PRIVILEGED AND CONFIDENTIAL
EVALUATION OF FISH PROTECTION ALTERNATIVES FOR THE CANAL GENERATING STATION
REVISED

Prepared by

Gregory Allen, Civil Engineer

Jonathan L. Black, Biologist

Thomas C. Cook, Director, Environmental Engineering

Prepared for

MIRANT CANAL, L.L.C.

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258-03/E1079F-R1

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229-03/E1079E

Table of Contents

List of Tables

List of Figures

SECTION 1
INTRODUCTION

Mirant Canal, L.L.C. (Mirant Canal) has requested that Alden Research Laboratory, Inc. (Alden) provide services necessary to respond to the United States Environmental Protection Agency Region 1 (EPA) Request for Supplemental Information, dated April 30, 2003, relative to the Section 316(b) permitting of the Mirant Canal Station. Alden has identified advances in fish protection technologies that may provide effective fish protection at the cooling water intake structures (CWIS) and has evaluated alternatives that are applicable to the Mirant Canal Station.

As requested, this evaluation allows EPA to determine whether the location, design, and capacity of the CWIS alternatives reflect the "best technology available (BTA) for minimizing adverse environmental impacts" (AEI).

The results of Alden's evaluation of available fish protection technologies that can be considered for possible use in reducing impingement mortality and entrainment at Canal Station are presented in this report. Section 2 summarizes the pertinent features associated with the existing intake structure and operations at Canal Station. Section 3 presents an assessment of intake technologies and flow reduction alternatives that have been studied or used for protection of various species and life stages/sizes of fish. A detailed evaluation and conceptual designs for the selected alternatives are provided in Section 4. The estimated costs for the alternatives are provided in Section 5. Conclusions are presented in Section 6.

SECTION 2
DESCRIPTION OF EXISTING POWER GENERATION FACILITY

2.1 Plant Features

Canal Station utilizes a once-through cooling water system with a shoreline intake structure and a submerged offshore discharge diffuser. The power plant is located on the Southern shore of the Cape Cod Canal, about 1,500 yards from the eastern exit to Cape Cod Bay as shown on Figure 2-1. Canal Station has two oil Units with a net plant output of approximately 1,120 MW_{net} (~ 560 MW_{net} per Unit). The nominal annual energy generated by Canal Station is about 4,755,678 MWh (2000-2003). This amounts to about a 48% plant capacity factor. A summary of pertinent plant data is presented in Table 2-1.

Circulating water for Units 1 and 2 are withdrawn through separate intake structures located on the Cape Cod Canal. The intake structures are located just west of the Harbor of Refuge (Figure 2-2).

Circulating water flow for each Unit is screened by trash racks and four traveling water screens before reaching the circulating water pumps. The four circulating water pumps, two per Unit, are located in separate screenhouses for each Unit. Service water is drawn from the circulating water system. Each Unit has separate circulating water systems and shares a common discharge diffuser. The plant's multiport diffuser is located about 900 ft east of Units 1 & 2 intake structures.

2.2 Intake Structure

The intake structures for Units 1 & 2 have sheet pile flumes lined with rip rap that convey water to screenwell/pump bays. The Unit 1 intake opening at Cape Cod Canal is 12 ft high and 27 ft wide with an invert at El -25.0 ft Mean Sea Level (MSL). Unit 2's intake opening is 16 ft high by 25 ft wide with an invert at El. -26.0 ft (MSL). The bottom of the Cape Cod Canal is at El. -35.0 ft (MSL) in front of Unit 2's intake opening and at El. -25.0 ft in front of Unit 1's intake opening. A plan of the intakes is shown on Figure 2-3 and sections of the intakes are shown on Figure 2-4 and Figure 2-5.

The bottom elevation of the Unit 1 intake begins at El. -25.0 ft at the entrance and slopes upwards to El. -15.0 ft around 40 ft out at a slope of 3H:1V. From Unit 1's intake entrance to 40 ft out, the width lessens from 26 ft to 20 ft. From 40 ft to 106 ft, the depth and width remain constant, but change after that. From 106 ft to a distance of 133 ft from the entrance, the width increases to about 31 ft and the depth increases to El. -24.0 ft. At 133 ft, the fronts of the screenwell bays are only 5 ft away.

The Unit 2 intake flume is similar to the Unit 1 intake flume, with the exception of a fish sill at the intake opening. A 9 ft sill is provided from the Cape Cod Canal bottom at El. -35.0 to the entrance invert at El. -26.0 ft.

Each intake structure is divided into two 14.85 ft wide intake bays. The intake bays are equipped with trash racks and vertical traveling water screens. Each Unit has two traveling water screens located 16 ft downstream of the trash racks. Each screen is 10 ft wide and has a mesh opening size of 3/8 in. A spray wash system is used to remove fish and debris from the screens. The spray wash consists of a front wash and back wash header at 80 psig.

Units 1 and 2 each have two vertical mix flow circulating water pumps. Unit 1 pumps are 500 hp, rated for 85,000 gpm at 24 ft of head and Unit 2 pumps are 700 hp, rated for 95,500 gpm at 26 ft head with all four pumps providing a combined maximum plant flow of 361,000 gpm, (804 cfs). The pumps are located 20 ft downstream of the traveling water screens. The discharge of each Unit's pumps are manifolded together to allow one or two of the pumps to be in operation.

2.3 Existing Hydraulic Conditions

Canal Station is located on Cape Cod Canal just inland of Cape Cod Bay. The canal is relatively narrow and deep. The cross-section of the canal in front of the intakes is about 1,000 ft wide with an average depth of about 40 ft at mean low water. The navigation channel is located in the center of the canal and is approximately 480 ft wide with a maximum depth of about 47 ft in the center at mean low water. The limit of the navigation channel is approximately 80 ft from the intake structures. Currents are produced in Cape Cod Canal from differences in amplitude and phase of semidiurnal tides in Cape Cod Bay and Buzzards Bay. Currents flowing in the westward direction (ebb tide) produce an average velocity of 3.2 ft/sec with an average flow of 90,000 cfs and currents flowing in the eastward direction (flood tide) produce an average velocity of 3.0 ft/sec with an average flow of 74,000 cfs (Stone and Webster, 1971).

At a plant flow of 804 cfs with low water levels, the average velocity at the Unit 1 flume entrance is 1.2 ft/sec and 1.1 ft/sec at the Unit 2 flume entrance. The average velocity midpoint in Unit 1's intake flume is 1.9 ft/sec and 2.1 ft/sec in Unit 2's intake flume. The average approach velocity at Unit 1's trash rack and traveling water screen is 0.7 ft/sec. The average velocity at the Unit 2 trash rack and traveling water screen is 0.8 ft/sec. Canal Station withdrawals about 1% (804 cfs) of the total average canal flow, 82,000 cfs.

2.4 Biological Considerations

The selection of technologies for the protection of aquatic organisms at Canal was based, in part, upon the species and life stages of fish in the vicinity of the intake, their temporal and spatial abundance, and there relative hardiness. The Regional Fisheries Management council established by the Magnuson-Stevenson Act (16 U.S.C. 1801 et seq.) in conjunction with the National Marine Fisheries Service (NMFS), federal and state agencies, and others, identified thirty-one species of aquatic organisms as targets for conservation and enhancement as part of the Essential Fish Habitat (EFH) process in the vicinity of the Cape Cod Canal (Table 2-1). An inter-agency working group established for the Canal Redevelopment Project, identified "priority finfish species" listed in Table 2-3. In addition, one invertebrate species, Lobster (*Homarus americanus*), was included for its commercial importance. Most of these species have been identified in either entrainment or impingement sampling at Canal. A subgroup of the priority species identified by Mirant as being common in entrainment and impingement samples were chosen for this evaluation.

2.4.1. Characterization of Entrainment and Impingement

The most recent entrainment sampling was conducted by Marine Research, Inc. (MRI) at Canal Station in 1999-2002. Fish eggs and larvae were collected in plankton nets from the station's cooling system along with other sampling locations in the Cape Cod Canal, Cape Cod Bay, and Buzzard's Bay. Samples were taken from late February 1999 through February 2002. Data are available for samples collected through June 15, 2001; the remaining samples were archived. Samples were collected weekly from late winter through summer and bi-weekly between October 1999 and February 2000. Samples were collected under a variety of conditions from March 1999 to March 2000 to determine the transport of ichthyoplankton from Cape Cod Bay and Buzzards Bay through the Cape Cod Canal. The numerically dominant species changed during the course of the sampling year. Atlantic Herring, sand lance, sculpins, rock gunnel, and cod were numerically dominant in winter and early spring. Labrids (cunner and tautog), winter flounder, hake, menhaden, and mackerel were dominant in the early summer. In addition to finfish ichthyoplankton, lobster larvae and eggs were also sampled in the same locations (MRI 2000). Densities of lobster larvae in Buzzards Bay greatly exceeded the numbers in Cape Cod Bay and in Cape Cod Canal. This reduced entrainment of lobster larvae through the Canal Station because cooling water for the station is drawn primarily from Cape Cod Bay due to its close proximity (Table 2-4).

MRI sampled impingement at the Canal Station formally from March 1999 through March 2000 (MRI 2000; Table 2-5). Most impingement occurred in November and December and corresponded to the presence of higher number of juvenile fish in the canal. Impingement was dominated by Atlantic menhaden, silverside, and river herring (alewife and blueback herring).

Table 2-1 Pertinent Project Data – Canal Station

Location – Sandwich, MA
Latitude – 41°,46',18"
Longitude – 70°, 30',32"

Water Body – Cape Cod Canal

Water Body Type – Navigation Canal

Estimated Project Intake Flow

Maximum – 804 cfs

Intake velocities

Entrance- Unit 1 – 1.2 ft/sec (full flow)
Unit 2 – 1.1 ft/sec (full flow)

Midpoint in intake flumes (max velocities in intakes) -
Unit 1 – 1.9 ft/sec (full flow)
Unit 2 – 2.1 ft/sec (full flow)

Trash racks & Traveling Water Screens -
Unit 1 – 0.7 ft/sec (full flow)
Unit 2 – 0.8 ft/sec (full flow)

Water Levels

Elevations –

Extreme High Water (MHHW)	El. 9.1 ft
Mean High Water (MHW)	El. 3.8 ft
Mean Sea Level (MSL)	El. 0.0 ft
Mean Low Water (MLW)	El. -4.9 ft
Extreme Low Water (MLLW)	El. -8.9 ft

Direction of flow -
Eastward, flood tide
Westward, ebb tide

Width of Canal
1,000 ft at intake
480 ft min navigation channel
800 ft average canal width

Water depths – (in front of intake)

Maximum – 47 ft
Minimum – 25 ft
Normal – 32 ft

Canal Flow (tidal) - (at intakes)

Eastward average flood tide	90,000 cfs
Westward average ebb tide	74,000 cfs

Project Structures

Intake structure

Location – Cape Cod Canal
Configuration – Shoreline
Length – 135 ft
Number of bays – 4 bays (2 per Unit)
Bay width – 14.85 ft
Bay invert - El. -24 ft
Curtain wall location – Entrance of intake
Bottom curtain wall at intake entrance –
Unit 1 – El. -13.0 ft
Unit 2 – El. -10.0 ft
Invert – Unit 1 - El. -25.0 ft
Unit 2 – El. -26.0 ft
Top of trash rack – El. 12.0 ft

Traveling water screens

Location – 20 ft upstream from the centerline of the pumps
Number – 4 (2 per Unit)
Width – 10 ft
Invert – El. -24 ft
Mesh size and geometry – 3/8in. square openings
Spray nozzle configuration – front and back wash
Volume – 264 gpm/ screen
Pressure – 80 psigg
Fish/Debris return – concrete trough to Unit 1 abandoned discharge channel

Circulating water pumps

Number of pumps – 4 pumps, (2 per Unit)
Type of pumps – vertical mixed flow
Inlet elevation – El. -16.7 ft
Rating (hp @rpm) – Unit 1 - 500 hp @350 rpm
Unit 2 – 700 hp @320 rpm
Flow per pump
Unit 1 – 189 cfs 85,000 (gpm)
Unit 2 – 213 cfs 95,500 (gpm)

Cooling water discharge

Location – 900 ft east of the plant and approximately 100 ft offshore
Depth – El. -32.0 ft
Number – 1
Type – submerged multi-port thermal diffuser
Discharge velocity (full flow) – 3.8 ft/sec
Transit time from condensers (full flow) – 5.5 min

Power Generation

Fuel Type (nuclear, coal, oil, gas) –
Unit 1 – oil
Unit 2 – combined oil and gas
Plant output (MW) – 1,120 MW_{net}
Operating mode – cycling
Plant capacity factor – 48%
Assumed cost of a MW for this evaluation – $55
Average annual energy – 4,755,678 MWH (2000 – 2003)

Table 2-2 Summary of Designated Essential Fish Habitat (EFH) Species and Lifestages – Cape Cod Canal

Species	Lifestage				
	EGG	YSL	PYSL	JUV	ADULTS
Artica islandica (ocean quahog)[1]	N/A	N/A			
Centropristus striata (black sea bass)	N/A			X	X
Clupea harengus (Atlantic sea herring)		X	X	X	X
Gadus morhua (Atlantic cod)	X	X	X	X	X
Glyptocephalus cynoglossus (witch flounder)					
Hippoglossoides platessoides (American plaice)	X	X	X	X	X
Hippoglossus hippoglossus (Atlantic halibut)	X	X	X	X	X
Illex illecebrosus (short finned squid)[1]	N/A	N/A	N/A	X	X
Loligo pealei (long finned squid)[1]	N/A	N/A	N/A	X	X
Lophius americanus (monkfish)	X	X	X		
Lopholatilus chamaeleonticeps (tilefish)					
Macrozoarces americanus (ocean pout)	X	X	X	X	X
Melanogrammus aeglefinus (haddock)	X	X	X		
Merluccius albidus (offshore hake)					
Merluccius bilinearis (whiting)	X	X	X	X	X
Paralichthys dentatus (summer flounder)					X
Peprilus tricanthus (butterfish)	X	X	X	X	X
Placopecten magellanicus (Atlantic sea scallop)	X	X	X	X	X
Pleuronectes americanus (Winter Flounder)	X	X	X	X	X
Pleuronectes ferruginea (yellowtail flounder)	X	X	X	X	X
Pollachius virens (pollock)		X	X	X	X
Pomatomus saltatrix (bluefish)				X	X
Scomber scombrus (Atlantic mackerel)	X	X	X	X	X
Scophthalamus aquosus (windowpane flounder)	X	X	X	X	X
Sebastes fasciatus (redfish)[2]	N/A				
Spisula solidissima (surf clam)[1]	N/A	N/A			
Squalus acanthias (spiny dogfish)[3]	N/A	N/A	N/A	X[2]	X
Stenotomus chrysops (scup)	X	X	X	X	X
Thunnus thynnus (bluefin tuna)				X	X
Urophycis chuss (red hake)	X	X	X	X	X
Urophycis tenuis (white hake)	X	X	X	X	X

1 Life stages of long-finned squid, short-finned squid, surf clam, and ocean quahog are referred to as pre-recruits and recruits which correspond to juvenile and adults, respectively.
2 Redfish are live-born and, therefore, there is no external egg life stage.
3 Spiny dogfish are born as live juveniles.

Table 2-3 Massachusetts Division of Marine Fisheries List of Priority Finfish Species

Family	Latin Name	Common Name
Ammodytidae	*Ammodytes americanus*	American sand lance
Bothidae	*Scophthalmus aquosus*	windowpane
Clupeidae	*Alosa aestivalis*	blueback herring
	Alosa pseudoharengus	alewife
	Brevoortia tyrannus	Atlantic menhaden
	Clupea harengus	Atlantic herring
Cottidae	*Myoxocephalus aenaeus*	grubby
Engraulidae	*Anchoa mitchilli*	bay anchovy
Gadidae	*Enchelyopus cimbrius*	fourbeard rockling
	Gadus morhua	Atlantic cod
	Melanogrammus aeglefinus	haddock
	Merluccius bilinearis	silver hake
	Pollachius virens	pollock
	Urophycis chuss	red hake
	Urophycis regia	spotted hake
	Urophycis tenuis	white hake
Labridae	*Tautoga onitis*	tautog
	Tautogolabrus adspersus	cunner
Lophiidae	*Lophius americanus*	goosefish – a.k.a. "monkfish"
Percichthyidae	*Morone saxatilis*	striped bass
Pleuronectidae	*Hippoglossoides platessoides*	American plaice
	Pleuronectes americanus	winter flounder
	Pleuronectes ferruginea	yellowtail flounder
Pomatomidae	*Pomatomus saltatrix*	bluefish
Scombridae	*Scomber scombrus*	Atlantic mackerel
Sparidae	*Stenotomus chrysops*	scup
Squalidae	*Squalus acanthias*	spiny dogfish
Stromateidae	*Peprilus tricanthus*	butterfish
Triglidae	*Prionotus carolinus*	northern searobin
Zoarcidae	*Macrozoarces americanus*	ocean pout

Table 2-4 Entrainment of Priority Species from March 1999 through March 2000

Species	Season	Egg Cohorts ($x10^6$)		Larval Stage	Larval Cohorts ($x10^6$)	
		1999	2000		1999	2000
spiny dogfish		0.00	0.00		0.00	0.00
river herring	Spr Sum	0.04	0.00		0.02	0.10
Atlantic menhaden	Spr Sum	3.00	3.22		1.91	0.36
Atlantic herring	Win Spr	0.00	0.00		0.25	2.93
bay anchovy	Spr Sum	0.03	0.05		0.37	0.00
fourbeard rockling	Spr Sum	72.63	68.89		5.90	20.81
Atlantic cod	Win Spr	0.91	1.13		0.59	1.29
haddock	Spr Sum	0.09	0.24		0.09	0.35
silver hake	Spr Sum	10.15	0.68		7.67	10.09
pollock	Spr Sum	0.00	0.00		0.00	0.00
hake	Spr Sum	44.11	50.07		4.83	14.29
goosefish	Spr Sum	0.88	0.53		0.00	0.66
silverside	Spr Sum	0.00	0.00		0.23	1.40
northern searobin	Spr Sum	4.10	7.55		0.07	0.07
grubby	Win Spr	0.00	0.00		6.47	7.64
striped bass	Spr Sum	0.00	0.00		0.00	0.00
bluefish		0.00	0.00		0.00	0.00
scup	Spr Sum	0.76	0.05		1.66	2.51
tautog	Spr Sum	119.17	154.12		3.97	8.14
cunner	Spr Sum	2227.81	2883.77		--	--
	Spr Sum			1	1.22	1.73
	Spr Sum			2	10.57	48.02
	Spr Sum			3	21.33	50.12
ocean pout	Spr Sum	0.00	0.00		0.00	0.00
sand lance	Win Spr	0.00	0.13		43.51	97.87
Atlantic mackerel	Spr Sum	208.34	269.58		0.89	18.02
butterfish	Spr Sum	1.16	2.06		0.56	2.15
windowpane	Spr Sum	43.69	61.81		3.74	2.39
American plaice	Spr Sum	2.22	1.66		0.53	0.83
winter flounder	Spr Sum	39.08	6.93		--	--
	Spr Sum			1	2.17	0.85
	Spr Sum			2	1.23	4.09
	Spr Sum			3	3.15	7.46
	Spr Sum			4	0.48	0.56
yellowtail flounder	Spr Sum	38.42	44.73		0.70	2.05
American lobster	Spr Sum			1	0.83	0.01
	Spr Sum			2	0.02	0.00
	Spr Sum			3	0.03	0.00
	Spr Sum			All	0.88	0.01

