocol to identify permitting requirements, permitting protocols to be expected, and supporting studies that are likely to be required when modifying a seawater intake to address IM&E impacts. Together, these components can be used as guidance for the intake permitting process.

There are likely to be substantial differences in the permitting requirements for existing intakes that are currently in operation versus those that are not. For example, a seawater intake co-located with an operational power plant intake may undergo less scrutiny relative to its intake impacts if feed water is withdrawn from the discharge side of the power plant (i.e., the water will have already been pre-screened); however, the biological efficacy of the power plant's existing intake screening system may come under question and trigger additional permitting conditions. On the other hand, an existing intake may be one that is not currently in operation, such as a power plant intake that has been decommissioned. In this case, the intake would likely be considered as new and would have to undergo essentially the full intake permitting process.

The intake-related studies that would be required for the permitting of a modified intake currently in operation versus one that has been decommissioned would vary. The former may have recent IM&E data available from existing permit-required monitoring as well as current source water characterization data describing the ambient populations of organisms near the intake. The latter may be required to conduct IM&E studies and collect new detailed baseline characterization data.

9.1 Intake-Related IM&E Studies

When modifying an intake, a permitting agency will likely require an estimate of the potential IM&E impacts at the site under consideration prior to construction. Permit writers require these detailed data in order to determine if the selected intake modification technology will meet the IM&E goals. The two principal populations of organisms that are of concern in IM&E studies are (1) those that naturally exist within the source water body and may be susceptible to IM&E; and (2) those that actually become impinged or entrained. As described previously, depending on the existing intake under consideration for modification, there may be robust, recent data available. For the purposes of this guidance document, however, the assumption is that a full suite of intake-related biological studies would be required as though it were a new intake. These various studies are described here in greater detail.

9.1.1 Baseline Characterization of Source Water Body

A baseline characterization study is designed to collect data to determine the species and life stages that would be susceptible to IM&E. In particular, the objective is to identify the species that are important commercially, recreationally, and ecologically (either as forage fish or as threatened or endangered fish). A typical baseline characterization study would include the following information (EPA, 2012). If this information is not available for the site under consideration, the expectation is that the project proponent would conduct the requisite field studies to collect the data.

- a review of existing pertinent data that would aid in identifying the species and life stages present
- a list of the species and life stages in the area and their relative abundance near the proposed intake location
- identification of the species and life stages most susceptible to IM&E
- identification of the primary periods of reproduction, larval recruitment, and peak abundances
- identification of the temporal (daily, seasonal) variations in abundance
- supplemental field studies conducted to collect data that were not available; these must document the study methods, statistical power, quality assurance/quality control process, and data analysis approach

9.1.2 Impingement Studies

The impacts of an intake modification on later life stages of aquatic organisms (juveniles and adults) can be estimated with a study that describes the susceptibility of marine organisms to impingement on a screen and their estimated post-impingement survival based on available data. Such a study would include the following details:

- species composition, abundance, distribution, and seasonality of the marine organisms in the vicinity of the proposed intake
- organisms that would be considered as species of concern or RIS
- swim speeds of the species and life stages likely to be in the vicinity of the proposed intake
- design flow rates and resulting intake velocities (approach and TSV)
- ability of the target species and life stages to avoid the design intake velocities
- review and summary of any impingement survival data available on the target species

When considering the locations where seawater desalination is being considered the most (e.g., California coast), most of the data should be readily available from IM&E studies conducted by the power generation industry; however, in the absence of available data, they would likely have to be collected in the field by the project proponent as part of the assessment of potential environmental impacts prior to construction of the project.

9.1.3 Entrainment Studies

The impacts of an intake modification on early life stages (eggs and larvae) of aquatic organisms can be estimated with an entrainment study prior to construction. An entrainment study is designed to enumerate the number of eggs and larvae that could be withdrawn through the intake screening system and killed in the process equipment.

Entrainment studies are typically composed of two parts: (1) sampling the ambient populations of eggs and larvae; and (2) sampling eggs and larvae collected through a pilot-scale intake screen. Towed plankton nets are used to collect the ambient samples. Pumps and pilot-scale screens are used to collect the entrainment samples. Water drawn through the pilot-scale screen is discharged through a plankton net. A flow meter is used to record the volume of water sampled. Entrained organisms are rinsed from the plankton net in the discharge stream, collected, and preserved. Samples are then transported to a laboratory where they are sorted, identified to the lowest taxonomic level practicable, and enumerated. The density of entrained organisms is then calculated based on organism abundance and sample volume (i.e., number of organisms per m^3).

Entrainment sampling should be designed to capture variations in organism abundance associated with depth, diel patterns, tidal cycles, ambient hydraulic conditions, and natural interannual variability in populations. The sampling program duration and sampling frequency will be functions of the variables listed previously. Determining the effects of these natural variables on organism abundance is useful for selecting the optimal location and operation of an intake prior to construction.

Ambient samples serve to establish a baseline against which densities of entrained organisms can be compared, allowing estimation of the biological efficacy of the screen. In addition, ambient samples serve as the basis for assessing the impacts of entrainment on local populations of organisms. Raw entrainment densities can be used to project total annual entrainment losses for a full-scale facility under actual and maximum design withdrawal by multiplying the pilot-scale entrainment densities by the total volume of water to be withdrawn. Total annual entrainment losses are used to assess the impacts of entrainment on local populations through a number of well-established impact assessment models (see Chapter 7). The resulting impact assessments can then be put in the context of their effect on local populations.

Beyond fulfilling permitting requirements, the results of an entrainment study aid in the identification of the best intake technology, location, and operating schedule, all of which can profoundly impact facility economics.

9.1.3.1 Entrainment Impact Assessment

As previously described, there are multiple impact assessment models that can be used to determine the impact of entrainment to ambient populations of fish. Each model has its own data requirements; if the data are not readily available, the project proponent may be required to collect these data in order for the model to be completed. For demographic models, data needs are mostly limited to basic life history information such as fecundity, age at maturity, life span, and survival through successive life stages. If available, these data should be available in the scientific literature. If not, assumptions will have to be made, and the level of uncertainty in the model output increases (Steinbeck et al., 2007). For conditional mortality models such as ETM, data needed as model inputs include the design flow rate for the proposed desalination intake, bathymetry for estimating source water volumes, ambient current data, and hydrodynamic data (for estuarine environments). Most of these data should be readily available from published sources; however, in tandem with an entrainment study, it may be appropriate to collect ambient current data by deploying current meters during the study

9.1.4 EPA Guidance on IM&E Monitoring

EPA offered guidance on the design of IM&E monitoring studies; however, these are studies that would be required (pursuant to input from the state-level permit writer) after commissioning a modified intake. Regardless, they provide some insight into what EPA may consider an effective IM&E study design.

EPA, in developing the Phase I and II 316(b) Rules, provided the following guidance relative to IM&E monitoring at operating facilities:

> Phase I Rule: *Impingement sampling*. You must collect samples to monitor impingement rates (simple enumeration) for each species over a 24-hour period and no less than once per month when the cooling water intake structure is in operation. (2) *Entrainment sampling*. You must collect samples to monitor entrainment rates (simple enumeration) for each species over a 24-hour period and no less than biweekly during the primary period of reproduction, larval recruitment, and peak abundance.

Proposed Phase II Rule: You must collect samples at least biweekly to monitor entrainment rates (simple enumeration) for each species over a 24-hour period during the primary period of reproduction, larval recruitment, and peak abundance.

For the former, the [proposed sampling] Plan would include the duration and frequency of monitoring (which EPA assumes would generally be conducted on a biweekly basis, although the exact frequency would be determined case-by-case), the monitoring location, the organisms to be monitored, and the method in which naturally moribund organisms would be identified and taken into account.(EPA 2011)

Sampling requirements can change between IM&E, source water body and facility, near- and far-field, and season (Tables 2.4 through 2.6). In addition, often agencies will require diel assessment and evaluation of tidal effects. Although all these components can be important in characterizing the baseline conditions in the source water body at the proposed point of withdrawal, the key component for determining biological efficacy is the number of organisms handled (i.e., sufficient test organisms are required to demonstrate efficacy). Costs for monitoring programs can be substantial ($100,000–>$500,000 per year) and are influenced by sampling frequency, detrital loads, organism abundance, number of samples required, and species composition.

The effect of natural variation in biological populations (either spatially or temporally) can render a structured program (e.g., one 24 h effort twice a month as EPA suggests) inadequate if a key species or life stage is missed during sampling. This could ultimately require a multi-year effort to verify biological efficacy. A more cost-effective program may be to sample 8 h per day (based on anticipated period of maximum abundance); 3 days per week; 52 weeks (i.e., at a greater frequency than that outlined by EPA). As noted, however, IM&E studies are designed to monitor impacts at operating intakes (i.e., to verify that projected performance goals are being met), not for demonstrating the potential impacts of a proposed modification to an existing intake.

