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HUNTERS POINT POWER PLANT COOLING WATER INTAKE STRUCTURES 316(b) DEMONSTRATION

PG and E

Prepared for:
PACIFIC GAS and ELECTRIC COMPANY

ECOLOGICAL ANALYSTS, INC.

HUNTERS POINT POWER PLANT
COOLING WATER INTAKE STRUCTURES
316(b) DEMONSTRATION

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Executive Summary

EXECUTIVE SUMMARY

The following report demonstrates compliance of the Hunters Point Power Plant with Section 316(b) of the Clean Water Act (PL 92-500 and 95-217). This report documents the results of a program conducted for Pacific Gas and Electric Company (PGandE) by Ecological Analysts, Inc. (EA). Section 316(b) requires that "...the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." Because of differences in source water body hydrology, characteristics of aquatic populations, and cooling water system operation, no single intake design can be considered to be the best technology available for all sites, and therefore compliance with the Act requires a site-specific analysis of intake-related environmental impacts and a site-specific determination of the best technology available for minimizing those impacts. A 316(b) program was developed to provide the necessary site-specific analysis (PGandE 1977) for the Hunters Point Power Plant's cooling water intake systems.

This report documents intake-related losses of organisms measured during one-year studies of entrainment (the drawing of organisms into the cooling water system) and impingement (the retention of organisms on the intake screens) and discusses the impacts of these losses. Alternative intake technologies are evaluated according to operating, engineering, and biological criteria, and the best technology available for minimizing entrainment and impingement losses is recommended for each existing cooling water structure at the Hunters Point Power Plant.

The Hunters Point Power Plant is located in an industrial area of San Francisco and withdraws water from the western edge of San Francisco Bay for the once-through cooling of its three steam electric generating units. Unit 1, a 52 MWe air-cooled combustion turbine generating unit that began commercial operation in 1976, replaces a 35 MWe steam generating unit that was retired in 1972 because of its age and low efficiency. Units 2 and 3, each with a gross generating capacity of 110 MWe, started operation in 1948 and 1949, respectively, and share a common once-through cooling water intake. Unit 4, with a gross capacity of 170 MWe, started operation in 1958 and has its own once-through cooling water system. Units 2, 3, and 4, the three units which have once-through cooling water systems, are discussed in this report.

Cooling water for all three units comes from San Francisco Bay through a pair of conduits located at the end of a long, shallow embayment which serves as a loading and holding area for the adjacent shipping terminal. Cooling water flows from the embayment through the conduits into a large basin in which the cooling water intake structures are located. Prior to extensive landfilling in the vicinity of the plant, the structures were located on the San Francisco Bay shoreline.

Under normal operating conditions, the cooling water flow rate for each of Units 2 and 3 is 49,000 gpm (3.1 m^3/sec) and for Unit 4 is 101,600 gpm (6.4 m^3/sec). Occasionally one extra circulating water pump is brought into service at Unit 2 or Unit 3, thereby increasing the flow rate of either unit to 89,000 gpm (5.6 m^3/sec). During the one-year 316(b) program (April 1978 - April 1979), the Units 2 and 3 cooling water system operated at an average of 98.9 percent of normal capacity; the Unit 4 system operated at an average of 95.6 percent of capacity.

Units 2, 3, and 4 are operated essentially as base load units, providing electrical power to meet normal daily demand from the San Francisco load center. Demand varies on a daily, weekly, and seasonal basis. Average capacity factors (actual gross generation as a percentage of the total generating capacity) for the one-year study period were 34, 40, and 67 percent for Units 2, 3, and 4, respectively.

Entrainment and impingement were monitored weekly during the one-year study period. Densities of aquatic organisms passing through the 3/8-in. (9.5-mm) mesh traveling intake screens and entrained into the cooling water flow were monitored by continuously sampling a portion of the cooling water flow of Unit 3 over one 24-hour period per week. Numbers of organisms impinged on the intake screens of all three units were monitored during one 24-hour period per week. The numbers of organisms entrained and impinged during the one-year study period were estimated from the weekly samples. Both the entrainment and impingement studies focused on fish and macroinvertebrates, as stated in the 316(b) study plan (PGandE 1977), since these organisms were considered to be most susceptible to the potential impact of entrainment and impingement.

An estimated 108 million fish larvae and juveniles and 268 million fish eggs were entrained at Units 2, 3, and 4 combined during the study period. The dominant fish

larvae and juveniles entrained were gobies (63 percent) and Pacific herring (28 percent). Twenty-two percent of the fish eggs entrained were northern anchovy; the rest could not be identified. A great variety of macroinvertebrates were entrained. Amphipods and the larvae of decapods (crabs and shrimp) were entrained in the greatest numbers, 4.1 billion and 1.8 billion, respectively. Other macroinvertebrates entrained include tanaidaceans (210 million), cumaceans (144 million), isopods (46 million), and opossum shrimp (21 million).

A large percentage of the ichthyoplankton and macroinvertebrates entrained did not complete transit from the intake to the discharge; they may have been consumed by fouling organisms lining the cooling water system conduits. Overall entrainment survival at the Hunters Point Power Plant for fish larvae, fish eggs, and macroinvertebrates is estimated to be 18, 35, and 23 percent, respectively. Despite the expected high (75 percent) survival of organisms completing cooling system passage, the high proportions lost due to cropping by predation in the system result in low net survival estimates.

An estimated 117,000 fish were impinged; 85,000 at Units 2 and 3, and 32,000 at Unit 4. Northern anchovy was the dominant species impinged (64 percent). Other species impinged include Pacific herring; plainfin midshipman; white, shiner, pile, and walleye surfperches; surf smelt; and white croaker. The most abundant macroinvertebrates impinged were jellyfish (Cnidaria): an estimated 102,000 were impinged, 67,000 at Units 2 and 3, and 41,000 at Unit 4. Other macroinvertebrates, including shrimp and crabs, were impinged in lower numbers: 3,000 at Units 2 and 3, and 2,000 at Unit 4. Only a small percentage of the impinged fish and macroinvertebrates at all units were estimated to have survived, based on the results of studies conducted at the Moss Landing Power Plant.

The impact of cooling water system operation on populations of fishes and macroinvertebrates in San Francisco Bay was assessed. For two species of fish, northern anchovy and Pacific herring, population dynamics and life history data were sufficient to allow estimation of the number of adults likely to have matured from the eggs, larvae, and juveniles lost to entrainment and the juveniles and adults lost to impingement. This approach conservatively assumes that the adult population size depends entirely on the numbers of early life stages present. If other factors control

adult population size, the number of adults equivalent to the entrainment and impingement losses will be overestimated. The 38 million northern anchovy eggs and 2 million northern anchovy larvae and juveniles lost to entrainment and the 75,000 juveniles and adults lost to impingement were estimated to be equivalent to 181,000 adults, equal to only 0.7-1.5 percent of the annual San Francisco Bay commercial catch. The 25 million Pacific herring larvae and juveniles lost to entrainment and the 12,000 juveniles and adults lost to impingement were estimated to be equivalent to 603,000 adults, equal to only 1.6 percent of the average annual San Francisco Bay commercial catch. The northern anchovy and Pacific herring populations were therefore considered not to be adversely affected by entrainment and impingement at the Hunters Point Power Plant.

The potential impact of entrainment and impingement on other populations of fishes and macroinvertebrates was examined, and was concluded to be negligible based on: (1) the abundance and widespread distribution in the Bay and ocean of the species entrained and impinged; (2) the high reproductive potential of most of the entrained and impinged species; and (3) the small volume of cooling water withdrawn compared to the large volume of San Francisco Bay and compared to the large volume of the daily tidal exchange with the Pacific Ocean. None of the species entrained or impinged was restricted to the immediate vicinity of the Hunters Point Power Plant, and therefore, the potential for adverse impact was concluded to be negligible.

Even though the impact of entrainment and impingement was concluded to be negligible, alternative intake technologies were evaluated that would further reduce biological losses and be feasible for application to each of the cooling water systems at the Hunters Point Power Plant. Alternative intake technologies were evaluated on the basis of the following four criteria:

1. the alternative technology is available and proven in an environmental setting similar to that at the Hunters Point Power Plant;
2. implementation will result in a reduction in the loss of aquatic organisms from the present operating conditions;
3. implementation is technically feasible at the Hunters Point Power Plant; and
4. the cost of the alternative technology is commensurate with the environmental benefits anticipated.

All intake technologies that were considered to be available and proven (Criterion 1) were evaluated in terms of their potential to reduce biological losses (Criterion 2). Alternatives satisfying the first two criteria were evaluated in terms of engineering feasibility and cost-effectiveness (Criteria 3 and 4). Technologies meeting each criterion are summarized in Table S-1.

The best intake technology available for both Units 2 and 3 and Unit 4 is judged to consist of the following:

- the existing once-through cooling water system,
- the existing intake configuration,
- the existing conventional vertical traveling intake screens with 3/8-in. (9.5-mm) mesh,
- continued use of intermittent screen rotation,
- continued use of intermittent chlorination to control condenser biofouling,
- continued use of the existing debris- and fish-return systems to return organisms to San Francisco Bay, and
- use of thermal shock treatment to control biofouling organisms.

Additional modifications to either the Units 2 and 3 or the Unit 4 intake to reduce impingement and entrainment are not recommended because of the low biological impact of the existing systems and the high cost of such intake modifications.

TABLE S-1 SUMMARY OF THE EVALUATION OF INTAKE TECHNOLOGIES AND OPERATIONAL ALTERNATIVES CONSIDERED FOR THE HUNTERS POINT POWER PLANT

	Demonstrated (Meets Criterion 1)	Biological Benefit (Meets Criterion 2)	Recommended (Meets Criteria 3 and 4)
Intake Technologies			
Cooling Water Systems			
Closed-cycle	No	--	--
Once-through[a]	Yes	--	Yes
Intake Locations			
Offshore	Yes	No	--
Onshore[a]	Yes	--	Yes
Intake Configurations			
Shoreline	Yes	No	--
Recessed[a]	Yes	--	Yes
Behavioral Barriers			
Velocity gradient	No	--	--
Electrical barrier	No	--	--
Louvers	No	--	--
Chemicals	No	--	--
Magnetic field	No	--	--
Chains and cables	No	--	--
Light	Yes	No	--
Sound	Yes	No	--
Bubble screen	Yes	No	--
Velocity cap	Yes	No	--
Physical Barriers			
Media filter	No	--	--
Porous dike	No	--	--
Radial well	No	--	--
Stationary screen	No	--	--
Horizontal traveling screen	No	--	--
Angled screen - louver	No	--	--
Caisson	No	--	--
Drum screen	Yes	No	--
Centerflow screen	Yes	No	--
Vertical traveling screen[a]	Yes	--	Yes
Fish Collection, Removal, and Conveyance Systems			
Vertical traveling screen modifications	Yes	No	--
Gravity sluiceway[a]	Yes	--	Yes
Fish pumps	Yes	No	--
Operational Alternatives			
Maintenance			
Dredging			
Units 2 and 3	Yes	No	--
Unit 4	Yes	No	--
Operational Modifications			
Circulating water pump volume reduction	Yes	Yes	No
Curtailment	Yes	Yes	No
Alternative biofouling control	Yes	Yes	Yes
Cooling system modifications	Yes	No	--
Temperature regulation	Yes	No	--

(a) Existing structure or operation at Units 2, 3, and 4.

Chapter 1

Introduction

1.1 Plant Location and Description

1.2 Description of 316(b) Studies

1.3 Organization of the Report

1.4 References

CHAPTER 1: INTRODUCTION

The following report demonstrates compliance of the Hunters Point Power Plant with Section 316(b) of the Clean Water Act (PL 92-500 and 95-217). The report documents the results of a program conducted for Pacific Gas and Electric Company (PGandE) by Ecological Analysts, Inc. (EA). It is submitted in accordance with the provisions of Order No. 76-60 of the California Regional Water Quality Control Board, San Francisco Bay Region (Regional Board), which granted National Pollutant Discharge Elimination System Permit No. CA 0005649 for the Hunters Point Power Plant.

Section 316(b) of the Act requires that "...the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." Because no single intake design can be considered to be the best technology available for all sites, compliance with the Act requires a site-specific analysis of intake-related environmental impacts and a site-specific determination of the best technology available for minimizing those impacts. In this report, intake-related environmental impacts resulting from entrainment (the drawing of organisms into the cooling water system) and impingement (the retention of organisms on the intake screens) are documented. Intake technologies are evaluated according to operating, engineering, and biological criteria; and the best technology available for minimizing entrainment and impingement impacts is recommended for each cooling water structure at the Hunters Point Power Plant.

1.1 PLANT LOCATION AND DESCRIPTION

The Hunters Point Power Plant is located in an industrial area of San Francisco, and withdraws water from the western edge of San Francisco Bay for the once-through cooling of three steam electric generating units. Unit 1, a 52 MWe air-cooled combustion turbine generating unit that began commercial operation in 1976, replaces a 35 MWe steam generating unit that was retired in 1972 because of its age and low efficiency. Units 2 and 3, each with a gross generating capacity of 110 MWe, started operation in 1948 and 1949, respectively, and share a common cooling water intake. Unit 4, with a gross capacity of 170 MWe, started operation in 1958 and has its own cooling water system. Units 2, 3, and 4 are discussed in this report.

1.2 DESCRIPTION OF 316(b) STUDIES

1.2.1 Initiation of the 316(b) Studies

In October 1977 Pacific Gas and Electric Company (PGandE) submitted to the Regional Board the Hunters Point Power Plant Cooling Water Intake Report and 316(b) Study Plan (study plan) (PGandE 1977), which assessed the potential for adverse impact on various biotic groups of the aquatic community and presented a plan for a one-year monitoring study. The study was designed to provide a basis for determining whether the existing cooling water intake structures or modifications of those structures represent the best technology available for minimizing adverse impact. The study plan was based on State and Federal 316(b) guidelines and was reviewed by several government agencies, including the Regional Board, the California Energy Commission, the State Water Resources Control Board, the California Department of Fish and Game, and Region IX of the U.S. Environmental Protection Agency (U.S. EPA). The plan was then revised to incorporate agency comments and suggestions. The one-year 316(b) field study program was initiated in April 1978.

1.2.2 Overview of the 316(b) Program

The objective of the program was to determine the extent of entrainment and impingement at the Hunters Point Power Plant and the environmental impact of the resultant losses. The numbers of aquatic organisms entrained and impinged were sampled weekly, and the potential survival of entrained and impinged organisms was considered. Based on these studies, the total annual losses of entrained and impinged organisms were estimated. These estimates formed the foundation for the assessment of impact of the intake systems on the aquatic populations of San Francisco Bay. The assessed impact in turn was used in conjunction with engineering and operating criteria in determining the best intake technology available for the Hunters Point Power Plant site.

1.2.3 Key Organisms Studied

The Hunters Point Power Plant 316(b) studies focused on the following aquatic organism groups, as specified in the study plan (PGandE 1977):

1. fish (all life stages), and
2. macroinvertebrates (e.g., decapods, amphipods, mysid shrimp, tanaidaceans, cumaceans, isopods, chaetognaths, and jellyfish).

These groups were selected because they may be entrained and impinged in abundance and because aspects of their life history and distribution place them among the organisms most susceptible to cooling water intake system impact. These organism groups generally have longer generation times and lower reproduction potential than phytoplankton, zooplankton, and benthos. Fish and macroinvertebrates were also selected because, in many cases, they are commercially or recreationally valuable or important in the food chain.

Organism groups not selected for study include:

1. phytoplankton,
2. zooplankton (small holoplanktonic and meroplanktonic invertebrates not included in the macroinvertebrates specified above), and
3. benthic invertebrates other than those included in the macroinvertebrates specified above (e.g., molluscs, echinoderms, annelids, tunicates, and others).

Phytoplankton and zooplankton were excluded because of their wide geographic distributions, short generation times, and population regeneration potential (U.S. EPA 1977). In addition, tidal currents continually replenish the phytoplankton and zooplankton populations near the plant, thus reducing the risk of localized population changes. Benthic invertebrates were excluded because of their bottom-dwelling habits, which result in minimal involvement with the cooling water systems.

1.3 ORGANIZATION OF THE REPORT

This report, a 316(b) demonstration, is a summary and analysis of the data collected during the one-year monitoring program at the Hunters Point Power Plant. All study elements specified in the study plan (PGandE 1977) are discussed in the order in which they appear in the study plan (Table 1-1).

TABLE 1-1 ORGANIZATION OF THE REPORT--LOCATION OF STUDY ELEMENTS SPECIFIED IN STUDY PLAN

Study Plan Element	Location in Report
1. Plant Operating Data	Chapter 2 Appendix A
2. Entrainment Abundance Studies	Chapter 3 Appendix B
3. Impingement Abundance Studies	Chapter 4
4. Impact Assessment	Chapter 5 Appendix C
5. Best Technology Evaluation	Chapter 6 Appendix D
6. Data Base (microfiche or paper copy)	Appendix E

The design and operation of the Hunters Point Power Plant and its cooling water systems are described in Chapter 2. Plant operating data specified in the study plan are presented in Section 2.1 and in Appendix A. The physical and chemical characteristics of the source water body in the vicinity of the plant are described in Sections 2.2.1-2.2.3; physical and chemical measurements made during the one-year study are reported there and in Appendix A. The aquatic biological environment of the source water body is described in Sections 2.2.4 and 2.2.5. Chapter 2 as a whole provides a framework for assessing the impacts of entrainment and impingement.

The experimental design, methods, and results of the entrainment and impingement abundance programs are presented in Chapters 3 and 4 (the data are tabulated in Appendix E). Estimates of total numbers of organisms entrained and impinged during the one-year study are reported. Based on these estimates and on estimates of the proportion of organisms failing to survive entrainment (discussed in Appendix B) and impingement, the total annual losses of entrained and impinged organisms are estimated for Units 2 and 3 and for Unit 4.

The estimates of entrainment and impingement losses developed in Chapters 3 and 4 are used in Chapter 5 to assess the impact of the combined losses on selected San Francisco Bay aquatic populations. The mathematical methods used for impact assessment are presented in Appendix C.

The best technology available for minimizing adverse environmental impact for each of the intake systems is evaluated in Chapter 6. The full range of possible intake technologies is presented in Appendix D. Technologies that are considered to be proven and available are evaluated on the basis of their potential for reducing the biological losses associated with entrainment and impingement. A site-specific feasibility analysis is presented for the technologies that have the potential to reduce losses. Finally, based on the combination of biological, engineering, and cost considerations, the best technology available for each intake system is recommended.

The report includes an Executive Summary, Chapters 1 through 6, and Appendixes A through E. Appendix E is bound into the report in microfiche form; it has also been printed as a separate volume.

1.4 REFERENCES

Pacific Gas and Electric Company (PGandE). 1977. Hunters Point Power Plant cooling water intake report and 316(b) study plan. Rev. ed. Submitted California Regional Water Quality Control Board, San Francisco Bay Region. PGandE, San Francisco.

U.S. Environmental Protection Agency (U.S. EPA). 1977. Guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment: section 316(b) P.L. 92-500. Draft. U.S. EPA, Office of Water Enforcement, Permits Division, Industrial Permits Branch, Washington, D.C. 59 pp.

Chapter 2

Description of the Hunters Point Power Plant and Characteristics of the Source Water Body

2.1 The Plant and Its Cooling Systems

2.2 Physical, Chemical, and Biological Characteristics of the Source Water Body, San Francisco Bay

2.3 References

CHAPTER 2: DESCRIPTION OF THE HUNTERS POINT POWER PLANT AND CHARACTERISTICS OF THE SOURCE WATER BODY

This chapter describes design and operational features of the Hunters Point Power Plant in the context of the aquatic environmental setting. Section 2.1 describes the plant and its cooling water systems, with emphasis on operational parameters outlined in the study plan (PGandE 1977) that are necessary for the calculation and interpretation of the entrainment and impingement estimates developed in Chapters 3 and 4 and the impact assessments in Chapter 5.

Section 2.2 characterizes physical, chemical, and biological aspects of the aquatic environment in which the plant operates, with emphasis on the parameters outlined in the study plan. The characterization of biological resources is used for impact assessment in Chapter 5, where species affected by the plant are discussed in more detail.

2.1 THE PLANT AND ITS COOLING SYSTEMS

The location, design, and operation of each unit's cooling water structure at the Hunters Point Power Plant has a direct influence on the abundance and survival of entrained and impinged organisms. This section describes the intake design and operational procedures for Units 2 and 3, and Unit 4. An analysis of whether these systems represent the best technology available is given in Chapter 6.

2.1.1 Location

The location of the Hunters Point Power Plant is shown in Figure 2-1. The plant is situated in the industrial southeast section of San Francisco (Figure 2-2). The Potrero Power Plant (488 MWe gross), approximately 1-1/2 mi (2 km) to the north, is the only other major generating facility in the central or south part of San Francisco Bay. The Hunters Point Power Plant is situated on the shore of India Basin adjacent to the Port of San Francisco's Lighter Aboard Ship Handling (LASH) facility (Figure 2-3).

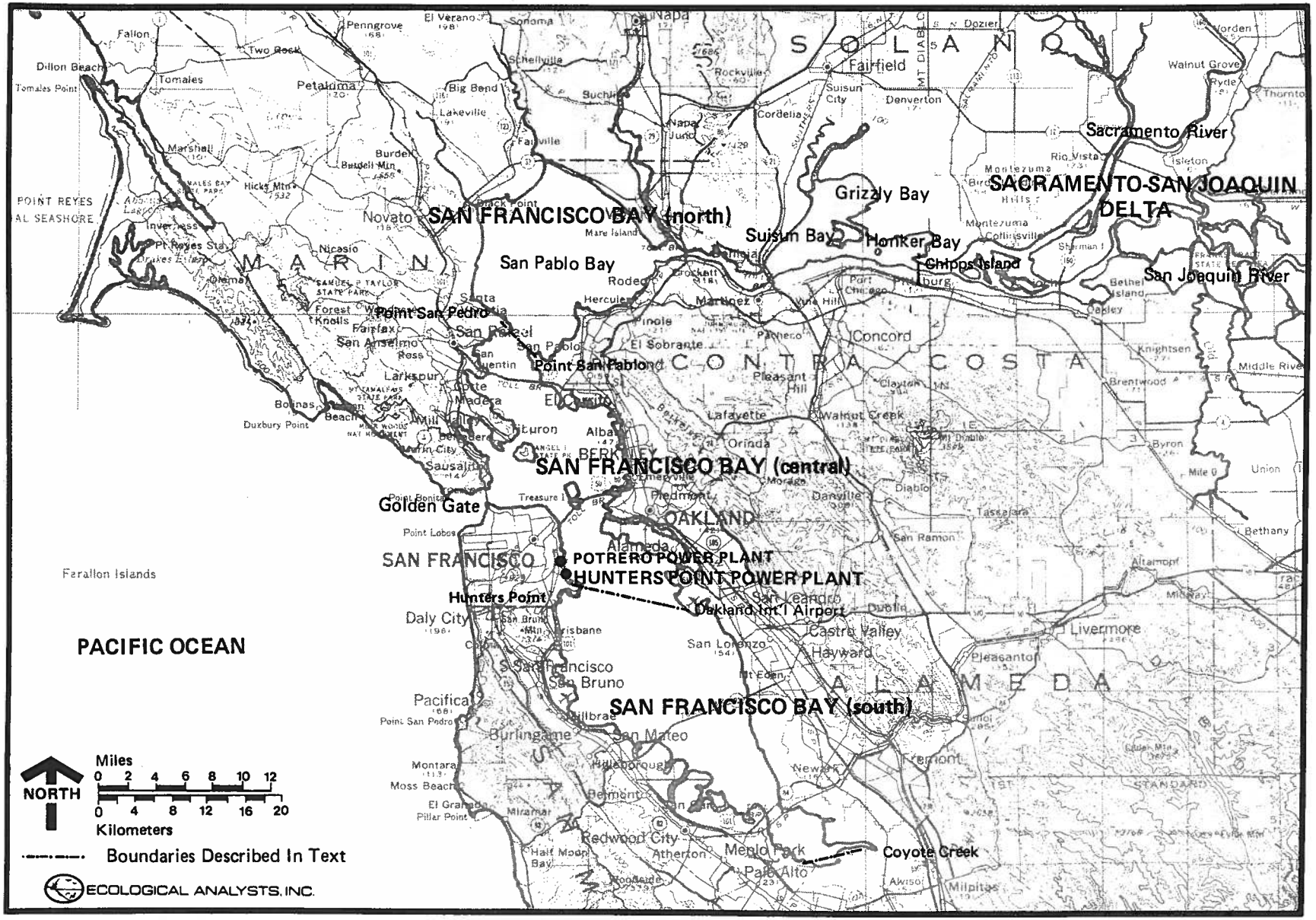


Figure 2-1. Location of the Hunters Point Power Plant in relation to San Francisco Bay and the Sacramento-San Joaquin Delta region.