Table 2-5 Impingement of Priority Species from March 1999 through March 2000

Species	Adjusted Total Impingement*	
Atlantic menhaden	23,901	✓
Atlantic silverside	12,742	✓
blueback herring	12,714	
cunner	3,982	3624
Atlantic herring	1,230	✓
grubby	1,108	997
Atlantic cod	671	✓
winter flounder	602	542
butterfish	505	
scup	374	✓
silver hake	332	
tautog	257	231
pollock	249	234
hake	145	131
windowpane	143	86
sand lance	50	25
yellowtail flounder	49	44
striped bass	30	✓
fourbeard rockling	22	✓
northern searobin	17	✓
goosefish – a.k.a. "monkfish"	6	
spiny dogfish	0	
bay anchovy	0	
haddock	0	
bluefish	0	
ocean pout	0	
Atlantic mackerel	0	
American plaice	0	
All fish	75,297	
American lobster	875	438

*Note: See Entrainment and Impingement Methods, Appendix A1-8

Figure 2-1 Vicinity Map

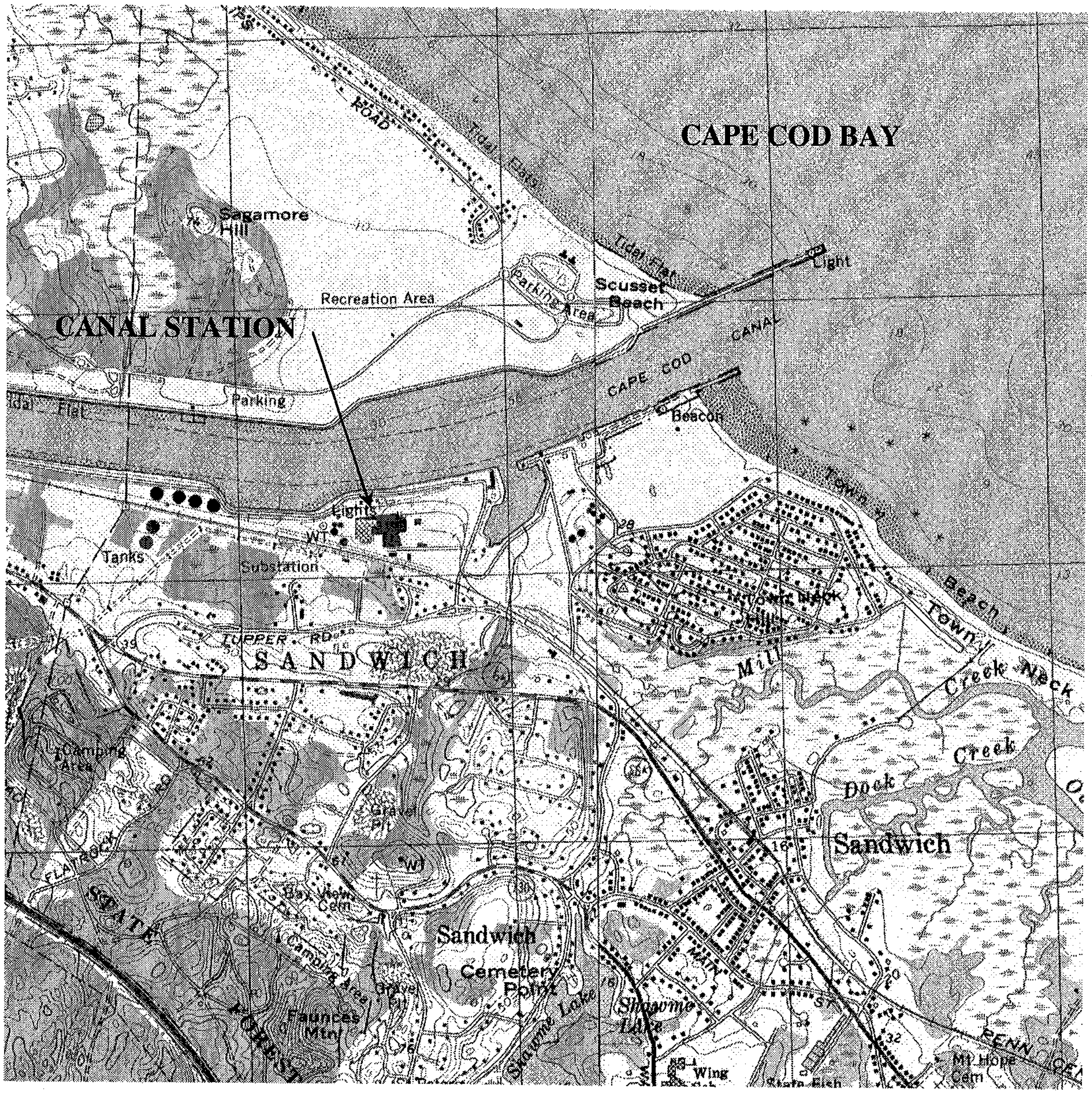

Figure 2-2 Site Layout

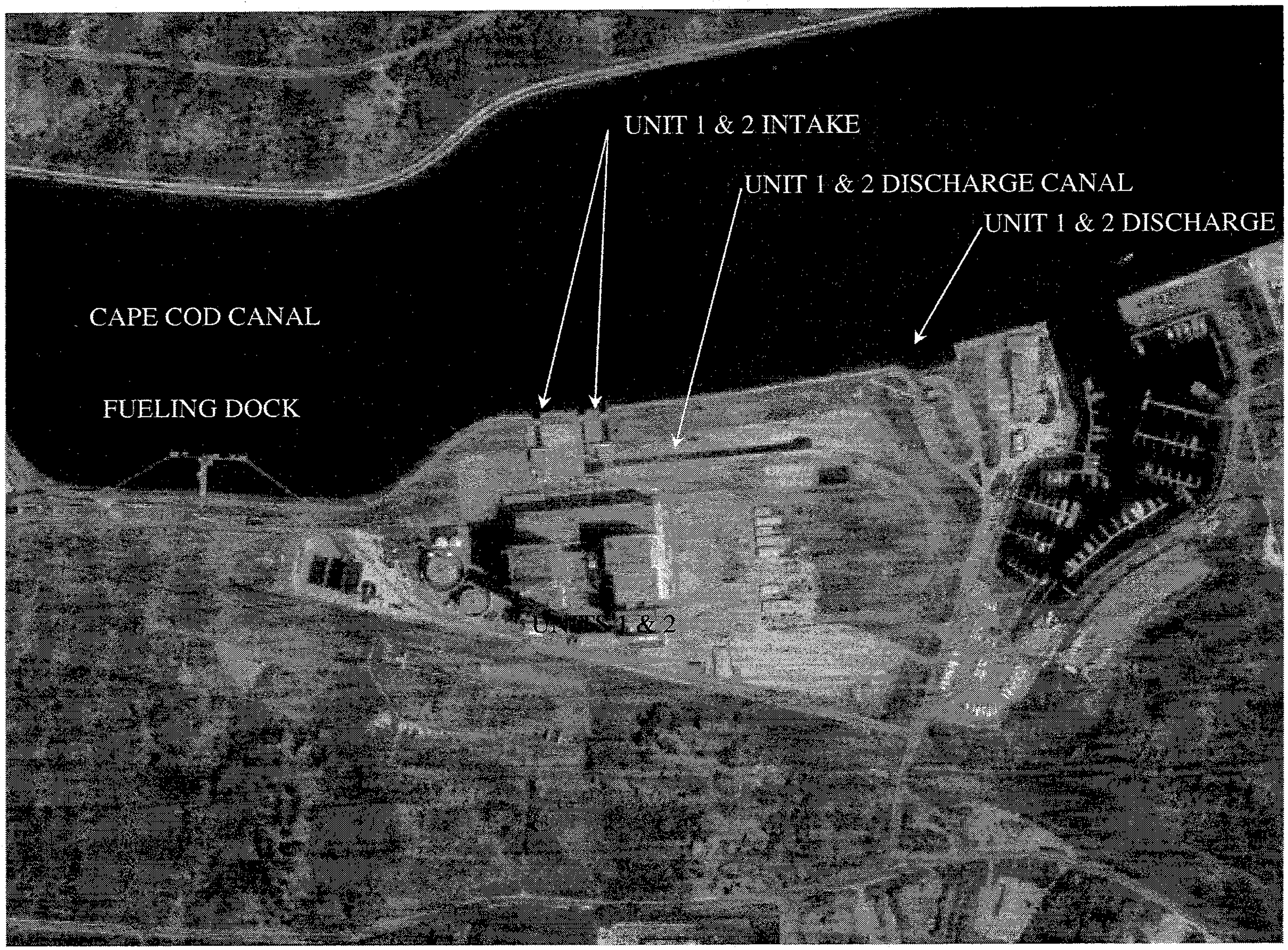

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Figure 2-3 Intake Structure – Plan

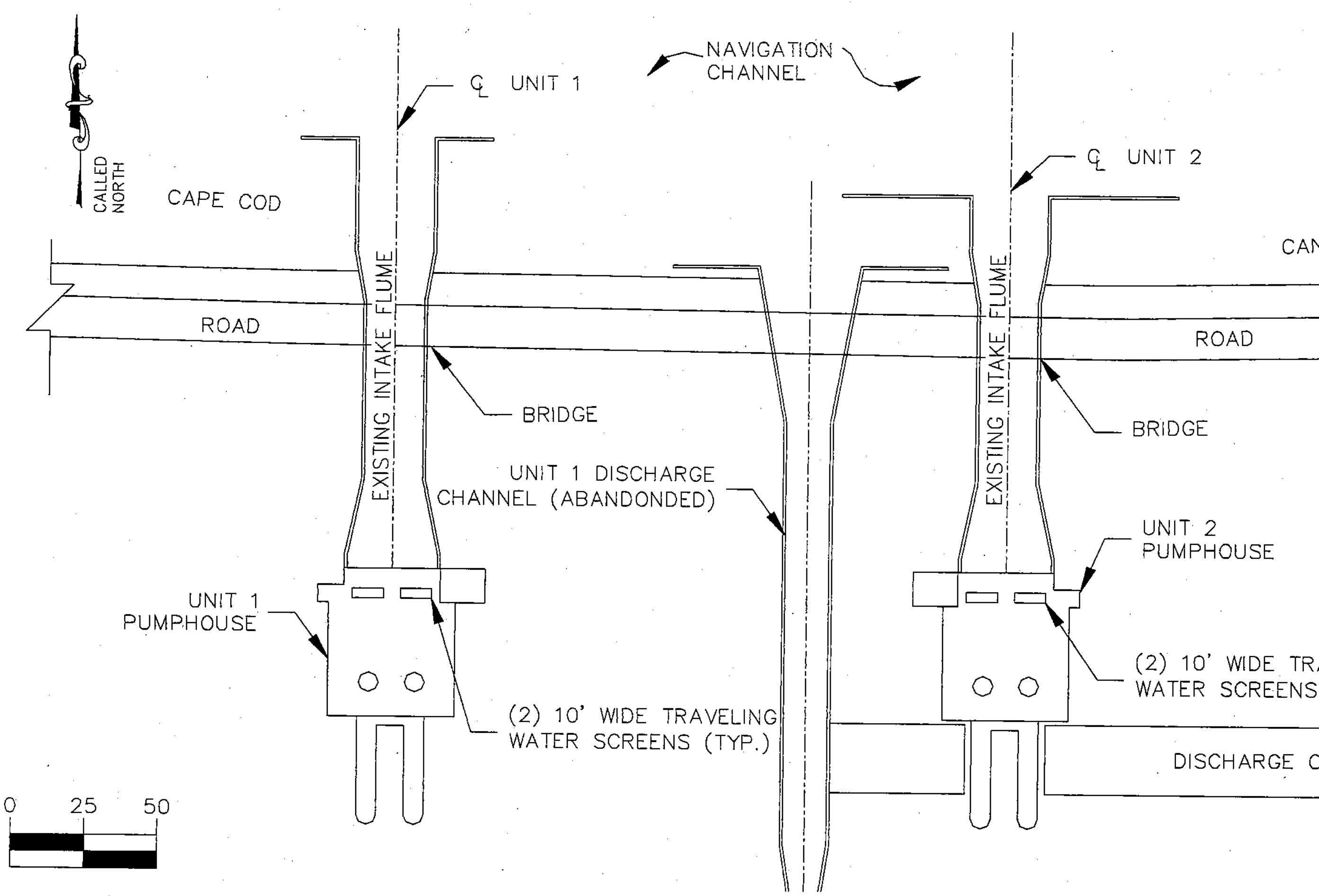

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Figure 2-4 Unit 1 Intake Structure – Section

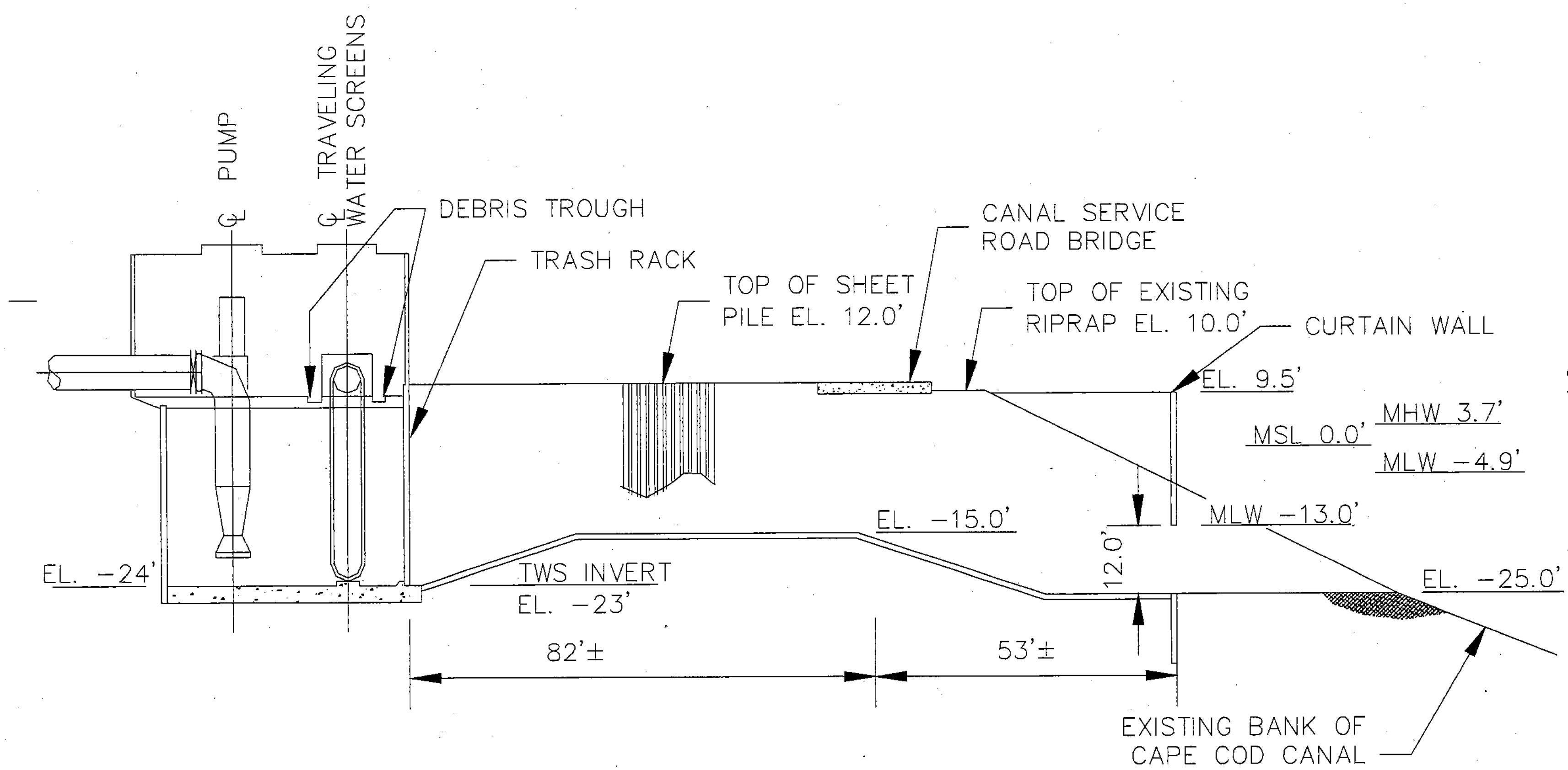
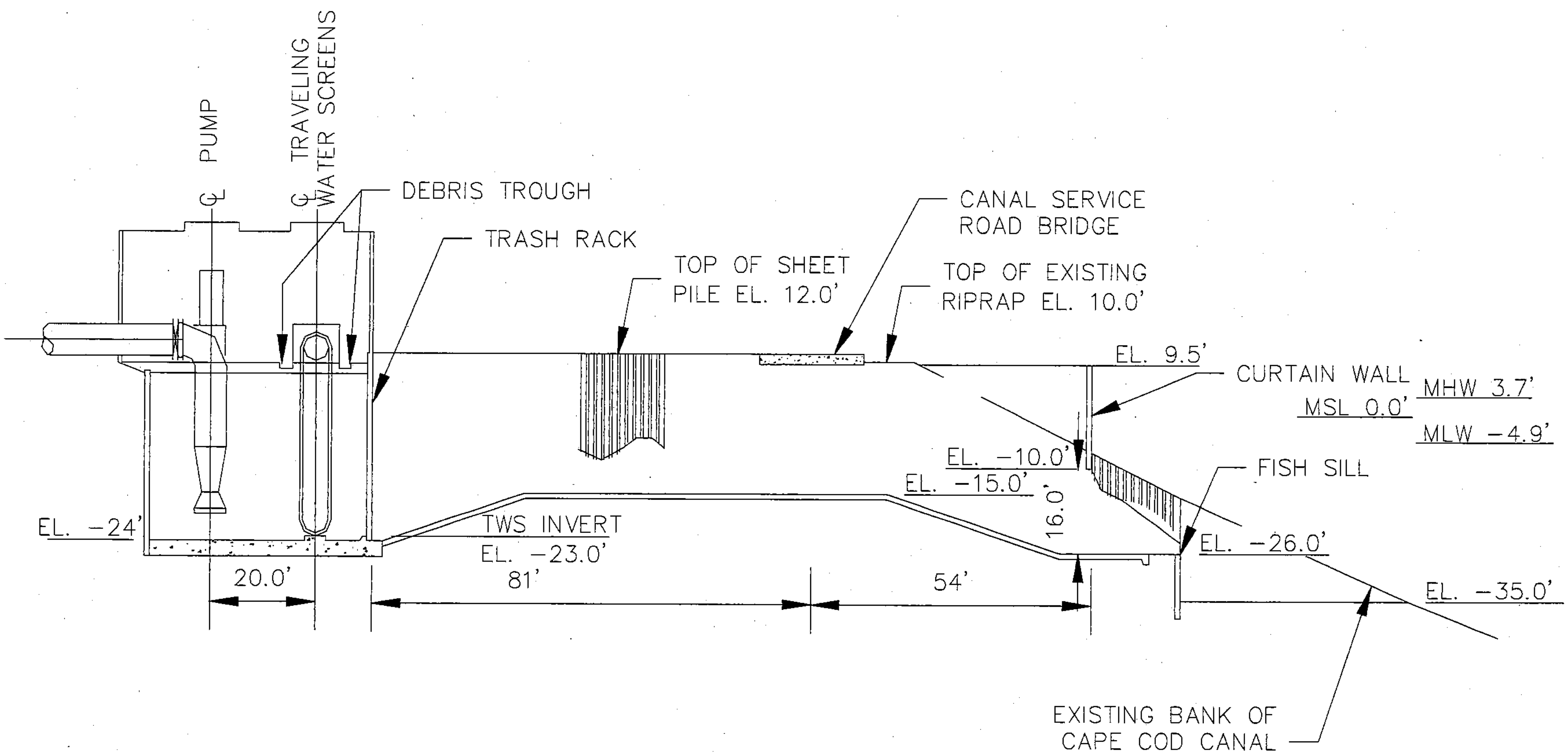


Figure 2-5 Unit 2 Intake Structure – Section



SECTION 3
ASSESSMENT OF FISH PROTECTION TECHNOLOGIES

A summary of technologies available for fish protection at water intakes is provided in Appendix A. All of the technologies in the appendix may not be appropriate for this facility. An overview of modified circulating water pump operation options and closed-cycle cooling systems are presented in Appendix B. Criteria used to evaluate alternatives that may be appropriate for application at Canal Station are defined in this section. The screening process used for selecting alternatives for preliminary evaluation is presented in Section 3.2 for intake technologies and Section 3.3 for reduced flow options.