9.2 Permitting Considerations

Modification of an existing intake to reduce IM&E will trigger review of the permits under which the intake is currently operating. The principal intake-related issues that will affect permitting will include each of the key considerations in determining the BTA under 316(b) as discussed in Chapter 4:

- *Location*—the location of the modified intake
- *Design*—the technology selected for modification
- *Construction*—the impacts of construction
- *Capacity*—the new capacity of the modified intake, including the intake velocities (approach and through-screen)

Therefore, although there are no federal regulations relative to intake impacts in the desalination industry, Section 316(b) of the CWA will likely be applied to ensure intake impacts are minimized. The intake-related regulations that are likely to be applied during an intake modification are reviewed in Section 2.2. Depending on the nature and extent of the intake modification, the permitting process may be quite different.

9.2.1 Existing Facility Status (Operational versus Decommissioned)

For an operating intake, a modification to add desalination capacity may present fewer permitting obstacles than an intake that has been decommissioned, whereas an active intake may likely be asked to reopen its NPDES permit for review in the event of a structural modification.

9.2.2 Extent of Intake Modification

The extent of the intake modification planned will have a bearing on the level of permitting scrutiny to which the project proponent may be held. For example, in cases where the intake may undergo substantial civil modifications to expand the footprint and add modified TWS (see Sections 6.4 and 6.5), the permitting authorities may treat it as a new intake. As such, it would be held to all the same state and federal permitting standards as those outlined previously in Section 2.2.1 and Table 2.3. Furthermore, when considering relocation of the intake from the shoreline to offshore, the expectation from the permitting authorities may be greater. For example, if modifying a conventional shoreline intake with offshore CWWS, new biological studies may be required to determine the potential reduction in entrainment provided by the new offshore location (i.e., a new entrainment study with subsequent impact assessment of local populations).

Alternatively, if the intake modification being considered does not require a change to the footprint of the existing intake but would simply require the replacement of conventional TWS with modified TWS, the permitting requirements may be more relaxed. This is illustrated in Section 6.3.1, in which a decommissioned shoreline intake with a capacity greater than that required by the proposed desalination facility is rehabilitated. Because the desalination facility requires less flow than the intake was originally designed for, the 0.5 ft/s TSV criterion would be satisfied through a simple replacement of the screens to ensure good biological performance. Replacement of the screens, in this case, would not require any major structural modifications and presumably would not trigger the permits associated with major construction in the ocean.

Finally, there are likely to be other intake modification scenarios in which there is some intermediate level of civil structural modification required. This would be the case when using an existing municipal wastewater treatment outfall pipeline for the construction of an offshore intake. By using the existing pipeline, it is reasonable to assume that the benthic impacts associated with laying a new pipeline using trench and fill will be avoided, and any permits associated with regulating benthic impacts would not be triggered. Despite the existing tunnel, modification to the terminus would be required to install CWWS or a velocity cap, so some environmental impact would be assumed along with the expectation of a permitting requirement to minimize that impact. The level of permitting scrutiny should be less in this scenario, however, because the potential impact to the environment is less because of reduced construction.

Ultimately, the level of permitting scrutiny will be wholly under the charge of the federal and state authorities overseeing the intake modification process. Given the complexities involved in desalination intake permitting and the lack of experience in this emerging industry in the United States, it is difficult to say with any certainty what permitting authorities may require. As is evident in the following example of a California desalination project developer, permitting an intake, whether modified or new, can be extremely unpredictable.

9.2.3 California Examples

Permitting a seawater desalination intake in California can be lengthy and expensive given the number of state agencies involved and the often high level of public scrutiny. Details about the intake permitting efforts associated with two proposed California seawater desalination projects are given in this section.

9.2.3.1 SCWD^2 Regional Seawater Desalination Project

The SCWD^2 Regional Seawater Desalination Project is a cooperative desalination project under development by the City of Santa Cruz Water Department and the Soquel Creek Water District. The proposed project would withdraw 7 MGD and produce 2.5 MGD of potable water. The project proponents have completed a number of intake-related studies in preparation for the permitting process. Table 9.1 provides an overview of the intake-related permits or approvals that are necessary for this project in Santa Cruz, CA.

The intake-related studies (shown in Figure 9.1) include the following:

- screened open-ocean intake effects study (Tenera, 2010a) to determine entrainment impacts of a CWWS intake and the effectiveness of the CWWS in reducing entrainment of early stages of marine life
- offshore geophysical study to determine whether a sub-seafloor intake is feasible
- intake feasibility study to evaluate the feasibility of all the intake options available

These studies should prepare the two water utilities to justify the intake design that is ultimately selected to the agencies during the permitting process. Taking all of these intake-related permits and approvals into consideration also requires developing a comprehensive project schedule with targeted milestones for items that will be required for securing the needed permits and approvals. Figure 9.1 presents a comprehensive EIR development schedule for the SCWD^2 Project. All intake-related steps appear in yellow boxes.

Although the SCWD^2 Project has not yet applied for permits for the full-scale facility, it has laid out a comprehensive permitting timeline. This timeline takes into account delays experienced by other desalination projects in development. For example, the proposed Carlsbad Desalination Plant (CDP) has experienced multiple delays leading to a permitting duration of nearly 15 years. The SCWD^2 permitting timeline presented in Figure 9.1 represents the sequencing of steps relative to the intake permitting process, including a conservative estimate of the duration of each step.

Table 9.1. State, Regional, and Local Agencies with a Role in Permitting Seawater Desalination Intakes in CA

State Agencies	Permits/Regulation	Comments
California Coastal Commission	Coastal development permit	Required for the portions of the project that lie within the Coastal Commission's jurisdiction
	Local coastal program (LCP) amendment	Required for City General Plan Amendment for Area A (see City of Santa Cruz Permits); may also be required or pursued in order to provide LCP coverage of Area B
California State Lands Commission	Land use lease (right-of-way permit) or modification of an existing lease	Required for the use of state tidelands and submerged lands within 3 nautical miles seaward of the ordinary high water mark
California Department of Fish and Game	Incidental take permit under the California Endangered Species Act	Required if take of endangered, threatened, or candidate species may occur
California Department of Transportation	Encroachment permit	Required if the project will encroach upon any portion of a state highway right-of-way, such as State Highway 1
California Department of Parks and Recreation, Office of Historic Preservation	Section 106 of the National Historic Preservation Act coordination	Required for any federal permit or project that may adversely affect properties listed or eligible for listing on the National Register of Historic Places; could apply to intake construction in sensitive areas
Regional/Local Agencies		
Central Coast Regional Water Quality Control Board	National Pollutant Discharge Elimination System (NPDES) general permit for storm water discharges associated with construction activity	Required for stormwater discharges associated with construction activity over 1 acre
	Section 402 of the Clean Water Act, NPDES permit amendment	Required for discharge of brine into the city's wastewater treatment plant outfall; the city's existing NPDES permit would be modified to address the addition of brine to the outfall
	Section 401 of the Clean Water Act, water quality certification	Required for Section 404 permits (discharge of dredged fill) to certify that the activity meets water quality standards; may also be required for a Section 10 permit

County of Santa Cruz	Local land use, design, and construction permits	Required if the project will encroach upon any portion of a County of Santa Cruz right-of-way
City of Capitola		Required if the project will encroach upon any portion of a City of Capitola right-of-way
City of Santa Cruz		Required if the project will encroach upon any portion of a City of Santa Cruz right-of-way