Figure 2-2. The Hunters Point Power Plant.

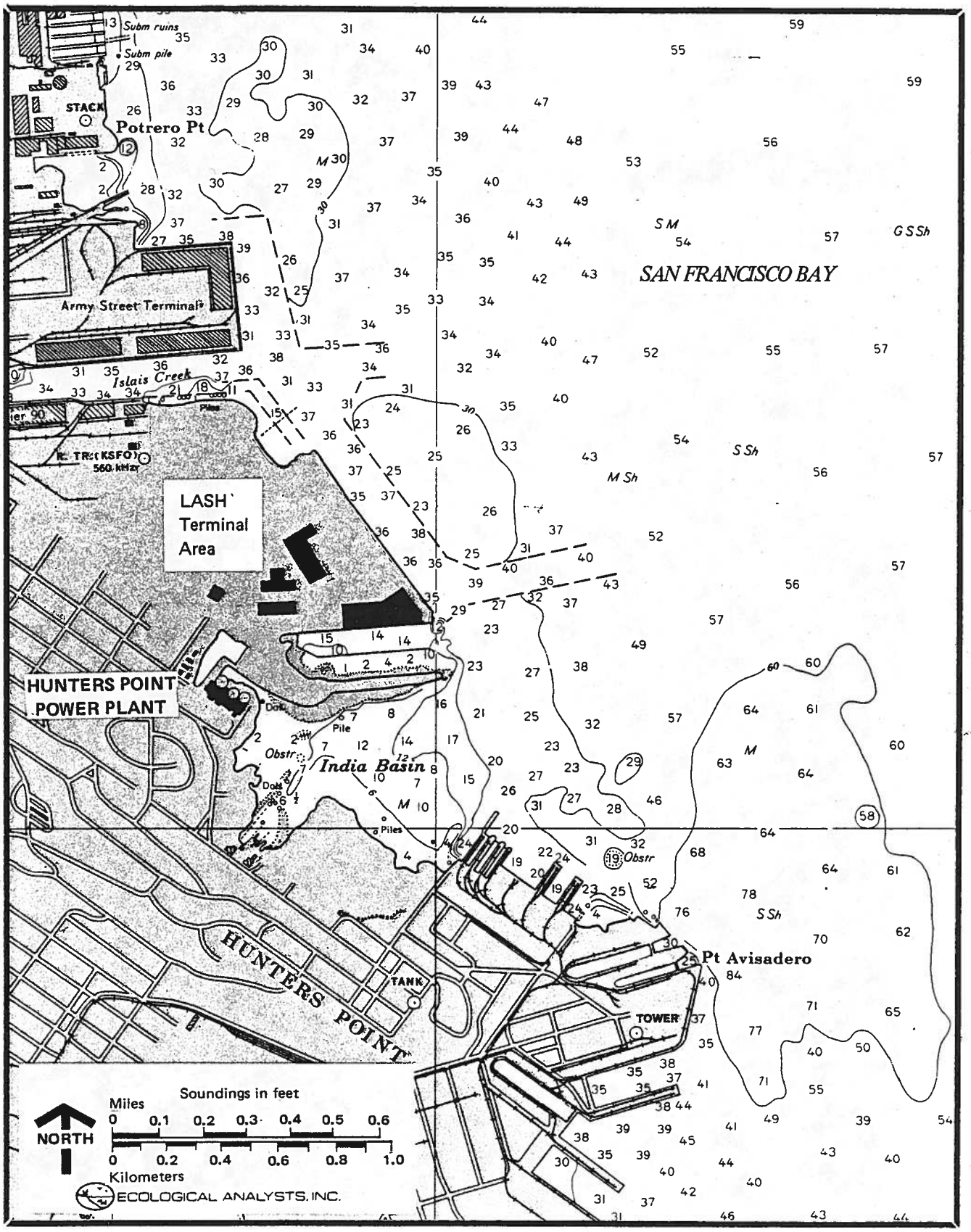


Figure 2-3. Shoreline and bathymetry of San Francisco Bay near the Hunters Point Power Plant (From NOAA 1979).

2.1.2 Plant Description and Operation

The Hunters Point Power Plant consists of four units with a combined gross generating capacity of 448 MWe. The general configuration of Units 2, 3, and 4 and their once-through cooling water systems is shown in Figure 2-4. The original Unit 1, a 35-MWe steam electric generating unit, was decommissioned in 1972 and replaced with a 52-MWe combustion turbine unit in 1976. This unit requires no cooling water and is not described further in this report. Units 2 and 3, put into commercial operation in 1948 and 1949, respectively, are steam electric generating units with gross generating capacities of 110 MWe each. Units 2 and 3 are each equipped with an auxiliary 3-MWe steam electric generator, referred to as a house unit, that is used to supply a portion of the energy required to operate its main unit. The house units are regarded as part of their respective main generating units and are included with them in further discussions of Unit 2 and Unit 3 unless otherwise noted. Unit 2 operates independently from Unit 3, but the units share a common cooling water intake. Unit 4, also a steam electric unit, rated at 170 MWe, began commercial operation in 1958 and has its own once-through cooling water intake and discharge system. Cooling water for all three of these gas- or oil-fired units (2, 3, and 4) comes from San Francisco Bay through a pair of conduits each 9 ft (2.7 m) in diameter, located at the end of a long, shallow embayment which serves as a loading and holding area for the adjacent shipping terminal. Cooling water flows from the conduits into a large basin in which the cooling water intake structures are located (Figure 2-5).

2.1.2.1 Units 2 and 3 Cooling Water System: Design and Operational Procedures

The cooling water system serving Units 2 and 3 is shown schematically in Figure 2-6. Their common intake structure is flush to the shoreline of the intake basin and consists of bar racks, traveling screens, a chlorinator, and two gravity-flow intake tunnels which deliver cooling water to the circulating water pumps of both Unit 2 and Unit 3. The cooling water systems of Unit 2 and Unit 3 remain separate from the circulating water pumps to their respective points of discharge into the discharge cove. Specifications of the Units 2 and 3 cooling water system are presented in Table 2-1.

Figure 2-7 shows major components of the cooling water intake structure for Units 2 and 3. Bars on 4-in. (10.2-cm) centers form racks that prevent the entry of large

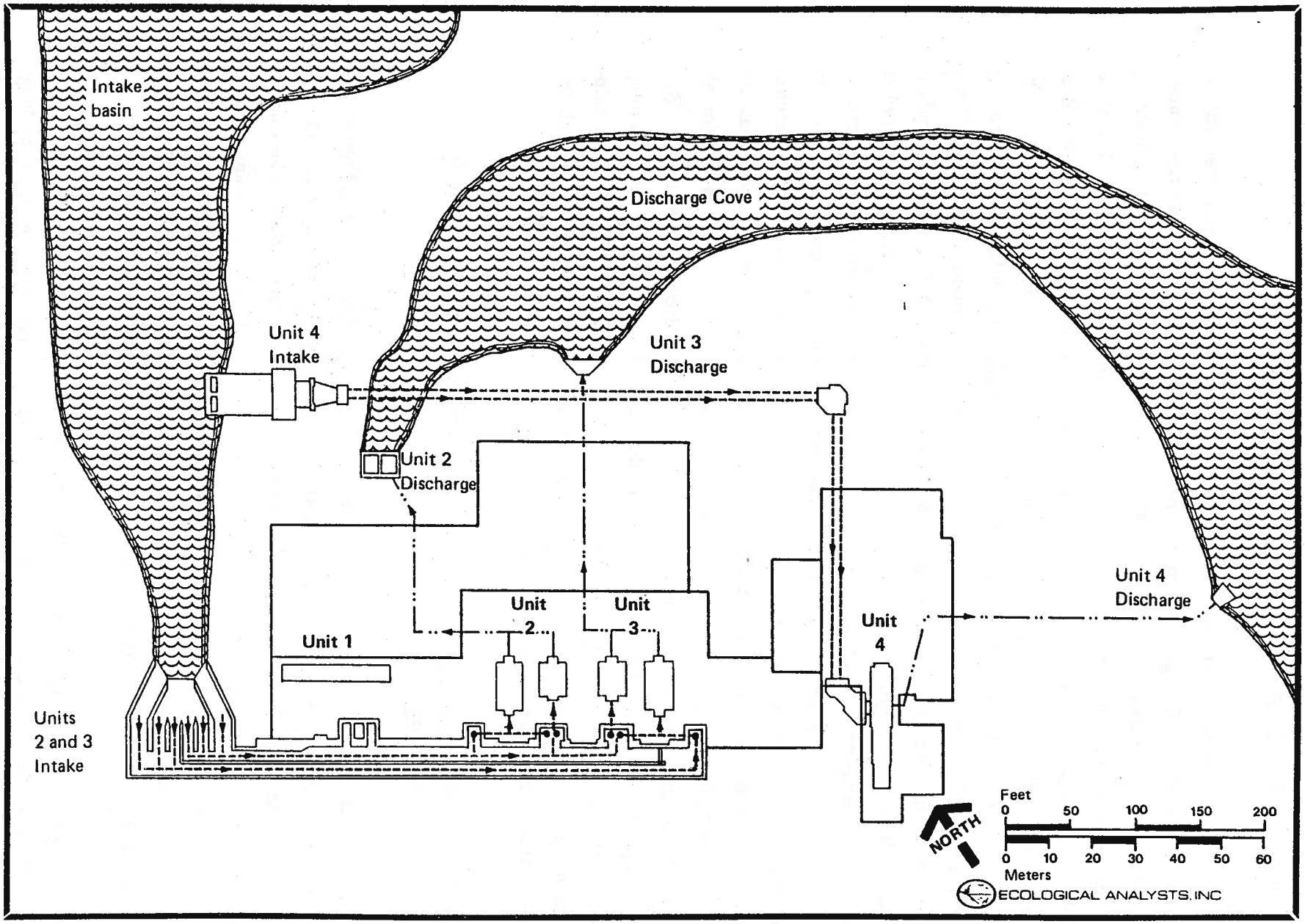


Figure 2-4. General configuration of the Hunters Point Power Plant.

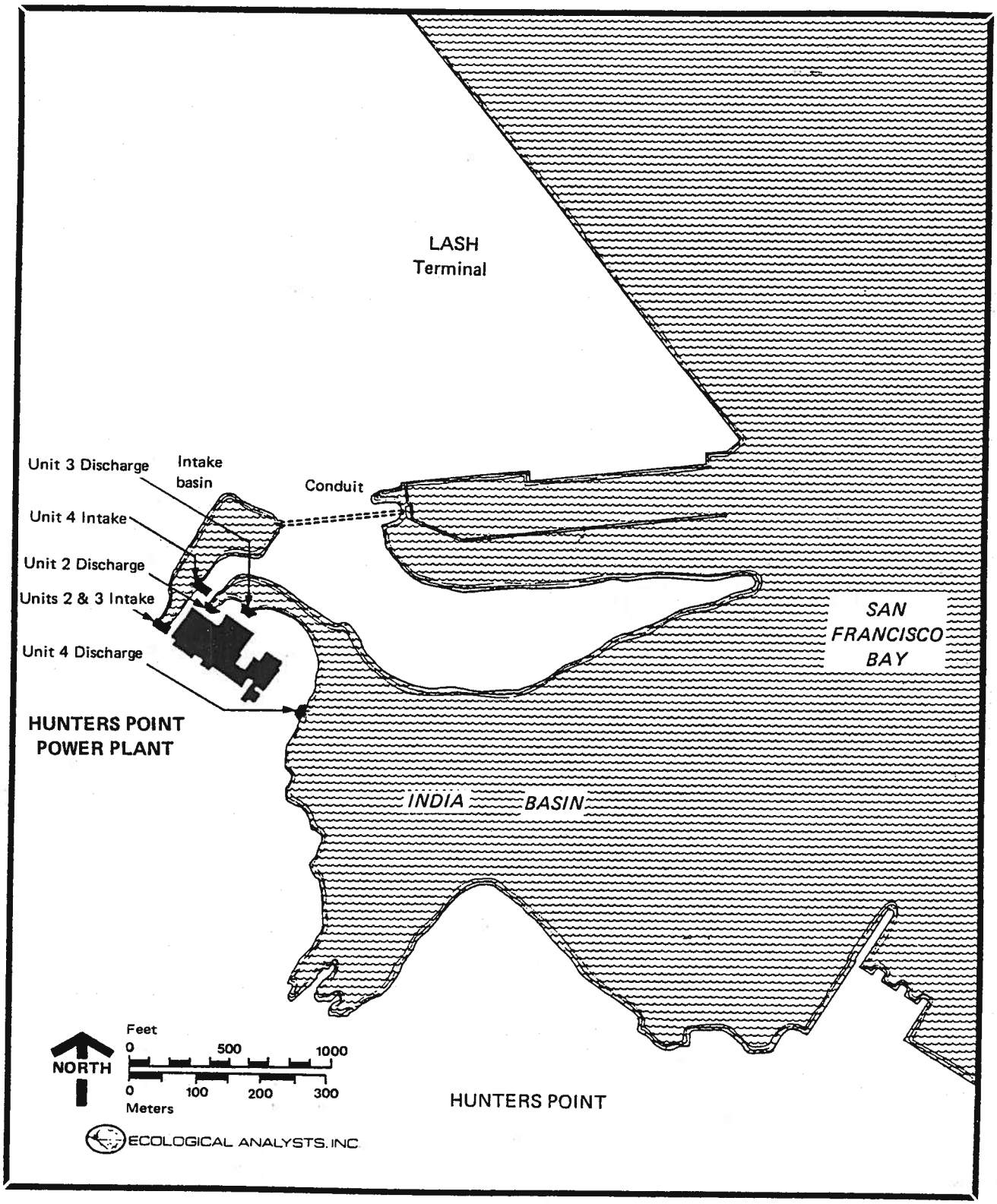
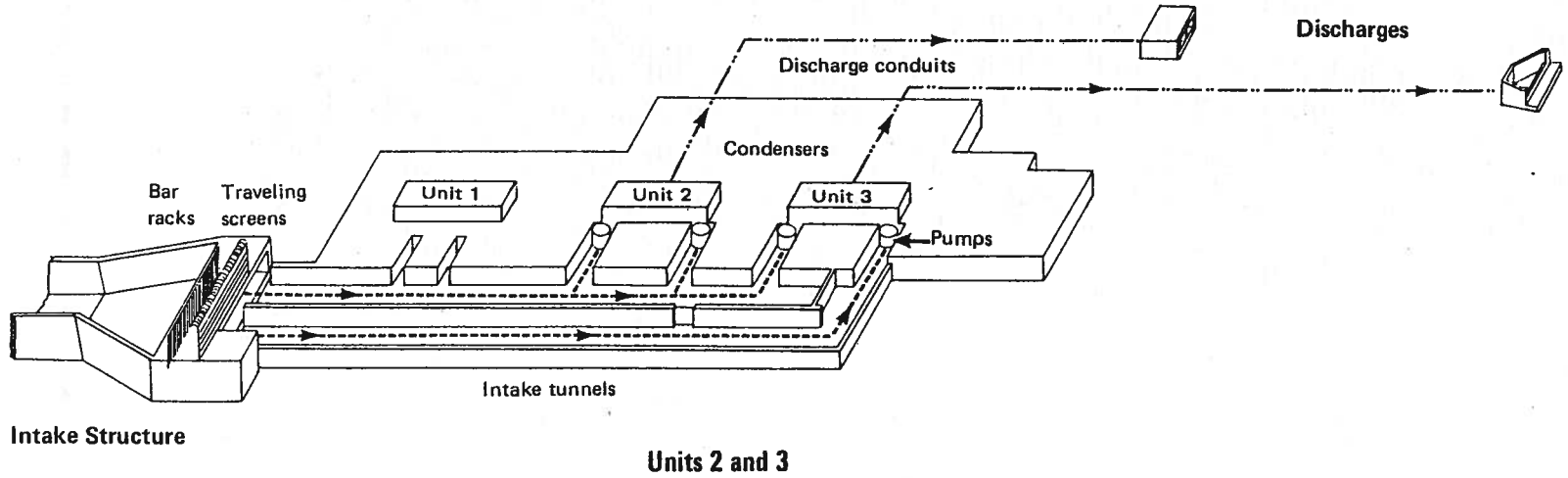


Figure 2-5. Plan of the cooling water system of the Hunters Point Power Plant in relation to the source water body.



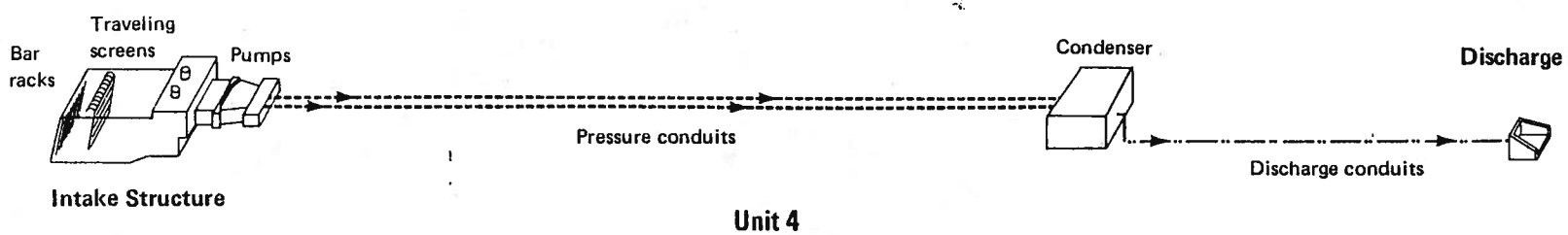


Figure 2-6. Schematic diagrams of the Hunters Point Power Plant Units 2 and 3 and Unit 4 cooling water system.

TABLE 2-1 SPECIFICATIONS OF COOLING WATER SYSTEMS AT THE HUNTERS POINT POWER PLANT

Specification	Unit 2	House Unit 2	Unit 3	House Unit 3	Unit 4
Bar racks					
Number	6	(a)	(a)	(a)	4
Location	Shoreline of intake channel				Shoreline of intake channel
Spacing O.C., in. (cm)	4.0 (10.2)				4.0 (10.2)
Bar size, in. (cm)	3 x 0.4 (7.6 x 0.9)				3 x 0.4 (7.6 x 0.9)
Intake tunnel to pumps					
Number	2	(a)	(a)	(a)	N/A
Size, ft (m)	9.0 x 6.0 (2.7 x 1.8)				
Length, ft (m)	West--400 (122) East--325 (91)				
Traveling screens					
Location	Shoreline	(a)	(a)	(a)	Shoreline
Number	6				2
Manufacturer	Link Belt				Rex Chain-Belt
Mesh size, in. (mm)	3/8 (9.5)				3/8 (9.5)
Pumps					
Location	East intake tunnel	East intake tunnel	One pump on east tunnel, one pump on west tunnel	East intake tunnel	Shoreline
Number	2	1	2	1	2
Manufacturer	Foster-Wheeler	Foster-Wheeler	Foster-Wheeler	Foster-Wheeler	C. H. Wheeler
Type	Mixed flow, centrifugal	Mixed flow, centrifugal	Mixed flow, centrifugal	Mixed flow, centrifugal	Mixed flow, centrifugal
Capacity, cfs	89.1	20.0	89.1	20.0	113.2
m^3/sec	2.52	0.57	2.52	0.57	3.20
gpm	40,000	9,000	40,000	9,000	50,800
Pressure conduits to condenser					
Number	2	1	2	1	2
Diameter, ft (m)	3.5 (1.07)	1.5 (0.5)	3.5 (1.07)	1.5 (0.5)	4.5 (1.4)
Length, ft (m)	20 (6.1)	20 (6.1)	20 (6.1)	20 (6.1)	700 (213)
Condenser					
Number of tubes	6,750	972	6,750	972	9,550
Tube material	Copper-nickel	Aluminum-brass	Copper-nickel	Aluminum-brass	Copper-nickel
Tube outside diameter, in. (cm)	7/8 (2.2)	7/8 (2.2)	7/8 (2.2)	7/8 (2.2)	7/8 (2.2)
Tube length, ft (m)	26.0 (7.9)	18.2 (5.5)	26.0 (7.9)	18.2 (5.5)	30.0 (9.1)
Design delta-T, F (C)	21 (11.7)	19 (10.6)	19 (10.6)	19 (10.6)	17 (9.4)

(a) Units 2 and 3 and their house units share a common intake structure.
(b) Discharges into main unit discharge conduit.
(c) Two values are reported where velocities and transit times vary substantially with the number of circulating water pumps in operation.

TABLE 2-1 (CONT.)

Specification	Unit 2	House Unit 2	Unit 3	House Unit 3	Unit 4
Discharge conduits					
Number	1	(b)	1	(b)	1
Size, ft	10.5 x 4.5		6.5 x 7.0		5.0 x 7.0
m	3.2 x 1.4		2.0 x 2.1		1.5 x 2.1
Length, ft (m)	276 (84.1)		310 (94.5)		310 (94.5)
Approximate travel times (sec)[c]					
Screens to pumps	45-107	45-107	70-281	70-246	31
Pumps to condenser	4	3	4	3	99
Through condenser	4-8	3	4-8	3	4
Condenser to discharge	66-120	66-120	71-129	71-129	47
Total through plant	119-239	117-233	149-422	147-381	181
Total heated	70-128	69-123	75-137	74-132	51
Total chlorinated	115-239	117-233	149-422	147-381	150
Design water velocities,[c] fps (cm/sec)					
Approach to bar racks	0.6 (18)	(a)	(a)	(a)	0.6 (18)
Through bar racks	1.0 (30)	(a)	(a)	(a)	0.6 (18)
Approach to screens	0.7 (21)	(a)	(a)	(a)	0.8 (24)
Through screens	1.7 (52)	(a)	(a)	(a)	1.6 (49)
Intake tunnel to pumps	1.6-5.5 (49-168)	1.6-5.5 (49-168)	1.6-5.5 (49-168)	1.6-5.5 (49-168)	N/A
Pump to condenser	9.3 (283)	9.2 (283)	9.3 (283)	9.3 (283)	7.1 (216)
Through condenser	3.2-6.4 (98-195)	3.0-6.0 (91-183)	3.2-6.4 (98-195)	3.0-6.0 (91-183)	7.0 (213)
Condenser to discharge	1.9-4.2 (58-128)	0.4-4.2 (12-128)	1.9-4.2 (58-128)	0.4-4.2 (12-128)	6.6 (201)