3.1 Evaluation Criteria

The following general considerations were used to develop conceptual designs of alternative fish protection technologies for application at Canal Station. The criteria were used to evaluate the relative advantages and disadvantages of each fish protection alternative and to select for more detailed development those alternatives that have the greatest potential to effectively protect fish. The criteria are not listed in order of priority.

- Alternatives should provide protection for the targeted species present in Cape Cod Canal and listed in Table 2-3.
- Alternatives should be designed to reduce entrainment of fish in early life stages.
- Alternatives should be designed to reduce impingement mortality of juvenile and adult fish.
- Alternative designs must have suitable conditions for fish protection over a range of intake flows.
- Alternatives should take into consideration current project design features
- Alternatives should provide effective protection throughout the entire water column such that they are effective with all fish species identified in Table 2-3.
- Alternatives should function under normal debris and ice loading conditions in the canal (i.e., reasonable cleaning techniques are available and demonstrated).

- Alternatives should be compatible with the aesthetic and recreational features of the region.

3.2 Identification of Intake Alternatives with Potential for Application

The available fish protection technologies were subjected to a screening process to determine which technologies offered the greatest potential for practicable application at Canal Station. The screening consisted of the identification of those technologies that have potential for application, as presented below, and development of alternatives for proper installation of the technologies at the site. The criteria used to screen the technologies are discussed above in Section 3.1.

Table 3-1 summarizes results of the preliminary screening of the fish protection technologies. A technology was considered to have potential for application at Canal Station if:

1. the technology has proven biological effectiveness,
2. the technology is currently available and does not require further research and engineering development, and
3. the technology has engineering and/or biological advantages over the other technologies evaluated.

The screening process was as objective as possible. However, in assessing the potential for application of fish protection schemes under physical, hydraulic, and environmental conditions in which they may never before have been applied, Alden used best professional judgment based on experience.

A technology was deemed to have proven biological effectiveness if test data (preferably from full-scale application) were available documenting that the technology had been effective for one or more of the targeted species when used at other sites. If engineering data existed in sufficient detail to develop a conceptual design and/or if the technology had been constructed at another site, it was judged to be an available technology. Each technology was qualitatively assessed to identify whether it had biological and/or engineering advantages over the other alternatives. 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 civil/structural requirements for installation are substantially less.

Based on the literature summarized in Appendix A, the following concepts are considered to have limited or no proven biological effectiveness (i.e., they have not substantially reduced entrainment or impingement in past applications as indicated in Table 3-1):

- Infrasound
- Mercury lights
- Chemicals

- Electric screens
- Water jet curtains
- Hanging chains
- Visual keys
- Inclined plane screens
- Submerged traveling water screens

As shown in Table 3-1, behavioral barriers have been shown to repel or attract fish by eliciting a response to a particular stimulus. In particular, sound, strobe lights, and air bubble curtains have been shown to effectively repel several species of fish including alewife, blueback herring, and American shad. However, these technologies are only effective with fish in later life stages since larval fish do not have sufficient mobility to overcome intake flow velocities. Therefore, sound, light, and air bubble curtains cannot be considered as alternatives to address entrainment at Canal Station, but they may be applicable for impingement reductions.

The focus of recent studies involving underwater sound technologies has been on the use of low- and high-frequency acoustic systems that were not available for commercial use until the 1990s. High-frequency (about 120 kHz) sound has been shown to effectively and repeatedly repel members of the genus Alosa (American shad, alewife, and blueback herring) at sites throughout the U. S. (Ploskey et al. 1995; Dunning 1995; Consolidated Edison 1994). Other studies have not shown sound to be consistently effective in repelling species such as largemouth bass, smallmouth bass, yellow perch, walleye, rainbow trout, gizzard shad, Atlantic herring, and bay anchovy (EPRI 1999, Consolidated Edison 1994). Because only members of the genus *Alosa* have shown a consistent avoidance response to high frequency sound and few individuals of this genus are impinged at Canal, Alden does not believe that this technology would be cost effective at Canal.

The existing intakes at Canal Station incorporates 3/8 in. square mesh traveling water screens that could be modified for installation of fine mesh Ristroph screens to reduce entrainment. One option to improve impingement survival would be to upgrade the existing traveling screens for continuous operation. However, extensive upgrades of moving parts are required to maintain the traveling screens for continuous operation. The costs associated with the upgrades to operate continuously are not substantially lower than the costs of retrofitting the intakes with Ristroph screens. In addition, the added costs of Ristroph screens are usually balanced by the increase in fish survival. Therefore, continuously operated screens were not evaluated further. The screen baskets on the Ristroph screens could be fitted with fine mesh and fish lifting buckets, which would also reduce entrainment. In addition, Ristroph screens are designed for continuous operation to minimize impingement duration. Fine mesh Ristroph screens can be considered a viable alternative for reducing both entrainment and impingement mortality at Canal Station.

Modification of the screenhouse to incorporate physical barriers or diversion systems, such as angled screens to prevent impingement, would be difficult. Traveling water screens have an engineering advantage over other physical barriers (angled fixed screen, rotary drum screen, barrier net, bar rack barrier, infiltration intakes, and porous dikes; Table 3-1). Installation of rotary drum screens and porous dikes would require a much larger area than conventional traveling screens because of the lower design velocity. Rotary drum screens are typically installed in channels where water elevations are relatively constant and water depths are less than 12 ft, less than the water depth in the channel approaching the intake structure at Canal Station.

Bar racks are typically designed to have spacing greater than 1 in. and would not be effective in preventing the entrainment of early life stages. Traveling water screens are designed to facilitate automatic screen cleaning at sites with high debris loading. This feature provides them with an engineering advantage over angled fixed screens, barrier nets, and bar rack barriers, all of which would require a cleaning system to ensure that the concept would function as designed. All existing barrier net systems are designed to be manually cleaned. Automatic cleaning capability allows mechanized screens to have a higher design approach velocity than barrier nets and angled fixed screens. However a barrier net, if held in position and maintained in a clean condition, might be a viable alternative for reducing impingement at Canal Station. Therefore, barrier nets and Ristroph screens are considered to be viable physical barrier alternatives for the Canal Station CWIS. The velocity approaching the existing traveling screens is less than 1 ft/sec which is lower than the approach velocity recommended by EPA to prevent impingement mortality. Therefore, the CWIS at Canal Station would not need to be expanded to accommodate new Ristroph screens to prevent impingement mortality. To meet the entrainment reduction standard with fine mesh ristroph screens, the intakes for each Unit would have to be expanded to reduce the approach screen velocity.

The Modular Inclined Screen (MIS) and Eicher Screen have a biological and engineering advantage over louvers, angled bar racks, and angled screens in preventing impingement. Both screens offer the potential to effectively divert most species utilizing smaller structures than the other screen concepts because the MIS is designed to operate at high velocities up to 10 ft/sec. However, the MIS has not been shown to protect larval fish and the Eicher screen is designed for installation in hydroelectric project penstocks. Therefore, these diversion technologies are not applicable to Canal Station where impingement and entrainment are both of concern.

The existing intake structure could be modified to incorporate cylindrical wedge wire screens. Other physical structures (porous dike, infiltration intake, and bar rack barriers) would require major modifications to the existing CWIS. Wedge wire screens, therefore, have an engineering advantage over other physical barriers (Table 3-1). Wedgewire screens also have cleaning features that give them an advantage over other fixed screens and barrier nets that are more difficult to maintain. Cylindrical wedge wire screens have a biological advantage because they exclude more life stages from the intake water than conventional screens and bar racks and could be a viable alternative for preliminary evaluation at Canal Station.

Aquatic filter barriers (AFB), like fine mesh traveling water screens, can reduce entrainment. The AFB has an engineering advantage over barrier nets relative to cleaning (Table 3-1). An AFB has two layers of material with an air purge system installed between the layers to permit automatic cleaning of accumulated silt and debris. This cleaning system can also free impinged fish eggs and larvae. However, the AFB requires a relatively large area for deployment to keep the design flow rate at 10 gpm per square foot. The Cape Cod Canal at the intake is not large enough for an AFB and, therefore, is not considered a viable alternative for preliminary evaluation. The limiting factor is the anchoring system which functions to a) hold the net in place, b) serve as a trigger to release the air blast biofouling control system and c) serve as a safety check to ensure that cooling water will continue to flow to the condensers in the event of net blockage and/or failure of the air blast system. This anchoring system would require placement such that it would be an impediment in this heavily used navigation channel.

The preliminary screening of intake technologies available for fish protection (Table 3-1) indicates that two intake alternatives have the greatest potential for application at Canal Station to reduce fish impingement mortality and entrainment:

- Expanded intake with fine mesh Ristroph screens
- Cylindrical wedgewire screens

Two additional intake alternatives have been identified that would act to reduce fish impingement only:

- Barrier net
- Modify Intake with Ristroph screens

EPA Region I has asked Mirant to evaluate both impingement and entrainment technologies for Canal Station. However, information on technologies which would only reduce impingement mortality is included to evaluate the benefits and costs of independently making an adverse impact evaluation for impingement losses.

The selected entrainment and impingement mortality reduction alternatives have proven biological effectiveness and have advantages over other concepts, as presented in Table 3-1. All of these concepts have been previously developed to a level such that a conceptual design could be prepared for application of the technology at Canal Station. A detailed evaluation of these alternatives is presented in Section 4. All of these alternatives would not require any changes to plant operation and would not affect the discharge thermal plume. Therefore, the hydrodynamic modeling results previously conducted for the discharge diffuser would be valid for the fish protection technologies evaluated in this report.

In addition to these CWIS technology alternatives, flow reduction options that are considered to have the potential for application at Canal Station to reduce entrainment are discussed in Section 3.3.

3.3 Reduced Flow Alternatives Selected for Evaluation

Two flow reduction options have been identified to reduce fish impingement mortality and entrainment at Canal Station:

- Modified pump operation
- Install closed-loop cooling system

Current plant operating procedures dictate operation of all pumps per Unit to maintain the plant discharge within the permitted thermal limits. Additional flow limitations could be implemented during periods of peak abundance of entrainable organisms. To maintain the plant discharge within the permitted thermal limits, reduced pump flow may require operation at reduced plant output.

Flow limitation could be achieved by shutting down pumps, throttling pump discharge valves, or installing variable speed drives on some of the pumps. To achieve a 60% reduction, one Unit could be shut down with the other operating at 80%. For this evaluation, Alden has assumed that discharge valves on the operating pumps could be used to control the flow without excessive wasted power. A more detailed analysis would be necessary to determine if variable speed drives on the circulating water pumps would be a more cost effective solution than throttling valves.

Closed-cycle cooling could greatly reduce both impingement mortality and entrainment at Canal Station. Mechanical or natural draft wet towers would require less modification to the existing circulating water system piping and less real estate than dry cooling towers. The costs for construction of a wet mechanical cooling tower are about 60% less than the natural draft wet cooling tower. Natural draft wet cooling towers require less energy to operate and have lower annual costs then a wet mechanical draft tower. However, wet mechanical draft towers generally have less aesthetic and air quality impacts than natural draft wet towers. Canal Station is near a development, the site is visible from a great distance, and so aesthetics and air quality issues would be greater for natural draft towers than for mechanical draft towers. For these reasons, wet mechanical draft towers were chosen as the closed-cycle cooling system option for preliminary evaluation.

Flow limitations would reduce the exit velocity in the discharge diffuser nozzles which would affect the thermal plume. However, the thermal mixing zone with a 60% flow reduction would be similar to the mixing zone of only one Unit operating. The result would essentially be a volumetric reduction in the size of the plume but a higher temperature in that volumetric area. A closed cycle cooling system would eliminate the need for the once through discharge diffuser.

- natural draft wet cooling tower
- wet mechanical draft tower

world energy council

Table 3-1 Initial Screening of Fish Protection Alternatives

Concept	Biological Effectiveness Proven	Engineering Alternative Available	Advantages Over Other Concepts	Potential for Application at Canal Station
Behavioral Barriers				
Sound	Yes	Yes	Yes	No
Infrasound	No	Yes	Yes	No
Strobe Lights	Yes	Yes	No	No
Mercury Lights	No	Yes	Yes	No
Chemicals	No	No	No	No
Electric Screens	No	Yes	No	No
Air Bubble Curtain	Yes	Yes	No	No
Water Jet Curtain	No	Yes	No	No
Hanging Chains	No	Yes	No	No
Visual Keys	No	Yes	No	No
Hybrid Barriers (e.g. Strobe light / air bubble curtain)	Yes	Yes	No	No
Physical Barriers				
Fixed Screens	Yes	Yes	No	No
Traveling Water Screens	Yes	Yes	No	No
Rotary Drum Screens	Yes	Yes	No	No
Coarse Mesh Barrier Net	Yes	Yes	No	Yes
Fine Mesh Barrier Net	Yes	Yes	No	No
Bar Rack Barrier	Yes	Yes	No	No
Infiltration Intakes	Yes	Yes	No	No
Porous Dike	Yes	Yes	No	No
Aquatic Filter Barrier	Yes	Yes	No	No
Wedge Wire Screens	Yes	Yes*	Yes	Yes

* For freshwater environments, some site-specific testing required in high fouling marine and estuarine environments.

Table 3-1 (continued)

Concept	Biological Effectiveness Proven	Engineering Alternative Available	Advantages Over Other Concepts	Potential for Application at Canal Station
Collection Systems				
Modified Traveling (Ristroph) Screens	Yes	Yes	Yes	Yes
Fish Pumps	Yes	Yes	No	No
Diversion Systems				
Louvers/Angled Bar Racks	Yes	Yes	No	No
Angled Screens (Fixed or Traveling)	Yes	Yes	No	No
Angled Rotary Drum Screens	Yes	Yes	No	No
Inclined Plane Screens	No	Yes	No	No
Eicher Screen	Yes	Yes	No	No
Modular Inclined Screens	Yes	Yes	No	No
Submerged Traveling Screens	No	Yes	No	No
Modifications to Reduce Intake Flow				
Modified Pump Operation	Yes	Yes	Yes	Yes
Variable Speed Pumps	Yes	Yes	No	No
Closed-cycle Cooling system (mechanical & natural draft and dry cooling towers)	Yes	Yes	Yes	Yes

SECTION 4 DETAILED EVALUATION OF ALTERNATIVES

Based on the screening of intake technologies and flow reduction options presented in Section 3, four options utilizing intake technologies for fish protection and two flow reduction options were selected as having potential for effective application at Canal Station. The alternatives selected for more detailed evaluation are:

Alternative 1 – Expand Intake with Fine Mesh Ristroph Screens

Alternative 2 – Retrofit Intake with Submerged, Cylindrical Wedge Wire Screens

Alternative 3 – Retrofit with Barrier Net

Alternative 4 –Install Coarse Mesh Ristroph Screens

Alternative 5 – Reduced Circulating Water Pump Operation

Alternative 6 – Retrofit Plant with Closed-Cycle Cooling System

Conceptual designs were prepared for each of these alternatives to serve as a basis for evaluating the effectiveness in reducing fish entrainment and impingement and to prepare cost estimates. General considerations addressed in the following sections for each option are:

(1) technical considerations associated with the design, installation, operation, and maintenance

(2) estimated construction costs and operating and maintenance costs, including replacement power, and

(3) estimated efficacy of reducing entrainment and impingement rates or changes in survival of impinged species at Canal Station.

For targeted species/life stages that occur at Canal Station, a projected range of effectiveness was identified. When data were not available for specific species/life stages, data from similar technologies and for similar species were reviewed. Those data were used to determine the relative hardiness or expected responses to technologies of these species by life stage in order to make judgments on the range of effectiveness that might be expected. The magnitude of the effectiveness estimate ranges presented indicates the relative certainty in the data available. In cases where limited data were available or the existing data were highly variable, the estimated range is wide. In cases where substantial or consistent data sets were available, smaller effectiveness ranges are presented.

The biological efficacy of a technology has to be measured differently depending upon its mode of action. For example, a behavioral barrier (such as a sound barrier) acts to elicit a behavioral response in adult or juvenile fish that repels them from the CWIS. With such a technology, the benefit lies in a reduction in the total number of fish impinged. It does not improve impingement survival (i.e., those fish that are not repelled will experience the same survival as they would in the absence of the technology). Therefore, the efficacy of such a technology is measured by a reduction in mortality. By contrast, a collection system (such as a Ristroph screen) improves the survival of impinged organisms over a traditional screen, but does nothing to prevent organism impingement. In such cases, an estimate of total mortality is presented. In cases where there were no data available, the geometric mean for the high and low values of other species were used.

4.1 Expand the Intake and Install Fine Mesh Ristroph Traveling Screens

The existing traveling water screens for both Units could be replaced with new state-of-the-art fine mesh Ristroph screens. To achieve a screen approach velocity of 0.5 ft/sec (about 1 ft/sec through-screen) at plant design flow, the CWIS would need to be expanded. Lowering the velocity and installing new flush-mounted Ristroph screens would reduce both impingement mortality and entrainment year-round. One new screen bay would be added to Unit 1, and one to Unit 2. New fish return and debris troughs would be added to the screens. All of the new screens would be designed for a 0.5 ft/sec approach velocity. A plan of the expanded CWIS is shown on Figure 4-1. The existing screenbays would not require extensive modification for installation of the new fine mesh Ristroph screens. The existing traveling water screens would be removed and completely replaced with new screens. The existing support frames, backwash headers and nozzles, and control systems may be compatible with the new screens and would not have to be replaced. The new screen baskets would have a mesh size of 0.5 mm. Each screen basket would have a fish bucket to hold collected organisms in about 2 in. of water while they were lifted to the fish recovery system. A section of the Ristroph traveling water screen is shown on Figure 4-2. A low-pressure spray (20 psig) would be used to gently remove the fish from the fish holding buckets into a fish sluice. A conventional high-pressure wash would then remove debris into a debris sluice. Both troughs would be located on the back side of the screens.

The two additional screens and pumps would be located in concrete bays adjacent to each side of the intakes. The new intakes would have trash racks, Ristroph screens, and fish and debris troughs similar to the replacement screens for the existing intakes. Circulating water pumps, each sized for their particular Unit, would be installed in the new intake bays. New circulating water pipes and valves would be installed between the new pumps and the existing circulating water pump discharge header.

New fish and debris troughs would be mounted above deck level on the downstream side of the screens. The new troughs would connect between Units and discharge at either end into the canal, West or East of the intakes depending on the tide condition. During ebb tide, debris/fish trough flow for both Units would discharge west of the intakes and during flood tide debris/fish trough flow would discharge east of the intakes. Discharging debris trough flow in this manner will reduce the likeliness of fish becoming re-impinged due to recirculation of debris/fish trough flow. The discharge pipe would be extended below the low water elevation to reduce predation by seagulls. The existing high-pressure screenwash pumps would be used to provide flow to the high pressure spray wash headers for the new fine mesh Ristroph screens located in the existing screenbays. Two new screenwash pumps, each with a 550 gpm capacity at 80 psig, would be installed for the high pressure spray wash headers for the new screens in the expanded screenbays. New screenwash pumps with a total of 1,190 gpm capacity at 20 psig would be installed for the low-pressure spraywash headers for all the screens.

Removal of the existing traveling water screens and installation of the new Ristroph screens would require about two weeks per screen to remove the original screen, install the new screens, and complete mechanical and electrical work. The screens would be replaced one at a time to minimize impacts on plant operation. The existing debris trough would remain in-place during installation of the replacement screens to allow other screens to operate during the switch-over. Installation of the new spraywash system, including the new debris and fish troughs, would be completed as each screen is replaced, allowing each new screen to become operational before initiating the next screen replacement. The construction of the new screenbays would require one construction season to complete. At this stage of construction, each Unit would be required to shutdown for about one month to connect the new circulating water pumps to the existing intake pipes. If this is done during a scheduled outage or when the plant is not operating, construction would not impact plant operations.