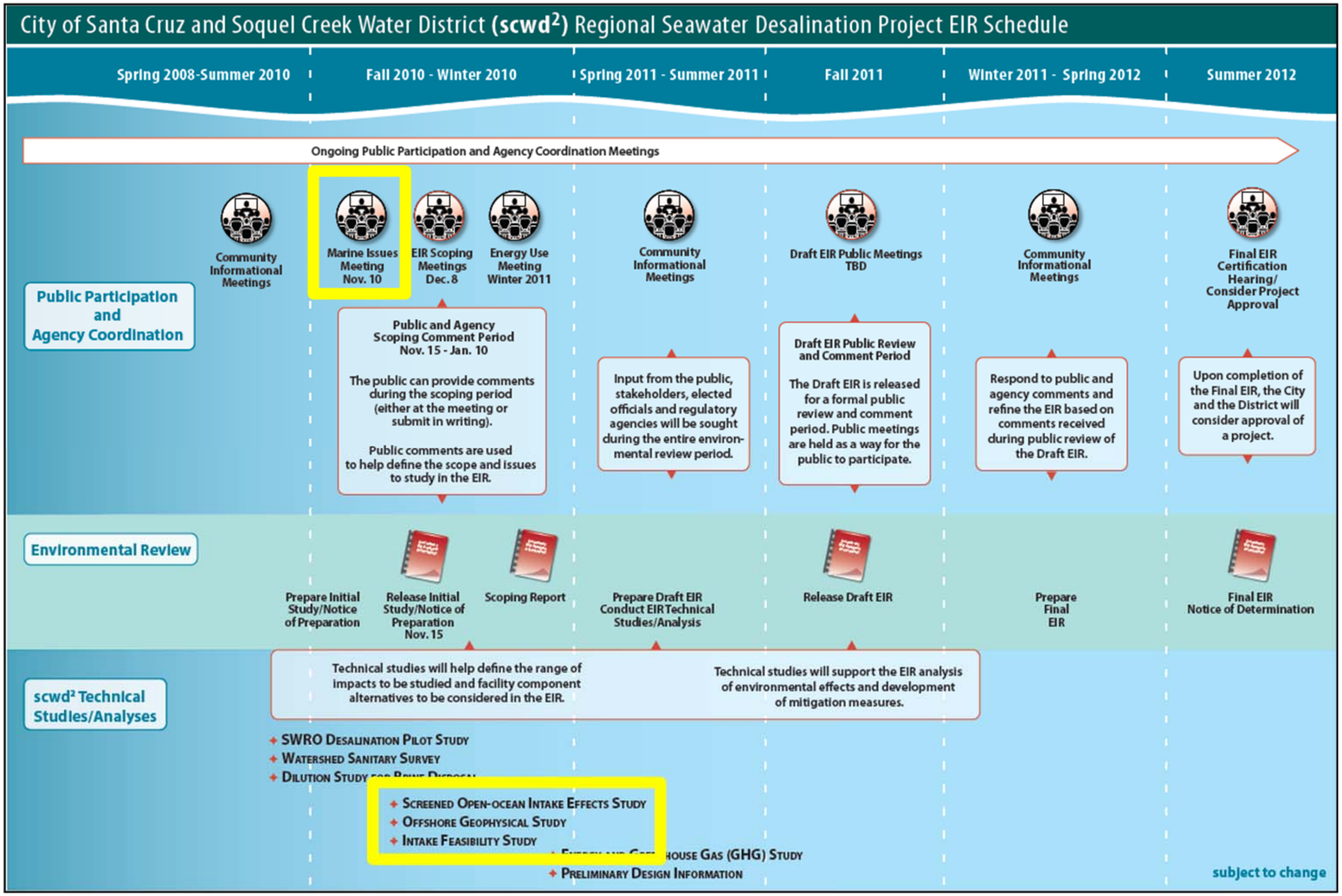


Figure 9.1. Detailed EIR schedule for SCWD project.

Source: courtesy SCWD², URS Corp., and CirclePoint

Note: Intake-related steps appear in yellow boxes.

9.2.3.2 Carlsbad Desalination Plant

The following section describes, as an example, the intake permitting process for the CDP. The CDP has been under development since 1998 and is proposed as a co-located facility, drawing feed water from the cooling water discharge conduit at the Encina Power Station (EPS). The permitted intake capacity of the EPS is 857 MGD. The CDP would draw approximately 100 MGD from the discharge of the power plant for use as feed water. Of the 100 MGD, approximately 50 MGD of potable water would be produced and 50 MGD rejected as concentrated brine. Although the CDP would be drawing feed water from the cooling water already being used by the EPS, it was required to investigate the impacts of a 304-MGD intake in the event that it is operated as a stand-alone facility (i.e., the EPS is decommissioned in the future or forced to retrofit to closed-cycle cooling). The extra intake capacity required by the CDP in this scenario is for dilution of the concentrated brine prior to discharge back to the Pacific Ocean.

The intake-related permitting issues for the CDP have been extensive. Poseidon, the project proponent, has been required to respond to concerns of the CCC, SWRCB, and RWQCB over the potential IM&E impacts. Each of these entities, the charge of which it is to protect the resources of California, also receives substantial feedback from nonprofit environmental groups with concerns over impacts to marine life.

In 2005, as part the EIR, Poseidon completed (Tenera, 2005) an assessment of the incremental increases to IM&E that can be expected because of the CDP intake operation in the EPS discharge stream. Because the CDP intake would not require any increase in flow at the EPS intake, IM would not change. Relative to entrainment, because through-condenser survival at the EPS is estimated at 2.4%, the incremental increase in entrainment losses attributable to the CDP intake would be between 0.01 and 0.28% of the ambient larval densities in the source water.

The timing of the major permits and approvals was as follows:

- final EIR certified and City of Carlsbad conditional use permit approved June 13, 2006
- NPDES approved August 16, 2006, and amended May 13, 2009
- conditional drinking water permit approved October 19, 2006
- coastal development permit approved November 15, 2007
- CDP permit conditions approved August 6, 2008
- lease application approved August 22, 2008
- construction initiated November 2009

Thirteen legal challenges were filed against the CDP in the 3 years following the issuance of the EIR. The final challenge came from the Surfrider Foundation, which claimed that the intake did not meet California Water Code because it did not represent the best site, design, and mitigation for minimizing impacts to marine life (Pankratz, 2011). That challenge and all of the preceding challenges were unsuccessful, and all of the project's permits and approvals were upheld. Given the persistent environmental concerns associated with IM&E, Poseidon was required to prepare a plan for stand-alone operation of the existing intake system in the event that the EPS ceases OTC. Poseidon Resource Corporation (2009) submitted a final flow, entrainment, and impingement minimization plan to address the questions of how the intake would be operated for a stand-alone desalination facility. As the final regulatory approvals, San Diego RWQCB issued amendments to Poseidon's NPDES permit in 2009 to operate a co-located facility that uses effluent from EPS as feed water and discharge concentrated brine into the power plant's discharge stream.

Since 2009, additional project delays have resulted from issues related to capital financing and pricing negotiations. A final water purchase agreement was approved by the San Diego County Water Authority in late Novemeber of 2012. Shortly after, project financing was secured in late December of 2012 and construction began.

As is evident in this example, permitting desalination facilities in California, particularly large ones that will be co-located with power plants, is a time-intensive proposition. For comparison, the permitting of the co-located 25 MGD Tampa Bay seawater desalination plant took only 18 months.

Chapter 10

Conclusion

This Guidance Document provides information to aid the desalination industry in utilizing existing seawater intakes for desalination purposes. Furthermore, details were provided on the intake technologies and modifications that have potential for mitigating IM&E of marine organisms. If existing intakes can be modified for desalination use, the seawater desalination industry may realize reduced capital costs associated with the construction of new intakes.

There are a number of steps involved in determining the potential for modifying existing intakes to meet environmental protection goals. First, the existing literature can often provide comprehensive background information on the empirical or theoretical efficacy of many of the most popular intake technologies; however, it is important to keep in mind that the performance of any intake technology can be very species- and site-specific. Next, consideration must be given to the state and federal regulatory framework that dictates the requisite biological performance criteria of seawater intake systems. In most cases, federal 316(b) standards are likely to be applied to seawater desalination facilities; however, state permit writers are given discretion to implement more stringent standards. For that reason, early and frequent coordination with state permitting and resource authorities is crucial to ensure an efficient regulatory process.

When considering which existing intakes may be appropriate for modification, it is necessary to consider each operational and structural detail of the existing intake because they will dictate the feasibility and potential success of a modification. A developer must carefully assess the intake's location, the existing screening technology employed and its biological effectiveness, intake velocity, intake capacity, and operational status. The intakes that offer the greatest potential to desalination developers are those used in the power generation industry. Furthermore, when considering only the capital costs (i.e., not accounting for environmental and regulatory costs), the intakes with the highest potential for cost-effective modification are those requiring the least structural modification. To that end, the existing intakes that represent the greatest opportunity to a desalination developer are decommissioned CWIS with sufficient capacity to produce the volume of feed water required and co-location at an existing CWIS that is undergoing an intake upgrade.

The location of an intake will also affect its potential to impinge or entrain organisms. An offshore intake withdrawal point has potential to reduce IM&E impacts because of its location in water that is potentially less productive, whereas intakes located at the shoreline are generally considered to be more likely to have potential IM&E impacts because they are in areas of greater biological productivity (e.g., spawning and nursery areas are typically near shore or in marshes and tributaries). A locational benefit is typically accepted for an intake located offshore when considering 316(b).

Once an existing intake is identified for modification, the proper intake technology must be selected to meet the IM&E standards. There are various intake technologies available for meeting the target IM&E reduction standards. Selecting the BTA is very site-specific; therefore, it is critical to understand the location, design, construction, and capacity of the intake being considered for modification. In addition, selecting the BTA is very species- and life stage–specific. The intake technologies that have the greatest potential to minimize IM&E impacts are those that focus on protecting the dominant species near the intake. The intake technologies selected must also be effective for multiple life stages: protecting adults and juveniles from IM and eggs and larvae from entrainment. Entrainment minimization is particularly important in states such as California that place a heavy regulatory emphasis on minimizing losses of early life stages of marine organisms. To be conservative, a developer should expect to be held to a stringent entrainment standard and evaluate intake technologies that are effective for minimizing entrainment. Of the behavioral, exclusion, collection, and diversion technologies available, those that generally hold the greatest potential for addressing entrainment are exclusion (e.g., CWWS) and collection (e.g., TWS) technologies. Systems in these groups also represent those most commonly used, most frequently evaluated, most often accepted by permitting authorities, and most likely to offer the greatest protection to multiple species.