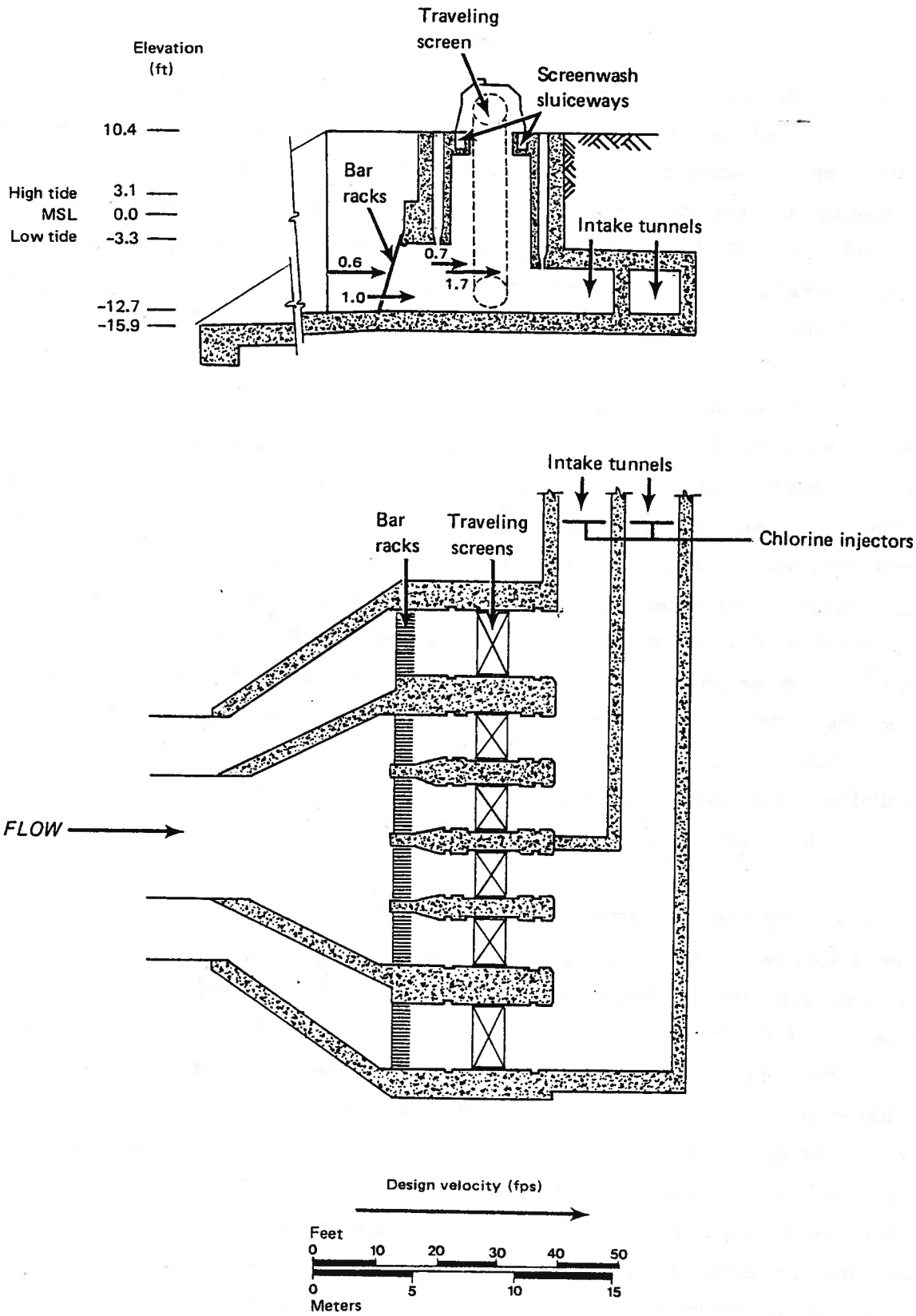
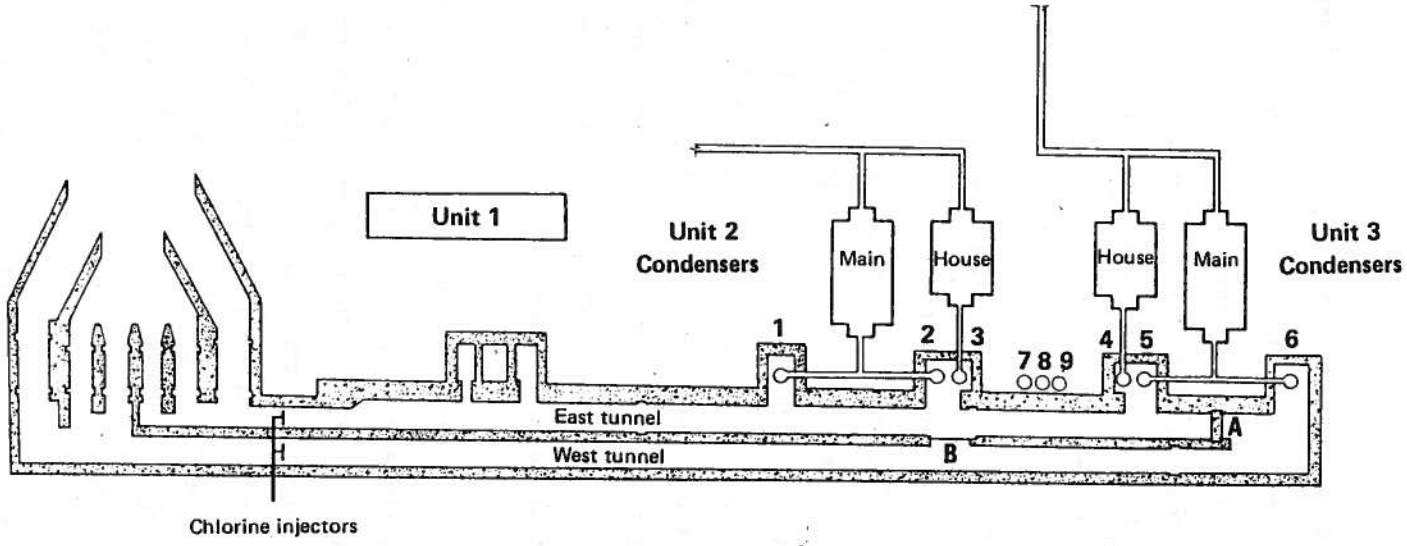


Figure 2-7. Plan and section of the Hunters Point Power Plant Units 2 and 3 intake structure.

objects into the cooling water system. Vertical traveling screens with a mesh size of 3/8 in. (9.5 mm) retain smaller objects. Debris, along with fish and invertebrates retained by the screens, is removed during screen rotation and washing, which is initiated by the plant operator at approximately 8-hour intervals under ordinary operating conditions. During screen washing, high-pressure (80 psi) spray nozzles wash debris and organisms into a gravity return sluiceway 18 in. (46 cm) wide, which drains into the Units 2 and 3 discharge channel.

Figure 2-8 shows the main features of the intake tunnel system for Units 2 and 3. Each of the intake tunnels, one referred to as the east intake tunnel and the other as the west intake tunnel, draws cooling water from three of the six intake forebays. Originally the east and west tunnels were connected near the pump wells, and thus water from both tunnels could flow to all of the circulating water pumps. For operational reasons a permanent partition was erected in the east tunnel, between the two main circulating water pumps of Unit 3 (A, Figure 2-8). Since then only one main circulating water pump of Unit 3 draws from the west tunnel, whereas any of the other five circulating water pumps that might be operating must draw from the east tunnel. The only connection between the tunnels is a stop log gate near the house unit circulating water pump of Unit 2 (B, Figure 2-8). At present this gate remains closed except during maintenance or repair operations.

The circulating water systems of Units 2 and 3 are essentially identical. Each system incorporates two 40,000 gpm (2.5 m^3/sec) circulating water pumps which service the main generating unit condenser and a 9,000 gpm (0.6 m^3/sec) pump which services the condenser of the house unit. In normal operation, one of the two main circulating water pumps on each unit is used in conjunction with the house unit pump. In the Unit 3 cooling water system, the main circulating water pump that draws from the west tunnel is run under normal operating conditions. Each unit can attain approximately 90 percent of full load capability with one circulating water pump in service. This constitutes normal operation for the units. Occasionally high load demand or condenser conditions (cleanliness, number of plugged tubes, high circulating water inlet temperatures, etc.) may necessitate the use of both main circulating water pumps. Under normal operating conditions the cooling water flow for each unit is 49,000 gpm (3.1 m^3/sec), for a combined normal flow of 98,000 gpm (6.2 m^3/sec) for both units in service. The maximum



A Permanent partition in east tunnel.
B Stop log gate between tunnels.

1,2 Unit 2 main circulating pumps
3 Unit 2 house circulating pump
4 Unit 3 house circulating pump
5,6 Unit 3 main circulating pumps
7,8,9 Auxiliary saltwater pumps

Figure 2-8. Schematic plan of the east and west intake tunnels at Units 2 and 3 of the Hunters Point Power Plant.

flow for the combined Units 2 and 3 cooling systems (i.e., with all circulating water pumps in operation) is 178,000 gpm (11.2 m^3/sec).

In addition to the six circulating water pumps, there are three auxiliary pumps which supply the auxiliary cooling water heat exchangers. Each of these pumps has a rated capacity of 6,000 gpm (0.4 m^3/sec). Under normal operating conditions one pump supplies bearing cooling water to both Units 2 and 3. The flow from these pumps is included in volume estimates used to calculate the number of organisms entrained through the Units 2 and 3 cooling water system.

Organisms entrained through the Units 2 and 3 cooling water systems are subject to both increases and decreases in pressure during transit through the system. Cooling water is under pressure from the discharge of the circulating water pumps to the discharge structure. Pressure increases from atmospheric (14.7 psia) ahead of the pumps to an estimated 22.7 psia at the pump discharge. Pressure drops gradually through the cooling system, with an estimated 5.4-psi drop across the condenser. Pressure returns to atmospheric at the discharge weir. During the lower tidal stages, pressure can increase by as much as 2 psi throughout the pressurized portion of the system. The design condenser temperature rise (delta-T) under normal full-load operating conditions is 21 F (11.7 C) for Unit 2 and 19 F (10.6 C) for Unit 3.

Cooling water structures provide habitat for mussels, which must be removed periodically to prevent clogging of the condenser tubes. Before 1975, mussels were controlled at Units 2 and 3 by reverse flow of heated circulating water (thermal shock treatment) through the intake tunnels to the cooling water intake. An increase in temperature of 28 C (50 F) for one hour was found to kill the mussels. This procedure was carried out every 4-6 weeks, depending on season and need as determined by inspection. Since 1975, mussel shells and other debris are mechanically cleaned from the condenser inlet boxes on a routine basis at intervals determined by condenser backpressure.

Chlorine is used to control bacterial slime on the condenser tube surfaces and colonization of the conduits by biofouling organisms. Chlorine is injected at the entrances of the two intake tunnels, behind the intake screens. Each tunnel is chlorinated separately once or twice a day for 30 minutes. The present schedule is 30 minutes once a day. During chlorination, total residual chlorine is maintained at approximately 0.4 mg/liter at the condenser inlet. The transit time from the chlorine injection

point to the discharge structure ranges from about 2 to about 7 minutes, depending on the unit and the number of pumps in operation (Table 2-1).

Dechlorination facilities were put into service in August 1980 that inject sulfur dioxide into the cooling water upstream of the discharge structure to eliminate the discharge of chlorine into the Bay. Since that time the usual analytical results show 0.0 mg/liter chlorine residual at the discharge, although a few trace residuals have been reported.

2.1.2.2 Unit 4 Cooling Water System: Design and Operational Procedures

The cooling water system serving Unit 4 is shown schematically in Figure 2-6. The intake structure is flush to the shoreline of the intake basin and consists of bar racks, traveling screens, a chlorinator, circulating water pumps, and two intake conduits leading to the two halves of the Unit 4 condenser. The discharge from the two condenser halves is combined in a single conduit. Cooling water is discharged from a structure located on the shore of India Basin. Cooling system design specifications are presented in Table 2-1.

Figure 2-9 shows major components of the intake structure. Bar racks spaced 4 in. (10.2 cm) on centers are located about 20 ft (6.1 m) in front of vertical traveling screens. The screens of Unit 4 are operated and cleaned in a manner similar to those of Units 2 and 3. Screen rotation and washing is controlled by timers set for 8-hour intervals, with a pressure-controlled override for automatic initiation of screen washing. Impinged debris and organisms washed from the screens are returned to the Bay through a gravity sluiceway 18 in. (46 cm) wide which merges with the Units 2 and 3 screenwash sluiceway approximately 15 ft (4.6 m) upstream from its discharge into the Units 2 and 3 discharge cove.

In normal operation, two 50,800 gpm (3.20 m^3/sec) circulating water pumps, located approximately 33 ft (10 m) behind the traveling screens, are run simultaneously and furnish 101,600 gpm (6.40 m^3/sec) of water.

Cooling water is under pressure from the outlet of the circulating water pumps to the discharge structure. Pressure increases from atmospheric (14.7 psia) at the intake to 20.8 psia at the circulating water pump discharge. Pressure decreases gradually

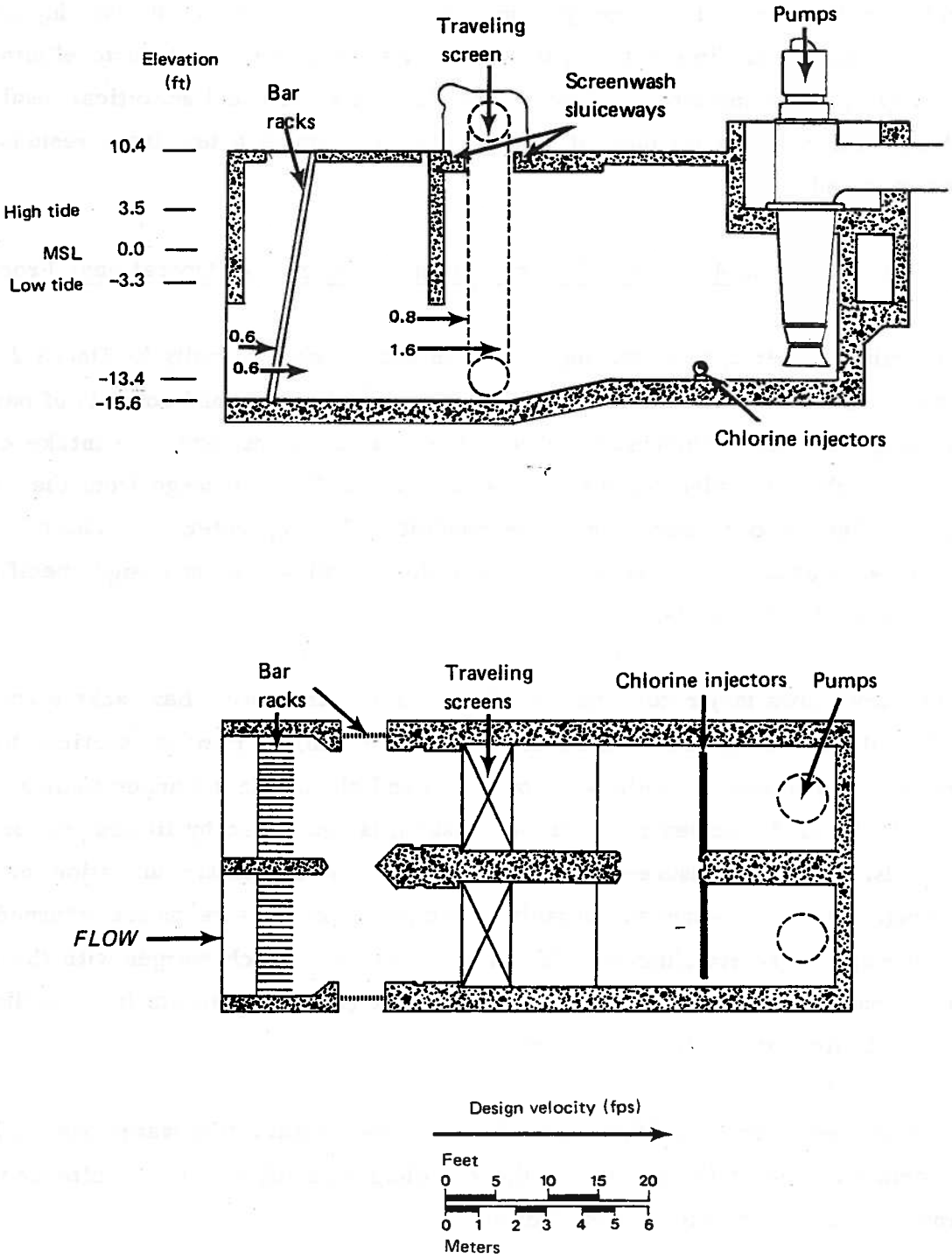


Figure 2-9. Plan and section of the Hunters Point Power Plant Unit 4 intake structure.

through the cooling system, with a drop of about 5 psi across the condenser. Relative pressures do not change during various tidal stages. The design delta-T is 15 F (8.3 C) under normal full-load operation.

Before 1975, mussels were controlled at Unit 4 by a reverse flow of heated circulating water through one condenser half back through the intake conduit to the cooling water intake. An increase in temperature of 30 C (54 F) for one hour was found to control mussel colonization effectively. This procedure was carried out on each condenser half every 4-6 weeks, depending on season and need as determined by inspection. Thermal shock treatment was discontinued at Unit 4 in 1975. Since then debris has been mechanically cleaned from the condenser inlet box on a routine basis at intervals determined by condenser backpressure.

Chlorine is injected into the cooling system just ahead of the circulating water pumps once or twice each day for 30 minutes to prevent condenser biofouling. The present chlorination schedule for Unit 4 is once each day. Each intake conduit and corresponding condenser half is separately chlorinated to 0.4 mg/liter residual chlorine as measured at the condenser inlet. Transit time from the point of chlorination to the discharge structure is about 3 minutes (Table 2-1). As at Units 2 and 3, dechlorination facilities were installed in August 1980. Since that time the usual analytical results show 0.0 mg/liter chlorine residual at the discharge, although a few trace residuals have been reported.

2.1.3 Cooling Water Systems Operations

The plant design specifications and operational procedures discussed in Section 2.1.2 apply primarily to operation under full-load conditions: continuous normal circulating water pump operation and generation at full capacity. Because fossil-fuel generating units are usually operated to respond to seasonal and daily fluctuations in demand for electrical energy, the actual load is generally well below 100 percent operating capacity when expressed as an average over a month or a year.

One convenient statistic for description of plant operational status is the plant or unit's "capacity factor," defined as the ratio of actual gross generation to maximum possible generation over a specified interval, expressed as a percentage. A second convenient indicator is the operation of circulating water pumps, which can be used

to calculate the total volume of water pumped through the condenser cooling system during any specific period of time.

2.1.3.1 Monitoring Procedures

Electrical generation load and pump operation were monitored routinely during daily activities and recorded in operational logs. The logs were read and data compiled to prepare monthly averages of capacity and pumped water volume. Velocity measurements were made of water approaching the intake structures, and a temperature decay survey of the plant's cooling water discharge plume was conducted.

Intake and discharge water temperatures for Units 2 and 3 and Unit 4 were continuously monitored from April 1978 through May 1979. Foxboro temperature sensors and recorders were located in:

1. the Unit 4 intake structure directly in front of the curtain wall,
2. the discharge canal directly below the Unit 2 outfall,
3. the Unit 3 discharge channel immediately upstream of the outfall weir, and
4. the Unit 4 discharge conduit approximately 50 ft ahead of the submerged discharge structure.

The intake temperature of Units 2 and 3 was assumed to be identical to the Unit 4 intake temperature, because the units share a common source of cooling water. Temperatures were recorded continuously throughout the study and read from the chart recordings at 3-hour intervals to calculate average weekly values. The temperature recorders were calibrated using a two-point calibration at 32 F and 100 F (0 C and 37.8 C) with a thermometer traceable to a National Bureau of Standards reference (see Section A.2).

Measurements of conductivity (salinity), intake water temperature, and dissolved oxygen (DO) were routinely made when biological samples were collected.

2.1.3.2 Study Year Operations

Electrical generation, circulating water pump operation, intake velocities, intake and discharge temperatures, and unit outages of the Hunters Point Power Plant are discussed for Units 2 and 3 and Unit 4 in the following sections. Circulating water pump operation and the water volumes pumped are used in Chapters 3 and 4 to estimate annual entrainment and impingement abundances under actual operating conditions of each unit. Temperature measurements and temperature decay of the discharge plume are related to entrainment survival estimates in Chapter 3. Intake water velocities are related to impingement in Chapter 4. Water quality measurements made during the study period are discussed in Section 2.2.3.

2.1.3.2.1 Units 2 and 3 Operation

A summary of the average monthly capacity factors (percent generation) for Units 2 and 3 from April 1978 through April 1979 is given in Table 2-2. Monthly generating capacity factors ranged from 0 to 68.4 percent for Unit 2 and from 0 to 71.6 percent for Unit 3. Capacity factors do not include the output of the house units, because their output is generally used within the plant and is not exported to the power distribution system. Average capacity factors for the study period were 33.7 percent for Unit 2 and 40.0 percent for Unit 3.

Monthly capacity factors for Units 2 and 3 generally ranged from 20 to 60 percent during 1971 and 1972 (PGandE 1977). This range is similar to that observed during the study period. During the drought period 1976-1977, capacity factors remained at the upper end of the range because of limited hydroelectric generation.

The average monthly capacity factors presented in Table 2-2 reflect, in part, seasonal fluctuations in the demand for electrical power. In addition, the operation of Units 2 and 3 was regulated to meet hourly and daily requirements for electrical power. Hourly demand is generally greatest between 0700 and 1000 hours and between 1600 and 2000 hours, and least between 2000 and 0700 hours. Greatest daily demands for electrical power occur from Monday to Friday. Thus, actual hourly and daily operation of Units 2 and 3 varies to a greater degree than is apparent from the average monthly capacity factor.

TABLE 2-2 MONTHLY CAPACITY FACTORS (%) FOR THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979

Month	Unit 2	Unit 3	Unit 4
APR 1978	0	21.8	52.4
MAY 1978	0	32.8	54.1
JUN 1978	15.5	33.1	77.9
JUL 1978	30.8	46.2	71.7
AUG 1978	36.7	30.6	80.2
SEP 1978	29.5	0	61.9
OCT 1978	57.1	42.6	68.7
NOV 1978	68.4	71.6	41.4
DEC 1978	65.7	65.4	80.9
JAN 1979	54.4	55.3	77.7
FEB 1979	37.3	38.8	73.6
MAR 1979	2.1	50.3	60.4
APR 1979	40.2	32.1	63.8
Mean	33.7	40.0	66.5

Note: Monthly capacity factor is defined as the ratio of actual monthly generation to the maximum possible generation.

Continuous normal circulating water pump operation for the Units 2 and 3 cooling water system is defined as the operation of one of each unit's two main circulating water pumps along with each unit's house pump, resulting in a cooling water flow of 98,000 gpm (6.2 m^3/sec). The estimated total cooling water volumes pumped during each month from April 1978 through April 1979 and the percentage of normal monthly cooling water capacity that these volumes represent are presented in Table 2-3. The percentage ranged from 51.1 to 121.7. Percentages in excess of 100 represent periods in which one or both of the remaining circulating water pumps were put into service for part of the month (e.g., if all pumps were to operate for an entire month, the percentage of normal capacity would be 181.7). The average percentage of normal capacity was 98.9.

Units 2 and 3 are operated essentially as base load units, providing electrical power to meet normal daily demand from the San Francisco load center. A summary of outages in excess of 12 hours is given in Table 2-4 for Units 2 and 3. Outages are divided into three categories: scheduled, unscheduled, and reserve shutdown. Scheduled outages are planned interruptions of unit operation required for inspections and preventive maintenance. Unit 2 had two extended outages of this type; those of Unit 3 were more frequent but of shorter duration. Unscheduled outages are interruptions in unit operation required by unanticipated problems that occur during operation. Only a small loss of operation was attributed to unscheduled outages of Units 2 and 3. Reserve shutdown outages occur during periods of low electrical demand when more efficient or economical generating units are capable of meeting the system demands. Units 2 and 3, being less efficient, were placed on reserve shutdown periodically, usually on weekends. During these outages the units are kept fully available for rapid return to service to meet peak energy demands if required.

Water velocities approaching the traveling screens of Units 2 and 3 were measured under two circulating water pump operating regimes by PGandE personnel (see Section A.1, Appendix A). Measurements were made at five tide heights in normal circulating water pump operation, which consists of two house unit and two main unit circulating water pumps operating at a combined flow rate of 98,000 gpm (6.2 m^3/sec), and at one tide height in full pump operation, which consists of two house unit circulating water pumps and four main unit circulating pumps operating at a combined flow rate of 396 cfs (11.2 m^3/sec). The one main unit circulating water pump that draws from the west intake tunnel operated at a rate of 89 cfs (2.5 m^3/sec) during both sets of

TABLE 2-3 MONTHLY COOLING WATER VOLUMES AND PERCENTAGES OF NORMAL CAPACITY OF UNITS 2 AND 3 OF THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979

	Volume						
	Unit 2		Unit 3		Total		
Month	English ($ft^3 \times 10^6$)	Metric ($m^3 \times 10^6$)	English ($ft^3 \times 10^6$)	Metric ($m^3 \times 10^6$)	English ($ft^3 \times 10^6$)	Metric ($m^3 \times 10^6$)	Percentage of Normal Capacity[a]
APR	0	0	288.9	8.18	288.9	8.18	51.1
MAY	25.9	0.74	300.6	8.51	326.5	9.25	55.9
JUN	159.4	4.52	290.2	8.23	449.6	12.74	79.5
JUL	352.9	9.98	312.3	8.84	665.2	18.83	113.8
AUG	404.6	11.45	306.9	8.69	711.5	20.14	121.7
SEP	294.6	8.34	239.0	6.76	533.7	15.11	94.4
OCT	364.7	10.33	339.9	9.62	704.6	19.95	120.6
NOV	308.1	8.72	315.5	8.93	623.6	17.66	110.3
DEC	319.5	9.05	333.9	9.46	653.4	18.50	111.8
JAN	336.5	9.53	341.9	9.68	678.4	19.21	116.1
FEB	263.9	7.48	263.9	7.48	527.9	14.95	100.0
MAR	173.2	4.92	344.8	9.76	518.2	14.68	88.7
APR	320.3	9.07	314.2	8.90	634.5	17.97	112.2
						Mean Percentage	98.9

(a) Normal capacity (metric) = 6.18 m^3/sec x 3600 x hours in month; normal capacity (English) = 218.4 cfs x 3600 x hours in month (normal circulating water pump operation is described on page 2-12).