Approach velocities perpendicular to the screen face would be about 0.5 ft/sec with the plant operating at maximum hydraulic capacity about 804 cfs.

Operation and maintenance of the Ristroph screens would be similar to that for the existing screens. Maintenance requirements for the circulating water pumps would not change. The screens would be operated continuously during periods of fish entrainment and when there is high debris loading on the screens. The operation and maintenance costs for this option were calculated based on twelve-months of continuous operation. The screens and high pressure screenwash pump would have similar maintenance requirements as the existing screen system, but would require an additional 1,972,000 kWh per year to operate continuously throughout the year. An additional 2,920 hours per year would be required to maintain the new screen system.

Visual impacts due to expanding the intake and adding fine mesh Ristroph screens would be minimal. A 20 ft wide addition would be added to each screen house to match the existing buildings. Noise impacts should not change from the current conditions and there will be no impacts to navigation.

Fine mesh screens at Canal would decrease the entrainment of larval fish and eggs through the circulating water system to some extent. There is very little information available on the species most commonly entrained at Canal (eggs of tautog, cunner, and Atlantic mackerel and the larvae of the same species plus grubby, hake, fourbeard rockling, and American sand lance).

However based on the diameters of eggs and head capsule size (determined from scale drawings), substantial retention would be expected for some of the species and life-stages commonly entrained. For example, tautog, cunner, and Atlantic mackerel eggs are all substantially greater in diameter than the 0.5 mm mesh and should be physically excluded from entrainment. There is greater variability in head capsule sizes of the commonly entrained larvae. Most notably, the head capsule size of early yolk-sac larvae of cunner and tautog are between 0.25 and 0.3 mm and may not be substantially retained on 0.5 mm mesh. Since the orientation of the larvae when encountering the mesh will determine whether larvae will impinge or entrain, it is difficult to assess *a priori* the ability of fine mesh to protect fish at Canal.

A second factor to consider with fine mesh screens is that such screens result in the impingement of fish that were previously entrained. Therefore, these screens are beneficial from an organism protection viewpoint only if impingement survival for important species and life stages is relatively high and exceeds entrainment survival levels. Therefore, use of fine mesh screens is a tradeoff. Some species and life stages benefit, but others might experience greater mortality than under existing conditions. Past studies show that egg and larvae survival following impingement on fine mesh is variable and species-specific. In addition, there is very little survival data available for most of the commonly entrained larvae at Canal. Therefore accurate predictions of survival of these species may not be possibly at this time. The projected effectiveness of fine mesh screens, as presented in Table 4-1, are based on extended survival estimates developed from studies at other power plants where fine mesh traveling screens have been used to collect and return impinged fish. Because of the lack of data available for many eggs and yolk-sac larvae, a wide range of 10-80% for eggs and 10-100% for yolk-sac larvae were used.

4.2 Retrofit Intake with Submerged, Cylindrical Wedge Wire Screens

Submerged, cylindrical wedge wire screen intakes could be installed to reduce fish entrainment and impingement. Cooling water could be conveyed through submerged, cylindrical wedge wire screens mounted on a bulkhead in front of the existing CWIS. The existing trash racks and traveling water screens would be removed from the intake structure. A plan and section of the submerged cylindrical wedge wire screens are shown on Figure 4-3 and Figure 4-4.

The bulkhead would consist of a sheet pile wall, steel piles, and a 10 ft wide platform extending the length of the bulkhead. The bulkhead would start from shore about 100 ft south of Unit 1's CWIS and extend in front of the intakes and end about 100 ft north of Unit 2's CWIS. The top of the bulkhead wall and platform would be at El. 10.0 ft (MSL) in water 25 ft deep below mean low water. The new bulkhead wall would create a plenum around the existing CWIS to isolate the intake from the canal.

The screens would have a 0.5 mm screen slot size and would be designed for a maximum slot velocity of 0.5 ft/sec. Fifty-seven T-54 screens would be required for total plant flow. Each screen would be 4.5 ft in diameter and T-shaped, with an overall length of about 15 ft. Two screen sections, each about 4.5 ft long, would be located on each side of a 6 ft long T section. The outlet pipe would be 3 ft in diameter and located in the middle of the T section. The outlet of the T would be flanged for connection to a slide gate attached to the sheetpile bulkhead. Two screens would be mounted to the slide gate which could be lifted by a hoist from the platform walkway to facilitate maintenance requirements. Both ends of the screen cylinders would be tapered to deflect submerged floating debris. A typical section of a wedge wire screen is shown on Figure 4-5. Two screens would be installed every 20 ft along the sheetpile bulkhead to provide a 4.5 ft (1 screen diameter) horizontal clear spacing and 9 ft (2 screen diameters) vertical clear spacing between screens.

An air backwash system, complete with necessary air compressors and controls, would be installed to clean the wedge wire screens. The air compressor and controls would be located in a new shelter near the existing CWIS. The air piping to each wedge wire screen would be installed under the platform walkway to the each screen. The air backwash system could be an effective method for maintaining the wedge wire screens at Canal Station in a clean condition. The relatively high water current velocities (1 ft/sec to 5 ft/sec) in the canal should transport debris and organisms downstream away from the screens. Periodic manual cleaning for removal of biofouling agents would likely be necessary.

Approach velocities at the wedge wire screens would be similar to canal currents. The maximum through-screen velocity would not exceed 0.5 ft/sec. Therefore, the screens should be highly protective of juvenile and adult fish. Head losses through the screens should not exceed one foot (assuming biofouling would not be a significant problem). However, a site-specific evaluation at the Canal Station may be necessary to design the air cleaning system for the conditions at the intake. Except for the slightly lower water level, flow characteristics in the intake channels between the bulkhead and CWIS with the wedge wire screens would not be any different than the existing intake. Flow patterns to the pumps would not change from the existing conditions.

Installation of the new wedge wire units and modifications to the existing intake structure would be accomplished in one construction season and would be sequenced to minimize impacts on plant operation during construction. Sheetpile walls forming the bulkhead would be driven, the walkway, screens, and slide gates would be installed, the existing trash racks and traveling water screens would be removed, and the air cleaning system equipment would be installed. Each circulating pump would have to be shutdown for approximately one month to remove the existing trash racks and screens, which could be done while the bulkhead wall is being completed. Sequencing construction in this manner would require the plant to be shutdown for one month to remove the traveling water screens and finish the bulkhead wall.

Operation and maintenance of the cylindrical wedge wire screens would eliminate operation and maintenance on the existing traveling water screens. Maintenance requirements for the circulating water pumps with the wedge wire screens in place would not change. To clean the wedge wire screens, an air-burst system would be used. For this evaluation, Alden assumes that the screens would need to be cleaned once a day, the actual number varying depending on the debris loading in the Canal. This would require two 60-hp air compressors operating 5 hours a day, resulting in additional operation and maintenance efforts. 164,000 kWh per year are needed to operate the air compressors and about 1,484 man-hours per year to monitor backwashing operation and to maintain the air supply equipment. In addition, the screens would require an annual inspection to identify any damage that could affect plant operations and to verify effective cleaning by the air backwash system. During the inspection, each screen would be manually cleaned, if necessary. This inspection and cleaning would take approximately one week using a hoist to lift the slide gates and screens to the platform elevation.

Implementation of this alternative would involve environmental impacts associated with installation of sheetpile bulkhead, dredging of bottom material behind the bulkhead, and disposing of dredge spoil. If analytical results of the dredged materials were to indicate excessive contamination by priority pollutants, disposal of the spoil could be a difficult problem. Disposal of the dredge spoil would have to comply with all applicable laws and regulations. Dredging would have to be performed in a manner to minimize adverse impacts to fish.

A new 500 ft bulkhead used to support the wedge wire screens located in front of the existing intakes will have a visual impact on the intake area. The bulkhead would be clearly visible from the canal service road which is heavily used by tourists. However, the appearance will be similar to the existing intake structures. Noise in the area will be increased due to the air compressors required for the screen's cleaning system. Two 60-hp compressors would operate about 5 hours a day located in an insulated building onshore. The bulkhead is located about 65 ft from the channel and could impact navigation patterns in the area. It is anticipated that permit requirements will dictate special construction activities due to the close proximity of the navigation channel and tourism on the canal service road.

Recent evaluations of wedge wire screens in the laboratory indicate that 0.5 mm screens designed with a slot velocity of 0.5 ft/sec are highly effective in reducing entrainment and impingement of larval fish and eggs of all species tested when channel velocities are greater then 0.5 ft/s (EPRI 2003). Estimated reductions in losses over the existing intake configuration are shown in Table 4-2. These estimates were largely based on the results from recent laboratory evaluations of the biological effectiveness of wedge wire screens conducted for EPRI (EPRI 2003). Estimates were adjusted for slack tides. It was assumed that the wedge wire screens would result in 0-10% mortality when tidal velocities are greater than 0.5 ft/sec and 100% during slack tides. Estimates also assume that there is a 45-minute slack tide during each 12-hour tide period. Water from Buzzards Bay is entrained 3.6 hours and from Cape Cod Bay 8.4 hours of each tidal cycle. A composite mortality rate that accounts for the slack tides would be 18.8% for Buzzards Bay and 28.8% for Cape Cod Bay.

4.3 Retrofit Intake with Barrier Net

A barrier net could be installed in front of each CWIS at Canal Station to reduce fish impingement mortality by reducing the number of fish impinged. This alternative could be particularly effective if entrainment is not an issue at Canal Station. Therefore, for the sake of completeness, a barrier net has been evaluated.

The net would have a 0.5 in mesh and would be designed for an average approach velocity of less than 0.25 ft/sec. This approach velocity was selected to reduce the effects of debris loading and to reduce impingement. Each CWIS would have a separate net. The Unit 1 CWIS would require a 70 ft length net and the Unit 2 CWIS would require an 80 ft length net assuming an average minimum depth of 25 ft. The nets would be located about 30 ft in front of the existing CWIS orientated parallel to the canal with isolation walls at each end. The location for the net would be close enough to the CWIS as not to interfere with barge traffic. The average water depths at the net would be about 25 ft with a maximum depth at high tide of about 35 ft. At normal low tide level, the velocity approaching each net would be about 0.2 ft/sec. The total area of the Unit 1 net would be 2,100 ft^2 and the total area for the Unit 2 net would be 2,800 ft^2. This includes extra material to allow the net to operate during high water conditions. The net configuration is shown on Figure 4-6.

The net would be supported by steel piles, floats, anchors, and sheet pile isolation walls. The bottom of the net would be contoured to follow the canal bottom topography. Floats would be used to prevent the top of the net from collapsing on itself. The ends of the net would be attached to sheet pile isolation walls and the net would be intermediately supported by steel piles between the isolation walls. The isolation walls would extend from the existing CWIS creating sufficient area to deploy the nets. Steel piles spaced 20 ft apart would be located in between the isolation walls to support the net. The steel piles and isolation wall would also support a 10 ft wide walkway to facilitate net cleaning and maintenance requirements. A section of the barrier net is shown on Figure 4-7.

The net would be fabricated in panels to facilitate installation and removal from the platform with assistance by divers, as required. Each panel would be 20 ft wide spaced between piles. Each panel would be fabricated to match the water depth at the specific installation position. A bottom anchor chain and top floatation would be fabricated into each net panel. The panels would be framed with rope to transfer forces to piles and to the top floatation and bottom anchor chain. Quick disconnect chain links would be installed by divers at 3 ft intervals to join the net panels to the pile supports. There would be some overlap between the panels to allow for compete protection. Top and bottom anchor lines would run between the piles and attach to net panels where they connect and about every 20 ft along their length.

Since the rate of debris loading and biofouling of a barrier net is not known at Canal Station and could not be determined until actual installation, Alden has assumed the net would have to be removed every week for cleaning. However, site-specific testing may be necessary to define the frequency for cleaning the net. Two nets would be needed to allow for this cleaning schedule. Net replacement would take approximately one day to remove the dirty net and install a clean one with assistance from divers. Alden assumed for this analysis that the net will be deployed year round. However, severe weather and winter conditions may not allow plant personal to maintain the net and may require net to be removed from the intake.

Installation of the net would require one construction season to complete. First, the isolation sheet pile walls and steel piles would be installed using barge mounted and shore based cranes. Next, the 10 ft wide walkway would be constructed and then the net would be installed. Construction efforts associated with the net would not impact plant operation.

Head losses across the net would be negligible at normal plant flow if the net was maintained in a clean condition. The design through-flow velocity during low water at the net would be about 0.25 ft/sec with no debris build-up. A breakaway panel would be installed in the center portion of the net to minimize damage to the net and support system if a severe debris loading condition occurred. Replacement of the net panels may be required as frequently as every year.

Implementation of this alternative would involve environmental impacts associated with installation of the isolation walls and piles. Installation of the barrier net supports would have to comply with all applicable laws and regulations and would have to be completed in a manner to minimize adverse impacts to aquatic life.

The barrier net support structure would be clearly visible from the canal service road and would have a visual impact on the area around the intake. However, the appearance of the structure will be similar to the existing intakes. The barrier net will have minimal impacts on current noise levels in the area. An electric hoist would be operated about twice a week for 8 hours. The location of the barrier net is about 50 ft from the navigation channel and could impact navigation in the area. It is anticipated that permit requirements will dictate special construction activities due to the close proximity of the navigation channel and tourism on the canal service road.

The net would not eliminate the need to operate the existing traveling water screens. When the net was in place, the screens would have to be ready to operate in the event of severe blockage of the net material such that the breakaway panels opened or material passed through the net during net changes. In order to assure reliable operation, each screen would have to be rotated daily and maintained on the routine basis that is currently scheduled. Maintenance requirements for the circulating water pumps would not change with the net in place.

Barrier nets have been shown to be effective in blocking the passage of fish at a number of hydroelectric projects and CWISs, but will not reduce the entrainment of eggs and larvae. The net mesh would have sufficiently small openings to act as a physical barrier to some juvenile and all adult fish. Estimates of biological effectives are presented in Table 4-3.

4.4 Install Coarse Mesh Ristroph Screens in Existing CWIS

If entrainment is not an issue at Canal Station, the existing traveling water screens in the CWIS could be replaced with new, state-of-the-art Ristroph coarse mesh (9.5 mm) screens (as described in Appendix A). The CWIS would not need to be expanded because the approach velocity is already less than 1.0 ft/sec.[1] (0.7 ft/sec for Unit 1 and 0.8 ft/sec at Unit 2 screen face). A section of a Ristroph screen is shown on Figure 4-2. The existing combined fish/debris trough would be used to return the impinged fish to the canal. This combined trough flows into Unit 1's abandoned discharge canal. All of the new screens would be designed for a 1.0 ft/sec approach velocity. No modifications would have to be made to the pump operation to reduce impingement survival.

The existing screenwell structure would require only minor modification for installation of new coarse mesh Ristroph traveling screens. The existing traveling water screens would be modified with new baskets, debris and fish troughs, backwash headers, and nozzles. Since the existing screens are not designed for continuous operation, the control systems and support frames would need to be replaced. Each screen basket would have a fish bucket to hold collected fish in about 2 in. of water while being lifted to the fish recovery system. A low-pressure spray (20 psigg) would be used to gently remove the fish from the fish holding buckets into a separate fish trough. A conventional high-pressure wash would then remove debris into a separate debris trough.

New fish and debris troughs would be mounted above deck level on the downstream side of the screens. The debris backwash system would use the existing high pressure screenwash pumps to provide flow to the high-pressure spray wash headers for all of the new Ristroph screens. Two new screenwash pumps, each with a 1,500 gpm capacity at 20 psig, would be installed for the low pressure spray wash headers for the new screens. No other screenhouse modifications would be needed.

Removal of the existing traveling water screens and installation of the new Ristroph screens would require about two weeks per screen to remove the original screen, install the new screens, and complete mechanical and electrical work. The screens would be replaced one at a time to

[1]For impingement survival purposes, Alden believes that 1.0 ft/sec velocity with Ristroph screens is protective.

minimize impacts on plant operation. The existing debris trough would remain in place during installation of the replacement screens to allow other screens to operate during the switch over. Installation of the new spraywash system, including the new debris and fish troughs, would be completed as each screen is replaced, allowing each new screen to become operational before initiating the next screen replacement.

Operation and maintenance of the Ristroph screens would be similar to that for the existing screens. Maintenance requirements for the circulating water pumps would not change. The screens would be operated continuously year round. The operation and maintenance costs for this option were calculated based on this assumption. The screens and high pressure screenwash pump would have similar maintenance requirements as the existing screen system, but would require an additional 1,315,000 kWh per year to operate the screens and cleaning system continuously. An additional 1,947 hours per year would be required to maintain the new screen system.

The replacement of the existing screens with new Ristroph screens would not change the current appearance or noise levels.

Coarse mesh Ristroph screens will not reduce the entrainment of eggs and larvae, but will provide a benefit to juvenile and adult fish. Ristroph screens do not reduce the number of fish impinged, but do increase the survival of impinged fish. Therefore, these screens are beneficial from an organism protection viewpoint only if impingement survival for important species and life stages is relatively high. Post-impingement survival is very species-specific. Species generally considered to be fragile (such as members of the Family Clupeidae and Engravlidae) typically have poor survival. For example reported bay anchovy survivals range from 0 to 72% with the majority of reported survivals in the 0-50% range. By contrast, species that are generally considered hardy (such as members of the Family Centrarchidae) typically have good survival. For example, the reported survival of Centrarchids ranges from 54 to 99%. Little or no data available for many of the species commonly impinged at Canal. The projected effectiveness of fine mesh screens as presented in Table 4-4 are based on extended survival estimates developed from studies at other power plants where coarse mesh traveling screens have been used to collect and return impinged fish.

4.5 Reduced Circulating Water Pump Operation

A reduction in entrainment could be accomplished by modifying the current circulating water pump operation during periods of high entrainment. A 60% reduction in pumping capacity during periods of high abundance of entrainable organisms could reduce entrainment by 60%. Targeting flow reductions during periods of peak entrainment may allow Mirant to achieve a 60% reduction in entrainment without reducing year round flows by 60%. A detailed analysis of impingement rates for all of the species and life stages at the Canal Station CWIS would be necessary to determine the potential reduction in impingement resulting from a flow reduction option.

The existing intake for each Unit has two pumps located downstream of a common plenum. This, along with the pump discharges manifolded together, allows for reduced intake flows without the addition of variable speed drives. There are also discharge valves on the circulating water pumps which allow the flow per individual pump to be further reduced. Different pumping scenarios and the reduced flow values that could be achieved are shown in Table 4-5. A 60% reduction in flow could be achieved by shutting down one pump for each Unit and operating the other Unit's pump at 80% capacity. By operating only one pump per Unit and the others at 40% capacity, an 80% flow reduction could be achieved. Modifications to the discharge diffusers may allow the Unit to operate at full capacity with less flow because of better mixing of the plant discharge with the Canal flow.

The existing intake structure, traveling water screens, and circulating water pumps would not require replacement or upgrade for this modified operation option. Operation and maintenance requirements would not change for the existing traveling water screens and circulating water pumps. The screen and pump equipment would not require any additional power and would require the same level of manpower for maintenance. Two-pump operation with the discharge valves throttled (60% flow reduction) during periods of high entrainment would reduce plant output to about 448 MW. Operating the plant in this manner during the months of high entrainment would limit the potential plant generation to about 323,000 MWh per month depending on valve operation.

Throttling the discharge valves would not substantially reduce current power requirements to operate the pumps. Reduced pump flow could be achieved by installing variable speed drives to the existing pumps. However, capital costs of the variable speed drives could offset the energy costs. A more detailed evaluation would be necessary to determine if variable speed drives would be a more cost effective option than throttling the circulating water pump discharge valves.

The modified pumping operation would not change the current aesthetics at the intake or noise levels.

Reduction in cooling-water flow would result in a greater change in the temperature of the cooling-water through the condensers, along with an associated temperature increase at the point of discharge in the canal. This option would also decrease the capacity of the Station, resulting in lost generation.