The potential of each intake alternative to minimize IM&E often becomes the driving criterion in the technology selection process; however, determining *a priori* the level of protection any given technology will provide is difficult. When available, empirical performance data from full-scale installations with similar species and life stages of organisms should always be relied on to determine a technology's potential for meeting the target IM&E standard. If no empirical performance data are available, the potential biological efficacy (i.e., exclusion and survival) can be estimated for candidate intake technologies. After an intake has been modified, verification monitoring can demonstrate its biological performance. The performance is typically measured as a reduction in IM&E by calculating the difference before and after the intake modification is made. The use of demographic models and other modeling approaches puts the IM&E impacts into the context of how populations may be affected by intake operations.

State-of-the-art intake technologies are designed to reduce potential environmental impacts and meet regulatory standards; however, intake modifications must also be cost-effective for desalination facilities. Modifying existing intakes (versus building new) should provide a financial benefit, although costs can vary considerably in accordance with intake design. Information was provided in this Guidance Document to illustrate how the costs can vary based on the type of intake being modified and the intake technology selected.

This Guidance Document provides information on the intake technologies and modifications that have potential for mitigating IM&E of marine organisms at existing seawater intake structures. If existing intakes can be modified for desalination use, the seawater desalination industry can realize reduced capital costs associated with constructing new intakes.

References

Alden Research Laboratory, Inc. (Alden). Laboratory Evaluation of Hydrolox Screens. Prepared for Hydrolox, Inc., 2006.

Alden Research Laboratory, Inc. (Alden). Laboratory Evaluation of the Filtrex Filter System for Protecting Ichthyoplankton at a Desalination Facility Intake. Prepared for Epsilon Associates, Inc., 2007.

Alden and Stone & Webster Engineering Corporation. Evaluation of the Modular Inclined Screen (MIS) at the Green Island Hydroelectric Project: 1996 Test Results. Prepared for Niagara Mohawk Power Corporation and New York State Energy Research and Development Authority, 1996.

Applied Science Associates (ASA). Gunderboom MLES™ Evaluation Study at the Lovett Generating Station. Results of 2004 Biological Monitoring. Final Report. Prepared for Mirant Lovett, LLC, 2004.

ASA. Gunderboom MLES™ Evaluation Study at the Lovett Generating Station. Results of 2005 Biological Monitoring. Final Report. Prepared for Mirant Lovett, LLC, 2006a.

ASA. Gunderboom MLES™ Evaluation Study at the Lovett Generating Station. Results of 2006 Biological Monitoring. Final Report. Prepared for Mirant Lovett, LLC, 2006b.

ASA. Evaluation of Impingement Survival on the Hydrolox™ Traveling Water Screen at the E. F. Barrett Generating Station October 2007–June 2008: Final Report, 2008.

Auer, N. A., Ed.; *Identification of Larval Fishes of the Great Lakes Basin with Emphasis on the Lake Michigan Drainage.* Great Lakes Fisheries Commission, Special Publication 82-3, 1982.

Bailey, D. E. Effectiveness, Operation and Maintenance, and Costs of a Barrier Net System for Impingement Reduction at the Chalk Point Generating Station. In *Proceedings of Symposium on Technologies for Protecting Aquatic Organisms from Cooling Water Intake Structures*. May 6–7, 2003, Arlington, VA. Sponsored by the U.S. Environmental Protection Agency, 2005.

Beck, S.; Miller, E.; Bailey, D.; Steinbeck, J. Quantification of Effectiveness of Velocity Caps. Presented at American Fisheries Society's 137th Annual Meeting, San Francisco, CA. September 2–6, 2007.

Bell, M. C. *Fisheries Handbook of Engineering Requirements and Biological Criteria*. U.S. Army Corps of Engineering. North Pacific Division, Fisheries Engineering Research Program. Portland, OR. National Technical Information Service. U.S. Department of Commerce, 1973.

Bell, M. C.; Nece, R. E.; Porter, R. G. A Report on the Laboratory Examination of a Permeable Dike as a Fish Barrier. Prepared for Consumers Power Company, 1974.

Bengeyfield, W.; Smith, H. A. Evaluation of Behavioral Devices To Divert Coho Salmon Smolts from the Penstock Intake at Puntledge Generating Station. B.C. Hydro Environmental Resources, 1989.

Bigbee, D. L.; King, R. G.; Dixon, K. M.; Dixon, D. A.; Perry, E. S. Survival of fish impinged on a rotary disk screen. *N. Am. J. Fish. Man.* **2010,** *30*, 1420–1433.

Brett, J. R.; MacKinnon, D. Preliminary Experiments Using Lights and Bubbles to Deflect Migrating Young Spring Salmon. *J. Fish. Res. Bd. Canada.* **1953**, *10* (8), 548–556.

Browne, M. E. Preliminary Engineering and Environmental Evaluation of Fine-Mesh Profile Wire as Powerplant Intake Screening. In *Passive Intake Screen Workshop*, Chicago, IL, December 1979.

Brueggemeyer, V.; Cowdrick, D.; Durrell, K.; Mahadevan, S.; Bruzek, D. Full-scale Operational Demonstration of Fine-Mesh Screens at Power Plant Intakes. In *Fish Protection at Steam Electric and Hydroelectric Power Plant*, San Francisco, CA, October 1987.

Bruzek, D.; Mahadevan, S. Fine Mesh Screen Survivability Study, Big Bend Unit 4, Tampa Electric Company. Prepared by Mote Marine Laboratory for Tampa Electric Company, 1986.

California Coastal Commission. Seawater Desalination and the California Coastal Act, 2004.

California Department of Water Resources (CADWR). *California Desalination Planning Handbook.* Prepared by California State University, Sacramento, Center for Collaborative Policy, 2008.

California Ocean Protection Council. Draft California Ocean Protection Council Five-Year Strategic Plan 2012–2017, 2011.

Callaghan, T. Regulatory Framework for Desalination Plants: Massachusetts. Alden Desalination Intake Solutions Workshop, 2008.

Cannesson, N.; Johnstone, P.; Mitchell, M.; Boerlage, S. Community, Environmental and Marine Impact Minimisation at the Gold Coast Desalination Plant. IDA World Congress on Desalination and Water Reuse, The Palm, Dubai, 2009.

Carolina Power and Light. Brunswick Steam Electric Plant Cape Fear River Studies Interpretive Report. Environmental Services Section, August 1985.

Colton, J. B., Jr.; Green, J. R.; Byron, R. R.; Frisella, J. L. Bongo net retention rates as effected by towing speed and mesh size. *Can. J. Fish. Aquatic Sci.* **1980,** *37*, 606–623.

Cooley, H.; Gleick, P. H.; Wolff, G. Desalination with a Grain of Salt: A California Perspective. Prepared by the Pacific Institute for Studies in Development, Environment, and Security, 2006.

Coutant, C. Turbulent Attraction Flows for Guiding Juvenile Salmonids at Dams. In C. Coutant, Ed.; *Behavioral Technologies for Fish Guidance*. American Fisheries Society, Symposium 26, Bethesda, MD, 2001, 57–77.

Craddock, D. R. A Review of Studies in Guiding Downstream Migrating Salmon with Light. In Progress Report on Fisheries Engineering Research Program. U.S. Army, North Pacific Division, Corps of Engineers, Portland, OR, 1–13.

Cramer, S. P.; Demko, D. B.; Van Dyke, E. S. Evaluation of an Acoustical Fish Guidance System. 1993 Annual Report: Evaluation of Sound and Electrical Fish Guidance Systems at the Wilkins Slough Diversion Operated by Reclamation District 118. Prepared by Cramer and Associates, 1993.

Cumbie, P. M.; Banks, J. B. Protection of Aquatic Life in Design and Operation of the Cope Station Water Intake and Discharge Structures. *The Environmental Professional* **1997,** *19,* 178–184.

Danley, M. L.; Mayr, S. D.; Young, P. S.; Cech, J. J., Jr. Swimming Performance and Physiological Stress Responses of Splittail Exposed to a Fish Screen. *N. Am. J. Fish. Man.* **2002,** *22*(4), 1241–1249.

Darland, T. J.; Evans, S. D.; Rondorf, D. W.; Rutz, G. L.; Feil, D. H.; Adams, N. S.; Merrill, C. F.; Serl, J. D. Test of Concept To Improve Fish Guidance Using Induced Water Currents at Cowlitz Falls Dam, Washington. Annual Report for 1999. U.S. Geological Survey, Columbia River Research Laboratory, Cook, WA, 2001.