TABLE 2-4 DURATIONS (hours) OF UNIT OUTAGES IN EXCESS OF 12 HOURS AT THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979

Unit	Beginning Date	Maintenance Outage Unscheduled	Maintenance Outage Scheduled	Reserve Shutdown
2	1 APR 78	0	0	720.0
	2 MAY 78	0	0	164.5
	9 MAY 78	0	984.3	0
	29 JUN 78	42.5	0	0
	30 JUN 78	0	0	30.7
	2 JUL 78	37.2	0	0
	3 JUL 78	0	0	34.6
	7 JUL 78	0	0	61.4
	14 JUL 78	76.7	0	0
	21 AUG 78	0	0	96.0
	15 SEP 78	0	0	55.5
	3 MAR 79	0	684.4	0
	31 MAR 79	0	0	38.0
	6 APR 79	0	0	119.5
3	7 APR 78	0	0	55.9
	14 APR 78	0	0	56.1
	21 APR 78	0	0	56.6
	28 APR 78	0	0	55.9
	6 MAY 78	0	15.1	0
	6 MAY 78	0	0	31.2
	14 MAY 78	0	0	20.4
	19 MAY 78	0	0	54.8
	23 JUN 78	0	48.5	0
	25 JUN 78	0	0	75.7
	11 AUG 78	0	19.5	0
	12 AUG 78	0	25.5	0
	13 AUG 78	0	0	185.5
	25 AUG 78	0	0	554.6
	18 SEP 78	0	0	21.9
	19 SEP 78	18.2	0	0
	19 SEP 78	0	0	309.4
	16 OCT 78	0	0	157.8
	10 FEB 79	0	53.2	0
	11 APR 79	0	0	124.8
	17 APR 79	0	60.2	0
	19 APR 79	0	0	13.6
	20 APR 79	22.3	0	0

TABLE 2-4 (CONT.)

Unit	Beginning Date	Maintenance Outage Unscheduled	Maintenance Outage Scheduled	Reserve Shutdown
4	10 APR 78	41.8	0	0
	10 MAY 78	46.9	0	0
	4 JUL 78	42.4	0	0
	9 JUL 78	36.4	0	0
	8 SEP 78	44.8	0	0
	25 OCT 78	556.3	0	0
	5 DEC 78	47.2	0	0
	16 JAN 79	38.1	0	0
	2 MAR 79	51.1	0	0
	17 MAR 79	38.0	0	0
	23 MAR 79	24.8	0	0

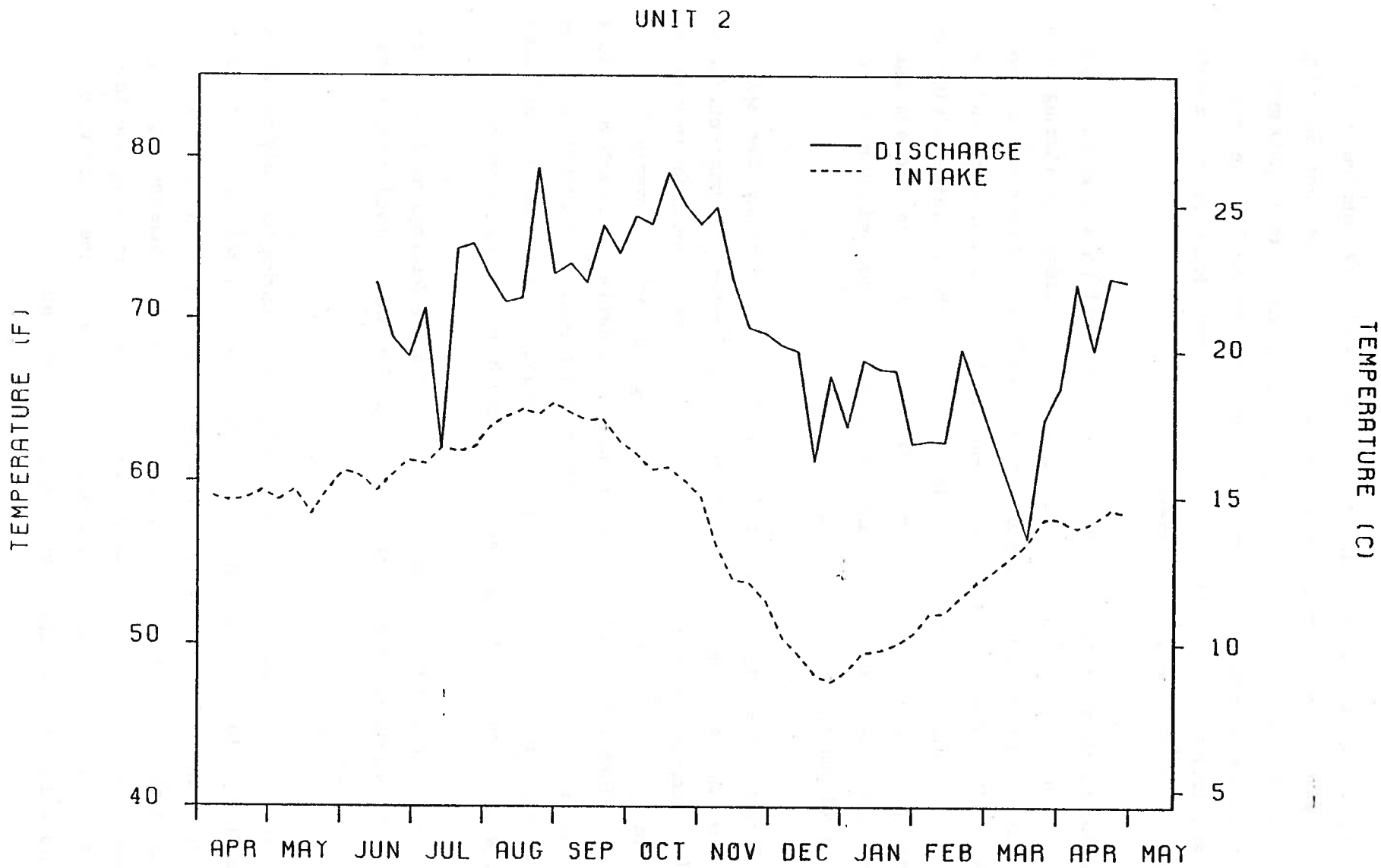
measurements. Since the other circulating water pumps all draw from the east intake tunnel, the flow rate through the east tunnel intake forebays changed from 58,000 gpm (3.7 m^3/sec), its flow rate under normal operating conditions, to 138,000 gpm (8.7 m^3/sec) when the remaining pumps were put into service to achieve full pump operation. Velocity measurements were made at an array of sampling locations approximately 1.5 m (5 ft) in front of the traveling screens.

Under normal operation, water velocities ranged from 0 to 1.4 fps (0–43 cm/sec) and averaged 0.8 fps (24 cm/sec) at a spring higher high tidal stage. At a spring lower low tidal stage, water velocities ranged from 0.2 to 1.3 fps (6–40 cm/sec) and averaged 0.9 fps (27 cm/sec). Since the tunnels were modified, the design approach velocity has been 0.6 fps (18 cm/sec) for the forebays serving the east tunnel and 0.4 fps (12 cm/sec) for those serving the west tunnel. Differences between the two in measured velocities were insignificant. (For a fuller treatment of normal and full pump operation design velocities, see PGandE 1979.)

Under full pump operation, velocities in the east tunnel intake forebays were substantially higher than velocities in the west tunnel intake forebays, ranging from 0.2 to 3.0 fps (6–91 cm/sec) and averaging 1.4 fps (43 cm/sec); velocities in the west tunnel intake forebays ranged from 0.1 to 1.4 fps (3–43 cm/sec) and averaged 1.1 fps (33 cm/sec). High velocities in the west tunnel intake forebays were attributed to a reduction in intake area of approximately 30 percent caused by removal of one of the three traveling screens for repairs. The higher velocities in the east tunnel intake forebays were attributed to the increased flow through this part of the intake.

No appreciable accumulation of sediment was found in the forebays serving the east intake tunnel. A sediment layer about 1.5 ft (0.4 m) deep was observed in the forebays serving the west tunnel.

Average weekly intake and discharge water temperatures during the study period are shown in Figure 2-10. The seasonal variations in ambient (intake) water temperature are evident, with highest temperatures in August and September and lowest temperatures in December and January. No attempt was made to determine the magnitude of the difference between intake and ambient water temperatures resulting from thermal recirculation. The lack of diurnal temperature variations at the intake in response to variations in plant load suggests that recirculation is minimal.



Gaps in the record are due to unit outage or recording instrument failure.

Figure 2-10. Mean weekly intake and discharge temperatures at Units 2 and 3 of the Hunters Point Power Plant, 1978–1979.

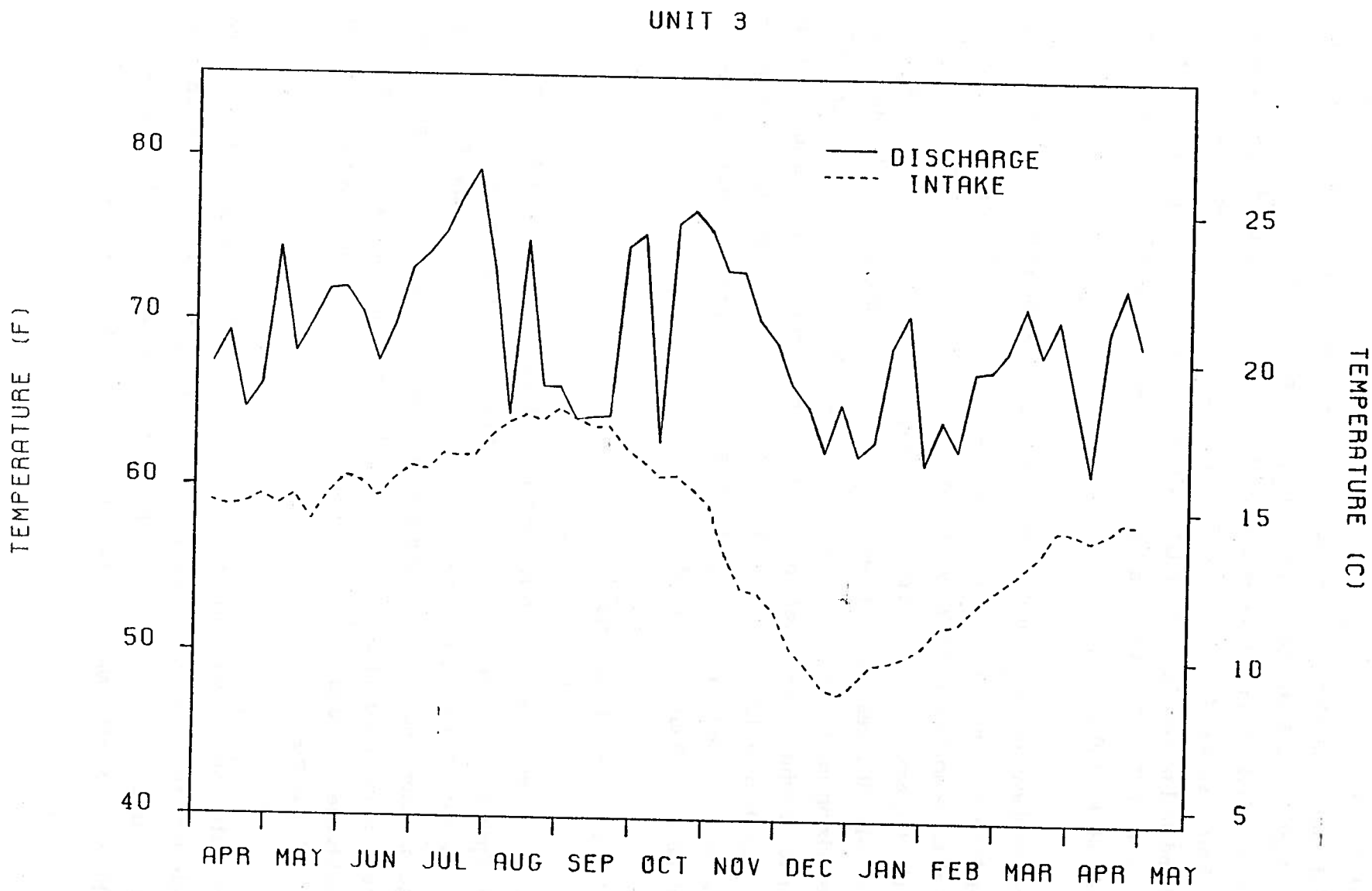


Figure 2-10. (Cont.)

Water temperatures recorded every 3 hours from the Unit 4 intake and from the discharges of Unit 2 and Unit 3 were used to characterize the temperature regime of the units (Table A-6). Intake temperatures ranged from 47 to 66 F (8.3-18.9 C) during the study, with 98.8 percent of the readings below 66 F (18.9 C). Discharge temperatures at Unit 2 ranged from 53 to 97 F (11.7-36.1 C), with 75 percent below 77 F (25.0 C) and 98.1 percent below 86 F (30.0 C). Unit 3 discharge temperatures ranged from 52 to 90 F (11.1-32.2 C), with 86.8 percent below 77 F (25.0 C) and 98.2 percent below 86 F (30.0 C).

Temperature decay of water discharged from the Hunters Point Power Plant cooling water systems was measured by PGandE personnel during flood, ebb, and slack tide. Results of these studies (PGandE 1973a) show that the warm water discharged by the plant's three generating units forms a surface plume that extends over an area of approximately 50 acres (20 hectares). The shoreline configuration of India Basin restricts mixing of the thermal plume with ambient Bay water, extending the time required for cooling water to return to ambient temperature. In three surveys conducted in September 1979 (PGandE unpublished data), the temperature of water discharged from the plant remained 3-5 C (5-9 F) above the ambient water temperature for a minimum of 60 minutes after discharge.

2.1.3.2.2 Unit 4 Operation

A summary of the average monthly capacity factors for Unit 4 from April 1978 through April 1979 is given in Table 2-2. Monthly capacity factors ranged from 41.4 to 80.9 percent. The average capacity factor for the study period was 66.5 percent. Average monthly capacity factors did not vary greatly between months, and no seasonal pattern was apparent in Unit 4 electrical generation. Unit 4 is relatively efficient and is operated to meet the long-term, consistent demand (base load) for electrical power in San Francisco.

Two circulating water pumps with rated capacities of 50,800 gpm (3.2 m^3/sec) each are available for use in the Unit 4 cooling system. In typical operation, the pumps are used simultaneously, resulting in a cooling water flow rate of 101,000 gpm (6.4 m^3/sec). Hours of operation and estimated total cooling water volumes pumped during each

TABLE 2-5 MONTHLY COOLING WATER VOLUMES AND PERCENTAGES OF NORMAL CAPACITY OF UNIT 4 OF THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979

Month	Volume: English Units ($ft^3 \times 10^6$)	Volume: Metric Units ($m^3 \times 10^6$)	Percentage of Normal Capacity[a]
APR	586.8	16.59	100.0
MAY	606.4	17.14	100.0
JUN	586.8	16.59	100.0
JUL	603.1	17.05	99.5
AUG	600.7	16.98	99.1
SEP	586.8	16.59	100.0
OCT	567.3	16.04	93.6
NOV	324.0	9.16	55.2
DEC	604.8	17.10	99.7
JAN	592.5	16.75	97.7
FEB	547.7	15.48	100.0
MAR	595.0	16.82	98.1
APR	586.8	16.59	100.0
		Mean percentage	95.6

(a) Normal capacity (metric) = 6.40 m^3/sec x 3600 x hours in month; normal capacity (English) = 226.4 cfs x 3600 x hours in month (normal circulating water pump operation is described on page 2-15).

month from April 1978 through April 1979 are summarized in Table 2-5. The percentage of continuous normal operation ranged from 55.2 to 100 percent, with an average of 95.6 percent for the study period.

One extended unscheduled outage of Unit 4 and its cooling system occurred during the study period. The outage resulted from a boiler superheater failure and lasted approximately 556 hours (25 October - 17 November 1978). Unit overhauls are scheduled on the basis of 50,000 hours of operation, which results in approximately five years between scheduled overhauls. An overhaul of Unit 4 would require an outage of approximately eight weeks. No scheduled outages or reserve shutdowns in excess of 12 hours occurred at Unit 4 during the study period.

Water velocities approaching the bar racks of Unit 4 were measured at four tide heights by PGandE personnel (see Section A.1). Velocity profiles were based on measurements made in an array of sampling locations in each of the two intake bays, approximately 1.5 ft (0.5 m) in front of each bar rack. Water velocities ranged from 0.1 to 0.9 fps (3-27 cm/sec). Average cross-sectional velocities ranged from 0.5 to 0.7 fps (15-21 cm/sec). Variations in average intake velocities at the Unit 4 intake are small in comparison to those at the Units 2 and 3 intake because the two Unit 4 circulating water pumps are almost always operated simultaneously, creating a relatively constant flow and velocity regime at the intake. Water velocities were not influenced substantially by tidal stage. The maximum average water velocity (0.7 fps; 21 cm/sec) is in close agreement with the design velocity (0.6 fps; 18 cm/sec) for the intake. Design velocities of water approaching the bar rack structure, approaching the vertical traveling intake screens, and passing through the intake screen mesh are shown in Figure 2-9.

Average weekly intake and discharge water temperatures during the study period are shown in Figure 2-11. Discharge temperatures at Unit 4 were similar to those at Units 2 and 3. Intake temperatures ranged from 47 to 66 F (8.3-18.9 C) during the study, with 98.8 percent of the readings below 66 F (18.9 C). Discharge temperatures ranged from 50 to 96 F (10.0-35.6 C) with 71.6 percent below 77 F (25.0 C) and 98.4 percent below 86 F (30.0 C) (Table A-6).

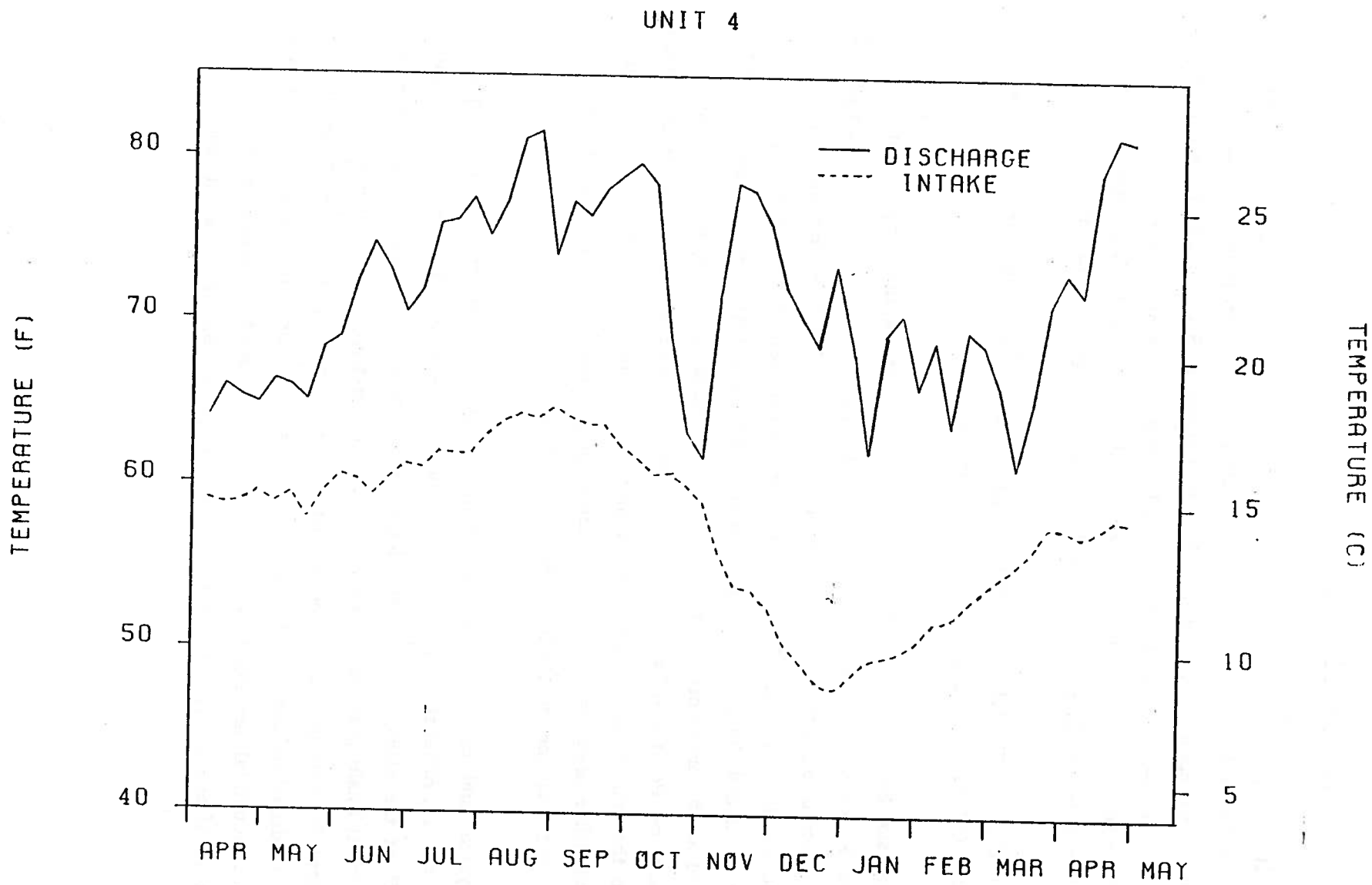


Figure 2-11. Mean weekly intake and discharge temperatures at Unit 4 of the Hunters Point Power Plant, 1978–1979.

2.1.3.3 Projected Future Operation

As a result of the close coordination in operation and electrical generation between the Potrero Power Plant and Hunters Point Power Plant, the projected future operation of these two plants which supply electrical power to San Francisco are considered together. Table 2-6 summarizes the projected capacity factors for each of the units at the Potrero and Hunters Point power plants, with and without the contribution of the Potrero Power Plant's proposed Unit 7, for the years 1982-1990.

2.2 PHYSICAL, CHEMICAL, AND BIOLOGICAL CHARACTERISTICS OF THE SOURCE WATER BODY, SAN FRANCISCO BAY

San Francisco Bay, as discussed in this report, comprises the body of water inland from the Golden Gate as far as Chipps Island at the outlet of the Sacramento and San Joaquin rivers (see Figure 2-1). The southern portion of the Bay, or south Bay, extends from the mouth of Coyote Creek at the southern extremity to a line drawn between Hunters Point and the southern tip of Oakland International Airport. The central Bay is defined as the area north of the south Bay and south of a line drawn between Point San Pedro and Point San Pablo. The northern portion of the Bay includes everything between the central Bay and Chipps Island: San Pablo Bay, Carquinez Strait, Suisun Bay, and other areas with more restricted geographical limits. The Hunters Point Power Plant is on the west side of the central Bay.

The physical and chemical parameters of the central Bay are generally typical of marine waters, reflecting the strong influence of the Pacific Ocean. Natural factors that affect the abundance and species composition of the aquatic community there include tidal flushing and current patterns and fluctuations in salinity and temperature. The morphology of the Bay in the vicinity of the Hunters Point Power Plant has been greatly modified by human activities: dredging, shoreline stabilization, extensive filling, and industrial development (See Section 2.2.2) and the consequent turbidity and deposition of sediment. This habitat and the organisms inhabiting it are described below.