Canal Station nearly always has a unit operating. Unit 1 cycles in load from about 200 MW_{net} to 560 MW_{net} and Unit 2 cycles from about 60 MW_{net} to 560 MW_{net} as needed by the distribution system grid. Demand for power and ancillary markets occurs without warning and any flow restrictions which reduce power generation would severely hinder Canal Station's ability to meet the power demands and maintain stability in the Southeastern Massachusetts distribution system.

When assessing the benefits, it was assumed that a reduction in entrainment was commensurate with reductions in flow and that an even distribution of larvae and egg were present during periods of flow reduction.

4.6 Retrofit Plant with Closed-Cycle Cooling System

Retrofitting the once-through cooling water system with a closed-cycle cooling system would reduce the water withdrawal from the canal and would eliminate the need for the existing discharge diffuser. The amount of cooling water required for Canal Station would be reduced by 98% to 72% for a cooling tower with a commensurate reduction in organism entrainment (EPA 2002). A 98% reduction would be typical of freshwater facilities, while the lower reduction would be typical for estuarine and marine facilities, which require more frequent blowdown of cooling water. An evaluation of cooling tower costs for retrofitting existing power stations was provided in EPRI's report entitled "Cooling System Retrofit Costs Analysis" prepared in July of 2002. This report was prepared in response to the proposed EPA Rulemaking. This study was conducted to provide generalized methods and supporting data for estimating the cost of retrofitting existing plants with re-circulating systems (EPRI 2002).

The EPRI 2002 report developed the likely costs for "all cooling towers." To develop these costs, three assumptions were made:

1. The addition of a cooling tower would connect to the existing condenser so circulating water rates would not change.

2. Portions of the existing condenser conduit systems can be used, even though some modifications may be required.

3. The cost methodology is based on new facilities and must be adjusted using multiplying factors to determine the cost of retrofitting an existing facility.

Using these assumptions, the costs were broken down into easy, average, and difficult retrofitting costs. These three cost levels are based mainly on site-specific factors (EPRI 2002).

A mechanical or natural draft cooling tower could be retrofitted to meet the cooling requirements of the plant. For the purpose of this evaluation, Alden has assumed that a mechanical draft tower would be installed at the site. Land is available at Canal Station for a cooling tower. However, mist eliminators and plume abatement measures would be necessary to reduce cooling tower drift and minimize impacts on transportation (shipping, highways, and railroad). For this reason, Canal Station would be classified as a difficult site relative to EPRI's cooling tower cost methodology.

Most of the condenser and cooling system components inside the turbine building would remain intact and would utilize approximately the same condenser flows. Cooling water that is currently discharged into the discharge canal would be redirected into a wet pit pump structure where booster pumps would convey cooling water to the cooling tower spray deck and back to the existing intake canal. Gravity would be used to convey the cooling water through the condensers similar to the existing once-through system. A new, smaller pump would be installed in the intake to supply makeup water from the intake canal for the closed-cycle cooling system.

Most of the construction efforts on the cooling tower would be independent of the existing circulating water system and would not affect plant operations. However, replacement power would be required to implement the intake modifications and the final circulating water pipe modifications. These efforts would require the plant to be shut down for about 6 months, which would amount to about 4,838,400 MWh.

The mechanical draft cooling tower would require approximately 1.2% of the total plant output for auxiliary power (EPRI 2002). The extra power would be required to operate the additional cooling water supply pumps for the tower, the tower fans, the blowdown facility equipment, and the makeup water pumps. Since the temperature of the cold water produced by the tower would be proportional to approach temperature (local wet bulb temperature), the closed-cycle system would produce warmer water than the current once-through cooling water. All retrofitted closed-cycle cooling system alternatives would cause a reduction in net generation and a corresponding increase in the heat rate, except for periods when the turbine output is currently limited by high backpressures. The higher water temperatures at the condenser inlet would reduce plant output by 1% of total plant capacity or about 98,112 MWh during the year (EPRI 2002). The net loss of salable power would be about 214,669 MWh per year.

Cooling towers require make-up water due to evaporation losses and blow-down discharges. The make up water required for cooling towers varies depending on the cycles of concentration at which the tower is operating. Typically, cooling water intake flow rates for cooling towers are reduced by 72% to 98% of that of once-through systems (EPA 2002). The expected make-up water intake flow rates for Canal Station would range from 16 cfs to 224 cfs.

Annual maintenance is necessary on the mechanical and electrical components of a mechanical draft tower and the other pumping components for a closed-loop cooling water system. Pumps, fans, motors, controls, fill sections, support structures, and the tower basin and hardware all require periodic inspections and maintenance. The EPRI study indicates that the operating and maintenance costs for a cooling tower retrofit would be 2% of the total construction costs.

A cooling tower would significantly diminish the aesthetics of the area around the plant due to size of the tower and the visible plume. Canal station is located near residential and tourism areas which place a high value on the surrounding scenery. Noise levels in the area would increase due to the number and size of fans required for the cooling tower. Other environmental impacts include disposal of waste water and solid waste, emissions of drift, visible plumes, and additional air emissions from increased fuel consumption (EPRI 2002).

As with other reduced flow options, it is assumed that the reduction in entrainment would be commensurate with reductions in flow. This assumes an even distribution of larvae and egg during periods of flow reduction.

Table 4-1 Percent Mortality Associated with New Fine-Mesh Ristroph Screens

Species	Eggs	YS Larvae	PYS Larvae	Juvenile/Adult
blueback herring	10-80	10-100	19-93	18-100
Atlantic menhaden	10-80	10-100	19-93	92-97
Atlantic herring	10-80	10-100	19-93	18-100
fourbeard rockling	10-80	10-100	63-84[a]	16-80
Atlantic cod	10-80	10-100	63-84[a]	16-80
hake	10-80	10-100	63-84[a]	16-80
pollock	10-80	10-100	63-84[a]	16-80
Atlantic silverside	10-80	10-100	99[b]	82
grubby	10-80	10-100	48-90[g]	13-18
striped bass	10-80	10-100	18-98	9-57
scup	10-80	10-100	98[c]	9-37[g]
tautog	10-80	10-100	63-84[a]	0-4
cunner	10-80	10-100	63-84[a]	0-4
butterfish	10-80	10-100	63-84[a]	68
windowpane	10-80	10-100	36-100[d]	2-21[d]
American plaice	10-80	10-100	36-100[d]	2-21[d]
winter flounder	10-80	10-100	36-100	2-21
yellowtail flounder	10-80	10-100	36-100[d]	2-21[d]
haddock	10-80	10-100	63-84[a]	M.I.
goosefish	10-80	10-100	48-90[g]	9-37[g]
northern searobin	10-80	10-100	63-84[a]	M.I.
American sand lance	10-80	10-100	96[e]	M.I.
Atlantic mackerel	10-80	10-100	63-84[a]	9-37[g]
American lobster	N.A.	N.A.	48-90[g]	0-12[f]

M.I. - life stage minimally involved
N.A. – not applicable

Surrogate Key

a Cynoscion sp.
b carps and minnows
c drums
d winter flounder
e clupeiforms
f crabs
g geometric mean of high and low values of other species

Table 4-2 Percent Mortality Associated with Submerged, Cylindrical Wedge Wire Screens

Species	Eggs	YS Larvae	PYS Larvae	Juvenile/Adult
blueback herring	0-10	0-10	0-10	0-2
Atlantic menhaden	0-10	0-10	0-10	0-2
Atlantic herring	0-10	0-10	0-10	0-2
fourbeard rockling	0-10	0-10	0-10	0-2
Atlantic cod	0-10	0-10	0-10	0-2
hake	0-10	0-10	0-10	0-2
pollock	0-10	0-10	0-10	0-2
Atlantic silverside	0-10	0-10	0-10	0-2
grubby	0-10	0-10	0-10	0-2
striped bass	0-10	0-10	0-10	0-2
scup	0-10	0-10	0-10	0-2
tautog	0-10	0-10	0-10	0-2
cunner	0-10	0-10	0-10	0-2
butterfish	0-10	0-10	0-10	0-2
windowpane	0-10	0-10	0-10	0-2
American plaice	0-10	0-10	0-10	0-2
winter flounder	0-10	0-10	0-10	0-2
yellowtail flounder	0-10	0-10	0-10	0-2
haddock	0-10	0-10	0-10	0-2
goosefish	0-10	0-10	0-10	0-2
northern searobin	0-10	0-10	0-10	0-2
American sand lance	0-10	0-10	0-10	0-2
Atlantic mackerel	0-10	0-10	0-10	0-2
American lobster	N.A.	N.A.	0-10	0-2

N.A – Not Applicable

Table 4-3 Percent Mortality Associated with Barrier Net

Species	Eggs[1]	YS Larvae[1]	PYS Larvae[1]	Juvenile/Adult
blueback herring	100	100	100	10-20
Atlantic menhaden	100	100	100	10-20
Atlantic herring	100	100	100	10-20
fourbeard rockling	100	100	100	10-20
Atlantic cod	100	100	100	10-20
hake	100	100	100	10-20
pollock	100	100	100	10-20
Atlantic silverside	100	100	100	10-20
grubby	100	100	100	10-20
striped bass	100	100	100	10-20
scup	100	100	100	10-20
tautog	100	100	100	10-20
cunner	100	100	100	10-20
butterfish	100	100	100	10-20
windowpane	100	100	100	10-20
American plaice	100	100	100	10-20
winter flounder	100	100	100	10-20
yellowtail flounder	100	100	100	10-20
haddock	100	100	100	10-20
goosefish	100	100	100	10-20
northern searobin	100	100	100	10-20
American sand lance	100	100	100	10-20
Atlantic mackerel	100	100	100	10-20
American lobster	N.A.	N.A.	N.A.	10-20

N.A. – not applicable

1. There is no site specific entrainment data available. At many facilities survival of early life stages can be significant especially during periods when biofouling control measures are not in use. However, in the absence of site specific survival data a conservative assumption of 100% mortality has been made.

Table 4-4 Percent Mortality from Existing Intake – Coarse Mesh Ristroph Screens

Species	Eggs[1]	YS Larvae[1]	PYS Larvae[1]	Juvenile
blueback herring	100	100	100	18-100
Atlantic menhaden	100	100	100	92-97
Atlantic herring	100	100	100	18-100
fourbeard rockling	100	100	100	16-80
Atlantic cod	100	100	100	16-80
hake	100	100	100	16-80
pollock	100	100	100	16-80
Atlantic silverside	100	100	100	82
grubby	100	100	100	13-18
striped bass	100	100	100	9-57
scup	100	100	100	9-36
tautog	100	100	100	0-4
cunner	100	100	100	0-4
butterfish	100	100	100	68
windowpane	100	100	100	2-21
American plaice	100	100	100	9-36
winter flounder	100	100	100	2-21
yellowtail flounder	100	100	100	2-21
haddock	100	100	100	9-36
goosefish	100	100	100	9-36
northern searobin	100	100	100	9-36
American sand lance	100	100	100	9-36
Atlantic mackerel	100	100	100	9-36
American lobster	N.A.	N.A.	100	9-36

N.A.- not applicable

1. There is no site specific entrainment data available. At many facilities survival of early life stages can be significant especially during periods when biofouling control measures are not in use. However, in the absence of site specific survival data a conservative assumption of 100% mortality has been made.

Table 4-5 Reduced Circulating Water Pump Scenarios

Scenerio	Unit 1 Pump A (cfs)	Unit 1 Pump B (cfs)	Unit 2 Pump A (cfs)	Unit 2 Pump B (cfs)	Total Intake Flow (cfs)	Percent Flow Reduction	Plant Output (MW)	Monthly Plant Generation during Entrainment Periods (MWH)
Full Capacity	189	189	213	213	804	0%	1120	806,400
1	off	189	213	213	615	24%	857	616,836
2	189	189	off	213	591	26%	823	592,764
3	off	189	off	213	402	50%	560	403,200
4, pumps throttled to 80% capacity	off	off	170	170	341	58%	475	341,817
5, pumps throttled to 80% capacity	off	151	off	170	322	60%	448	322,560
6, pumps throttled to 40% capacity	off	76	off	85	161	80%	224	161,280