Davis, R. W.; Matousek, J. A.; Skelly, M. J.; Anderson, M. R. Biological Evaluation of Brayton Point Station Unit 4 Angled Screen Intake. In *Proceedings: Fish Protection at Steam and Hydroelectric Power Plants,* San Francisco, CA, October 28–31, 1987. Sponsored by Electric Power Research Institute, 1988. CS/EA/AP-5663-SR.

Department of Energy (DOE). Energy Technology Engineering Center: Closure Project. http://www.etec.energy.gov/About/Regulations.html (accessed on July 13, 2012).

Detroit Edison Company. Progress Report on Best Available Technology for the Monroe Power Plant. Prepared for submission to the Chief Engineer of the Michigan Water Resources Commission, February 1975.

Ditty, J. G.; Shaw, R. F.; Fuiman, L. A. Larval Development of Five Species of Blenny (Teleostei: Blenniidae) from the Western Central North Atlantic, with a Synopsis of Blennioid Family Characters. *J. Fish Biol.* **2005,** *66*(5), 1261–1284.

Dunning, D. Ultrasound Deterrence: Alewife at a Nuclear Generating Station in New York. In Using Sound To Modify Fish Behavior at Power-Production and Water-Control Facilities: A Workshop, 1997. Sponsored by U.S. Department of Energy and Bonneville Power Administration, 1997, DOE/BP-62611-11.

Dunning, D. J., Ross, Q. E.; Geoghegan, P. G.; Reichle, J. J.; Menezes, J. K.; Watson, J. K. Alewives Avoid High-Frequency Sound. *N. Am. J. Fish. Man.* **1992,** *12,* 407–416.

EA Science and Technology. Results of Entrainment and Impingement Monitoring Studies at the Westchester RESCO Facility, Peekskill, NY. Prepared for Westchester RESCO, 1986.

Ehrler, C.; Raifsnider, C. Evaluation of the Effectiveness of Intake Wedge Wire Screens. In Power Impacts on Aquatic Resources Conference, Atlanta, GA, April 12–15, 1999. Sponsored by Electric Power Research Institute, 1999.

Electric Power Research Institute (EPRI). Assessment of Downstream Migrant Fish Protection Technologies for Hydroelectric Application, 1986a. EPRI AP-4711.

EPRI. Research Coordination for Field Testing of Cooling Water Intake Systems, Annual Report, 1986b. EPRI RP2214-4 1985.

EPRI. Fish Protection Systems for Hydro Plants: Test Results, 1990. EPRI GS-6712.

EPRI. Biological Evaluation of a Modular Inclined Screen for Protecting Fish at Water Intakes, 1994a. EPRI TR-104121.

EPRI. Research Update on Fish Protection Technologies for Water Intakes, 1994b. EPRI TR-104122.

EPRI. Evaluation of the Modular Inclined Screen (MIS) at the Green Island Hydroelectric Project: 1995 Test Results, 1996. EPRI TR-106498.

EPRI. Review of Downstream Fish Passage and Protection Technology Evaluations and Effectiveness, 1998. EPRI TR-111517.

EPRI. Fish Protection at Cooling Water Intakes: Status Report, 1999. EPRI TR-114013.

EPRI. Evaluation of Angled Bar Racks and Louvers for Guiding Fish at Water Intakes, 2001. EPRI TR-1005193.

EPRI. Development and Design of a Cooling Water Intake Structure Database. Palo Alto, CA, 2002. EPRI TR-1005497.

EPRI. Laboratory Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes. Palo Alto, CA, 2003. EPRI TR-1005339.

EPRI. Laboratory Evaluations of an Aquatic Filter Barrier (AFB) for Protecting Early Life Stages of Fish. Palo Alto, CA, 2004. EPRI TR-1005534.

EPRI. Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes. Palo Alto, CA, 2005. EPRI TR- 1010112.

EPRI. Laboratory Evaluation of Modified Ristroph Traveling Screens for Protecting Fish at Cooling Water Intakes. Palo Alto, CA, 2006. EPRI TR-1013238.

EPRI. Fish Protection at Cooling Water Intake Structures: A Technical Reference Manual. 2007a. EPRI TR-1014934.

EPRI. Latent Impingement Mortality Assessment of the Geiger Multidisc™ Screening System at the Potomac River Generating Station. 2007b. EPRI 1013065.

EPRI. Laboratory Evaluation of Fine-Mesh Traveling Water Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes. Palo Alto, CA, 2008. EPRI Technical Update #1014021.

EPRI. Beaudrey Water Intake Protection (WIP) Screen Pilot-Scale Impingement Survival Study. Palo Alto, CA, 2009a. EPRI TR-1018490.

EPRI. Laboratory Evaluation of 2.0 mm Fine-Mesh Traveling Screens for Protection of Larval Fish: Exclusion and Survival Studies—2009 Preliminary Findings. Palo Alto, CA, 2009b. EPRI Technical Update #1020663.

EPRI. Laboratory Evaluation of Fine-Mesh Traveling Water Screens. Palo Alto, CA, 2010. EPRI TR-1019027.

EPRI. National and Regional Summary of Impingement and Entrainment of Fish and Shellfish Based on an Industry Survey of Clean Water Act §316(b) Characterization Studies. Palo Alto, CA, 2011. EPRI TR-1019861.

Empire State Electric Energy Research Corporation. Laboratory Evaluation of Fine-Mesh Screening for the Protection of Fish Larvae at Intakes. EP 8–6. Prepared by Alden Research Laboratory and Stone & Webster Engineering Corporation, 1981.

Envirex, Inc. Fish Survival Enhancement with Envirex Non-Metallic Fish Baskets and Improved Fish Spray Wash Design. Envirex, Inc., Waukesha, WI, 1996.

Environmental Protection Agency (EPA). Development Document for Best Technology Available for the Location, Design, Construction, and Capacity of Cooling Water Intake Structures for Minimizing Adverse Environmental Impact. EPA 440/1-76/015a. Washington, DC, 1976.

EPA. Guidance for Evaluating the Adverse Impact of Cooling Water Intake Structures on the Aquatic Environment: Section 316(b) [Draft]. Office of Water, Washington, DC, 1977.

EPA. Economic and Benefits Analysis for the Proposed Section 316(b) Phase II Existing Facilities Rule. U.S. EPA Office of Sci. and Tech., Eng. and Analysis Div., Washington, DC, February 28, 2002a.

EPA. Case Study Analysis for the Proposed Section 316(b) Phase II Existing Facilities Rule. U.S. EPA Office of Sci. and Tech., Eng. and Analysis Div., Washington, D.C., February 28, 2002b.

EPA. National Pollutant Discharge Elimination System—Final Regulations To Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities. Fed. Reg. 69(131), July 9, 2004a, 41576–41693.

EPA. Chapter 4: Efficacy of Cooling Water Intake Structure Technologies. In Technical Development Document for the Final Section 316(b) Phase II Existing Facilities Rule, 2004b. http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/phase2/devdoc_final.cfm (accessed February 22, 2012).

EPA. National Pollutant Discharge Elimination System—Cooling Water Intake Structures at Existing Facilities and Phase I Facilities. Fed. Reg. 76(76), April 20, 2011.

EPA. General Permit for Discharges from the Offshore Subcategory of the Oil and Gas Extraction Point Source Category to the Territorial Seas off Texas. Permit No. TXG260000, 2012.

Executive Office of Energy and Environmental Affairs (EOEEA). About MEPA. http://www.mass.gov/eea/agencies/mepa/about-mepa/ (accessed on July 13, 2012).

EOEEA. Desalination Policy Draft July 2007. Commonwealth of Massachusetts, 2007.

EOEEA. Siting and Monitoring Protocols for Desalination Plants. July 2008. Commonwealth of Massachusetts, 2008.

Feist , B.E.; Anderson, J.J. Review of Fish Behavior Relevant to Fish Guidance Systems. Fisheries Research Institute, School of Fisheries WH-10, University of Washington, Seattle, WA, 1991. FRI-UW-9102

Fletcher, R. I. Flow Dynamics and Fish Recovery Experiments: Water Intake Systems. *Trans. Am. Fish. Soc.* **1990,** *119,* 393–415.

Goetz, F. A.; Dawson, J. J.; Shaw, T.; Dillon, J. Evaluation of Low-Frequency Underwater Sound Transducers for Guiding Salmon away from a Navigation Lock. *American Fisheries Society Symposium*. **2001**, *26*, 91–104.

Gordon, H. F.; Viskovich, P. G.; Thompson, A. L.; Costanzo, S. D.; West, E. J.; Boerlage, S. F. E. Impacts of Desalination on the Marine Environment—Some Significant Benefits. IDA World Congress, Perth, Western Australia, 2011.

Grotbeck, L. B. Evaluation of an Air Curtain as a Fish Deterrent Device at Prairie Island Generating Plant Cooling Water Intake. Northern States Power, 1975 Annual Report, Environmental Monitoring and Ecological Studies Program, Prairie Island Nuclear Generating Plant, 1975, II, 2.8-1–2.8-25.