TABLE 2-6 PROJECTED CAPACITY FACTORS[a] (%), 1982-1990, FOR THE POTRERO AND HUNTERS POINT POWER PLANTS WITH AND WITHOUT PROPOSED UNIT 7 OF THE POTRERO POWER PLANT

		Potrero Power Plant Units							Hunters Point Power Plant Units			
	Year	1	2	3	4[b]	5[b]	6[b]	7	1[b]	2	3	4
Without Unit 7	1982	--	--	65.9	0	0	0	--	0	12.5	18.3	72.6
	1983	--	--	65.9	0	0	0	--	0	13.1	20.8	80.7
	1984	--	--	67.3	0	0	0	--	0	13.6	23.5	78.4
	1985	--	--	69.0	0.4	0.4	0.4	--	0.2	15.4	25.3	68.8
	1986	--	--	70.7	0.4	0.4	0.4	--	0.2	17.8	26.9	69.8
	1987	--	--	72.0	0.6	0.6	0.6	--	0.6	20.1	28.4	70.6
	1988	--	--	73.1	1.5	1.5	1.5	--	1.5	22.5	31.1	71.4
	1989	--	--	74.6	1.6	1.6	1.6	--	1.6	24.7	34.7	72.8
	1990	--	--	75.7	2.4	2.4	2.4	--	2.4	27.0	37.6	73.7
With Unit 7	1982	--	--	58.1	0	0	0	53.4	0	0.2	0.2	67.9
	1983	--	--	50.1	0	0	0	70.1	0	0.8	1.4	71.1
	1984	--	--	50.0	0	0	0	77.7	0	0.8	1.6	67.6
	1985	--	--	34.0	0	0	0	60.2	0	1.1	3.6	37.6
	1986	--	--	25.7	0.2	0.2	0.2	61.8	0.1	1.3	3.7	32.4
	1987	--	--	24.5	0.4	0.4	0.4	63.3	0.2	1.4	4.7	31.7
	1988	--	--	25.3	0.6	0.6	0.6	63.9	0.4	4.1	9.5	31.8
	1989	--	--	28.3	0.8	0.8	0.8	65.1	0.9	5.6	11.5	35.8
	1990	--	--	33.4	1.4	1.4	1.4	65.8	1.5	1.0	12.1	37.7

(a) These capacity factors represent unit operating levels calculated from current load forecasts and existing and planned generating capacity. Any of these units may be operated at a higher or lower capacity factor, depending on load growth, other available resources, availability of energy from outside of the PGandE planning area, and the need to serve PGandE load and or the loads of PGandE's neighbors under conditions of major equipment outage. A projected capacity factor of 0 should therefore not be taken to mean that a unit has been retired from service.

(b) Indicates a 52 MWe combustion turbine generating unit. Projected capacity factor was estimated for all 4 units combined, and distributed among the individual units. Actual distribution depends on system demand and unit availability.

Note: (--) indicates unit is decommissioned or not built.

2.2.1 Hydrology

San Francisco Bay has a surface area of 435 mi^2 (1,126 km^2) at mean tide and an estimated volume of 235 billion ft^3 (7.16 billion m^3). Tidal exchange between San Francisco Bay and the Pacific Ocean occurs through the narrow Golden Gate, providing a continuing supply of seawater to the Bay, and thereby maintaining the marine characteristics of the Bay environment. In addition, the Bay receives the surface water runoff from a land area amounting to more than 64,000 mi^2 (165,000 km^2) (SWRCB 1975), over 90 percent of which is the Sacramento - San Joaquin drainage basin. Freshwater inflow and tidal exchange are the two major factors influencing current and circulation patterns and water quality and hence the biological characteristics of San Francisco Bay.

Tides in the Bay are nearly semidiurnal. The tidal prism amounts to approximately 56 billion ft^3 (1.59 billion m^3), about 24 percent of the Bay's volume (Conomos and Peterson 1976). The tidal flow brings in approximately 24 billion ft^3 (0.68 billion m^3) of new ocean water (ocean water which has not previously entered the Bay) during each 25-hour tidal cycle, providing an important flushing mechanism for the Bay, even during periods of low freshwater outflow (Brown and Caldwell 1971). The tidal flow provides a transport mechanism for planktonic organisms passing into and out of the Bay.

The predominant currents in the central portion of the Bay move in a southeasterly direction during flood tide; the reverse circulation pattern occurs during ebb tide (Figures 2-12 and 2-13). These tidal currents and the pattern of circulation influence the distribution of organisms within the Bay.

Freshwater inflow to San Francisco Bay affects circulation patterns and modifies the chemical characteristics of the Bay. Inflow from the Sacramento and San Joaquin rivers accounts for more than 90 percent of the freshwater input. The Napa River, Alameda Creek, Coyote Creek, and several other small streams account for the remaining inflow (SWRCB 1975). Inflow varies on a seasonal basis. The governing factors are the precipitation cycles and the release of water from impoundments that have been constructed on a majority of the rivers that drain into the Bay. Outflow from the Sacramento and San Joaquin rivers (Figure 2-14) is generally greatest during the winter (January-February) and least during the summer (July-August). Freshwater

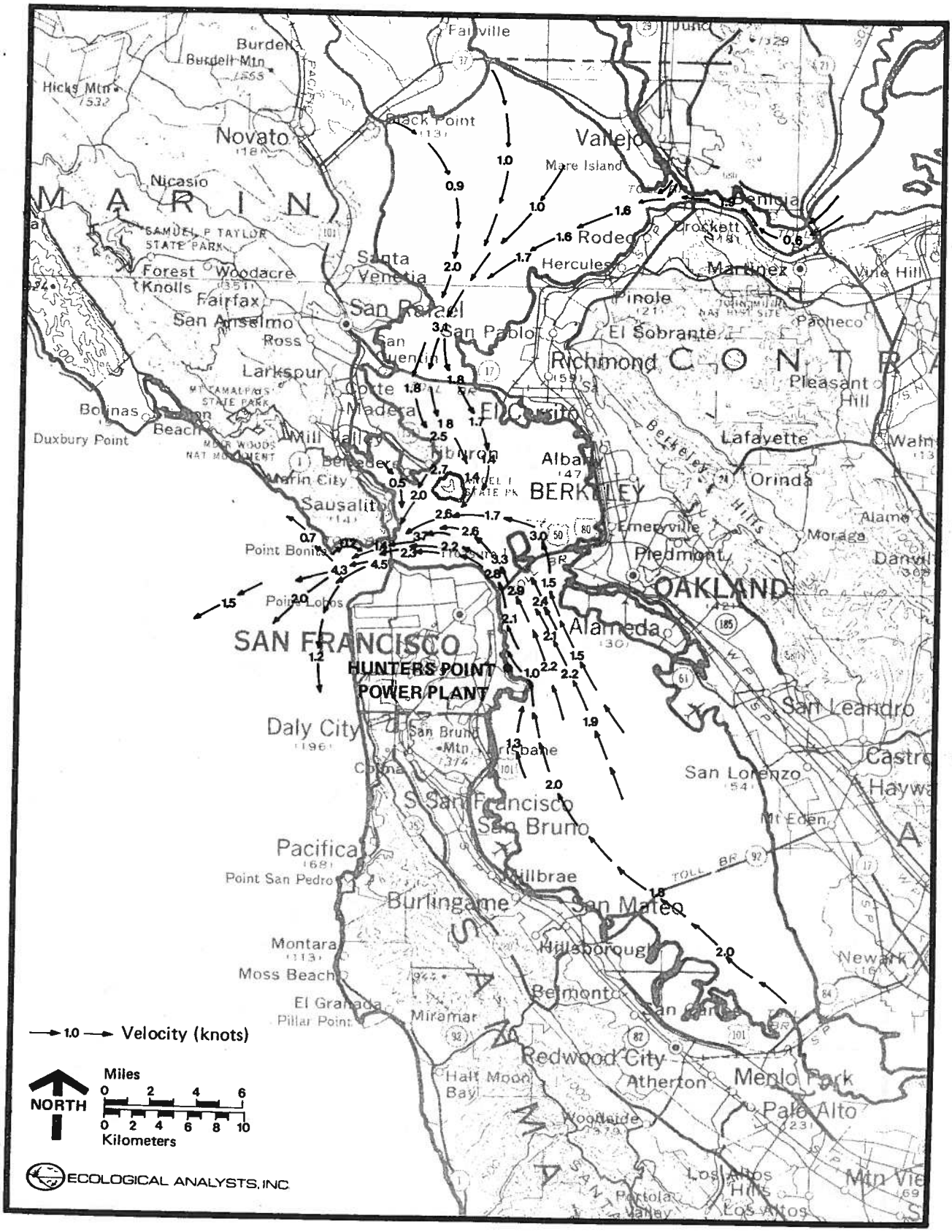


Figure 2-12. Tidal currents in and near San Francisco Bay at maximum ebb at Golden Gate. (From SWRCB 1975.)

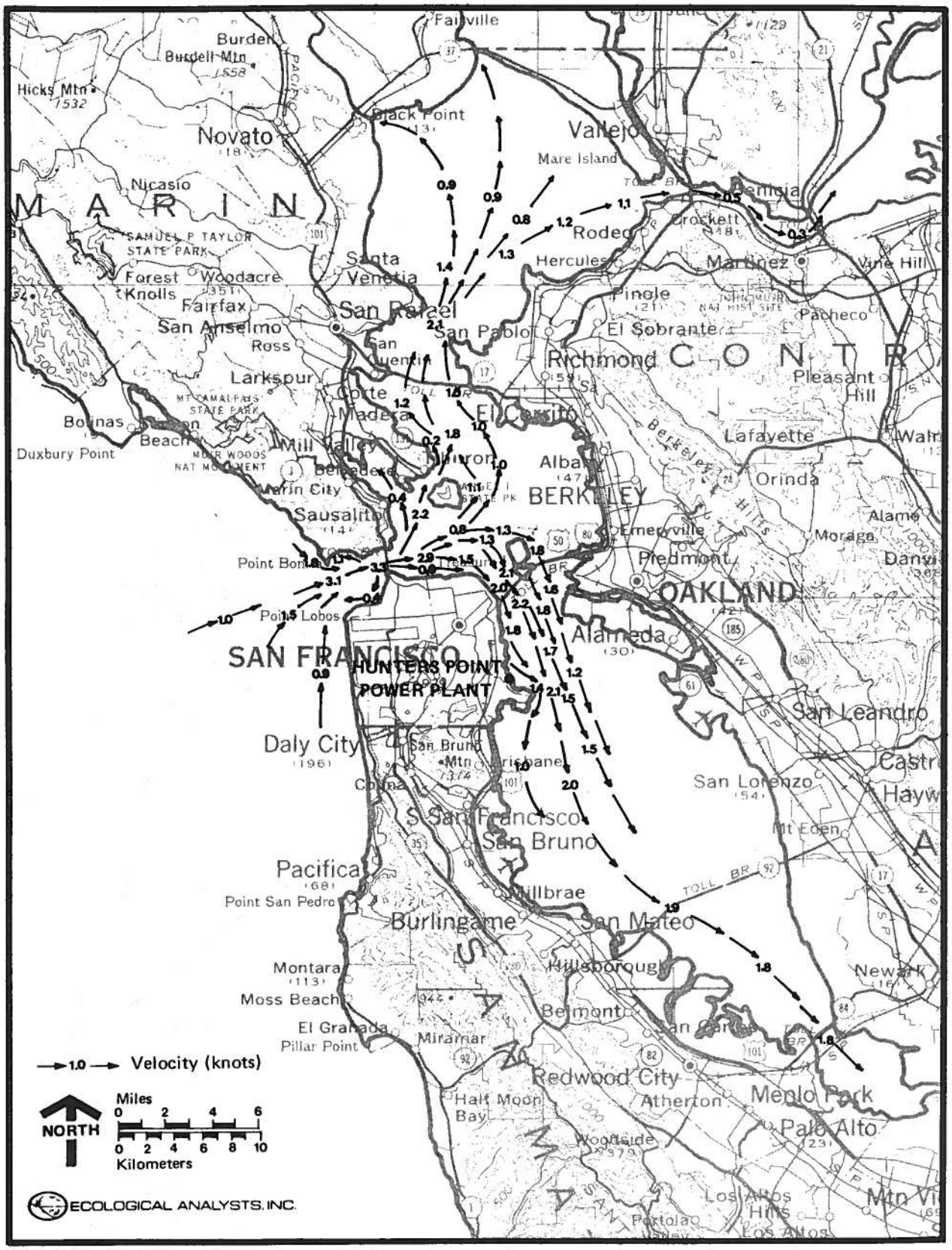


Figure 2-13. Tidal currents in and near San Francisco Bay at maximum flood at Golden Gate. (From SWRCB 1975.)

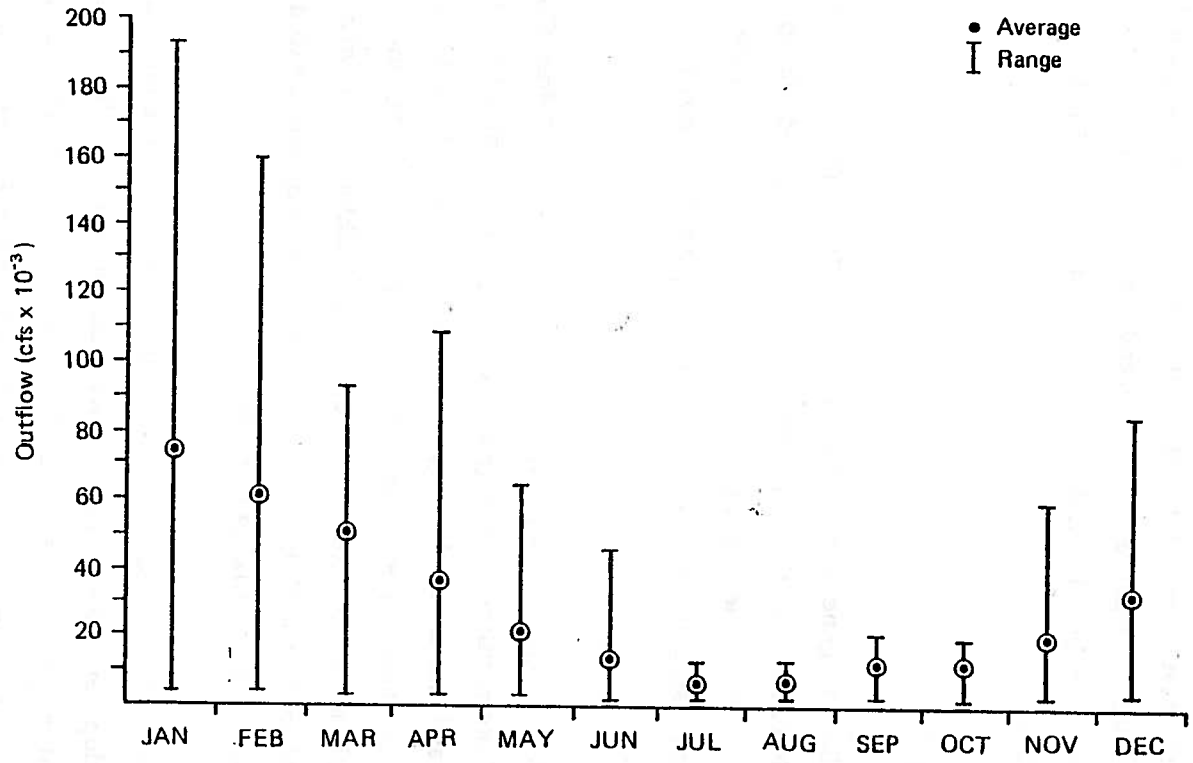


Figure 2-14. Ten-year monthly average and range of Delta outflow estimated at Chipps Island, 1969–1978. (Data from Calif. Dep. Water Resour., unpublished.)

inflow is one of the primary factors influencing the seasonal patterns of salinity in the Bay.

The freshwater inflow contains significant amounts of nutrients and dissolved minerals and transports a large volume of sediment from the drainage area. When these are mixed with the relatively nutrient-deficient seawater, a highly productive water mass is created. Sediments dispersed in the mixed water column settle out in the shallow areas of the Bay, creating rich habitat and continually filling and changing the shape of the Bay's bottom.

2.2.2 Morphology

San Francisco Bay is generally shallow. Maximum depths are found in the narrow outlet channel between the Golden Gate and Alcatraz Island where high-velocity currents continually scour the bottom. The shallow nearshore waters typically exhibit different species assemblages than the deeper, rapidly moving water of the mid-channel.

Development of the San Francisco Bay area as an important West Coast industrial and shipping center has resulted in changes in the Bay. The demand for land on the waterfront for piers and industrial development has resulted in a significant amount of land filling along the shore, particularly in the portion of the Bay south of the San Francisco - Oakland Bay Bridge. The erection of bulkheads and wharves and the stabilization of the shoreline with broken concrete and riprap has created a new habitat for fish, crustaceans, and colonizing organisms.

The Hunters Point Power Plant is located in an area where land filling and subsequent industrial development have dramatically changed the shoreline of the Bay. Since the turn of the century virtually all of India Basin north of Hunters Point has been filled. The progress of this shoreline expansion is depicted in Figure 2-15.

In 1930, when the original Unit 1 was first put into service, the plant site was actually a point on the shore of India Basin. The cooling water intake and discharge, located within 200 ft of each other, were separated by a narrow spit which provided isolation of the two structures sufficient to prevent recirculation of heated water from the discharge back to the intake.

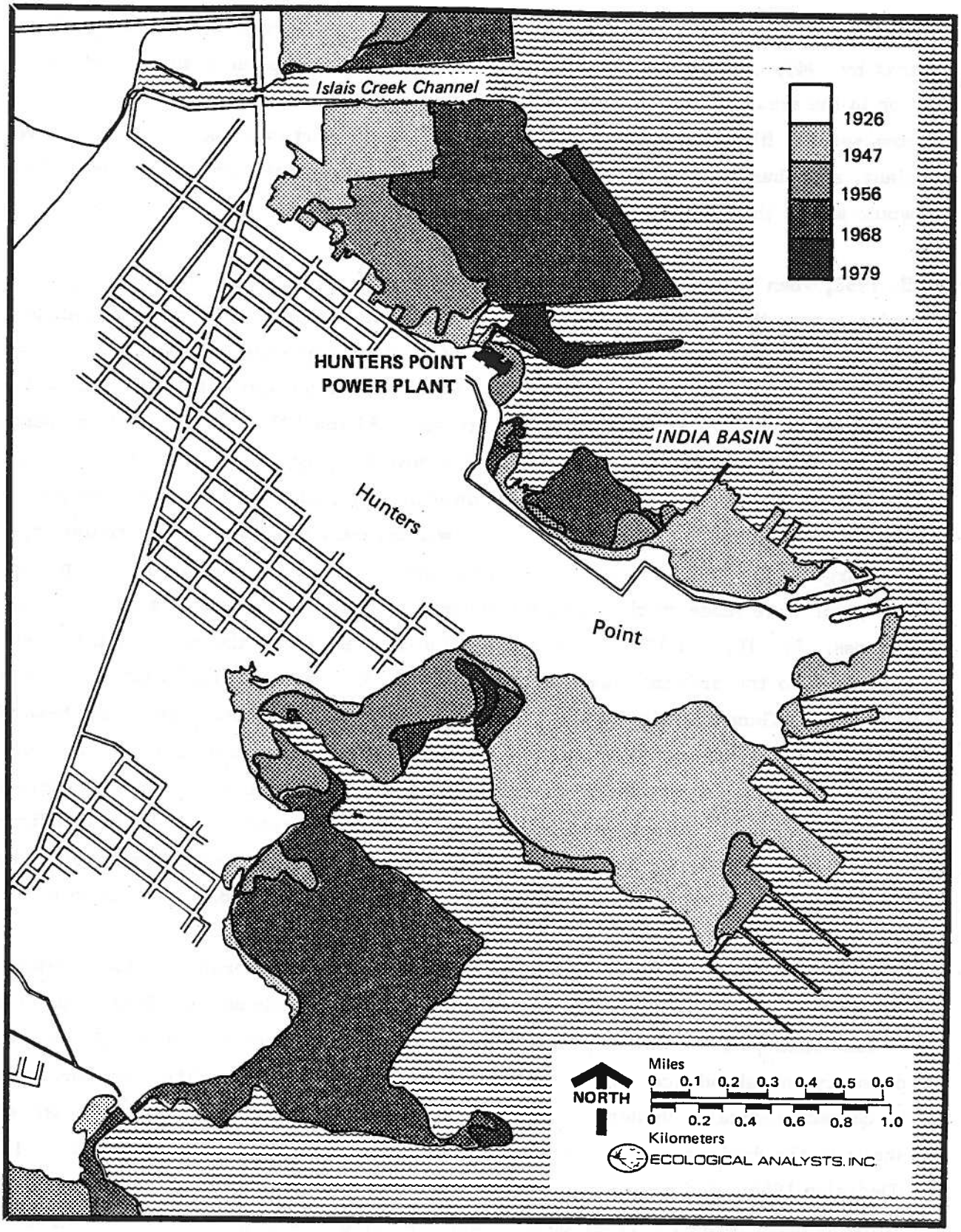


Figure 2-15. Evolution of the San Francisco shoreline near the Hunters Point Power Plant, 1926–1979. (Based on various USGS maps.)

Throughout the 1930s and 1940s, industrial interests continued filling in India Basin, so that by 1949, when Units 2 and 3 were added to the power plant, a significant reduction in the area of India Basin to the north of the plant had occurred. Up to this time, however, no filling operation had encroached on the northwest border of the power plant, and thus no major changes in nearshore current patterns had occurred that would affect the dispersion of the plant's thermal effluent.

By 1958, when Unit 4 began operation, filling of the shore zone northwest of the plant had extended the shoreline approximately 100 m (330 ft) into the Bay and eliminated most of what once was India Basin. Even after this change the plant intake, although somewhat more channelized than before, withdrew cooling water from the Bay without significant levels of recirculation. Between 1958 and 1970, however, filling operations associated with the construction of a new shipping terminal at Hunters Point extended the land mass in an easterly direction so that open access of the plant's intakes to the ambient waters of the Bay was severely obstructed. Recirculation of discharge water back through the plant became a serious problem during this period. Attempts were made to channel the discharge flow away from the intake, with little success. In 1971 and 1972 water temperatures measured at the plant's intake were compared to the ambient water temperature of San Francisco Bay in the vicinity of the plant (PGandE 1973a, b). Monthly maximum intake temperatures were 8-22 F (4.4-12.2 C) higher than the monthly maximum ambient temperatures during the study period. Recirculation frequently reduced operating efficiency of the generating units and occasionally required curtailment in unit operation. In 1973 modifications were made in the intake area which eliminated the recirculation problem by providing for cooling water to be drawn more directly from the Bay (see Figure 2-5).

Low current velocities in the intake basin and in India Basin permit continued deposition of fine silts and sand in the area. This results in a fairly uniform benthic habitat in the vicinity of the power plant which influences the characteristics (e.g., species diversity and abundance) of the benthic community in this area. The nearshore area is characteristically shallow, with a mud/silt bottom changing to rock and broken shells in the dredged area in front of the plant's cooling water intakes (Figure 2-16) (Dederian 1966). Sediment types in the vicinity of the Hunters Point Power Plant have probably not changed a great deal in spite of all of the filling that has been done since 1960.