Figure 4-1 Expand Intake with Fine Mesh Ristroph Screens – Plan

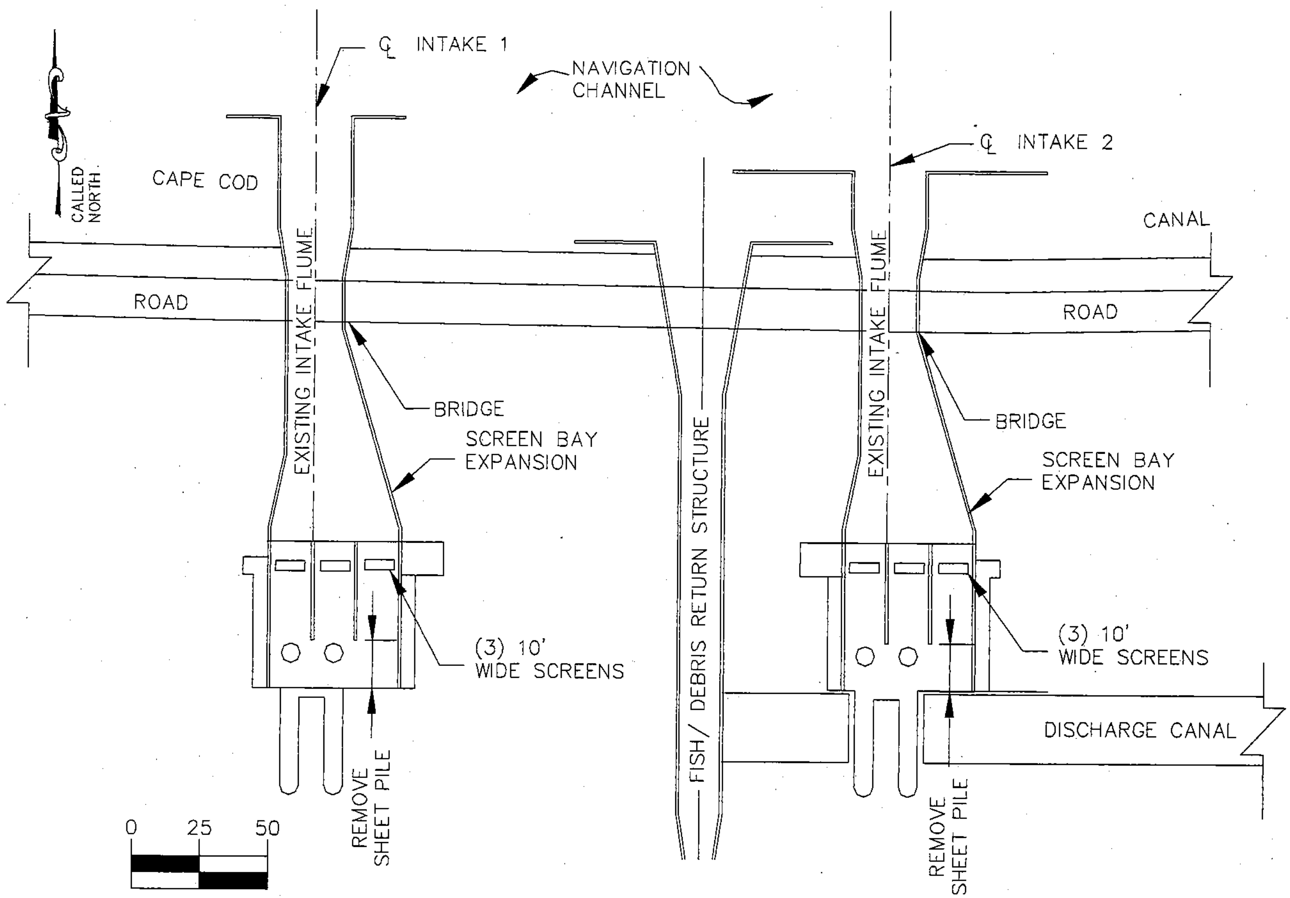


Figure 4-2 Ristroph Screen Section

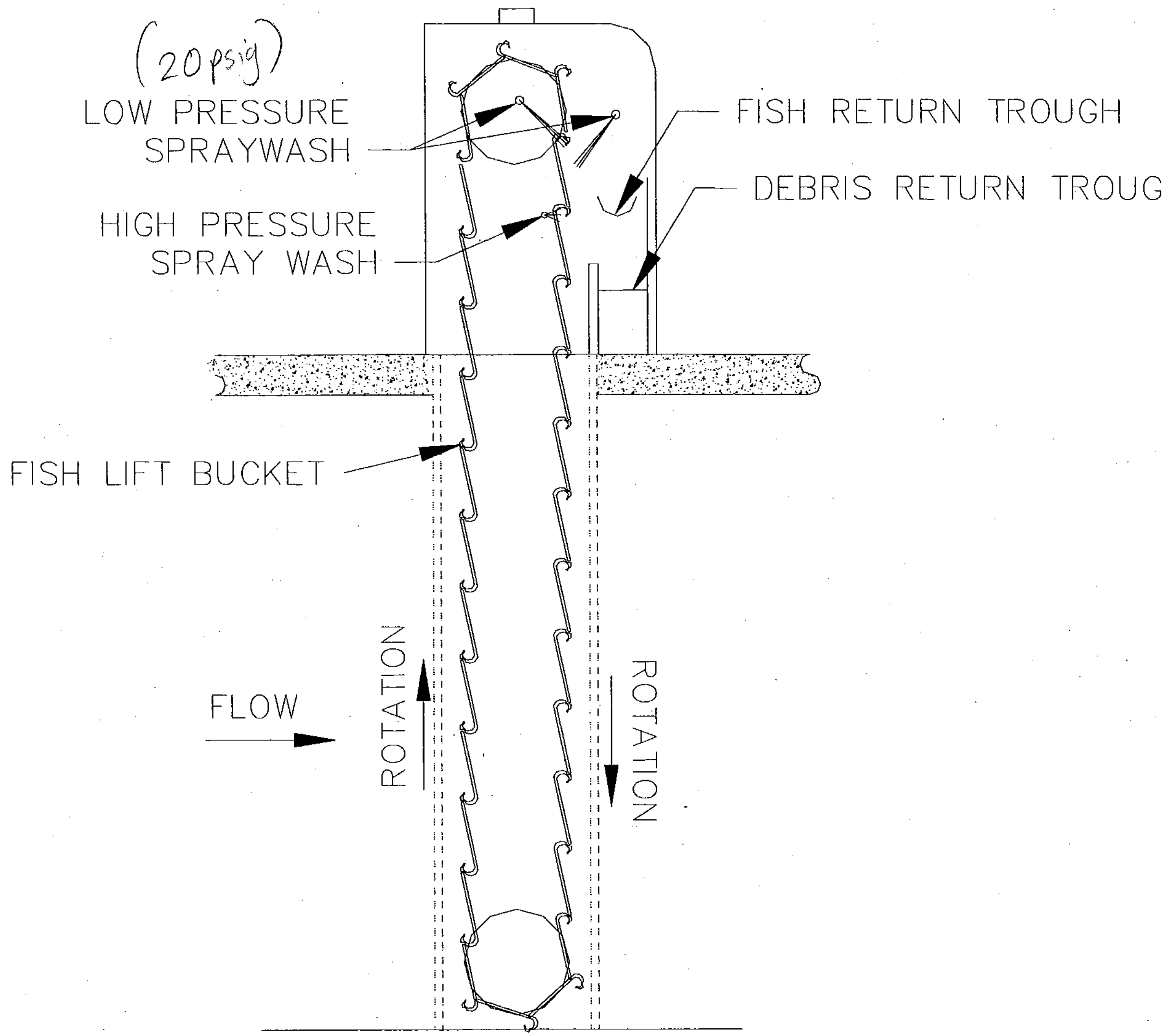


Figure 4-3 Cylindrical Wedge Wire Screens – Plan

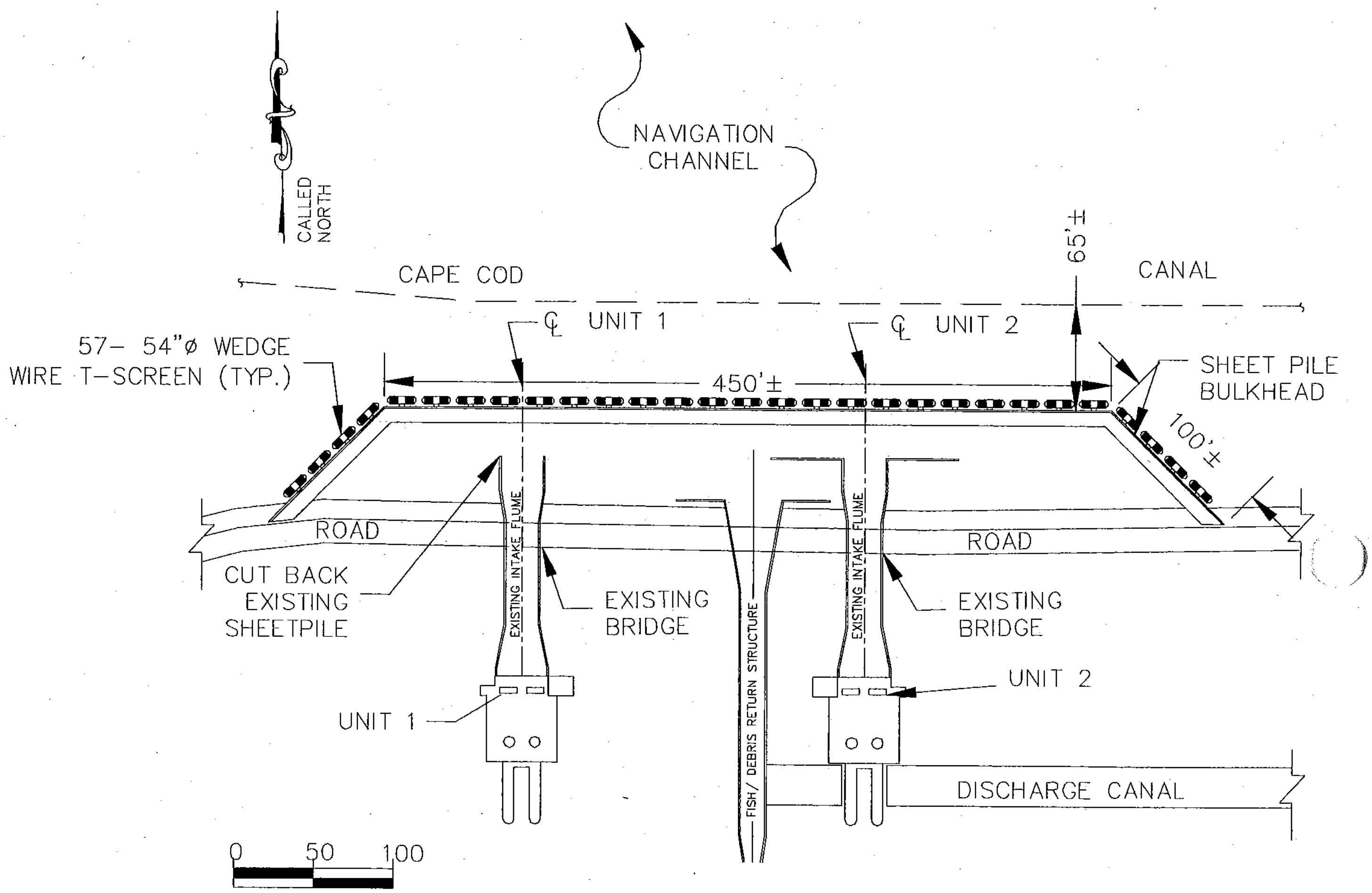


Figure 4-4 Cylindrical Wedge Wire Screen – Section

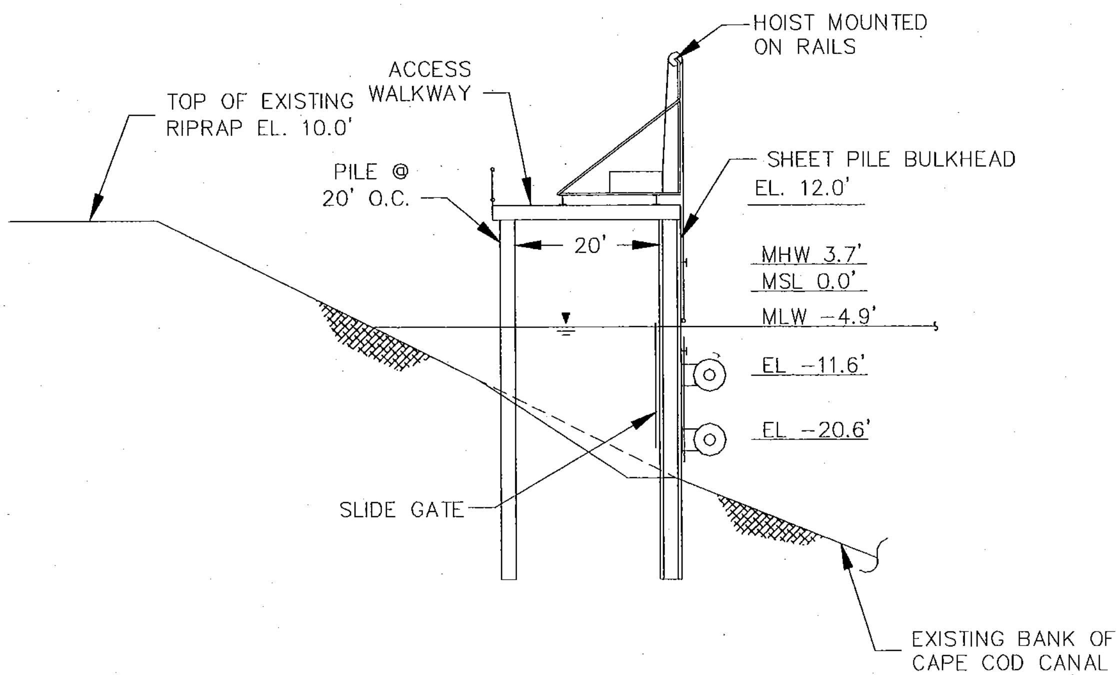


Figure 4-5 Cylindrical Wedge Wire – Typical Section

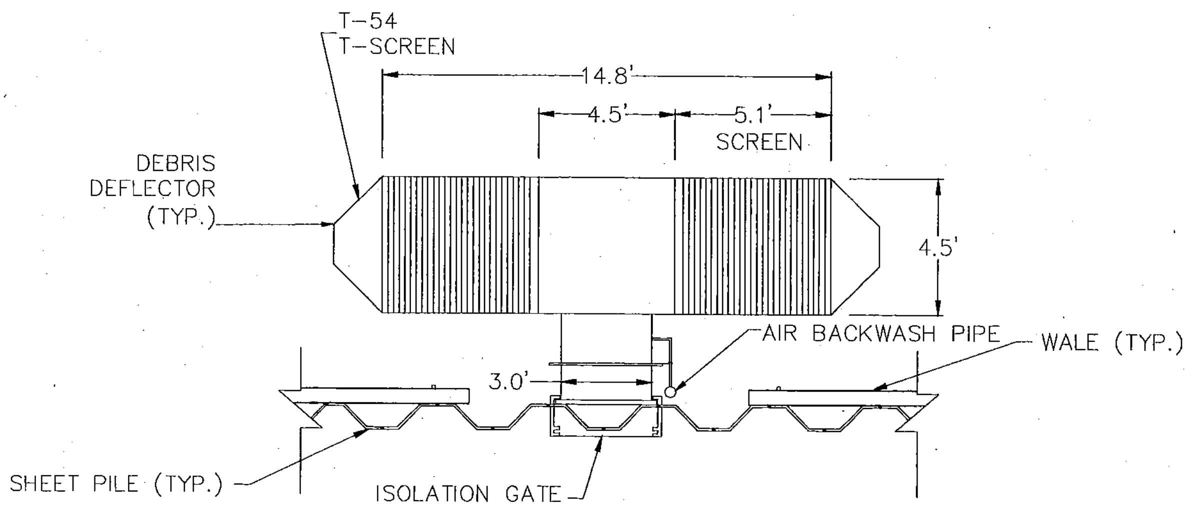


Figure 4-6 Barrier Net – Plan

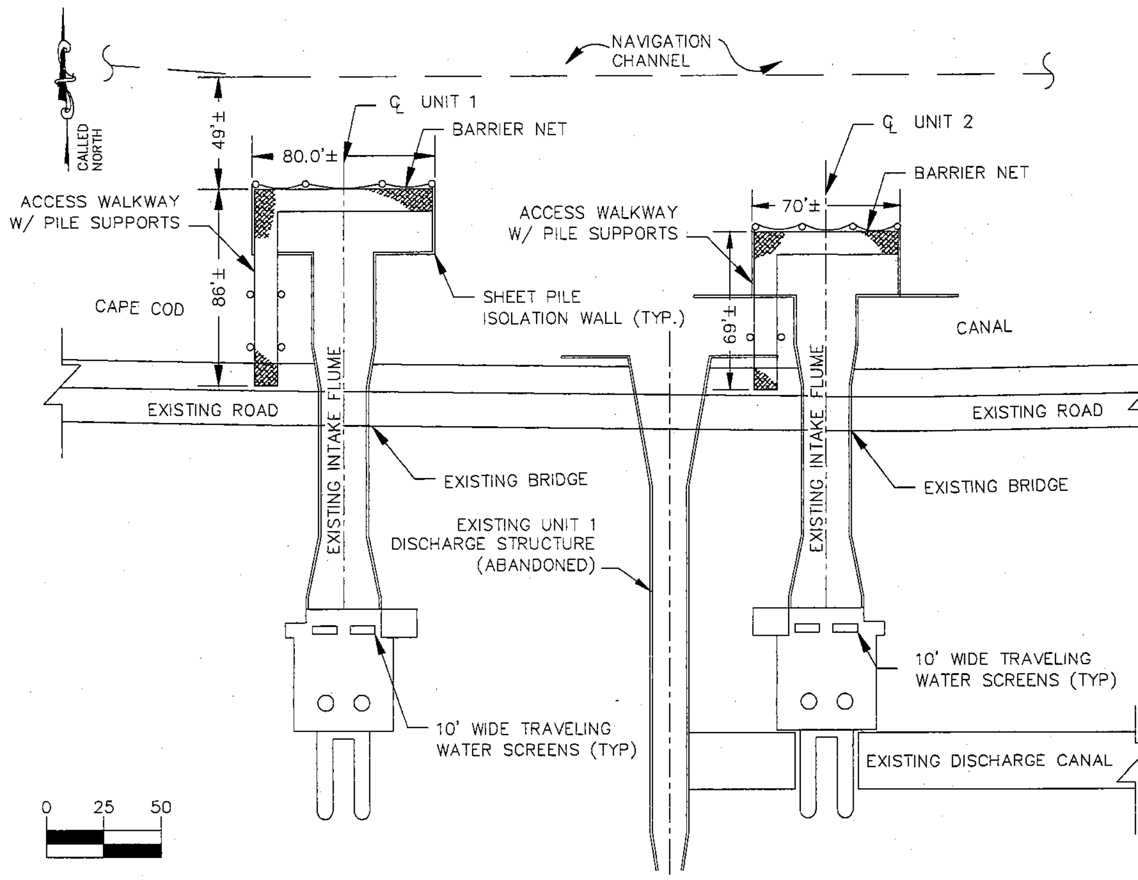
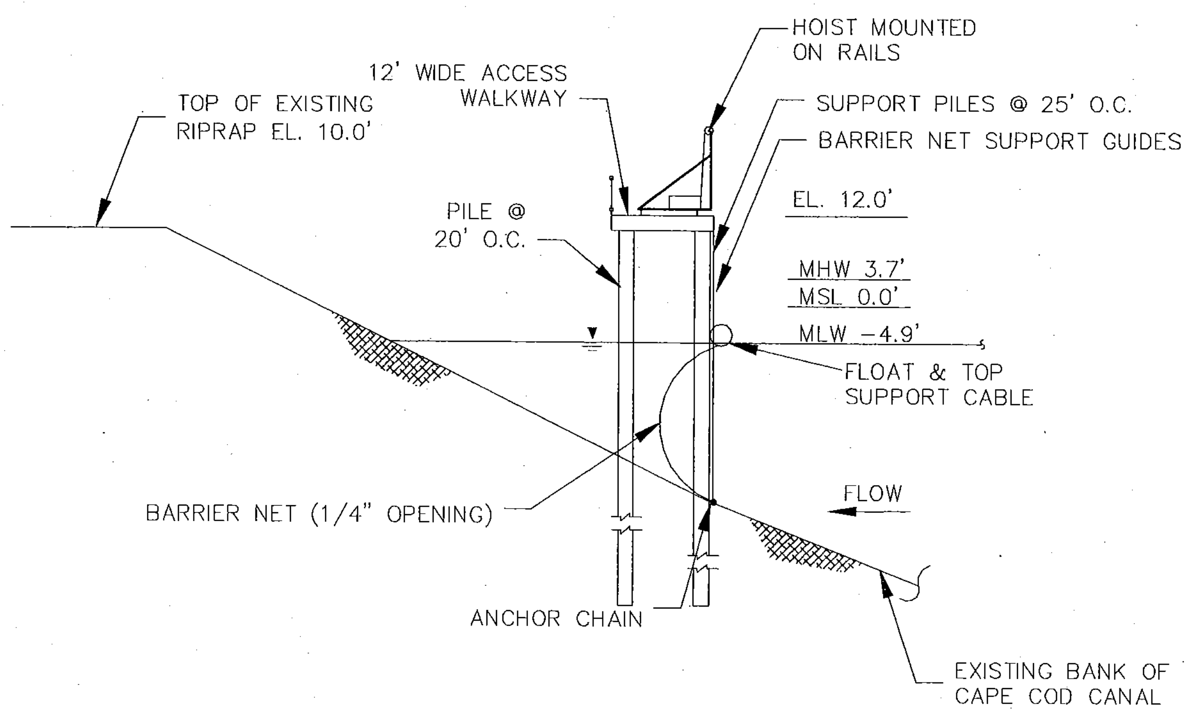


Figure 4-7 Barrier Net Section



SECTION 5
ESTIMATED COSTS

Costs for the intake modification alternatives and reduced pump flow options were based on quantities developed from conceptual designs for each alternative and historical data from other projects. The cost data were adjusted for identifiable differences in project size, operations, and best professional judgment. The estimates are intended to identify the relative cost differences between alternatives.

Costs in Alden's historical database typically reflect the following assumptions:

- Present-day prices and fully contracted labor rates as of September 2003.
- Forty-hour workweek with single-shift operation for construction activities that do not impact plant operations and fifty-hour workweek with double-shift operation for construction activities that impact plant operations.
- 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 during construction. These costs have been taken as 85-100% 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.
- Allowance for indeterminates to cover uncertainties in design and construction at this preliminary stage of study. An allowance for indeterminates is a judgment factor that is added to estimated figures to complete the final cost estimate, while still allowing for other uncertainties in the data used in developing these estimates. The allowance for indeterminates has been taken as 10% of the direct, distributable, and indirect costs of 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 data base costs typically do not include the following items that should be included to estimate total capital costs:

- Costs to perform additional laboratory or field studies that may be required, such as impingement or entrainment characterization studies, biological evaluations of prototype fish protection systems, soil sampling, and wetlands delineation and mitigation.

- Costs to dispose of any hazardous or non-hazardous materials that may be encountered during excavation and dredging activities.
- Costs for administration of project contracts and for engineering and construction management incurred by Mirant.
- Escalation
- Permitting costs

The estimated project costs for the coarse-mesh Ristroph screens, fine-mesh Ristroph screens, wedge wire screens, and barrier net are presented in Table 5-1 through Table 5-4.

The estimated costs and parameters relative to each intake technology or closed-cycle cooling option that would impact operation of Canal Station are summarized in Table 5-5. These parameters include the estimated incremental increase in annual operating and maintenance costs, the estimated annual energy required for operating additional equipment, and the estimated plant outage necessary for construction for each alternative. The operating and maintenance considerations and the outage durations are based on the requirements discussed in Section 4.

Cost for the closed-cycle cooling system alternative was estimated from information provided in the EPRI 2002 report. This study reflected retrofit cost data from 50 nuclear and fossil plants on fresh, brackish, and saline water sources. Plant sizes were 100 to 2,600 MW with cooling tower retrofit costs ranging from $11 million to over $860 million. Costs are $125/gpm for "easy" projects, $200/gpm for "average" projects, and $250-$300/gpm for "difficult" projects (EPRI 2002). Power to operate cooling towers is typically 1-1.5% of the plant capacity and operating and maintenance costs are typically 1-2% of the tower capital costs (EPRI 2002)

Capital costs for the intake alternatives to meet the entrainment standard range from $10,410,000 to expand the intake and install fine mesh Ristroph screens to $11,251,000 to retrofit the intake with submerged cylindrical wedge wire screens. If Canal Station only has to meet the impingement mortality standard, then the capital costs range from $2,295,000 to modify the existing intake with coarse mesh Ristroph screens to $2,379,000 to retrofit the intake with a barrier net. Limiting the plant flow during periods of high entrainment would meet the entrainment standard at no additional capital costs. This would, however, carry a large energy penalty. Reduction in flow up to 60% would reduce generating capacity by 2,943,360 MWh per year resulting in a replacement power cost of $161,885,000 (assuming $55 per MWh). Cooling tower retrofit costs for Canal Station would be about $108,251,000. Canal Station is categorized as a difficult cooling tower site because of the site-specific factors related to available land area, potential drift, and noise. Cooling tower costs (capital and O&M) estimates are based on the EPRI study.