Gulvas, J. A.; Zeitoun, I. H. Cylindrical Wedge Wire Screen Investigations in Offshore Lake Michigan for the J. H. Campbell Plant, 1979. In *Passive Intake Screen Workshop*, Chicago, IL, December 1979.

Hanson, B. N.; Bason, W. H.; Beitz, B. E.; Charles, K. E. A Practical Intake Screen which Substantially Reduces Entrainment. In Johnson, L. D., Ed.; *Fourth National Workshop on Entrainment and Impingement,* Chicago, IL, December 5, 1977. Sponsored by Ecological Analysts, 1978.

HDR, Inc. Entrainment Effects of the Haverstraw Water Supply Project; September 2008. Republished in Appendix 9A.2 of the Haverstraw Water Supply Project Draft Environmental Impact Statement; United Water New York, Inc.: Rockland, NY, January 13, 2012.

Henderson, P. A.; Seaby, R. M.; Cailes, C.; Somes, J. R. Gunderboom Fouling Studies in Bowline Pond. Prepared by Pisces Conservation, Ltd., 2001.

Heuer, J. H.; Tomljanovich, D. A. A Study on the Protection of Fish Larvae at Water Intakes Using Wedge-Wire Screening. TVA Technical Note B26, 1978.

Hogarth, W. T.; Nichols, K. Brunswick Steam Electric Plant Intake Modifications To Reduce Entrainment and Impingement Losses. Carolina Power and Light, New Hill, NC, 1981.

Hutchinson, J. B., Jr.; Matousek, J. A. Evaluation of a Barrier Net Used To Mitigate Fish Impingement at a Hudson Power Plant Intake. *Am. Fish. Soc. Monogr.* **1988,** *4,* 280–285.

Ichthyological Associates. An Evaluation of the Effectiveness of the Strobe Light Deterrent System at Milliken Station Cayuga Lake, Tomkins County, NY. New York State Electric and Gas Corporation, 1994.

Ichthyological Associates. An Evaluation of Fish Entrainment and Effectiveness of the Strobe Light Deterrent System at Milliken Station Cayuga Lake, Tomkins County, NY. New York State Electric and Gas Corporation, 1997.

Johnson, C.; Ettema, R. Passive Intake System for Shallow Sand-Bed River. *J. Hydraul. Eng.* **1988,** *114,* 662–674.

Johnson, L.; Thomas, G. L.; Thorne, R. E.; Acker, W. C. A Field Examination of the Effectiveness of a Velocity Cap in Minimizing Entrapment. University of Washington College of Fisheries, Fisheries Research Institute Report FRI-UW-7928. Prepared for Southern California Edison, 1980.

Kalmijn, A. J. Hydrodynamic and Acoustic Field Detection. In Atema, J.; Fay, R. R.; Popper, A. N.; Tavolga, W. N., Eds.; *Sensory Biology of Aquatic Animals*. Springer-Verlag: New York, 1988, pp 83–130.

Kelley, A. H. A Call for Consistency: Open Seawater Intakes, Desalination, and the California Water Code. *Golden Gate University Environmental Law Journal* **2011,** *4,* 277–301.

Ketschke, B. A. Field and Laboratory Evaluation of the Screening Ability of a Porous Dike. In Dorn, P. B.; Johnson, J. T., Eds.; *Advanced Intake Technology for Power Plant Cooling Water Systems*. 1981, pp 84–90.

Knudsen, F. R.; Enger, P. S.; Sand, O. Awareness Reactions and Avoidance Responses to Sound in Juvenile Atlantic Salmon, *Salmo salar*. *J. Fish Biol.* **1992,** *40,* 523–534.

Knudsen, F. R.; Enger, P. S.; Sand, O. Avoidance Responses to Low Frequency Sound in Downstream Migrating Atlantic Salmon Smolt, *Salmo salar. J. Fish Biol.* **1994.** *45,* 227–233.

Kupfer, G. A.; Gordon, W. G. An Evaluation of Air Bubble Curtain as a Barrier to Alewives. *Commercial Fisheries Review* **1966,** *28*(9), 1–9.

Latvaitis, R. W.; Berhard, H. F.; McDonald, D. B. Impingement Studies at Quad-Cities Station, Mississippi River. In Jensen, L. D., Ed.; *Proceedings of the Third National Workshop on Entrainment and Impingement,* New York, NY, February 24, 1976.

Lawler, Matusky & Skelly Engineers (LMS). Fish Protective Intake Test Facility: Angled Screen Diversion Study. Prepared for Empire State Electric Energy Research Corporation, 1985.

LMS. Intake Technology Review Oswego Steam Station Units 1–6. Prepared for Niagara Mohawk Power Corporation, April 1992.

LMS. Effectiveness Evaluation of a Fine-Mesh Barrier Net Located at the Cooling Water Intake of the Bowline Point Generating Station. Orange and Rockland Utilities, Inc., 1994.

LMS. Lovett Generating Station Gunderboom Evaluation Program 1995. Prepared for Orange and Rockland Utilities, Inc., 1996.

LMS. Lovett Generating Station Gunderboom Evaluation Program 1996. Prepared for Orange and Rockland Utilities, Inc., 1997.

LMS. Lovett Generating Station Gunderboom System Evaluation Program 1998. Prepared for Orange and Rockland Utilities, Inc., 1998.

LMS. Lovett Generating Station Gunderboom Deployment Program 2000. Prepared for Mirant, New York, Inc., 2001.

Lee, D. A Porous Dike Structure for Reducing Fish Impingement at a Power Plant. Presented at the 141st Annual Meeting of the American Fisheries Society, Washington State Convention Center, Seattle, WA, September 4–8, 2011.

Lenarz, W. H. Mesh retention of *Sardinops caerulea* and *Engraulis mordax* by plankton nets. *Fish. Bull. U.S.* **1972,** *70*, 839–848.

Lifton, W. Biological Aspects of Screen Testing on the St. Johns River, Palatka, FL. In *Passive Intake Screen Workshop*, Chicago, IL, December 1979.

Lifton, W. S.; Storr, J. F. The Effect of Environmental Variables on Fish Impingement. In Jensen, L. D., Ed.; *Proceedings of the Fourth National Workshop on Entrainment and Impingement.* EA Communications, 1978. ISBN: 0-931842-01-8.

Loar, J. M.; Griffith, J. S.; Kumar, K. D. An Analysis of Factors Influencing the Impingement of Threadfin Shad at Power Plants in the Southeastern United States. In Jensen, L. D., Ed.; *Fourth National Workshop on Entrainment and Impingement*. EA Communications: Melville, NY, 1978, pp 245–255.

Maes, J.; Turnpenny, A. W. H.; Lambert, D. R.; Nedwell, J. R.; Parmentier, A.; Ollevier, F. Field Evaluation of a Sound System To Reduce Estuarine Fish Intake Rates at a Power Plant Cooling Water Inlet. *J. Fish Biol.* **2004,** *64,* 938–946.

Malcolm Pirnie. Permit Requirements Technical Memorandum: Final, May 2011. Prepared for Coquina Coast Seawater Desalination Project, 2011.

Martin Marietta Environmental Systems. Effects of Screen Slot Size, Screen Diameter, and Through-Slot Velocity on Entrainment of Estuarine Ichthyoplankton Through Wedge-Wire Screens. Prepared for Maryland Department of Natural Resources, Annapolis, MD, 1984. PB85-185379.

Matousek, J. A.; Wells, A. W.; McGroddy, P. M.; Daley, M. W.; Micheletti, W. C. Biological Evaluation of Behavioral Barrier Devices at a Power Plant Intake Located on the Hudson River. In *Proceedings: Fish Protection at Steam and Hydroelectric Power Plants,* San Francisco, CA, October 28–30, 1987. Electric Power Research Institute, 1988. CS/EA/AP-5663-SR.

MBC Applied Environmental Sciences, Tenera Environmental, and URS Corporation. Final Report: Scattergood Generating Station Clean Water Action Section 316(b) Velocity Cap Effectiveness Study. Prepared for the City of Los Angeles, Department of Water and Power, June 28, 2007a.

MBC Applied Environmental Sciences, Tenera Environmental, and URS Corporation. Final Report: Harbor Generating Station Clean Water Action Section 316(b) Impingement Mortality and Entrainment Characterization Study. Prepared for the City of Los Angeles, Department of Water and Power, December 26, 2007b.

MBC Applied Environmental Sciences, Tenera Environmental, Bonterra Consulting, and URS Corporation. Characterization Baseline Study Report. Prepared for the City of Los Angeles Department of Water and Power, October 7, 2010.

McMillen, M. D.; Smith, C. W. Comparison of Water Backwash and Brush Cleaning Systems for Vertical Panel Fish Screens. In North American Water and Environmental Congress, New York, NY, 1996. Sponsored by American Society of Civil Engineers.

Michaud, D. T. Wisconsin Electric's Experience with Porous Dike and Leaky Dam Intake Structures on Lake Michigan. In Dorn, P. B.; Johnson, J. T., Eds.; *Advanced Intake Technology for Power Plant Cooling Water Systems,* 1981.