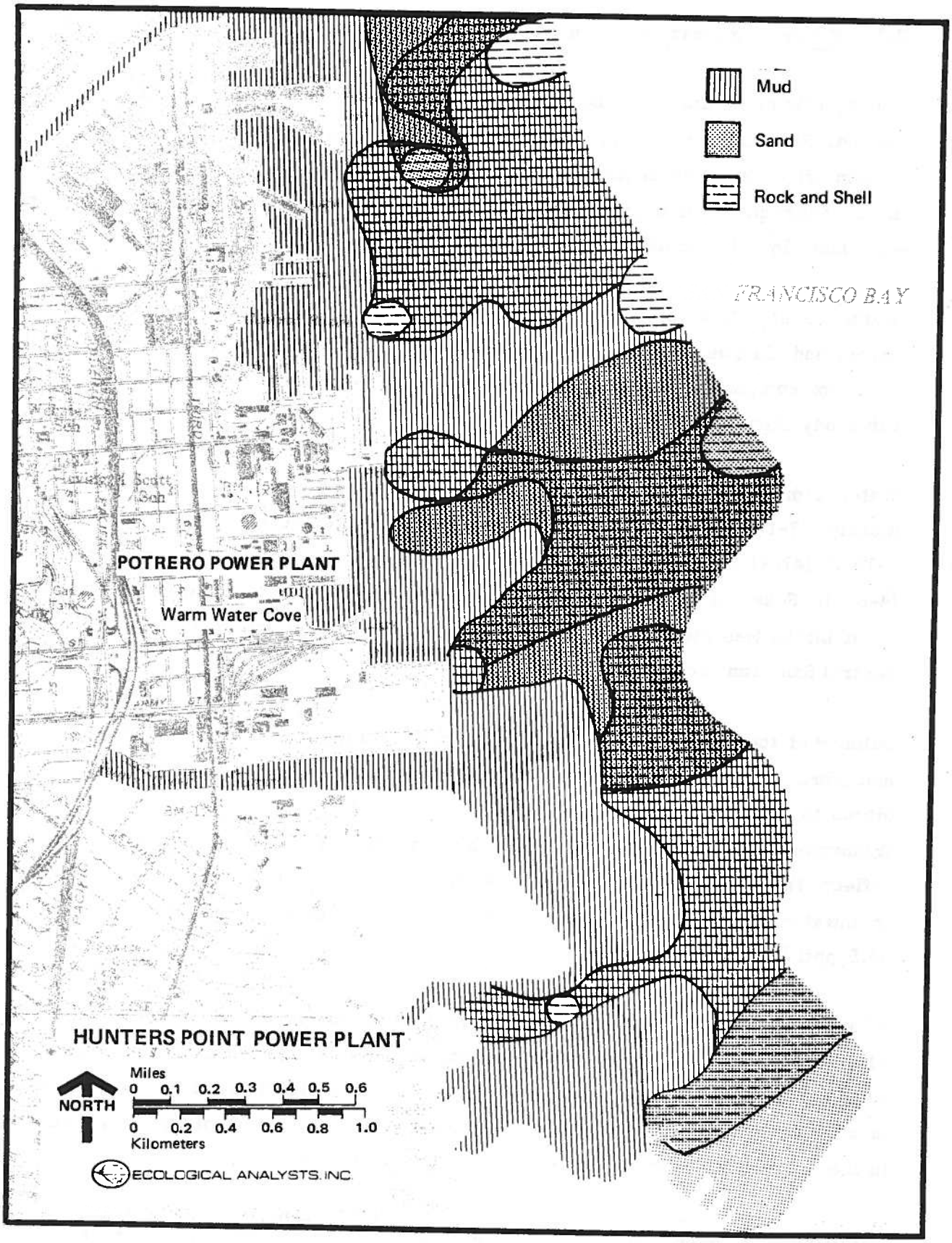


Figure 2-16. Substrate near the Hunters Point Power Plant, 1961–1962. (From Dederian 1966.)

2.2.3 Water Temperature, Salinity, and Dissolved Oxygen

The aquatic environment in the vicinity of the Hunters Point Power Plant is typically marine. Seasonal changes in water temperature, salinity, and dissolved oxygen concentration affect the species composition and abundance of the aquatic community in the area. Water quality in the vicinity of the plant is influenced by freshwater inflow, and even more by tidal exchange with the ocean (Section 2.2.1).

Water quality data for San Francisco Bay are available (Storrs et al. 1965, 1966; Brown and Caldwell 1971; Liu et al. 1975; City and County of San Francisco 1976, 1977) for comparison with observations made at the Hunters Point Power Plant during this study (Appendix A.2).

Water temperatures at the plant were highest during August-September, approximately 17-19 C (62-66 F), and lowest during December-January, approximately 8-10 C (47-51 F) (Table A-5). The daily temperature range was typically 2-3 C (4-6 F). Seasonal trends in water temperature observed at the Hunters Point Power Plant intake (see Figure 2-10) are similar to those reported by Storrs et al. (1965) for central San Francisco Bay.

Salinity at the Hunters Point Power Plant Unit 4 intake measured between May 1978 and April 1979 averaged 27.7 ppt. Mean monthly salinity ranged from 22.9 ppt in March to 32.0 ppt in August. Salinities were lowest in winter, during periods of high freshwater inflow (Table A-3). The high average salinity for August, 32.0 ppt, reflects the influence of tidal exchange with the Pacific Ocean during a period of low freshwater inflow (typical salinities in the Gulf of the Farallones range from 32 to 33.5 ppt) (Brown and Caldwell 1971).

PGandE (1973a) reported salinities averaging 24-26 ppt in the winter months and 31-32 ppt during midsummer in the vicinity of Hunters Point. Similar seasonal trends were reported by Storrs et al. (1965). Although vertical salinity gradients were commonly observed by Storrs et al. (1966) in the more northern areas of the Bay, gradients in the central Bay were insignificant—less than 3 ppt variation.

Dissolved oxygen measured at the Unit 4 intake between May 1978 and April 1979 averaged 7.5 mg/liter. Mean monthly dissolved oxygen concentrations ranged from

6.5 mg/liter in September to 8.2 mg/liter in March (Table A-4). The highest dissolved oxygen concentrations generally occurred in late winter and spring (between January and May); the lowest concentrations in late summer and early fall. A similar seasonal trend was reported by Storrs et al. (1965). Saturation generally varied between 80 and 95 percent. Dissolved oxygen does not appear to be a limiting factor for aquatic populations inhabiting the vicinity of the Hunters Point Power Plant.

2.2.4 Aquatic Habitats

The portion of San Francisco Bay from which the Hunters Point Power Plant withdraws cooling water is characteristic of a marine inshore environment. The following sections briefly describe the major aquatic habitats and the biological community of San Francisco Bay, with emphasis on organisms inhabiting waters near the Hunters Point Power Plant.

The plant site and adjacent areas of San Francisco Bay include several marine biological habitats. Nearshore habitats include the intertidal and subtidal zones (or benthic habitats), wharves and pilings. Offshore habitats include the open water (pelagic) zone and subtidal (benthic) zone.

2.2.4.1 Intertidal Zone

This zone comprises the area that is submerged at high tide and exposed at the lowest tide. Shoreline development has modified this habitat in the immediate vicinity of the Hunters Point Power Plant and contiguous areas. The concrete rubble and metal debris associated with filling and dumping are common in this area. The intertidal area near the intakes is primarily composed of mud substrates which have been deposited over the coarse fill as a result of low current velocities and reduced turbulence. The intertidal area in the vicinity of the Units 2 and 3 and Unit 4 discharge structures is composed primarily of mud and rock substrate.

The mud substrates in the area provide a limited amount of habitat for benthic organisms, particularly polychaete worms, crustaceans (mainly amphipods), and bivalve molluscs. Rocky surfaces and larger outcroppings of metal debris provide areas of attachment for sessile organisms such as barnacles and algae. Various species of shore

crabs also inhabit the rocky areas. Fish commonly associated with the intertidal area include sculpins, surfperches, and flatfishes.

2.2.4.2 Subtidal Zone

The subtidal zone extends offshore from the lowest area exposed by the tide. In this zone, water flow and the depth and texture of the substrate are important factors influencing the species, size, and distribution of benthic infauna and bottom dwellers.

Benthic infauna and epibenthic invertebrates in the vicinity of the site have been surveyed by several investigators (Dederian 1966; PGandE 1973a, b; Liu et al. 1975; Brown and Caldwell 1975). Dominant benthic groups reported in these surveys include polychaete worms, crustaceans, and bivalve molluscs. Polychaete worms were generally the most diverse taxon, amphipods were the dominant crustacean, and several clams were widely distributed. Bay shrimp, represented by the genus Crangon (= Crago) is a common macroinvertebrate occupying this area (Brown and Caldwell 1975). The subtidal area also provides habitat for a variety of fishes. Some of the more common fishes found in shallow areas include surfperches, flounders, herrings, striped bass, silversides, sculpins, sharks, and rays (PGandE 1973a; Brown and Caldwell 1975).

Much of the southern San Francisco waterfront consists of wharves on pilings. Wharves provide shade and shelter to fish and to bottom-dwelling invertebrates, and untreated pilings provide additional cover and habitat for mussels, barnacles, hydroids, spider crabs, tunicates, and burrowing worms. These organisms provide an additional food source for resident fishes (e.g., rockfish).

2.2.4.3 Open Water (Pelagic) Zone

The offshore open water zone provides habitat for a variety of planktonic and free-swimming (nektonic) organisms. Plankton, consisting of phytoplankton (plants) and zooplankton (animals), floats or drifts passively with the prevailing current. Nekton is composed of large, motile fish, crustaceans, and marine mammals.

The phytoplankton of San Francisco Bay undergoes an annual cycle of increases and decreases in standing crop. In the central Bay, the highest concentration of phytoplankton are generally observed between March and May and the lowest in late fall

(Storrs et al. 1966; Skinner 1972). Diatoms are the dominant group throughout the year.

Zooplankton may be further divided into holoplankton and meroplankton. Holoplankton is composed of copepods, ctenophores, and other groups which remain floating throughout their life cycle. Meroplankton are those forms, such as eggs and larval forms of fish (ichthyoplankton) or benthic organisms, that are temporary members of the plankton community but eventually develop into benthic or nektonic forms. In San Francisco Bay, peaks in zooplankton populations often follow peaks in phytoplankton populations (Storrs et al. 1965). The most common zooplankters collected near the Hunters Point Power Plant are copepod adults and nauplii, polychaete larvae, and barnacle larvae (PGandE 1973a).

The open-water areas of San Francisco Bay provide habitat for a variety of marine and anadromous fish species. Marine species are distributed throughout south and central San Francisco Bay and San Pablo Bay. Reduced freshwater flows allow saline water to move upstream in summer, and many marine fish enter Carquinez Strait and Suisun Bay at that time. Important fish groups include sharks, skates and rays, silversides, herrings, surfperches, sculpins, flounders, sturgeon, steelhead trout, salmon, striped bass, and American shad (Harvey et al. 1977). Striped bass is the only anadromous fish that spends any significant time in the vicinity of the Hunters Point Power Plant (Aplin 1967; Wooster 1971).

2.2.5 Aquatic Populations

A diverse assemblage of marine organisms inhabits San Francisco Bay. This section provides a brief summary of previous investigations of the phytoplankton, zooplankton, benthos, and fish populations of San Francisco Bay in the vicinity of the Hunters Point Power Plant and discusses the distribution and abundance of major fish and invertebrate species.

2.2.5.1 Phytoplankton

Phytoplankton are a diverse flora and are important primary producers. In San Francisco Bay, the principal phytoplankton groups are marine neritic (inhabiting inshore areas) diatoms (Bacillariophyta), including the genera Asterionella, Skeletonema,

Thalassiosira, Coscinodiscus, and Chaetoceros. Diatoms are most abundant during the spring at densities above 100,000 cells per liter (Storrs et al. 1966).

The phytoplankton near the plant are typical of populations found throughout San Francisco Bay in general and are dominated by the genus Coscinodiscus, which is common in marine neritic habitats along the Pacific coast (Treber 1973).

2.2.5.2 Zooplankton--Holoplankton and Meroplankton

The predominant holoplankton found in the Bay are copepod crustaceans of the genus Acartia (Storrs et al. 1965; Icanberry and Adams 1974). These planktonic copepods are filter feeders, feeding primarily on phytoplankton. Other zooplankton include microzooplankton (principally protozoans), jellyfish (Cnidaria), and arrow worms (Chaetognatha). Barnacle larvae (nauplii) are the most abundant meroplankton in the Bay (Storrs et al. 1965). Other meroplankton include the larvae of shrimp, crabs, clams, and fish.

A list of zooplankton that are common in San Francisco Bay is presented in Table 2-7.

2.2.5.3 Benthic and Epibenthic Invertebrates

The benthic and epibenthic communities of marine inshore waters include a diverse group of marine invertebrates. These include the gastropods (snails), echinoderms (sea urchins and starfish), polychaetes (sea worms), bivalves (mussels and clams), and crustaceans (barnacles, isopods, amphipods, crabs, and shrimps). The most abundant benthic groups in San Francisco Bay are the bivalves and polychaetes (Dederian 1966; PGandE 1973a, b; Liu et al. 1975). The bivalves include Gemma gemma (Transenella tantilla?), Macoma nasuta, and Macoma inquinata. The dominant polychaetes include Tharyx parvus, Streblospio benedicti, Exogone lourei, and Mediomastus californiensis.

Crustaceans dominate the epibenthic fauna in San Francisco Bay (Dederian 1966; PGandE 1973a, b; Liu et al. 1975; Brown and Caldwell 1975). The amphipods including Corophium spp., Ampelisca milleri, and Photis brevipes are the most abundant. Other common crustaceans include the crabs (Cancridae, Majidae, Xanthidae, and Pinnotheridae) and shrimp-like forms (Crangon spp., Palaemon macrodactylus, Neomysis

TABLE 2-7 ZOOPLANKTON COMMON TO SAN FRANCISCO BAY IN THE AREA OF THE HUNTERS POINT POWER PLANT-

PHYLUM
Sub-phylum
Class
Subclass
Division
Order
Sub-order
Section
Tribe
Family
Genus species

CNIDARIA
Hydrozoa (hydroids)
Tubularia crocea
Polyorchis penicillatus
Polyorchis sp.
Scyphozoa (jellyfish)

ARTHROPODA
Mandibulata
Crustacea
Branchiopoda
Cladocera
Evadne nordmanni
Podon polyphemoides
Copepoda
Calanoida
Acartia clausi
Acartia tonsa
Aetideus pacificus
Calanus pacificus
Candacia bipinnata
Centropages abdominalis
Clausocalanus acruicornis
Ctenocalanus nanus
Epilabidocera longipedata
Eurytemora asymmetrica
Eurytemora affinis (=*hirundoides*)
Labidocera trispinosa
Lucicutia flavicornis
Metrida pacifica
Paracalanus parvus
Pluromamma borealis
Pseudocalanus elongatus

Sources: Ecological Analysts, unpublished data; Caskey 1976.

TABLE 2-7 (CONT.)

PHYLUM
Sub-phylum
Class
Subclass
Division
Order
Sub-order
Section
Tribe
Family
Genus species

Pseudodiaptomus euryhalinus
Rhincalanus nasutus
Tortanus discaudatus
Cyclopoida
Oithona plumifera
Harpacticoida
Corycaeus anglicus
Cirripedia (nauplius, cypris) (barnacles)
Malacostraca
Peracarida
Mysidacea
Acanthomysis macropsis
Archaeomysis grebnitzkii
Neomysis kadiakensis
Neomysis mercedis
Eucarida
Euphausiacea (Calyptopis, furcilia)
Decapoda
Natantia
Caridea (shrimps)
Hippolytidae (larva)
Alphaeidae
Betaeus sp. (larva)
Crangonidae (larva)
Palaemonidae
Palaemon macrodactylus (larva)
Brachyura (crabs)
Cancridae (*Cancer* crabs)
Cancer antennarius (zoea, megalops)
Cancer gracilis (zoea, megalops)
Cancer productus (zoea)
Grapsidae
Hemigrapsus oregonensis (zoea, megalops)
Pachygrapsus crassipes (zoea)
Majidae (zoea, megalops)
Pinnotheridae (zoea, megalops)
Pinnixa sp. (megalops)
Xanthidae (zoea)

TABLE 2-7 (CONT.)

PHYLUM
Sub-phylum
Class
Subclass
Division
Order
Sub-order
Section
Tribe
Family
Genus species

Anomura
Callianassidae
Callianassa sp. (larva)
Upogebia pugettensis (larva)
Paguridae
Pagurus sp. (zoea, megalops)

CHAETOGNATHA (arrow-worms)
Sagitta sp.
Sagitta euneritica

spp., Acanthomysis macropsis, and Upogebia pugettensis). A list of benthic and epibenthic invertebrates common to the waters of San Francisco Bay in the area of the Hunters Point Power Plant is presented in Table 2-8.

Several invertebrate species found in the Bay are important commercially and recreationally. The Dungeness crab fishery is one of the most important in the Bay area. Originally these crabs were taken in San Francisco Bay, but the fishery moved outside the Bay before 1900 (Skinner 1962). At present, very few Dungeness crabs of legal size are found in the Bay, and total catches in the area have declined significantly since the early 1960s (Frey 1971). There is no commercial crab fishery in the Bay now.

Two species of shrimp, Crangon nigricauda and C. franciscorum, are commercially important in the Bay area. During the early 1930s one of the main shrimping grounds for San Francisco Bay was located northeast of Hunters Point (Bonnot 1932). Shrimp landings for the entire Bay have declined steadily since 1935, and in the early 1960s shrimping was virtually eliminated. In 1965 a new bait fishery was developed, and it continues today in northern sections of the Bay. At present, netting is done mostly in San Pablo Bay and, to a lesser extent, in the central area of the Bay. The commercial fishery is limited by demand, and these shrimps are used almost exclusively as bait. No commercial shrimp fishery exists in the vicinity of the plant.

Two edible clam species occur in the intertidal zone of San Francisco Bay in sufficient numbers to be considered potentially harvestable in a sport fishery (Harvey et al. 1977; SWRCB 1975). These are the soft-shell clam (Mya arenaria) and the Japanese littleneck clam (Tapes japonica). Wooster (1968a) estimated that there were approximately 16 million adult soft-shell clams and approximately 5.3 million Japanese littleneck clams in south and central San Francisco Bay and San Pablo Bay. Other clams found in San Francisco Bay include the gaper clam (Tresus nuttalli), the native littleneck clam (Protothaca staminea), the bentnose clam (Macoma nasuta), the Baltic clam (Macoma balthica), the basket cockle (Clinocardium nuttalli), and the Washington clam (Saxidomus nuttalli). Most of these species are either too small or occur in numbers too low to represent potentially harvestable resources (Harvey et al. 1977).

Three species of oysters, including the eastern oyster (Crassostrea virginica), Pacific oyster (C. gigas), and the native oyster (Ostrea lurida), were historically harvested

TABLE 2-8 BENTHIC, EPIBENTHIC, AND MACROINVERTEBRATE ORGANISMS COMMON TO SAN FRANCISCO BAY IN THE AREA OF THE HUNTERS POINT POWER PLANT

PHYLUM
Sub-phylum
Class
Subclass
Division
Order
Sub-order
Section
Tribe
Family
Genus species

CNIDARIA
Hydrozoa (hydroids)
Aglaophenia struthionides
Plumularia (*lagenifera*)[a]
Anthozoa (anemones)
Metridum senile
Diadumene leucolena
Halcampa sp.
Stylatula elongata

PLATYHELMINTHES
Polycladida

NEMERTEA
Cerebratulus sp.
Tubulanus pellucidus

ANNELIDA (segmented worms)
Polychaeta
Halosydna brevisetosa
Harmothöe impricata
Lepidonotus (*caelorus*)[a]
Pholoe tuberculata
Anaitides williamsi
Eteone californica
Eteone lighti
Oxydromus arenicolus globrus[a]
Kefersteinia cirrata[b]

(a) Dederian 1966 (possibly an incorrect species name).
(b) Dederian 1966 (possibly an incorrect identification).
(c) Possibly *Gemma gemma* (S. Marelli, Calif. Acad. Sci., 1979, personal communication).

Sources: Dederian 1966; Ecological Analysts, unpublished data.

TABLE 2-8 (CONT.)

PHYLUM
Sub-phylum
Class
Subclass
Division
Order
Sub-order
Section
Tribe
Family
Genus species

Polychaeta (cont.)

Ancistrosyllis bassi[b]
Exogone spp.
Nephtys caecoides
Nephtys cornuta franciscana
Nephtys parva
Platynereis bicanaliculata
Glycera americana
Glycinde polygnatha
Diopatra (tridentata)[a]
Driloneris falcata
Dorvillea articulata
Haploscoloplos elongatus
Naineris dendritica
Polydora brachycephala
Polydora ligni
Spiophanes (cirrata)[a]
Laonice cirrata
Streblospio benedicti
Disoma franciscanum
Cirratulus cirratus
Cirratulus (spirabrancha)[a]
Tharyx parvus
Pherusa papillata
Armanida bioculata
Capitella capitata
Heteromastus filobranchus
(Maldane sarsi)[b]
Phragmatopoma californica
Sabellaria gracilis
Pectinaria californiensis
Amphicteis (scaphobranchiata)[a]

Clitellata
Oligochaeta

SIPUNCULA

Golfingia (eremita californica)[a]
Golfingia (pugettensis)[a]
Phascolosoma agassizii

TABLE 2-8 (CONT.)

PHYLUM
Sub-phylum
Class
Subclass
Division
Order
Sub-order
Section
Tribe
Family
Genus species

MOLLUSCA
Gastropoda (snails, sea slugs)
Prosobranchia
Crepidula nummaria
Crepidula convexa
Granulina margaritula
Lacuna marmorata
Littorina scutulata
Margarites spp.
Mitrella carinata
Nassarius mendicus
Opisthobranchia
Archidoris montereyensis
Hermissenda crassicornis
Okenia plana
Rictaxis punctocaelatus
Tenellia pallida
Bivalvia (clams)
Clinocardium nuttalli
Gemma gemma
Lyonsia californica
Macoma inquinata
Macoma nasuta
Macoma yoldiformis
Mactra californica
Musculus senhousia
Mya arenaria
Mytilus edulis
Ostrea lurida
Petricola carditoides
Protothaca staminea
Solen sicarius
Sphenia pholadidea[b]
Tapes japonica
Transenella tantilla[c]
Zirfaea pilsbryi

TABLE 2-8 (CONT.)

PHYLUM
Sub-phylum
Class
Subclass
Division
Order
Sub-order
Section
Tribe
Family
Genus species

ARTHROPODA
Mandibulata
Crustacea
Ostracoda
Cirripedia (barnacles)
Balanus crenatus
Pollicipes polymerus
Malacostraca
Leptostraca
Nebalia pugettensis
Peracarida
Mysidacea
Acanthomysis macropsis
Archaeomysis grebnitzkii
Neomysis kadiakensis
Neomysis mercedis
Cumacea
Cumella vulgaris
Cyclaspis sp.
Diastylopsis sp.
Diastylopsis dawsoni
Eudorella pacifica
Lamprops quadriplicata
Tanaidacea
Anatanais normani
Leptochelia dubia
Tanais vanis
Isopoda
Epicaridea
Valvifera
Synidotea marmorata
Flabellifera
Gnorimosphaeroma oregonensis
Limnoria quadripunctata
Limnoria tripunctata
Lironeca californica
Lironeca vulgaris

TABLE 2-8 (CONT.)

PHYLUM
Sub-phylum
Class
Subclass
Division
Order
Sub-order
Section
Tribe
Family
Genus species

Asellota
Ianiropsis analoga
Amphipoda
Gammaridea
Ampelisca milleri
Ampithoe sp.
Anisogammarus confervicolus
Chelura terebrans
Corophium acherusicum
Corophium baconi
Corophium insidiosum
Corophium stimpsoni
Elasmopus antennatus
Ericthonius hunteri
Grandidierella japonica
Hyale sp.
Hyale plumulosa
Jassa falcata
Melita dentata
Metopa spp.
Microdeutopis spp.
Paraphoxus obtusidens
Parapleustes pugettensis
Photis brevipes
Podocerus spongicolus
Stenothoe valida
Tiron biocellata
Caprellidea (skeleton shrimp)
Caprella californica
Caprella equilibra
Caprella laeviuscula
Caprella mutica
Caprella verrucosa
Perotripus brevis
Eucarida
Decapoda
Natantia
Caridea (shrimps)

TABLE 2-8 (CONT.)

PHYLUM
Sub-phylum
Class
Subclass
Division
Order
Sub-order
Section
Tribe
Family
Genus species

Peneidae
Peneus californiensis
Palaemonidae
Palaemon macrodactylus
Hippolytidae
Heptacarpus brevirostris
Heptacarpus cristatus
Heptacarpus palpator
Heptacarpus paludicola
Alphaeidae
Betaeus harrimani
Crangonidae
Crangon franciscorum
Crangon nigricauda
Crangon nigromaculata
Lissocrangon stylirostris
Reptantia
Brachyura (crabs)
Majidae
Loxorhynchus crispatus
Pugettia producta
Pyromaia tuberculata
Cancridae (*Cancer* crabs)
Cancer antennarius
Cancer anthonyi
Cancer gracilis
Cancer magister
Cancer productus
Xanthidae
Lophopanopeus bellus
Pinnotheridae
Pinnixa franciscana
Pinnixa schmitti
Pinnixa occidentalis
Grapsidae
Hemigrapsus oregonenesis
Pachygrapsus crassipes

TABLE 2-8 (CONT.)

PHYLUM
Sub-phylum
Class
Subclass
Division
Order
Sub-order
Section
Tribe
Family
Genus species

Anomura
Callianassidae
Callianassa californiensis
Upogebia pugettensis
Paguridae
Pagurus beringanus
Pagurus hirsutiusculus
Porcellanidae
Pachycheles pubescens
Pachycheles rudis
Hippidae
Emerita analoga
Chelicerata
Pycnogonida
Pycnogonum rickettsi

ECHINODERMATA
Ophiuroidea (brittle stars)
Amphiodia occidentalis
Amphiodia (periercta)[a]
Amphipholis pugetana
Asteroidea (sea stars)
Pisaster brevispinus

commercially in San Francisco Bay. Ribbed horsemussel (Ischadium demissum) are common at the southern end of the Bay, and the bay mussel (Mytilus edulis) is common throughout the Bay (SWRCB 1975).