Table 5-1 Expand Intake and Add Fine Mesh Ristroph Screens

Item	Estimated Cost ($ x 10^3)
Direct Costs	
Mobilization and Demobilization	688
Screen Well Bays	2,719
Screenhouse Modifications	225
Fish and Debris Return System	192
Trash Racks	21
Fine Mesh Ristroph Screens and Circulating Water Pumps	2,419
Cranes and Equipment	1,263
Cost of Lost Generation due to Construction (assumed $0.055/Kwh)	44
Direct Costs (September 2003 $)	$7,571
Indirect Costs	757
Subtotal	$8,328
Allowance for Indeterminates/Contingencies	2,082
Total Estimated Project Costs (September 2003 $)	$10,410

Impacts on Plant Operation	
Item	**Impact**
Construction	
Duration	1 year
Unit 1 Outage	1 month
Unit 2 Outage	1 month
Incremental Annual Operation and Maintenance	
Labor, (hr)	2,920
Component Replacement	$173,000
Energy (kwh)	1,972,000
Peak Power (kw)	150

Table 5-2 Retrofit Intake with Submerged, Cylindrical Wedge Wire Screens

Item	Estimated Cost ($ x 10^3)
Direct Costs	
Mobilization and Demobilization	744
Bulkhead Isolation Wall	3,097
Walkway	493
Hoist	267
Cylindrical Wedge Wire Screens	2,833
Air Backwash System	705
Cost of Lost Generation due to Construction (assumed $0.055/Kwh)	44
Direct Costs (September 2003 $)	$8,183
Indirect Costs	818
Subtotal	$9,001
Allowance for Indeterminates/Contingencies	2,250
Total Estimated Project Costs (September 2003 $)	$11,251

Impacts on Plant Operation

Item	Impact
Construction	
Duration	1 year
Unit 1 Outage	1 month
Unit 2 Outage	1 month
Incremental Annual Operation and Maintenance	
Labor, (hrs)	1,484
Component Replacement	$118,000
Energy (kwh)	164,000
Peak Power (kw)	130

Table 5-3 Retrofit with Barrier Net

Item	Estimated Cost ($ x 10^3)
Direct Costs	
Mobilization and Demobilization	157
Isolation Wall	1,260
Walkway	16
Hoist	267
Barrier Net	26
Wire Rope and Floatation	4
Direct Costs (September 2003 $)	$1,730
Indirect Costs	173
Subtotal	$1,903
Allowance for Indeterminates/Contingencies	476
Total Estimated Project Costs (September 2003 $)	$2,379

Impacts on Plant Operation	
Item	**Impact**
Construction	
Duration	6 months
Unit 1 Outage	None
Unit 2 Outage	None
Incremental Annual Operation and Maintenance	
Labor, (hrs)	1,664
Component Replacement	$259,000
Energy (kwh)	37,440
Peak Power (kw)	23

Table 5-4 Install Coarse Mesh Ristroph Screens

Item	Estimated Cost ($ x 10^3)
Direct Costs	
Mobilization and Demobilization	152
Fine Mesh Ristroph Screens and Circulating Water Pumps	1,120
Screenhouse Modifications	145
Fish and Debris Return System	169
Cranes and Equipment	83
Direct Costs (September 2003 $)	$1,669
Indirect Costs	167
Subtotal	$1,836
Allowance for Indeterminates/Contingencies	459
Total Estimated Project Costs (September 2003 $)	$2,295

Impacts on Plant Operation

Item	Impact
Construction	
Duration	2 months
Unit 1 Outage	None
Unit 2 Outage	None
Incremental Annual Operation and Maintenance	
Labor, (hr)	1,947
Component Replacement	$117,000
Energy (kwh)	1,315,000
Peak Power (kw)	100

Table 5-5 Cost Comparison of Evaluated Alternatives

Alternative	Capital Costs		Incremental Annual O&M [1]		Power Penalty from Baseline d Limitations	
	Construction Cost ($ x 10^3)	Replacement Power During Construction (MWh)	Incremental Annual Energy (MWh) [1,2]	Incremental Annual O&M Cost ($ x 10^3) [1]	Capacity (MW)	Energy (MWh)
Expand Intake and Install Fine Mesh Ristroph Screens	$10,410	806,400	1,972	$398	0	0
Retrofit Intake with Submerged, Cylindrical Wedge Wire Screens	$11,251	806,400	164	$188	0	0
Retrofit Intake with Barrier Net	$2,379	0	37,440	$328	0	0
Install Coarse Mesh Ristroph Screens in Existing Intake	$2,295	0	1,315	$267	0	0
Modified Plant Operations (Flow Limitation)	$0	0	0	$0	672	2,943,360
Retrofit Plant with Closed-Cycle Cooling System	$108,251[3]	4,838,400[3]	116,557[3]	$2,165[3]	11[3]	214,669[3]

1. Incremental annual operating & maintenance (O&M) costs for each concept include labor to maintain components, replacement parts and subcontractor costs, and energy to operate equipment.
2. Based on base loaded operation (100% utilization)
3. Based on EPRI 2002

SECTION 6
SUMMARY

Available fish protection technologies were subjected to a screening process to determine which technologies offered the greatest potential for effective application at Canal Station to reduce fish impingement mortality and entrainment. Those technologies that were deemed to be commercially available, practicable from an engineering stand-point, and potentially biologically effective were further developed to a level necessary to estimate installation and O&M costs. Two technologies to reduce entrainment (modified fine mesh traveling screens and wedge wire screens) were developed, as well as two reduced flow options (modify plant operation and closed cycle cooling towers). Two of the entrainment reducing technologies (wedge wire screens and fine-mesh Ristroph screens) will also eliminate impingement. Fine mesh Ristroph screens will not reduce impingement, but will increase impingement survival for juvenile and adult fish. The flow reduction options will reduce entrainment commensurate with the reduction in flow. Some level of impingement reduction would be achieved through the implementation of flow reduction options, but not necessarily proportional to the flow reduction. In addition, a barrier net and a modified coarse mesh screen option were developed for their potential to increase impingement survival, but not reduce entrainment. All of the technologies have substantial life cycle costs associated with their installation, operation, and maintenance.

Studies conducted at other water withdrawals and in the laboratory indicate that all of the entrainment reducing technologies considered may be effective in reducing both impingement mortality and entrainment of several of the dominant species and life stages at Canal Station. However, further study may be needed to refine technology designs to assure effective operation for the site specific conditions at Canal Station, (ie. debris loading, high ambient velocities, and effects of nearby navigation traffic).

Modified traveling screens could be used to reduce impingement mortality and/or entrainment depending upon mesh size. Upgrading the existing screens with fish removal features could reduce impingement mortality for most species and life stages at a cost of about $2,295,000. Installation of modified fine mesh traveling screens with fish return would require expanding the CWIS to incorporate more screens to reduce velocities to a desired level, and would cost about $10,410,000 to complete. Overall entrainment could be substantially reduced. However, traveling screens with fish returns often handle fragile species and could potentially result in high mortality rates. Also, because there is limited data available on the hardiness of several species and lifestages commonly entrained at Canal, it is difficult to assess the potential biological effectiveness of entrainment reducing technologies entrainment by 72% to 98%, but would cost on the order of $108,000,000 depending on the type of tower.

SECTION 7
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APPENDIX A
OVERVIEW OF INTAKE TECHNOLOGIES AVAILABLE FOR FISH PROTECTION

Overview of Intake Technologies

Depending on their mode of action, available fish protection systems fall into one of four categories: behavioral barriers, which alter or take advantage of natural behavior patterns to attract or repel fish; physical barriers, which physically block fish passage; collection systems, which actively collect fish for their return to a safe release location; and diversion systems, which divert fish to bypasses for return to a safe release location. A review of the biological effectiveness, engineering practicability, and costs of these systems and devices is presented in detail in three Electric Power Research Institute (EPRI) reports prepared in 1986, 1994 and 1999 (EPRI 1986, 1994, 1999). The EPRI reports, along with results of recent research, provide the basis for screening alternatives for potential use at the Station, as presented in this appendix.

Extensive research has been conducted since the early 1970s in an attempt to develop technologies that will minimize entrainment and impingement. As a result, a suite of technologies is available that can be considered for application as BTA at CWISs. The ability of a given technology to meet BTA requirements is influenced by a wide variety of biological, environmental and engineering factors that must be evaluated on a site-specific basis.

Technology Category	Mode of Action	System/Technology
Physical Barriers	Physically block fish passage (usually in combination with low water velocity)	Traveling screens Stationary screens Drum screens Cylindrical wedge wire screens Barrier nets Aquatic filter barrier Porous dikes Radial wells Artificial filter beds Rotary drum screens
Collection Systems	Actively or passively collect fish for transport through a return system	Modified traveling screens Fish pumps

Diversion Systems	Divert fish to a return system or safe area	Angled screens Modular Inclined Screen Eicher Screen Angled rotary drum screens Louvers/Angled bar racks Inclined plane screens Vertical/Horizontal traveling screens
Behavioral Deterrent Technologies	Alter or take advantage of natural behavior patterns to repel or attract fish	Strobe light Mercury light Other light sources Acoustic systems Infrasound Air bubble curtains Hybrid systems Other behavioral technologies

As support for the screening process and selection of alternatives for further evaluation, the following is a brief summary of the status of available fish protection technologies by category.

PHYSICAL BARRIERS

Traveling Screens (Through flow, Dual flow, Center flow, Drum, etc). The traveling water screen is a standard feature at most CWISs. The ability of traveling screens to act as a barrier to fish, while not resulting in impingement, is dependent on many site-specific factors such as size of fish, flow velocity, location of screens, and presence of escape routes. As barrier devices, traveling screens cannot be considered for protection of early life stages or aquatic organisms that have little or no motility.

Cylindrical Wedge Wire Screens. Wedge wire screens have the potential to reduce both entrainment and impingement at water intakes. In order to effectively reduce impingement and entrainment, the following conditions must exist:

- sufficiently small screen slot size to physically block passage of the smallest life stage to be protected (typically 0.5 to 1.0 mm for egg and larval life stages);

- low through-slot velocity (on the order of 0.5 to 1.0 ft/s); and
- an ambient current cross-flow to carry organisms and debris around and away from the screen);

To date, large-scale CWIS applications of wedge wire screens have been limited to two plants (J.H. Campbell Unit 3 and Eddystone Station) where relatively large slot openings have been used (i.e., they have not been targeted specifically to prevent entrainment of early life stages). These screens have been biologically effective in preventing impingement of larger fish and have not caused any unusual maintenance problems.

EPRI and the U. S. Environmental Protection Agency (EPA) sponsored laboratory evaluations of wedge wire screens with eggs and/or larvae of nine fish species commonly entrained at CWISs (EPRI 2003, in press). General entrainment and impingement trends observed in the data collected included: 1) impingement decreased with increases in slot size; 2) entrainment increased with increases in slot size; 3) entrainment and impingement increased with increases in through-slot velocities; 4) entrainment and impingement decreased with increases in channel velocity, and 5) within a species, larval fish length did not appear to be a factor, although the lengths of most species evaluated were within a narrow size range.

Wedge wire screens can generally be considered for application at CWISs. Since the only two large CWISs to employ wedge wire screens to date use 6.4 and 10.0 mm slot openings, the potential for clogging and fouling with slot sizes as small as 0.5 to 1.0 mm (as would be required for protection of many entrainable life stages) is unknown. In general, consideration of wedge wire screens with small slot dimensions for CWIS application should include *in situ* prototype 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.

Aquatic Filter Barrier (AFB). The aquatic filter barrier is a relatively recent technology for the protection of all life stages of fish at water intakes. As a result, there are limited data available on their deployment for this purpose. The AFB consists of polyester fiber strands that are pressed into a water-permeable fabric mat. Beginning in 1995, Mirant, New York, LLC. has sponsored an evaluation of the AFB to determine its ability to minimize ichthyoplankton entrainment at the Lovett Generating Station on the Hudson River (ASA 1999, 2000). Despite difficulties in keeping the boom deployed and providing adequate cleaning in 1995-1997 studies, results of studies in 1998 show a large reduction in entrainment and it appears that deployment and cleaning problems may have been resolved for this site. Results analyzing the rate of ichthyoplankton entrainment between two side-by-side water intakes (one protected by an AFB and the other unprotected) have shown the potential biological effectiveness of this technology (ASA 1999; 2001).

Laboratory studies on retention and survival of the early life stages of five species of fish exposed to aquatic filter barrier fabric were conducted in 2002 (Black et al., in press). Results of testing with three perforation sizes (0.5, 1.0, and 1.5 mm) and two flow rates (10 gpm/ft^2 and 20 gpm/ft^2) indicate that, in general, survival of organisms was not significantly correlated to either flow rate or perforation size. Retention of organisms, however, appeared to decrease significantly with increasing flow rate for one species of fish (rainbow smelt). In addition, increasing perforation sizes appeared to significantly decrease retention of three species of fish tested (common carp, rainbow smelt, and striped bass), which potentially limits the effectiveness of larger perforation sizes in protecting the earliest life stages of these species.

At this time, the AFB system is considered to be experimental despite its potential biological effectiveness. However, continued improvements in anchoring and cleaning systems make AFBs a technology to be considered when evaluating fish protection alternatives.

Infiltration Intakes. Radial wells and artificial filter beds have been successfully used to supply small quantities of water. While such systems have little if any biological impact, they have not been developed for screening large flow volumes or for CWIS application.

Rock Structures. Rock structures such as rock cribs and porous dikes allow water to pass while preventing passage of juvenile and adult fish. Such structures have been shown to be effective on an experimental basis. Rock structures have been used on a limited basis to filter large quantities of water but should be considered a potentially viable option for use at a CWIS depending upon the species and life stages to be protected and the presence of suitable hydraulic conditions.

Barrier Nets. Under the proper hydraulic conditions (primarily low velocity) and without heavy debris loading, barrier nets have been effective in blocking fish passage into water intakes. There have been several recent applications of barrier nets in the Midwest (Michaud and Taft 1999). At the Ludington Pumped Storage Plant on Lake Michigan, a 2.5-mile long barrier net, set in open water around the intake jetties, has been successful in reducing entrainment of all fish species occurring in the vicinity of the intake (Reider et al. 1997). The net was first deployed in 1989. Modifications to the design in subsequent years have led to a net effectiveness for target species (five salmonid species, yellow perch, rainbow smelt, alewife and chub) of over 80% since 1991, with an overall effectiveness of 96% in 1995 and 1996.

In 1993 and 1994, Orange and Rockland Utilities, Inc. sponsored a study of a 3.0-mm, fine mesh net at its Bowline Point Generating Station on the Hudson River (LMS 1996). In 1993, clogging with fine suspended silt caused the net to clog and sink. In 1994, spraying was not effective in cleaning the net when it became fouled by the algae *Ectocarpus*. Excessive fouling caused two of the support piles to snap, ending the evaluation (LMS 1996). In both years, abundance of the target ichthyoplankton species, bay anchovy, was too low to determine the biological effectiveness of the net. On the basis of studies to date, the researchers concluded that a fine mesh net may be a potentially effective method for preventing entrainment at Bowline Point (LMS 1996). However, pending further evaluation, this concept is considered to be experimental.

In conclusion, barrier nets can be considered a viable option for protecting fish provided that relatively low velocities (generally less than 1 ft/sec) can be achieved and debris loading is light. A thorough evaluation of site-specific environmental and operational conditions is generally recommended. At this time, barrier nets can only be considered for reducing impingement of larger fish at CWIS.

FISH COLLECTION SYSTEMS

Modified Traveling Water Screens. Conventional traveling water screens have been altered to incorporate modifications that improve survival of impinged fish. Such state-of-the-art modifications minimize fish mortality associated with screen impingement and spraywash removal. Screens modified in this manner are commonly called "Ristroph screens." Each screen basket is equipped with a water filled lifting bucket that safely contains collected organisms as they are carried upward with the rotation of the screen. The screens typically operate continuously to minimize impingement time. As each bucket passes over the top of the screen, fish are rinsed into a collection trough by a low pressure spraywash system. Once collected, the fish are transported back to a safe release location. Such features have been incorporated into through flow, dual flow, and center flow screens.

Ristroph screens have been shown to improve fish survival and have been installed and evaluated at a number of power plants. Improvements have recently been made to the Ristroph screen design that have resulted in increased fish survival. The most important advancement in state-of-the-art 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 these 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, PSE&G performed a biological evaluation of the improved screening system installed at the Salem Generating Station in the Delaware River (PSE&G 1999; Ronafalvy 1999). The reported survival rates for this installation are among the highest for any traveling screen system. (PSE&G 1999).

Modified traveling water screens continue to be an available technology that can reduce fish losses due to impingement. Unless modified to incorporate fine mesh, as discussed below, these screens do not reduce entrainment losses.

Fine-mesh Traveling Screens. In addition to the fish handling provisions noted above, traveling water screens have been further modified to incorporate screen mesh with openings as small as 0.5 mm to collect fish eggs and larvae and return them to the source water body. For many species and early life stages, mesh sizes of 0.5 to 1.0 mm are required for effective screening. Various types of traveling screens, such as through flow, dual flow, and center flow screens, can be fitted with fine mesh screen material.

A number of fine mesh screen installations have been evaluated for biological effectiveness. Results of these studies indicate that survival is highly species-specific and life stage-specific. Species such as bay anchovy and *Alosa* spp. have shown low survival while other species, such as striped bass, white perch, yellow perch, and invertebrates, show moderate to high survival. Therefore, evaluating fine mesh screens for potential application at a CWIS requires careful review of all available data on the survival potential of the species and life stages to be protected as well as non-target species.

In addition to these field applications, survival data on a variety of species and life stages following impingement on fine-mesh screens is available from extensive laboratory studies. In these studies, larval life stages of striped bass, winter flounder, alewife, yellow perch, walleye, channel catfish, and bluegill were impinged on a 0.5 mm screen mesh at velocities ranging from 0.5 to 3.0 ft/sec and for durations of 2, 4, 8 or 16 minutes. As in the field evaluations, survival was variable between species, larval stages, impingement duration, and velocity (ESSERCO 1981).

The primary concern with fine mesh screens is that they function by impinging early organism life stages that are entrained through coarse mesh screens. Depending on species and life stage, mortality from impingement can exceed entrainment mortality. In order for fine mesh screens to provide a meaningful benefit in protecting fish, impingement survival of target species and life stages must be substantially greater than survival levels when pulled through the circulating water system.

Fish Pumps. Several pumps have demonstrated an ability to transfer fish with little or no mortality. These include the Hidrostal and Archimedes screw pumps that have undergone extensive research (Liston et al. 1993). These pumps by themselves do not represent a technology for protecting fish. However, when coupled with fish bypass systems such as angled screens and louvers, fish pumps are biologically effective.

FISH DIVERSION SYSTEMS

Angled Screens. A variety of species have been shown to guide effectively on screens given suitable hydraulic conditions. Angled screens require uniform flow conditions, a fairly constant approach velocity, and a low through-screen velocity to be biologically effective. Angled screen systems have been installed and biologically evaluated at a number of cooling water intakes on a prototype and full scale basis. Angled screen diversion efficiency varies by species, but is generally quite high for most species evaluated. Survival following diversion and pumping (as required to return fish to their natural environment) has been more variable. Overall survival rates of relatively fragile species following diversion can be low. Heartier species exhibit higher survival rates resulting in overall system efficiency values (diversion and survival) ranging from 50 to nearly 100%.

In addition to the CWIS applications, angled fish diversion screens leading to bypass and return pipelines are being used extensively for guiding salmonids in the Pacific Northwest. These screens are mostly of the rotary drum or vertical, flat panel (non-moving) types and have provided effective downstream protection for juvenile salmonids at several diversion projects in the Pacific Northwest (Neitzel et al. 1991; EPRI 1998). 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 entrainment and impingement and to divert them to a bypass for return to the source water body (Pearce and Lee 1991).

Angled screens can be considered a viable option for protecting juvenile and adult life stages provided that proper hydraulic conditions can be maintained and debris can be effectively removed. To date, all angled screen applications at cooling water intakes have involved the use of conventional traveling water screens modified to provide a flush surface on which fish can guide to a bypass. Fish eggs, larvae, and small invertebrates would not be protected by angled screens unless fine mesh screening was used.

Eicher Screen. The Eicher screen is a passive pressure screen that has proven effective in diverting salmon at hydroelectric projects. The first prototype of an Eicher Screen was constructed and installed in a 9-ft diameter penstock at a hydroelectric project in the Pacific Northwest. Field testing of the screen conducted in 1990 and 1991 demonstrated that the Eicher screen effectively diverted over 98% of the steelhead, coho, and chinook smolts (EPRI 1992). The first full-scale Eicher screen installation (two screens in two, 10-ft diameter penstocks; total flow of 1,000 cfs) at B. C. Hydro's Puntledge Project has shown similar results. Survival of chinook and coho salmon smolts exceeded 99%, and survival of steelhead, sockeye, and chum salmon fry was 100%, 96%, and 96%, respectively, at penstock velocities up to 6 ft/sec (Smith 1997). While biologically effective, the Eicher Screen was not designed for use at steam electric station cooling water intakes.

Modular Inclined Screens. The Modular Inclined Screen (MIS) has recently been developed and tested by the Electric Power Research Institute (EPRI 1994; EPRI 1996; Taft et al. 1997). The MIS is intended to protect juvenile and adult life stages of fish at all types of water intakes. An MIS module consists of an entrance with trash racks, dewatering stoplogs in slots, an inclined screen set at a shallow angle (10 to 20 degrees) to the flow, and a bypass for directing diverted fish to a transport pipe. The module is completely enclosed and is designed to operate at relatively high water velocities ranging from 2 to 10 ft/sec, depending on the species and life stages to be protected.

The MIS was evaluated in laboratory studies to determine the design configuration which yielded the best hydraulic conditions for safe fish passage, and the biological effectiveness of the optimal design in diverting selected fish species to a bypass (EPRI 1994). Biological tests were conducted in a large flume with juvenile walleye, bluegill, channel catfish, American shad, blueback herring, golden shiner, rainbow trout (two size classes), brown trout, chinook salmon, coho salmon, and Atlantic salmon. Screen effectiveness (diversion efficiency and latent mortality) was evaluated at water velocities ranging from 2 ft/sec to 10 ft/sec. Diversion rates approached 100% for all species except American shad and blueback herring at water velocities up to at least 6 ft/sec. Generally, latent mortality of test fish that was adjusted for control mortality was low (0 to 5%).