Monterey Bay National Marine Sanctuary and National Oceanic and Atmospheric Administration. Guidelines for Desalination Plants in the Monterey Bay National Marine Sanctuary, 2010.

Moser, H. G., Ed.; *The Early Stages of Fishes in the California Current Region. California Cooperative Oceanic Fisheries Investigations Atlas,* 1996, *33.* ISBN 0-935868-82-8. 1505 pp

Murdoch, W. W.; Fay, R. C.; Mechalas, B. J. Final Report of the Marine Review Committee to the California Coastal Commission. MRC Doc. No. 89-02. August 1989.

National Marine Fisheries Service. Fish Screening Criteria for Anadromous Salmonids. Southwest Region, January 1997.

Neitzel, D. A.; Abernethy, C. S.; Lusty, E. W. Evaluation of rotating drum screen facilities in the Yakima River Basin, South-Central Washington State. In Fisheries Bioengineering Symposium, *Am. Fish. Soc. Symp.* **1991,** *10*.

Nemeth, J. M.; Anderson, J. J. Response of Juvenile Coho and Chinook Salmon to Strobe and Mercury Vapor Lights. *N. Am. J. Fish. Man.* **1992,** *12,* 684–692.

Nestler, J. M.; Ploskey, G. R.; Pickens, J.; Menezes, J.; Schilt, C. Responses of Blueback Herring to High-Frequency Sound and Implications for Reducing Entrainment at Hydropower Dams. *N. Am. J. Fish. Man.* **1992,** *12,* 667–683.

New York State Department of Environmental Conservation. CP-#52/Best Technology Available (BTA) for Cooling Water Intake Structures. New York State Department of Environmental Conservation DEC Policy, 2011.

Nieder, W. C. The Relationship Between Cooling Water Capacity Utilization, Electric Generating Capacity Utilization, and Impingement and Entrainment at New York State Steam Electric Generating Facilities. New York State Department of Environmental Conservation Technical Document. Albany, NY, July 2010.

Normandeau Associates, Inc. (NAI). Evaluation of a Cylindrical Wedge-Wire Screen System at Beal Lake, AZ 2006. Prepared for the U.S. Bureau of Reclamation, Lower Colorado Regional Office, Boulder City, NV, 2007a.

NAI. Filtrex Filter System Taunton River Field Test Program. Prepared for Inima USA Corporation, 2007b.

NAI. 2010 IPEC Wedgewire Screen Laboratory Study. Prepared for the Indian Point Energy Center, Buchanan, NY, 2011a.

NAI. 2011 IPEC Wedgewire Screen Laboratory Study. Prepared for the Indian Point Energy Center, Buchanan, NY, 2011b.

NRS Consulting Engineers (NRS). Feasibility and Pilot Study: South Padre Island Seawater Desalination Project: Final Report. Prepared for Laguna Madre Water District and the Texas Water Development Board, 2010.

NRS. Texas Desal Project. Prepared for the Texas Water Development Board, 2011.

Oregon Department of Fish and Wildlife. Fish Screening and Passage Program: Fish Screening Criteria, 2006.

Osenberg, C.; Schmitt, R.; Holbrook, S.; Abu-Saba, K.; Flegal, A. Detection of Environmental Impacts: Natural Variability, Effect Size and Power Analysis. In Schmitt, R.; Osenberg, C., Eds.; *Detecting Ecological Impacts. Concepts and Applications in Coastal Habitats*. Academic Press, 1996, pp 83–108.

Owen, C. Regulatory Considerations in the Permitting of Seawater Desalting Facilities. *Florida Water Resources Journal* April 2011, 6–8.

Pankratz, T., Ed.; Acoustics, Screens Keep Fish Out. In *Water Desalination Report* **2009**, *45*(8), 1.

Pankratz, T., Ed.; Last Remaining Legal Challenge Ended. In *Water Desalination Report* **2011,** *47*(27), 2.

Pankratz, T., Ed.; Desal Through the Looking Glass. In *Water Desalination Report* **2012,** *48*(6), 2–3.

Patrick, P. H. Responses of Fish to Air Bubble Barriers. Ontario Hydro Research Division, 1982. Report number 82-362-K.

Patrick, P. H.; McKinley, R. S.; Micheletti, W. C. Field Testing of Behavioral Barriers for Cooling Water Intake Structures — Test Site I — Pickering Nuclear Generating Station — 1985/86. Electric Power Research Institute, 1988. CS/EA/AP-5663-SR.

PBS&J. Tampa Bay Desalination Facility Hydrobiological Monitoring Data Summary 2002-2010. Prepared for Tampa Bay Water, 2010.

Pearce, R. O.; Lee, R. T. Some design considerations for approach velocities at juvenile salmonid screening facilities. In Fisheries Bioengineering Symposium. *Am. Fish. Soc.* **1991,** *10,* 237–248.

Pender, J. J., Jr. Fish Entrainment Problem at Scattergood Steam Plant. California State Polytechnic University, Pomona, 1975. 105 pp.

Port, C.; Roddy, S.; Trousdale, S. Sydney's SWRO Project—Working Towards Sustainability. *Int. Desal. Water Reuse Q.* **2009,** *18*(4), 21–33.

Poseidon Resource Corporation. Carlsbad Seawater Desalination Project. Flow, Entrainment, and Impingement Minimization Plan. Prepared for San Diego Regional Water Quality Control Board, Region 9, San Diego Region, 2009. Order No. R-9-2006-0065, NPDES No. CA0109223.

Public Service Gas and Electric (PSEG). Biological Efficacy of Intake Structure Modifications. PSE&G Renewal Application Salem Generating Station, 1999. Permit No. NJ0005622.

PSEG. Salem Generating Station NPDES Permit No. NJ0005622—Custom Requirement G.9.b.ii—Entrainment Extrusion Studies Task #1, Morphometric Analysis, 2002.

PSEG. Phase 2 Report Custom Requirement G.5 Multi-sensory Hybrid Intake Protection Technology Feasibility Study Section 316(b) Special Condition. Prepared by Alden Research Laboratory and Skalski Statistical Services, 2005.

Radle, E. Experiments with Exposure of American Shad Eggs and Larvae to the Gunderboom Marine Life Exclusion System. Memorandum, July 25, 2001.

Ronafalvy, J. P. Circulating Water Traveling Screen Modifications To Improve Impinged Fish Survival and Debris Handling at Salem Generating Station. *Proceedings of the EPRI/DOE Power Generation Impacts on Aquatic Resources Conference,* Atlanta, GA, 1999.

Ross, Q. E.; Dunning, D. J.; Thorne, R.; Menezes, J. K.; Tiller, G. W.; Watson, J. K. Response of Alewives to High-Frequency Sound at a Power Intake on Lake Ontario. *N. Am. J. Fish. Man.* **1993,** *13,* 291–303.

Ross, Q. E.; Dunning, D. J.; Menezes, J. K.; Kenna, M. J., Jr.; Tiller, G. Reducing Impingement of Alewives with High Frequency Sound at a Power Plant on Lake Ontario. *N. Am. J. Fish. Man.* **1996,** *16,* 548–559.

Schneeberger, P. J.; Jude, D. J. Use of fish larva morphometry to predict exclusion capabilities of small-mesh screens at cooling-water intakes. *Trans. Am. Fish. Soc.* **1981,** *110,* 246–252.

Schuler, V. J. Experimental Studies in Guiding Marine Fishes of Southern California with Screens and Louvers. Prepared for Southern California Edison by Ichthyological Associates, Inc., 1973.

Schuler, V. J.; Larson, L. E. Improved Fish Protection at Intake Systems. *J. Environ. Eng. Div.: Proc. ASCE* **1975,** *101* (EE6), 897–910.

Smith, L. W.; Ferguson, D. J. Cleaning and clogging tests of passive intake screens in the Sacramento River, CA. In *Passive Intake Screen Workshop*, Chicago, IL, December 1979.

Smith, P. E.; Counts, R. C.; Clutter, R. I. Changes in Filtering Efficiency of Plankton Nets Due to Clogging Under Tow. *ICES J. Marine Sci.* **1968,** *32,* 232–248.

Smith-Root. Fish Barriers and Guidance. Product manual. 2012, 29 pp.

Sonny, D.; Knudsen, F. R.; Enger, P. S.; Kvernstuen, T.; Sand, O. Reactions of Cyprinids to Infrasound in a Lake at the Cooling Water Inlet of a Nuclear Power Plant. *J. Fish Biol.* **2006,** 69, 735–748.

Sparks, R. E.; Barkley, T. L.; Creque, S. M.; Dettmers, J. M.; Stainbrook, K. M. Evaluation of an Electric Fish Dispersal Barrier in the Chicago Sanitary and Ship Canal. In Chapman, D. C.; Hoff, M. H., Eds.; *Invasive Asian carps in North America*. American Fisheries Society Symposium 74, Bethesda, MD. 2011, 139–161.