No significant populations of potentially harvestable shellfish exist in the vicinity of the Hunters Point Power Plant (SWRCB 1975; Harvey et al. 1977; Wooster 1968b).

2.2.5.4 Fish

The San Francisco Bay and Delta provide habitat for a variety of estuarine, marine, and anadromous fishes which use the Bay for a feeding, spawning, and nursery area and as a migratory pathway. Detailed reviews of these resources are found in works by Skinner (1962), Aplin (1967), U.S. Fish and Wildlife Service (1970), Newcombe and Mason (1972), California Department of Fish and Game (1968), and Tetra Tech, Inc. (1976). A comprehensive list of fish collected in the above studies and in the entrainment (Chapter 3) and impingement (Chapter 4) collections from this study is presented in Table 2-9. The table also serves to equate species names with widely used common names, those recognized by the California Department of Fish and Game (Miller and Lea 1972, 1976) in the case of marine fishes; otherwise following Bailey et al. (1970). Common names are used for fish in the text of this report rather than species names.

Anadromous fishes are considered the most important group of fishes in the Bay system (SWRCB 1975). The most important species include striped bass, king salmon, steelhead trout, green sturgeon, white sturgeon, and American shad. They range from salt water to fresh water, and all migrate into or through the Sacramento - San Joaquin Delta system to spawn.

Salmon, steelhead, and American shad reside in the Bay only for short periods during their downstream migrations as young and their upstream spawning migrations as adults. Mature and immature white sturgeon may be found in San Pablo and Suisun bays through most of the year and in a larger portion of the San Francisco Bay system during their upstream spawning migrations. Green sturgeon spend a greater proportion of their life cycle in the ocean than do white sturgeon (Miller 1972). When found in the Bay, anadromous species generally appear on a direct route between the Delta and the ocean through the Golden Gate.

TABLE 2-9 FISHES FOUND IN SAN FRANCISCO BAY[a]

Class / Order / Family / Genus species	Common Name
Agnatha	
Petromyzontiformes	
Petromyzontidae	
Lampetra (=*Entosphenus*) *tridentata*	Pacific lamprey
Lampetra ayresi	river lamprey
Chondrichthyes	
Hexanchiformes	
Hexanchidae	
Notorynchus maculatus	sevengill shark
Hexanchus griseus	sixgill shark
Squaliformes	
Carcharhinidae	
Mustelus henlei	brown smoothhound
Mustelus californicus	gray smoothhound
Triakis semifasciata	leopard shark
Galeorhinus zyopterus	soupfin shark
Squalidae	
Squalus acanthias	spiny dogfish
Alopiidae	
Alopias vulpinus	common thresher
Rajiformes	
Torpedinidae	
Torpedo californica	Pacific electric ray
Rajidae	
Raja binoculata	big skate
Myliobatidae	
Myliobatis californica	bat ray

(a) Marine fish names from Miller and Lea (1972, 1976); others from Bailey et al. (1970).

Note: (*) indicates freshwater fishes occasionally found in marine areas during winter months.

Sources: Herald and Ripley 1951; Herald and Simpson 1955; Ganssle 1966; Messersmith 1966; Aplin 1967; PGandE 1973a,b; de Wit 1975; Steitz 1975a,b; Ecological Analysts, unpublished data.

TABLE 2-9 (CONT.)

Class / Order / Family / Genus species	Common Name
Osteichthyes	
Acipenseriformes	
Acipenseridae	
Acipenser medirostris	green sturgeon
Acipenser transmontanus	white sturgeon
Clupeiformes	
Clupeidae	
Alosa sapidissima	American shad
Clupea harengus pallasi	Pacific herring
Dorosoma petenense	threadfin shad
Sardinops sagax caeruleus	Pacific sardine
Engraulidae	
Engraulis mordax	northern anchovy
Salmoniformes	
Salmonidae	
Oncorhynchus tshawytscha	king salmon
Salmo gairdneri gairdneri	steelhead trout
Osmeridae	
Allosmerus elongatus	whitebait smelt
Hypomesus pretiosus	surf smelt
Hypomesus transpacificus	delta smelt
Spirinchus starksi	night smelt
Spirinchus thaleichthys	longfin smelt
Cypriniformes	
Cyprinidae*	
Cyprinus carpio	carp
Carassius auratus	goldfish
Hesperoleucus symmetricus	California roach
Lavinia exilicauda	hitch
Mylopharodon conocephalus	hardhead
Notemigonus crysoleucas	golden shiner
Orthodon microlepidotus	Sacramento blackfish
Pimephales promelas	fathead minnow
Pogonichthys macrolepidotus	splittail
Ptychocheilus grandis	Sacramento squawfish
Catostomidae*	
Catostomus occidentalis	Sacramento sucker

TABLE 2-9 (CONT.)

Class / Order / Family / Genus species	Common Name
Siluriformes	
Ictaluridae*	
Ictalurus catus	white catfish
Ictalurus punctatus	channel catfish
Ictalurus melas	black bullhead
Ictalurus nebulosus	brown bullhead
Batrachoidiformes	
Batrachoididae	
Porichthys notatus	plainfin midshipman
Gadiformes	
Gadidae	
Microgadus proximus	Pacific tomcod
Merluccidae	
Merluccius productus	Pacific hake
Ophidiidae	
Chilara taylori	spotted cusk-eel
Atheriniformes	
Scomberesocidae	
Cololabis saira	Pacific saury
Cyprinodontidae	
Lucania parva	rainwater killifish
Poeciliidae	
*Gambusia affinis**	mosquitofish
Atherinidae	
Atherinops affinis	topsmelt
Atherinopsis californiensis	jacksmelt
Menidia audens	Mississippi silverside
Gasterosteiformes	
Gasterosteidae	
Gasterosteus aculeatus	threespine stickleback
Syngnathidae	
Syngnathus leptorhynchus (=griseolineatus)	bay pipefish
Perciformes	
Percichthyidae	
Morone saxatilis	striped bass
Centrarchidae*	
Archoplites interruptus	Sacramento perch
Lepomis cyanellus	green sunfish

TABLE 2-9 (CONT.)

Class / Order / Family / Genus species	Common Name
Centrarchidae (cont.)	
Lepomis gibbosus	pumpkinseed
Lepomis macrochirus	bluegill
Lepomis gulosus	warmouth
Micropterus salmoides	largemouth bass
Pomoxis annularis	white crappie
Pomoxis nigromaculatus	black crappie
Percidae*	
Percina macrolepida	bigscale logperch
Sciaenidae	
Genyonemus lineatus	white croaker
Seriphus politus	queenfish
Embiotocidae	
Cymatogaster aggregata	shiner surfperch
Damalichthys vacca	pile surfperch
Embiotoca jacksoni	black surfperch
Embiotoca lateralis	striped surfperch
Hyperprosopon argenteum	walleye surfperch
Hyperprosopon anale	spotfin surfperch
*Hysterocarpus traski**	tule perch
Micrometrus minimus	dwarf surfperch
Phanerodon furcatus	white surfperch
Rhacochilus toxotes	rubberlip surfperch
Hypsurus caryi	rainbow surfperch
Amphistichus argenteus	barred surfperch
Brachyistius frenatus	kelp surfperch
Micrometrus aurora	reef surfperch
Clinidae	
Gibbonsia metzi	striped kelpfish
Cebidichthyidae	
Cebidichthys violaceus	monkeyface prickleback
Pholidae	
Pholis ornata	saddleback gunnel
Anarhichadidae	
Anarrhichthys ocellatus	wolf-eel
Ammodytidae	
Ammodytes hexapterus	Pacific sandlance

TABLE 2-9 (CONT.)

Class / Order / Family / Genus species	Common Name
Gobiidae	
Acanthogobius flavimanus	yellowfin goby
Clevelandia ios	arrow goby
Gillichthys mirabilis	longjaw mudsucker
Ilypnus gilberti	cheekspot goby
Lepidogobius lepidus	bay goby
Tridentiger trigonocephalus	chameleon goby
Eucyclogobius newberryi	tidewater goby
Stromateidae	
Peprilus simillimus	Pacific butterfish (=pompano)
Scorpaenidae	
Sebastes atrovirens	kelp rockfish
S. auriculatus	brown rockfish
S. flavidus	yellowtail rockfish
S. melanops	black rockfish
S. mystinus	blue rockfish
S. paucispinis	bocaccio
S. rastrelliger	grass rockfish
S. saxicola	stripetail rockfish
S. serranoides	olive rockfish
Hexagrammidae	
Hexagrammos decagrammus	kelp greenling
Ophiodon elongatus	lingcod
Cottidae	
Artedius notospilotus	bonyhead sculpin
*Cottus asper**	prickly sculpin
Enophrys bison	buffalo sculpin
Leptocottus armatus	staghorn sculpin
Nautichthys oculofasciatus	sailfin sculpin
Scorpaenichthys marmoratus	cabezon
Hemilepidotus hemilepidotus	red Irish lord
Liparidae (= Cyclopteridae)	
Liparis pulchellus	showy snailfish
Pleuronectiformes	
Bothidae	
Citharichthys stigmaeus	speckled sanddab
Paralichthys californicus	California halibut
Hippoglossina stomata	bigmouth sole

TABLE 2-9 (CONT.)

Class / Order / Family / Genus species	Common Name
Pleuronectidae	
Hypsopsetta guttulata	diamond turbot
Parophrys vetulus	English sole
Platichthys stellatus	starry flounder
Psettichthys melanostictus	sand sole
Lyopsetta exilis	slender sole
Pleuronichthys decurrens	curlfin turbot
Cynoglossidae	
Symphurus atricauda	California tonguefish

The striped bass is the only anadromous fish that can be considered a resident of the southern part of the Bay. Tagging studies of small- to medium-sized bass (38-71 cm) have indicated a shift in major distribution from south and central San Francisco Bay to San Pablo Bay during the winter and an associated reduced oceanic range (Orsi 1971). Summer ranges varied between the south and central Bay and the north Bay. Large bass (over 71 cm) were generally concentrated in the ocean and in San Francisco Bay during summer months. In fall and spring these fish moved upstream toward and into the Delta. In the winter, large bass are concentrated in San Pablo Bay. Most of the party-boat sport fishery for striped bass is concentrated in the central part of the Bay and San Pablo Bay; less than 2 percent of the effort and catch came from southern San Francisco Bay (McKechnie and Miller 1971).

Young and yearling striped bass are distributed throughout much of the Sacramento - San Joaquin Delta and San Francisco Bay system (Skinner 1972). In the fall and winter, young of the year concentrate in the low-salinity zone of the estuary around Suisun Bay. In the spring and summer, yearlings are generally distributed from San Pablo Bay to the Delta. Yearlings and young have been collected in central San Francisco Bay (Wooster 1971), but they are concentrated on the east side above the San Francisco - Oakland Bay Bridge.

Marine species are the other main group of fishes inhabiting San Francisco Bay. Some species are transient, only using the Bay for short periods or stages of their life cycle; others are lifelong residents.

The most abundant species found in California marine waters are the schooling, pelagic bait and forage fishes, including sardines, anchovies, herrings, silversides, and whitebait (Skinner 1962). Of these, the northern anchovy and Pacific herring are probably the most abundant in San Francisco Bay. The heaviest concentration of northern anchovy off the central and northern California coast is between Point Reyes and Monterey Bay, including San Francisco Bay. Feeding schools of anchovies observed in the Bay have been estimated to contain several hundred tons of fish (Aplin 1967). They are known to spawn in the Bay (Skinner 1962), and larval and juvenile stages are generally present from late summer through the winter (Eldridge 1977). They are an important source of food for striped bass and king salmon.

Pacific herring migrate from offshore waters into coastal waters to spawn in late fall and winter (Eldridge 1977). San Francisco Bay and Tomales Bay are the most important spawning grounds in California (Eldridge and Kaill 1973; Skinner 1962). In San Francisco Bay, the heaviest concentration of spawning is on rocky shorelines near the Golden Gate Bridge (Eldridge and Kaill 1973). Larval herring are abundant during the winter and early spring (Eldridge 1977). Juvenile herring are abundant in late spring and early summer, but by late summer very few adults or young are found in the Bay.

The species supports a substantial commercial fishery in the Bay area, and it is an important forage fish for striped bass.

Other bait and forage fish abundant in the Bay are silversides and the true smelt. Silversides (jacksmelt and topsmelt) range throughout the Bay, swimming in loose schools and quite often occurring together. The true smelts in San Francisco Bay are mainly whitebait, nightsmelt, and surfsmelt.

Flatfish are another important group of marine fishes. English sole, starry flounder, and sanddabs are found throughout San Francisco Bay. The starry flounder is an important sport fish whose largest populations are found in San Pablo Bay. The presence of large numbers of immature flatfish throughout the Bay suggests that it is an important spawning and nursery area for the offshore fishery (Skinner 1962). No significant commercial fishery exists for flatfish in the Bay.

Rockfish are marine neritic fishes that inhabit the Bay. They sustain important commercial and sport fisheries offshore. Spawning occurs in the Pacific Ocean, and nursery areas may be found in both the ocean and the Bay.

Saltwater perches are an important group of the fishes that reside in the Bay. The shiner surfperch, one of the most common residents, is found off beaches, under wharves, and around pilings. It supports a considerable sport fishery (Skinner 1962; Harvey et al. 1977).

A wide variety of other fishes are found in the Bay. Some of the more abundant species are the bay goby, white croaker, Pacific tomcod, Pacific staghorn sculpin, plainfin midshipman, and various sharks and rays. None of these is an important sport or commercial fish within the Bay.

2.3 REFERENCES

Aplin, J. A. 1967. Biological survey of San Francisco Bay, 1963-1966. Calif. Dep. Fish Game, Mar. Resour. Oper., MRO Ref. 67-4. 131 pp.

Bailey, R. M., J. E. Fitch, E. S. Herald, E. A.Lachner, C. C. Lindsey, C. R. Robins, and W. B. Scott. 1970. A list of common and scientific names of fishes from the United States and Canada. 3rd ed. Am. Fish. Soc., Spec. Publ. 6. 149 pp.

Bonnot, P. 1932. Soft shell clam beds in the vicinity of San Francisco Bay. Calif. Fish Game 18(1):64-66.

Brown and Caldwell (BC). 1971. A predesign report on marine waste disposal. Volumes I-II. Prepared for City and County of San Francisco. BC, San Francisco.

Brown and Caldwell (BC). 1975. A predesign report on marine waste disposal. Volume IV. Prepared for City and County of San Francisco. BC, San Francisco.

California Department of Fish and Game. 1968. Fish and wildlife resources of San Francisco Bay and Delta: description, environmental requirements, problems, opportunities and the future. A final report to the Bay-Delta Water Quality Control Program on the California Department of Fish and Game portion of Task VII-1b. 338 pp.

California State Water Resources Control Board (SWRCB). 1975. Water Quality Control Plan, San Francisco Bay Basin (2). SWRCB, Regional Water Quality Control Board, San Francisco Bay Region, Oakland. 2 vols.

Caskey, P. S. 1976. Spatial and temporal aspects of the zooplankton distribution in San Francisco Bay. M.A. thesis, California State University, Hayward. 89 pp.

Conomos, T. J. and D. H. Peterson. 1976. Suspended-particle transport and circulation in San Francisco Bay: an overview, in Estuarine processes. Vol. II. Circulation, sediments, and transfer of material in the estuary (M. Wiley, ed.), pp. 82-97. Academic Press, New York.

de Wit, L. A. 1975. Changes in the species composition of sharks in south San Francisco Bay. Calif. Fish Game 61(2):106-111.

Dederian, S. L. 1966. A survey of benthic marine invertebrates along the San Francisco waterfront. M.S. thesis, University of San Francisco. 117 pp.

Eldridge, M. B. 1977. Factors influencing distribution of fish eggs and larvae over eight 24-hr samplings in Richardson Bay, California. Calif. Fish Game 63(2):101-116.

Eldridge, M. B. and W. M. Kaill. 1973. San Francisco Bay area's herring resource—a colorful past and a controversial future. U.S. Natl. Mar. Fish. Serv., Mar. Fish. Rev. 35(11):25-31.

Frey, H. W., ed. 1971. California's living marine resources and their utilization. California Department of Fish and Game. 148 pp.

Ganssle, D. 1966. Fishes and decapods of San Pablo and Suisun Bays, in Ecological studies of the Sacramento-San Joaquin Estuary. Part 1 (D. W. Kelley, comp.), pp. 64-94. Calif. Dep. Fish Game, Fish Bull. 133.

Harvey, H. T., H. L. Mason, R. Gill, and T. W. Wooster. 1977. The marshes of San Francisco Bay: their attributes and values. A report to the San Francisco Bay Conservation and Development Commission. 156 pp.

Herald, E. S. and W. E. Ripley. 1951. The relative abundance of sharks and bat stingrays in San Francisco Bay. Calif. Fish Game 37(3):315-329.

Herald, E. S. and D. A. Simpson. 1955. Fluctuations in abundance of certain fishes in south San Francisco Bay as indicated by sampling at a trash screen. Calif. Fish Game 41(4):271-278.

Icanberry, J. W. and J. R. Adams. 1974. Zooplankton survival in cooling water systems of four thermal power plants on the California coast: interim report, March 1971-January 1972, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 13-22. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Liu, D. H. W., K. D. Martin, and C. R. Norwood. 1975. San Francisco Bay benthic community study: technical evaluation. Prepared for U.S. Army Engineer District, San Francisco, Corps of Engineers. Contract DACW 07-74-C-0005. SRI Project LSU-2894. Stanford Research Institute, Menlo Park, Calif. 244 pp.

McKechnie, R. J. and L. W. Miller. 1971. The striped bass party boat fishery: 1960-1968. Calif. Fish Game 57(1):4-16.

Marelli, S. G. 1979. Personal communication. California Academy of Sciences, San Francisco.

Messersmith, J. 1966. Fishes collected in Carquinez Strait in 1961-1962, in Ecological studies of the Sacramento-San Joaquin Estuary. Part 1 (D. W. Kelley, comp.), pp. 57-63. Calif. Dep. Fish Game, Fish Bull. 133.

Miller, L. W. 1972. Migrations of sturgeon tagged in the Sacramento-San Joaquin Estuary. Calif. Fish Game 58(2):102-106.

Miller, D. J. and R. N. Lea. 1972, 1976. Guide to the coastal marine fishes of California. Calif. Dep. Fish Game, Fish Bull. 157. 249 pp.

National Oceanic and Atmospheric Administration (NOAA). 1979. San Francisco Bay: Candlestick Point to Angel Island (1:20,000) Nautical Chart 18690. U.S. Department of Commerce, NOAA, National Ocean Survey, Washington.

Newcombe, C. L. and H. L. Mason. 1972. An environmental inventory of the north San Francisco Bay-Stockton ship-channel area. Part II. North San Francisco Bay to Point Edith, Suisun Bay area. San Francisco Bay Marine Research Center, Inc., Lafayette, Calif.

Orsi, J. J. 1971. The 1965-1967 migrations of the Sacramento-San Joaquin Estuary striped bass population. Calif. Fish Game 57(4):257-267.

Pacific Gas and Electric Company (PGandE). 1973a. An evaluation of the effect of cooling water discharges on the beneficial uses of receiving waters at Hunters Point Power Plant. PGandE, San Francisco.

Pacific Gas and Electric Company (PGandE). 1973b. An evaluation of the effect of cooling water discharges on the beneficial uses of receiving waters at Potrero Power Plant. PGandE, San Francisco.

Pacific Gas and Electric Company (PGandE). 1977. Hunters Point Power Plant cooling water intake report and 316(b) study plan. Revised edition. Submitted to California Regional Water Quality Control Board, San Francisco Bay Region. PGandE, San Francisco.

Pacific Gas and Electric Company (PGandE). 1979. Hunters Point Power Plant units 2 and 3 and unit 4 intake velocity studies. PGandE, Dep. Eng. Res., Rep. 420-79.102. San Ramon, Calif.

San Francisco, City and County of. 1976. Southeast Water Pollution Control Plant Annual Receiving Water Data Summary. As cited in Pacific Gas and Electric Company, 1978, Application for Certification, Potrero Power Plant Unit No. 7, Appendix D.2.

San Francisco, City and County of. 1977. Southeast Water Pollution Control Plant Annual Receiving Water Data Summary. As cited in Pacific Gas and Electric Company, 1978, Application for Certification, Potrero Power Plant Unit No. 7, Appendix D.2.

Skinner, J. E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay area. Calif. Dep. Fish Game, Water Projects Branch Rep. 1. 226 pp.

Skinner, J. E., compiler. 1972. Ecological studies of the Sacramento-San Joaquin Estuary. Calif. Dep. Fish Game, Delta Fish Wildl. Prot. Study Rep. 8. 94 pp.

Steitz, C. E. 1975a. Angler use and catch composition in the vicinity of the discharges of Hunters Point Power Plant. PGandE, Dep. Eng. Res., Rep. 7712.12-75. San Ramon, Calif.

Steitz, C. E. 1975b. Angler use and catch composition in the vicinity of the discharges of Potrero Power Plant. PGandE, Dep. Eng. Res., Rep. 7712.13-75. San Ramon, Calif.

Storrs, P. N., R. E. Selleck, and E. A. Pearson. 1965. A comprehensive study of San Francisco Bay, 1963-64: north, central, and lower San Francisco Bay areas. Fourth annual report. Univ. Calif., Berkeley, Sanit. Eng. Res. Lab., SERL Rep. 65-1.

Storrs, P. N., E. A. Pearson, and R. E. Selleck. 1966. A comprehensive study of San Francisco Bay. Final report. Volume V. Summary of physical, chemical, and biological water and sediment data. Univ. Calif., Berkeley, Sanit. Eng. Res. Lab., SERL Rep. 67-2. 140 pp.

Tetra Tech, Inc. 1976. 316(a) Demonstration Contra Costa Power Plant. Prepared for Pacific Gas and Electric Company. Tetra Tech Rep. TC-638. Lafayette, Calif. 206 pp.

Treber, L. D. 1973. Environmental factors influencing plankton and productivity in the southern portion of central San Francisco Bay. M.S. thesis, University of San Francisco. 89 pp.

U.S. Fish and Wildlife Service. 1970. Effects on fish resources of dredging and spoil disposal in San Francisco and San Pablo Bays, California. 36 pp.

Wooster, T. W. 1968a. Clams, native oysters and mussels, in Fish and wildlife resources of San Francisco Bay and Delta: description, environmental requirements, problems, opportunities and the future, pp. 123-145. A final report to the Bay-Delta Water Quality Control Program on the California Department of Fish and Game portion of Task VII-1b. California Department of Fish and Game.

Wooster, T. W. 1968b. The San Francisco Bay commercial oyster industry, in Fish and wildlife resources of San Francisco Bay and Delta: description, environmental requirements, problems, opportunities and the future, pp. 147-159. A final report to the Bay-Delta Water Quality Control Program on the California Department of Fish and Game portion of Task VII-1b. California Department of Fish and Game.

Wooster, T. W. 1971. Occurrence of juvenile forage and game fishes over the intertidal mudflats of the San Francisco Bay complex. Calif. Dep. Fish Game, Anad. Fish. Branch Admin. Rep. 71-2. 10 pp.

Chapter 3

Entrainment

3.1 Entrainment Abundance

3.2 Entrainment Survival

3.3 Estimation of Total Entrainment Losses at the Potrero Power Plant

3.4 Entrainment Summary

3.5 References

CHAPTER 3: ENTRAINMENT

Entrainment is one of two major ways in which aquatic organisms can be directly involved with the cooling water intakes of power plants; the other way is impingement, the subject of Chapter 4. Entrainment is the hydraulic capture and subsequent exposure of organisms to a cooling water system. The organisms involved are small, capable of passing through the 3/8-in. (9.5-mm) mesh intake screens, and include phytoplankton, zooplankton including early life stages of fish (ichthyoplankton), and macroinvertebrates. As these entrained organisms pass through the cooling system, they can be exposed to several types of stresses. These include mechanical stress from contact with the internal surfaces of pumps, pipes, and condenser tubes; pressure stress from exposure to relatively rapid pressure changes; shear stress from exposure to complex water flows; thermal stress from exposure to elevated temperatures in the condensers; and, where applicable, chemical stress from exposure to biocides used in biofouling control. The environmental impact of a cooling water intake system is in part a function of the number of organisms that do not survive as a result of passage through the system.