Based on the laboratory results, a pilot scale evaluation of the MIS was conducted at Niagara Mohawk Power Corporation's Green Island Hydroelectric Project on the Hudson River near Albany, NY (EPRI 1996). The results obtained in this field evaluation with rainbow trout, largemouth and smallmouth bass, yellow perch, bluegill, and golden shiners were similar to those obtained in laboratory studies (Taft et al. 1997).

The combined results of laboratory and field evaluations of the MIS have demonstrated that this screen is an effective fish diversion device that has the potential for protecting fish at water intakes. Studies to date have only evaluated possible application at hydroelectric projects. Further, no full-scale MIS facility has been constructed and evaluated. As a result, the potential for effective use at cooling water intakes is unknown. Any consideration of the MIS for CWIS application should be based on future large-scale, prototype evaluations.

Louvers. A louver system consists of an array of evenly spaced, vertical slats aligned across a channel at a specified angle and leading to a bypass. Bar racks can also be angled to act as louvers. Results of louver studies to date have varied by species and site. Most of the louver installations in the U.S. are in the Pacific Northwest at water supply intakes. Louvers generally are not considered acceptable by the fishery resource agencies in that region since they do not meet the current 100% effectiveness criterion. However, numerous studies have demonstrated that louvers can be on the order of 70 to 95% effective in diverting a wide variety of species over a wide range of conditions (EPRI 1986; Stira and Robinson 1997; LMS 1997).

Until recently, the effectiveness of diversion devices for non-anadromous fish has been largely unknown. Recent studies by the Electric Power Research Institute (EPRI) evaluated the potential for 15 and 45 degree louvers for guiding riverine species (smallmouth bass, largemouth bass, walleye, channel catfish, and golden shiner) and others (lake sturgeon, shortnose sturgeon, and American eel) (EPRI 2001, Amaral *et al.*, 2002). Results indicate that 15-degree structures have considerable potential for guiding fish to a bypass.

Most of the louver applications to date have been with migratory species in riverine environments. The ability of louvers to protect species commonly impinged at CWISs is largely unknown because there have been so few louvers installed at CWISs. A system of guiding vanes and louvers has been installed at San Onofre Nuclear Generating Station to direct fish away from the traveling screens into a collection area. Biological effectiveness of these louvers is unknown.

Due to the large spacing of the louver slats, louver systems do not protect early life stages of fish. Future consideration of louver systems for protecting fish at cooling water intakes is warranted but will require large-scale evaluations.

BEHAVIORAL BARRIERS

Strobe Lights. The use of strobe lights to elicit a behavioral response is supported by the results of laboratory and cage test studies that have demonstrated strong avoidance by several fish species to strobe light. Strobe has been evaluated for repelling or guiding fish away from water intakes and, in some cases, towards bypasses for transport to a safe release location (EPRI 1994, 1999). 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 indicated that flashing light produced stronger avoidance reactions than continuous light and that responses appeared to be affected by species tested, developmental stage (i.e., age or size of fish), and light adaptation level (Feist and Anderson 1991). More recent studies with salmonids have corroborated these findings (Puckett and Anderson 1987; EPRI 1990; Nemeth and Anderson 1992).

Research examining the potential for strobe light to be used as a fish deterrent expanded considerably in the 1980s, including laboratory studies with anadromous salmonids and Alosa species, several riverine and estuarine species, and the catadromous American eel. These studies involved both controlled experiments (laboratory and cage tests) and field studies. Extensive research with strobe lights has continued in the 1990s, including laboratory and/or cage test evaluations with Pacific salmon, American eel, and several freshwater species, open water tests with kokanee salmon, and field tests with freshwater species and Atlantic salmon.

Although many studies have evaluated strobe lights as a primary barrier system, strobes are often evaluated as part of an integrated fish protection and passage system that includes other devices such as screens, narrow-spaced bar racks, bypasses, and/or other behavioral systems (EPRI 1994, 1999). As a secondary system, strobe lights have the potential to incrementally increase fish protection effectiveness.

Air Bubble Curtains. These curtains generally have been ineffective in blocking or diverting fish in a variety of field applications. Air bubble curtains have been evaluated at number of sites on the Great Lakes with a variety of species. All air bubble curtains at these sites have been removed from service.

Sound. The focus of recent fish protection studies involving underwater sound technologies has been on the use of new types of low and high frequency acoustic systems that have not previously been available for commercial use. High frequency (120kHz) sound has shown to effectively and repeatedly repel members of the Genus *Alosa* (American shad, alewife and blueback herring) at sites throughout the U. S. (Ploskey et al. 1995; Dunning 1995; Consolidated Edison 1994). Other studies have not shown sound to be consistently effective in repelling species such as largemouth bass, smallmouth bass, yellow perch, walleye, rainbow trout (EPRI 1998), gizzard shad, Atlantic herring, and bay anchovy (Consolidated Edison 1994).

Given the species-specific responses to different frequencies that have been evaluated and the variable results that often have been produced, additional research is warranted at any sites where there is little or no data to indicate that the species of concern may respond to sound.

Infrasound. In the first practical application of infrasound (frequencies below 100 Hz) for repelling fish, Knudsen and colleagues (Knudsen et al. 1992; 1994) found a piston-type particle motion generator operating at 10 Hz to be effective in repelling Atlantic salmon smolts in a tank and in a small diversion channel. Following this success, there was a general belief in the scientific commUnity that infrasound could represent an effective fish repellent since there was a physiological basis for understanding the response of fish to particle motion. The potential for currently available infrasound sources to effectively repel fish has been brought into question by the results of more recent studies. Given these results, it appears that infrasound sources need to be further developed and evaluated before they can be considered an available technology for application at CWISs.

Mercury Light. Response to mercury light has been shown to be species-specific; some fish species are attracted, others repelled, and others have demonstrated no obvious response. Therefore, careful consideration must be given for any application of mercury lights to avoid increasing impingement of some species while reducing impingement of others.

Electric Screens. Electric barriers have been shown to effectively prevent the upstream passage of fish. However, attempts to divert or deter the downstream movement of fish have met with limited success (Bengeyfield 1990; Kynard and O'Leary 1990). Consequently, past evaluations have not lead to permanent applications. Electric screens that use DC current have been used to prevent passage of fish at relatively low flow intakes (e.g. irrigation canals) and to prevent upstream passage of invasive fish species. The potential effectiveness of these barriers for application at CWISs is unknown. Given their past ineffectiveness and hazard potential, electric screens are not considered a viable technology for application at CWISs.

Other behavioral barriers. Devices such as water jet curtains, hanging chains, visual cues, and chemicals have been suggested, and in some cases evaluated, as fish protection measures. However, no practical application of these devices has been developed, and they are not considered available technologies for application at CWISs.

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APPENDIX B
OVERVIEW OF REDUCED FLOW OPTIONS FOR FISH PROTECTION

Reducing flow into power plant intakes can reduce fish entrainment. Flow can be reduced by: 1) modifying existing pump operations by reducing the number of operating pumps or throttling valves, 2) installing variable speed drives on the circulation water pumps, or by 3) retrofitting the plant with a closed-cycle cooling system. Reduction in entrainment for all three options would be roughly proportional to the flow reduction. Operating fewer pumps or installing variable speed motors on the existing circulating water pumps would allow operation at reduced flow rates during periods of high entrainment. A lower pump capacity would reduce the screen approach velocity, thereby potentially reducing impingement as well as entrainment. Make-up water for closed loop cooling systems can be as little as 2% of the flow into a once-through cooling system, thereby greatly reducing entrainment potential. However, the reduced effects of closed-cycle cooling systems on the aquatic environment resulting from small makeup water requirements can be countered by major airborne impacts such as noise impacts, aesthetic impacts, icing of roads and streets, reduced visibility from the tower vapor plume, and drift dispersion.

Modified pump operation options and closed-loop cooling water alternatives that are available to reduce intake flow and fish entrainment are discussed in the following sections.

MODIFIED PUMP OPERATION

Reducing circulating water could be accomplished by reducing the number of operating pumps or by reducing the flow from each pump. If multiple circulating water pumps discharge into a common pipe to convey water to the plant condensers, operating fewer pumps would be possible. If pumps can not be shut off because of the piping configuration, throttling of discharge valves or variable speed drivers (power frequency or eddy current couplings) could be used to reduce flow. In any case, reduced flow would result in higher discharge water temperatures for the same heat transfer and, in some cases, plant output might have to be limited to meet permit requirements for thermal discharges.

Estimates of the amount of flow reduction that is acceptable for satisfactory condenser performance are needed to evaluate modified pump operation alternatives. Pump performance characteristics must be reviewed to define operating limits if discharge valves are used to reduce flow. Throttling valves could require more power to operate the pump with less flow. Hydraulic grade lines must be developed to determine if negative pressures at the condenser outlet water boxes will be a problem. Installation or modifications of vacuum priming systems may be necessary to assure that the structural integrity and performance of the condenser is maintained.

Important considerations that have to be addressed relative to backfitting motors with variable speed drivers are:

- Eddy current couplings are large and the size increases with lower speed requirements. Large eddy current couplings that would be necessary for large circulation water pumps are as big as the pump motors.

- Voltage spikes from a variable frequency drive (VFD) can cause damage to the motor insulation. A reactor on the incoming line or between the VFD and the motor may be necessary to prevent damage to the insulation.
- At slower speeds, existing motor cooling fans may not be able to remove the heat. Additional fans may be needed to cool the motor and prevent damage to the motor insulation.
- Harmonics from a VFD may backfeed into the incoming power line affecting other power users. This problem has been eliminated with the newer VFD designs.

All of the above issues should be discussed with the existing pump and motor manufacturers and variable speed drive suppliers to fully evaluate reduced flow alternatives.

CLOSED-CYCLE COOLING SYSTEMS

Cooling towers and cooling reservoirs are the primary closed-cycle cooling systems that are employed at power plants. Cooling reservoirs generally have very large surface areas, on the order of 4,000 to 10,000 acres, depending on the plant design. Cooling towers require less area than reservoirs, and for the purpose of this study, cooling towers are considered to be better suited for potential retrofit at existing plants than cooling reservoirs. Therefore, cooling reservoirs have not been included in this evaluation as a potential alternative to reduce fish entrainment.

Wet and dry cooling towers are the two types of cooling towers that are typically used. Wet towers are the most common and reduce cooling water temperatures by direct contact with large volumes of air. Wet towers are classified as natural or mechanical draft, depending on how the airflow is induced through the tower. Cooling water in dry towers does not come in direct contact with air. Where plumes from towers are a concern, hybrid wet-dry towers can be used (EPA 2002). Wet-dry towers combine dry heat exchange surfaces with conventional wet cooling towers.

Retrofitting any closed-cycle cooling system to an existing power plant is a difficult engineering, scheduling, and construction effort because most plants are not originally designed to accommodate unusual modifications (Burns et al, 1994b). The complexity and high costs associated with retrofitting a cooling tower to an existing plant are due to:

- Permanence of existing site features and structures.
- Fundamental design differences between once-through cooling systems and any alternative closed-cycle cooling technologies.
- New construction must accommodate existing plant operational requirements and regulatory restrictions.
- Installation of the tower facilities and long, underground, large diameter piping runs to and from the towers are difficult without contacting buried obstructions or contaminated soils.

Each of the retrofitted closed-cycle cooling systems, if installed, would reduce net generation because of design differences between closed- loop and once-through cooling systems. Reasons why retrofit of closed-cycle cooling at once-through plants cause reduced generation include (Parsons 2002):

1. Turbine exhaust pressures are higher with a closed-loop cooling system than with a once-through system because of the seasonally higher water temperatures that the closed-loop system delivers to the condenser inlet. Higher turbine back pressure penalizes the Unit heat rate and reduces power output.

2. Cooling water has to be pumped to and up into cooling towers, requiring significantly more power than a once-through system.

3. Except in the case of the natural draft tower, major amounts of energy are consumed in conveying the necessary fresh air through closed-cycle cooling equipment with the fans.

4. Water flow through the condensers designed for once-though cooling must be appreciably reduced for closed-loop cooling to utilize cooling towers that are of a cost-effective size. In the case of a natural draft towers, reduced flow is sometimes necessary to develop suitable draft. To be compatible with the required heat transfer conditions in a condenser with lower cooling water flow than the once-through design, the turbine backpressure must correspondingly rise which further reduces the plant output.

Mechanical draft and natural draft cooling towers both have visible plumes that can cause concern. During periods of cooler weather, high relative humidity, and low winds, a visible plume out of the top of the towers are evident because the exit air temperature is higher than the ambient air temperature and is essentially at 100% relative humidity. As the air cools down to ambient conditions, the water vapor in the air becomes visible.

A brief description of natural draft and mechanical draft wet cooling towers, dry cooling towers, hybrid wet-dry towers, and design considerations are presented below.

Natural Draft Cooling Tower. A natural draft cooling tower transfers heat in the condenser closed-loop cooling water to ambient air that is induced to flow through the tower by the chimney effect (i.e., the density difference between the exhaust air inside the shell and the ambient air density surrounding the shell). Warm water from the condenser is distributed uniformly to the top of the fill section, which is located near the base of the tower. The fill section disperses the water into small droplets and thin sheets as it falls by gravity through the fill into the basin. The cooling effect provided in the fill section is mostly by the evaporation of a small percentage of the heated discharge water as it contacts the cooling air (Brocard and Burns, 1985). The remaining cooled water is recycled back through the condenser. The cooling (heat transfer) section of the natural draft tower is the fill which is typically an anti-fouling, non-clogging, plastic PVC material.

Important environmental considerations associated with natural draft cooling towers are effects on air quality, ambient noise, and aesthetics. Natural draft cooling towers are large and, because of their size, the towers and their plumes have a major visual and aesthetic impact on the surrounding area. Natural draft towers overshadow all the surrounding structures and are visible from several miles away. The vapor plumes can also be considered obtrusive because during ambient conditions that are stable, cold, and humid with little wind, the plumes extend far from the plant and with a slightly rising trajectory. Because of the height of the towers, ground fog does not occur with natural draft towers. The falling water in a natural draft cooling tower creates sound levels that are typically less than 45 A-weighted decibels (dba) within 3,000 ft of the base of the tower. Noise attenuation measures can be incorporated into a natural draft tower design, but these measures could increase the tower costs by up to 15% (EPA 2002)

Natural draft cooling towers typically concentrate the chemical and minerals in the makeup water drawn from the water body about five times. Concentration of the water is an inherent, natural consequence of the evaporation process for all types of wet cooling towers

Mechanical Draft Cooling Towers. In a mechanical draft wet cooling tower, heat in the discharged warm condenser water is transferred to ambient air that is induced to flow through the tower by large, slow speed fans. The warm water is distributed uniformly to the top of the fill section of each cell of the tower and is dispersed into small droplets and thin sheets as it falls by gravity through the fill into the basin. The cooling effect provided in the fill section is mostly by the evaporation, similar to the natural draft cooling tower. The fill section is similar to natural draft towers and consists of anti-fouling, non-clogging, plastic PVC material.

Environmental considerations associated with mechanical draft cooling towers are similar to the considerations for natural draft cooling towers. An opaque plume can be expected to occur and can extend downwind 500 to 1000 feet from the cooling tower, especially during the colder seasons. This may lead to icing of the roads under certain conditions. Drift dispersion from a mechanical draft tower is very local because the exhaust is close to the ground. Modern drift eliminator designs can limit drift to less than 6 gpm during normal operation. The usual dispersion pattern results in salt deposition and saline air concentrations that are relatively small and remain mostly within the site boundaries. At a 2-to-1 concentration level, the drift droplets would be comprised of a maximum of 40,000 ppm of salt and could cause some surface corrosion to the tower components and may damage vegetation in the area. To prevent the release of potentially harmful leacheate from the fill material, fiberglass fill is often used.

Noise as high as 50 dba typically occurs within 3,000 ft of the tower. Similar to natural draft towers, noise attenuation treatments can reduce these effects, but would increase the tower costs by up to 25 percent.

Blowdown from the closed-loop cooling system would have water quality constituents concentrated at twice the natural water body chemistry levels and slightly elevated in temperature. The cooling system blowdown would have to be treated and cooled to comply with applicable EPA and state mandated guidelines and regulations before being discharged.

Dry Cooling Towers. A dry cooling tower rejects heat to the atmosphere in manner similar to the steam turbine condenser. Water or steam from the condenser is pumped through finned tubes, and large diameter fans force cooling air over the tube surface and the heat of the water or steam inside the tubes is transferred to the cooling air. There are two important differences in the heat transfer process between dry and wet cooling towers. The first is that the dry tower transfers the rejected plant heat in proportion to the difference between its operating temperature and the ambient dry bulb temperature. Depending on the relative humidity, the dry bulb temperature can be 15 F to 20 F warmer than the wet bulb temperature and so the dry tower usually produces a warmer return to the plant The second difference is that dry towers require about four times of the air quantity needed by wet towers because the evaporative heat transfer process that occurs in wet cooling towers essentially humidifies the cooling air. This higher airflow in dry towers must be created by fans resulting in a significantly higher operating cost than mechanical wet draft towers.

Dry towers do not require any water use except for a very small amount that compensates for piping, tubing, and pump seal leakage. Installation of dry cooling towers at an existing plant would virtually eliminate all environmental effects relative to the water body and air quality. No makeup water or blowdown discharges are necessary with a dry tower and the plume is invisible. However, dry cooling towers have never been retrofitted to an electric utility generating Unit. High capital costs, high pumping and fan power requirements, extremely poor performance during the warm weather months, potential for freezing in winter, potential for high noise emissions, and high maintenance requirements make dry cooling towers impractical to retrofit at existing plants (Brocard and Burns, 1985).

There are two general types of dry cooling towers, direct and indirect. As the name implies, the direct dry cooling tower directly condenses the steam from the turbine. A large steam duct carries the sub-atmospheric turbine exhaust steam from the turbine exit inside the power block area to a location outside the building at the dry cooling tower. Here, the turbine exhaust steam condenses inside finned round, square, or elliptically shaped tubing. The direct dry tower design replaces the condenser. To produce the transfer of the heat of condensation from the steam in the tubes to the ambient cooling air, a relatively large number of fans is required. The non-contact heat transfer coefficient of the finned tube surface is very low, and this has a significant effect that increases the dry direct tower size. In addition, the quantity of cooling air required is much greater than other types of towers. As a result, direct dry cooling towers are very large and require significant auxiliary power from the plant. In a direct dry cooling tower, after condensation, the condensate of the steam is collected and pumped back to the conventional plant feedwater system equipment where the steam power cycle repeats. Air in-leakage and non-condensable gases are removed from the condensation process and compressed to atmospheric pressure by relatively large capacity steam jet air ejectors or vacuum pumps.

An indirect dry cooling system would use a water cooled condenser, and the heat of the condensing turbine exhaust steam is transferred into the cooling water within the condenser. The circulating water pumps typically pump the cooling water through the condenser to the cooling tower supply basin. Booster pumps convey the heated water to the dry cooling tower where it is cooled within a finned tube surface and returned again to the circulating water pumps and the condenser. The indirect dry tower can be more flexibly sited than direct dry towers. Indirect dry towers avoid the use of the large reinforced steam duct from the turbine that would be difficult to route through the existing turbine building. However, the indirect dry tower introduces an intermediate heat transfer step that further decreases the cooling efficiency of the system.

Relative to the wet cooling tower, both the direct and indirect dry towers require significantly more attention and maintenance during the winter months in cold climates to prevent freezing. Furthermore, the dry tower designs and housings must incorporate features for operation at below freezing temperatures.

Hybrid Wet-Dry Cooling Towers. Hybrid wet-dry towers utilize closed-loop air cooling systems for the turbine steam condensers and a separate closed-loop cooling water system with a wet tower to transfer heat from the condenser cooling system to the atmosphere. Concerns with retrofitting a hybrid wet-dry cooling tower at a plant with a once-through cooling system are similar to the concerns discussed above for natural and mechanical draft wet cooling towers and for dry cooling towers.

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