State Water Resources Control Board (SWRCB). California Ocean Plan Triennial Review Workplan 2011–2013. Issue 4: Desalination Facilities and Brine Disposal. Draft issued March 1, 2011.

SWRCB. Ocean Standards. Desalination and Brine Disposal, 2012. http://www.swrcb.ca.gov/water_issues/programs/ocean/desalination/. Accessed on February 8, 2012.

SWRCB. Porter-Cologne Water Quality Control Act. 2013.

Steinbeck, J. S.; Hedgepeth, J.; Raimondi, P.; Cailliet, G.; Mayer, D. Assessing Power Plant Cooling Water Intake System Impacts. Prepared for the California Energy Commission, 2007. CEC-700-2007-010.

Stewart, P. A. M. An Investigation into the Reactions of Fish to Electrified Barriers and Bubble Currents. *Fish. Res.* **1982,** *1,* 3–22.

Stone & Webster Engineering Corporation. Studies To Develop an Intake Design for Reducing Entrainment Losses, Unit No. 4 Big Bend Station. Prepared for Tampa Electric Company, 1980.

Swanson, C.; Young, P. S.; Cech, J. J., Jr. Close Encounters with a Fish Screen: Integrating Physiological and Behavioral Results To Protect Endangered Species in Exploited Ecosystems. *Trans. Am. Fish. Soc.* **2005,** *134*(5), 1111–1123.

Taft, E. P.; Mussalli, Y. G. Angled Screens and Louvers for Diverting Fish at Power Plants. *J. Hydraul. Div.* May 1978, 13731: HY5.

Taft, E. P.; Horst, T. J.; Downing, J. K. Biological Evaluation of a Fine-Mesh Traveling Screen for Protecting Organisms. In Workshop on Advanced Intake Technology, San Diego, CA, April 22–24, 1981.

Taft, E. P.; Winchell, F. C.; Amaral, S. V.; Cook, T. C.; Plizga, A. W.; Paolini, E. M.; Sullivan, C. W. Field Evaluations of the New Modular Inclined Fish Diversion Screen. In *Waterpower '97, Proceedings of the International Conference on Hydropower,* Atlanta, GA, August 5–8, 1997, 665–671.

Tenera Environmental (Tenera). Carlsbad Desalination Facility: Intake Effects Assessment. Prepared for Poseidon Resources Corporation, 2005.

Tenera. Marin Municipal Water District Desalination Facility Intake Effects. Prepared by Tenera, 2007. Appendix C of Final Environmental Impact Report (EIR) Marin.

Tenera. City of Santa Cruz Water Department & Soquel Creek Water District ($SCWD^2$) Desalination Program: Open Ocean Intake Study Effects, 2010a. ESLO2010-017.1.

Tenera. Bay Area Regional Desalination Project Entrainment and Source Water Study Report. Appendix F of Pilot Testing at Mallard Slough Pilot Plant Engineering Report. Prepared by MWH, 2010b.

Tenera. West Basin Ocean Water Desalination Demonstration Facility Intake Effects Assessment: Quarterly Progress Report. First Quarter 2011. Prepared for Mr. Phil Lauri, West Basin Municipal Water District, 2011a.

Tenera. West Basin Ocean Water Desalination Demonstration Facility Intake Effects Assessment: Quarterly Progress Report. Second Quarter 2011. Prepared for Mr. Phil Lauri, West Basin Municipal Water District, 2011b.

Tenera. West Basin Ocean Water Desalination Demonstration Facility Intake Effects Assessment: Quarterly Progress Report. Third Quarter 2011. Prepared for P. Lauri, West Basin Municipal Water District, 2011c.

Thomas, G. L.; Thorne, R. E.; Acker, W. C.; Stables, T. B.; Kolok, A. S.; Johnson, L.; Miller, K.; Yuge, J.; Kulik, B.; Shiba, S. The Effectiveness of a Velocity Cap and Decreased Flow in Reducing Fish Entrapment. University of Washington College of Fisheries, Fisheries Research Institute Report FRI-UW-8027. Prepared for Southern California Edison, 1980.

Thompson, T. Intake Modifications To Reduce Entrainment and Impingement at Carolina Power and Light Company's Brunswick Steam Electric Plant, Southport, NC. *Environ. Sci. Pol.* **2000,** *3*, 417–424.

Thompson, T. Intake Technologies Used at the Brunswick Steam Electric Plant To Achieve a Reduction in Impingement Mortality to a Level Similar to Closed Cycle Cooling. American Fisheries Society Annual Meeting, Seattle, WA, 2011.

Trousdale, S.; Henderson, E. Sydney's Desalination Plant: Addressing Environmental Issues Using Innovative Design, Planning and Monitoring. IDA World Congress on Desalination and Water Reuse, The Palm, Dubai, 2009.

Truebe, J. P.; Truebe, E. P. Current Inducer and Downstream Bypass System at Upper Penacook Hydroelectric Plant, July 1997. Prepared by Lakeside Engineering, Inc. Mirror Lake, NH, for Essex Hydro Associates, Boston, 1997.

Truebe, J. P.; Truebe. E. P. 1998 Fish Passage Report for Upper Penacook Falls. Prepared by Lakeside Engineering, Inc. Mirror Lake, NH, for Essex Hydro Associates, Boston, 1998.

Turnpenny, A. W. H. An analysis of mesh sizes required for screening fishes at water intakes. *Estuaries,* **1981,** *4*(4), 363–368.

Turnpenny, A.; Nedwell, J.; Maes, J.; Taylor, C.; Lambert, D. Development and Operation of Acoustic Fish Deterrent Systems at Estuarine Power Stations, 2008. Presentation available at: http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/upload/2008_06_10_316b_meetings_symposium_turnpenny.pdf (accessed October 3, 2011).

Underwood, A. On Beyond BACI: Sampling Designs that Might Reliably Detect Environmental Disturbances. In Schmitt, R.; Osenberg, C., Eds.; *Detecting Ecological Impacts. Concepts and Applications in Coastal Habitats.* Academic Press, 1996, pp 151–175.

United States Bureau of Reclamation. Fish Protection at Water Diversions: A Guide for Planning and Designing Fish Exclusion Facilities. Water Resources Technical Publication, 2006.

URS Corporation. Bay Area Regional Desalination Project Pre-Feasibility Study Final Report. Prepared for East Bay Municipal Utility District, Contra Costa Water District, Santa Clara Valley Water District, and San Francisco Public Utilities Commission, 2003.

Vanderwalker, J. G. Response of Salmonids to Low Frequency Sound. Bureau of Commercial Fisheries Fish-Passage Research Program, Seattle, WA, 1967.

Vannucci, M. Loss of organisms through the meshes. In Tranter, D. J., Ed.; Part I, Review on zooplankton sampling methods. *UNESCO Monogr. Oceanogr. Methodol. 2, Zooplankton sampling*. 1968, pp 77–86.

Veneziale, E. J. Design of a Wedge Wire Screen Intake System To Replace Traveling Intake Screens at Eddystone Generating Station. In *Proceedings of American Power Conference,* 1991.

Victorian Government Department of Sustainability and Environment Melbourne. Victorian Desalination Project Environment Effects Statement. Summary Brochure, 2008. http://www.water.vic.gov.au/__data/assets/pdf_file/0006/15396/EES-Summary-Brochure.pdf (accessed July 14, 2011).

Wang, J. C. S.; Kernehan, R. J. *Fishes of the Delaware Estuaries.* A guide to the early life histories. 1979. ISBN: 0-931842-02-6. 410 pp.

Water Research Foundation and Watereuse Research Foundation (WRF). Assessing Seawater Intake Systems for Desalination Plants. Prepared by Carollo Engineers, Water Research Foundatoin: Denver, CO, 2011a.

WateReuse Research Foundation. Desalination Plant Intakes: Impingement and Entrainment Impacts and Solutions White Paper, 2011b.

WateReuse Research Foundation. Overview of Desalination Plant Intake Alternatives White Paper, 2011c.

Weight, R. H. Ocean Cooling Water System for 800 MW Power Station. *J. Power Div. ASCE* **1958**, Paper #1888.

Weisburg, S. B.; Burton, W. H.; Jacobs, F.; Ross, E. A. Reductions in Ichthyoplankton Entrainment with Fine-Mesh, Wedge Wire Screens. *N. Am. J. Fish. Man.* **1987,** *7,* 386–393.

Welton, J. S.; Beaumont, W. R. C.; Clarke, R. T. The Efficacy of Air, Sound and Acoustic Bubble Screens in Deflecting Atlantic Salmon, *Salmo salar* L., Smolts in the River Frome, UK. *Fisheries Management and Ecology*, **2002,** *9*, 11–18.

Younos, T. Permits and Regulatory Requirements. *J. Contem. Water Res. Educ.* **2005,** *132,* 19–26.

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