A major objective of the 316(b) program for the Hunters Point Power Plant is to estimate the numbers and taxa of organisms lost during cooling system passage. To achieve this objective, a study was proposed in the study plan (PGandE 1977) designed to estimate the total numbers and taxa of organisms entrained. To estimate the proportion of organisms entrained that do not survive cooling system passage, the study plan proposed extrapolating results of entrainment survival studies conducted at the Potrero Power Plant to the Hunters Point Power Plant. Combining the results of the two studies permits estimation of the total numbers of organisms lost to entrainment.

The Hunters Point Power Plant entrainment studies focused on planktonic early life stages of fish (ichthyoplankton) and on selected macroinvertebrate groups, including amphipods, isopods, cumaceans, tanaidaceans, mysidaceans, decapods, and chaetognaths, as summarized in Chapter 1.

The results of the entrainment abundance and survival studies are presented in the following sections of this chapter. Entrainment abundance results are presented in

Section 3.1, including estimated total numbers of ichthyoplankton and macroinvertebrates entrained at Units 2, 3, and 4 during the study period. Section 3.1 also describes a study designed to determine the best location in the cooling system for sampling entrainment abundance (i.e., the location from which the most representative estimates of total numbers entrained may be obtained). The potential survival of entrained ichthyoplankton and macroinvertebrates is estimated in Section 3.2, based on the results of laboratory and field entrainment survival studies that are summarized in Appendix B. In Section 3.3, the total numbers of ichthyoplankton and macroinvertebrates lost to entrainment are estimated on the basis of the entrainment abundance and survival results. The data upon which Chapter 3 is based are presented in the data summary accompanying this report (Appendix E).

The estimates provided in this chapter of the total number of entrained ichthyoplankton and macroinvertebrates lost to entrainment, along with similar estimates of impingement losses (Chapter 4), form part of the foundation upon which the impact of cooling water withdrawal on the aquatic populations of San Francisco Bay is assessed (Chapter 5). These estimates of losses also form part of the foundation used in Chapter 6 for determining the best intake technology available for minimizing adverse impact.

3.1 ENTRAINMENT ABUNDANCE

The entrainment abundance study was designed to estimate the numbers of ichthyoplankton and macroinvertebrates entrained at Units 2, 3, and 4. The study was also designed to determine (1) the species composition of the entrained biota, (2) the size (length) composition of the entrained ichthyoplankton, and (3) the seasonal and diel patterns of entrainment.

The numbers of organisms entrained were estimated by sampling a portion of the cooling water flow on a weekly basis for one year, and then multiplying the densities of ichthyoplankton and macroinvertebrates observed by the volume of cooling water passing through the plant.

Densities of entrained ichthyoplankton and macroinvertebrates observed at Unit 3 were used in estimating total numbers entrained at all three units. Since the Bay water used for cooling all three units comes through a common pair of conduits into

the intake area, the numbers and species composition of organisms entrained were expected to be similar at all three units.

As specified in the study plan (PGandE 1977), the discharge area was selected for sampling. Because of turbulence and through-plant mixing, organisms there were expected to be distributed more uniformly than in the intake. Samples collected at the discharge were expected to represent more accurately the true densities of entrained organisms than samples collected at the intake, provided that no losses of organisms were occurring during transit through the cooling system. The null hypothesis that organism densities were not different in the intake and discharge (i.e., that no through-plant losses of organisms were occurring) was tested. The results, presented in detail in Section 3.1.2.2, indicated that significant through-plant losses of organisms were occurring, contrary to expectation. To compensate for through-plant losses, entrainment densities measured at the discharge were multiplied by a correction factor derived from the results of the studies described in Section 3.1.2.2.

3.1.1 Methods and Materials

Entrainment abundance was sampled by filtering water pumped from the Unit 3 discharge conduit (Figure 3-1) during one 24-hour period per week from 20 April 1978 to 16 April 1979. Eight 3-hour samples were collected during each 24-hour sampling period.

Major features of the sampling equipment are shown in Figure 3-2. Water samples were collected with a 4-in. (10.2-cm) diameter recessed-impeller pump. A 3-in. (7.6-cm) diameter PVC intake line to the pump was directed into the cooling water flow. The current velocity in the sampling inlet substantially exceeded cooling water flow velocity, preventing any backpressures around the inlet that might reduce organism collection efficiency. The pump discharged into a 4-in. (10.2-cm) diameter PVC line leading to the mouth of a 0.5-m (1.6-ft) plankton net with 335- m mesh that was suspended in a cylindrical polyethylene tank. The water level in the tank was maintained below the mouth of the net by an overflow prevention siphon and a drain rate control valve.

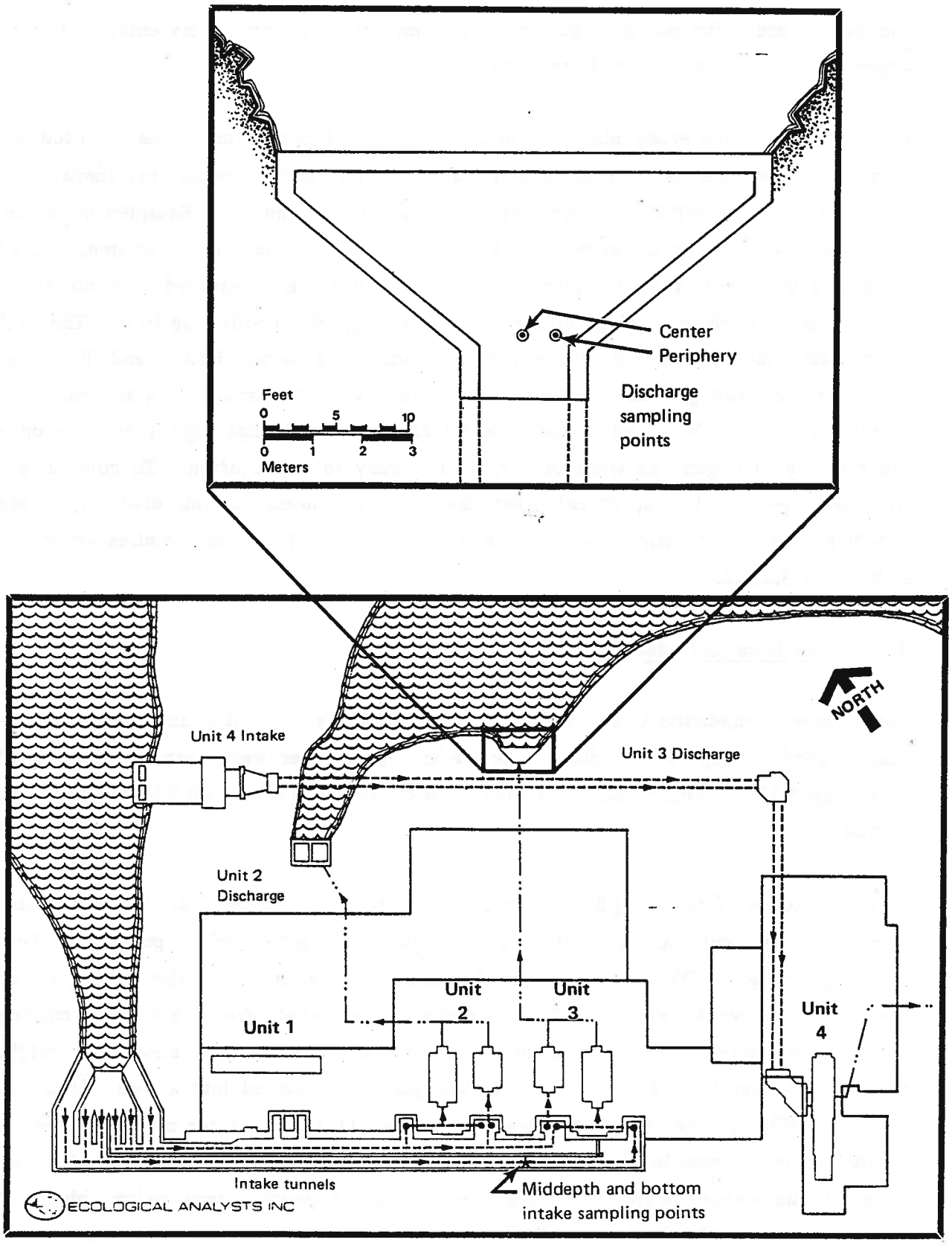


Figure 3-1. Sampling locations used for abundance and mass-balance studies at the Hunters Point Power Plant.

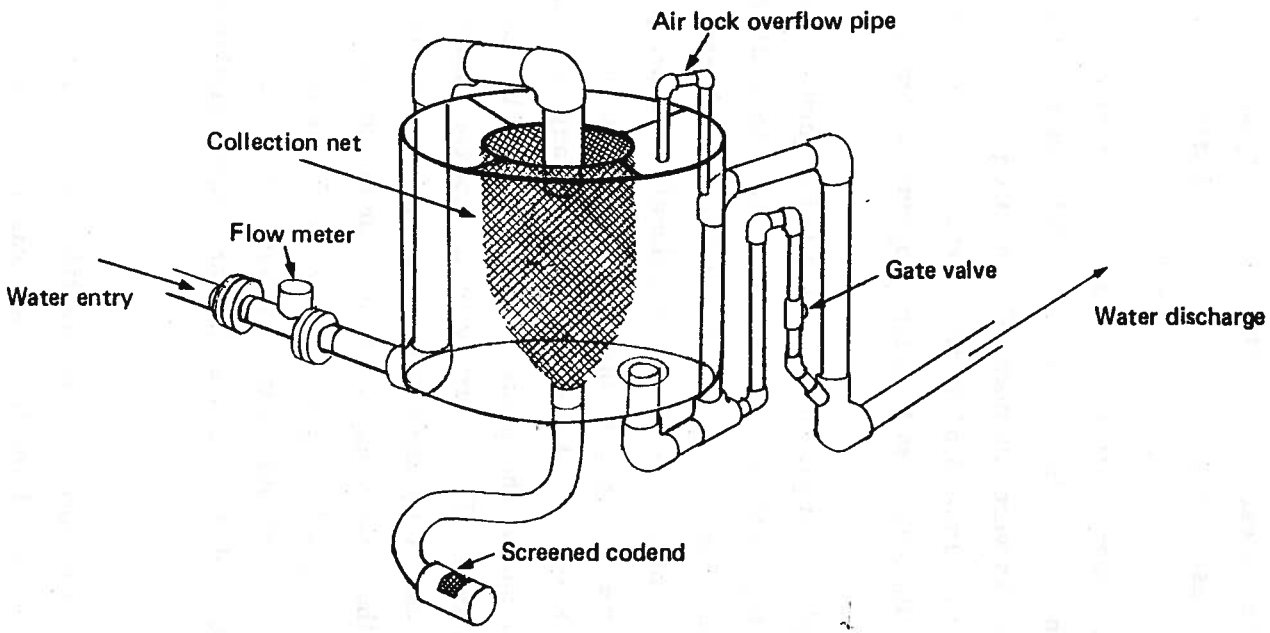


Figure 3-2. Entrainment abundance sampling equipment used at Unit 3 of the Hunters Point Power Plant.

Sample volume and flow rate were measured with an inline Sparling-Master Flo Meter (factory calibrated at ±2 percent accuracy) in the pump discharge line. The flow rate was maintained at about 0.9 m^3/min (0.5 cfs). The pump was normally turned off for 10 minutes at the end of each 3-hour interval while the sample was collected from the net. Organisms were collected by draining the tank, rinsing the net from the outside with filtered water, concentrating the organisms in a screen-walled collection container, and preserving them in 10 percent buffered formalin.

After sample collection, samples were returned to the laboratory for processing. Ichthyoplankton were sorted from all samples. Biweekly samples were examined under a microscope and macroinvertebrates were enumerated. This frequency was concluded to be adequate for estimating total numbers of macroinvertebrates entrained because their densities were observed to fluctuate less than ichthyoplankton densities.

Samples were split to 1/8 or 1/64 with a plankton splitter before macroinvertebrates were counted, because of the large numbers collected relative to ichthyoplankton. Samples were split into 8 equal subsamples in one split or 64 subsamples in two consecutive splits. This is in contrast to the conventional Folsom-type splitter, where three consecutive splits are required to obtain a 1/8 subsample and six consecutive splits are required to obtain a 1/64 subsample. Since any error in splitting is compounded in all subsequent splits, the plankton splitter used in this study was more accurate than the Folsom type. The accuracy of the splitter was statistically tested using a chi-square goodness-of-fit test comparing the numbers of organisms found in 8 or 64 subsamples to the number expected to occur in each subsample when the number of organisms in the original sample was known. In eight replications of such a test, the resulting chi-square statistic was never significant ($\alpha = 0.05$). Thus, it was concluded that the splitter accurately partitioned samples into 8 or 64 subsamples.

Both ichthyoplankton and macroinvertebrates were identified to the lowest taxonomic level practicable with available keys and the life stage was noted. Eggs of northern anchovy and silversides were identified and counted. Other fish eggs were counted but not identified. Total lengths of fish larvae and juveniles were measured to the nearest millimeter. All sample processing operations and taxonomic identifications were subject to a strict quality assurance program.

Densities, expressed as the number of organisms per cubic meter of cooling water, were computed for each taxon observed in each 3-hour sample. Mean densities for each 24-hour sampling day were computed as the simple average of the densities for the eight 3-hour samples. The densities and mean densities were used to study the diel and seasonal patterns of entrainment, respectively. Length statistics (mean, standard deviation, and range) were also computed for the ichthyoplankton collected.

The total numbers of organisms in each ichthyoplankton and macroinvertebrate taxon entrained were estimated, following a stratified sampling design (Cochran 1977). The one-year period was divided into strata, two weeks in length for ichthyoplankton and four weeks for macroinvertebrates. For each stratum, the total number in each taxon entrained was estimated for each 3-hour period on at least two sampling days:

$$\hat{y}_{ijk} = V_{ijk} \frac{\hat{x}_{ijk}}{v_{ijk}} \qquad (3\text{-}1)$$

where

$\hat{y}_{ijk}$ = estimated number of a given taxon entrained during the kth 3-hour period on the jth sampling day in the ith stratum

V_{ijk} = total cooling water flow during period k on sampling day j in stratum i

v_{ijk} = volume sampled in period k on sampling day j in stratum i

$\hat{x}_{ijk}$ = estimated number of organisms in a given taxon sampled in period k on sampling day j in stratum i.

When only a portion of the sample for a 3-hour period was processed, as in the case of macroinvertebrates, $\hat{x}_{ijk}$ was computed as

$$\hat{x}_{ijk} = \frac{z_{ijk}}{p_{ijk}} \qquad (3\text{-}2)$$

where

z_{ijk} = number in a given taxon actually counted in sample k on sampling day j in stratum i

p_{ijk} = sample splitting proportion (1/8 or 1/64) for period k on sampling day j within stratum i.

Having estimated y_{ijk} for each 3-hour sampling period in a given stratum, the mean number of organisms in a given taxon entrained per day during the stratum, $\bar{y}_i$, was calculated as

$$\bar{y}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \hat{y}_{ij} \tag{3-3}$$

where

$$\hat{y}_{ij} = \sum_{k=1}^{n_j} \hat{y}_{ijk}$$

n_i = number of sampling days in stratum i

n_j = number of 3-hour periods sampled on sampling day j in stratum i.

The total number of organisms of a given taxon entrained over the entire year (E) was then estimated by summing over all strata the product of the mean number entrained per day and the number of days the cooling system was in operation during each stratum:

$$\hat{E} = \sum_{i=1}^{L} N_i \bar{y}_i \tag{3-4}$$

where

N_i = number of days of cooling system operation in stratum i

L = number of strata in the one-year study period.

The variance of $\hat{E}$ includes three nested components associated with the three sampling stages:

1. variance related to sampling selected days during each stratum,
2. variance related to sampling a portion of the cooling water flow on a given day, and
3. variance related to processing a portion of a 3-hour sample (applicable to macroinvertebrates only).

Working within the framework presented by Cochran (1977, pp. 285-289) and Yamane (1967, p. 300), the variance of E was computed as

$$\hat{Var}(\hat{E}) = \sum_{i=1}^{L} N_i \left[(N_i - n_i) \frac{s_i^2}{n_i} + \sum_{j=1}^{n_i} \sum_{k=1}^{n_j} \frac{V_{ijk}}{n_i} \left((V_{ijk} - v_{ijk}) \frac{\hat{x}_{ijk}}{v_{ijk}^2} + \frac{\hat{Var}(\hat{x}_{ijk})}{v_{ijk}} \right) \right] \tag{3-5}$$

where

$$s_i^2 = \frac{1}{(n_i - 1)} \sum_{j=1}^{n_i} (\hat{y}_{ij} - \bar{y}_i)^2 \tag{3-6}$$

$$\hat{Var}(\hat{x}_{ijk}) = z_{ijk} \frac{1 - p_{ijk}}{p_{ijk}^2} \tag{3-7}$$

The first component, s_i^2/n_i, is an unbiased estimate of day-to-day variability within strata (Cochran 1977, p. 95). The second component, $\hat{x}_{ijk}/v_{ijk}^2$, an unbiased estimate of the volume-to-volume variability within a given 3-hour period, results from the assumption that the number of observed organisms in a given sample follows the Poisson distribution. The third component, $\hat{Var}(\hat{x}_{ijk})/v_{ijk}$, an unbiased estimate of the variability caused by splitting the volume sampled, results from the assumption that the number of organisms observed in a split subsample follows the binomial distribution.

The 95 percent confidence limits for the total number of a given taxon entrained over the entire year is equal to $\hat{E} \pm 1.96\ \widehat{S.E.}(\hat{E})$, in which the standard error is the square root of the variance: $\widehat{S.E.}(\hat{E}) = \sqrt{\widehat{Var}(\hat{E})}$.

The estimated total number in each taxon entrained during the study period, E, and its standard error, S.E.(E), were computed for each cooling water system independently and for the combination of all three. In the latter case, the combined entrainment estimates ($\hat{E}$) were obtained simply by adding the entrainment estimates for the individual cooling water systems. The combined standard error estimates were obtained using Equation 3-5, where V_{ijk} became the combined total cooling water flow in period k on sampling day j in stratum i, and where N_i became the greater of the number of days of cooling system operation during stratum i for Unit 2 or 3 or 4.

Total numbers entrained, (E), were estimated based both on actual cooling water flows during the study period and on cooling water flows characteristic of continuous normal operation of Units 2, 3, and 4.

The methodology just described was expanded for northern anchovy and Pacific herring to make it possible to estimate numbers of individuals entrained as a function of total body length; these estimates are used in Chapter 5 and Appendix C in the estimation of equivalent adult losses of Pacific herring and northern anchovy. Equations 3-1 through 3-4 were applied separately to each length class (usually set at 1-mm increments) of a given taxon. The number of individuals in a 3-hour sample of a given length class ($\hat{x}_{ijk}$) was computed by modifying Equation 3-2 as follows:

$$\hat{x}_{ijk} = \frac{z_{ijk}\ \hat{f}_{ijk}}{p_{ijk}} \qquad (3\text{-}8)$$

where

$\hat{f}_{ijk}$ = the observed proportion of individuals measured in the sample that were of the given length class.

Next, the total number in the given length class entrained during the study year (E) was estimated as before, using Equations 3-1, 3-3, and 3-4 unchanged.

The methodology for computing $\hat{Var}(\hat{E})$ was also modified. Equation 3-7 became

$$\hat{Var}(\hat{x}_{ijk}) = \frac{z_{ijk}\,\hat{f}_{ijk}}{p_{ijk}^2}\,(1 - p_{ijk}) + \left[\frac{(z_{ijk} - m_{ijk})\,(1 - \hat{f}_{ijk})}{p_{ijk}\,(m_{ijk} - 1)}\right] \qquad (3\text{-}9)$$

where

m_{ijk} = the number of measured individuals in a 3-hour sample.

Equations 3-5 and 3-6 were used unchanged.

3.1.2 Entrainment Abundance Support Studies

In this section two studies are described that support the entrainment abundance experimental design, as specified in the study plan (PGandE 1977). The first is an evaluation of the collection efficiency of the sampling gear. The second is a mass balance study comparing the densities of entrained organisms between the Unit 3 intake and the discharge.

3.1.2.1 Entrainment Abundance Gear Evaluation

The collection efficiency of the entrainment abundance sampling gear was documented in an experiment where known numbers of stained organisms were directly released into the suction line of the sampling pump, and the numbers recovered in a 335- or 505-μm mesh net were recorded. After release the pump was operated at 1,900 rpm, delivering 0.9 m^3/min (240 gpm) for test periods of 30, 60, 90, and 180 minutes, at the end of which the pump was turned off, the tank drained, the net rinsed, and the sample recovered. The number of organisms recovered was then determined.

Tests were conducted at the Contra Costa, Potrero, and Moss Landing power plants using brine shrimp and fish larvae. Recovery of brine shrimp was high (92-96 percent) for 30- and 60-minute tests with both 335- and 505-μm nets, but was low (40-85 percent) for 90- and 180-minute tests with the 505-μm net (Table 3-1). In the longer tests, a large proportion of the brine shrimp recovered were mutilated.

TABLE 3-1 RESULTS OF COLLECTION EFFICIENCY TESTS OF ENTRAINMENT ABUNDANCE SAMPLING GEAR

Date	Test Number	Duration of Collection (min)	Mesh Size (μm)	Organism	Number Released	Number Recovered	Condition[a]	Percentage Recovery
19 OCT 79	1	30	505	Live brine shrimp	100	95	Good	95
	2	60	505	Live brine shrimp	100	96	Good	96
25 OCT 79	3	30	505	Live brine shrimp	100	93	Good	93
	4	90	505	Live brine shrimp	100	85	Poor	85
	5	90	505	Live brine shrimp	100	64	Poor	64
	6	180	505	Live brine shrimp	100	84	Poor	84
	7	180	505	Live brine shrimp	100	43	Poor	43
1 NOV 79	8	180	505	Assorted larval fish	75	64	Good	85
21 NOV 79	9	60	335	Live brine shrimp	100	92	Good	92
	10	60	335	Assorted larval fish	100	100	Good	100
	11	60	335	Live brine shrimp	100	96	Good	96
	12	60	335	Assorted larval fish	100	98	Good	98
	13	30	335	Live brine shrimp	100	92	Good	92

(a) Good = organisms generally intact (not mutilated).
Poor = organisms generally not intact (mutilated).

Brine shrimp are very delicate, soft-bodied invertebrates, and are more susceptible to sampling damage than most of the macroinvertebrates entrained at the Hunters Point Power Plant. Additional tests conducted with larval fish and both mesh sizes resulted in 85-100 percent recovery (Table 3-1). It was concluded that the sampling gear collected larval fish and macroinvertebrates effectively, except for the most fragile forms, which may be mutilated by turbulence and abrasion in the collection net during long samples.

3.1.2.2 Intake-Discharge Mass Balance Study

3.1.2.2.1 Methods and Materials of Mass Balance Study

The null hypothesis that organism densities in the intake and discharge are the same (i.e., that entrained organisms are not lost during cooling system passage) was tested in this study. Cooling water samples were simultaneously collected with entrainment sampling gear at Unit 3 from two intake and two discharge locations a total of eight times on each of two sampling days. The densities of target organisms were determined for each sample, and the mean densities computed for the intake and discharge were compared statistically.

Samples were collected at Unit 3 by pumping water at 0.9 m^3/min (240 gpm) into 335-μm mesh plankton nets suspended in water-filled tanks, in the same manner as done during routine entrainment abundance sampling (Section 3.1.1). Sampling locations at the intake and discharge are shown in Figure 3-1. Intake locations were in the west intake tunnel between the traveling screens and the circulating water pumps, 107 m (350 ft) downstream of the traveling screens; one location, designated mid-depth, was located approximately 4 ft (1.2 m) above the floor of the tunnel; the other, designated the bottom, was approximately 2 ft (0.6 m) above the floor. At the discharge, one location was at the center of the 6.5- x 7-ft (2.0- x 2.1-m) conduit where it emptied into San Francisco Bay. The other location was at the same height as the center location but 2 ft (0.6 m) toward the periphery of the conduit.

Samples were collected for periods of one hour. The volumes of water pumped during each sampling period were determined with inline flowmeters. At the end of each sampling period, organisms and debris retained in each net were concentrated into the codend of the net, placed in glass jars, and preserved in 10 percent buffered formalin.

Several taxa were selected as target organisms to be sorted from all samples: fish eggs, fish larvae and juveniles, brachyuran (crab) zoeae and megalopae, and anomuran larvae (Upogebia pugettensis, Callianassa spp.). The macroinvertebrate taxa selected were among the most abundant taxa entrained at the Hunters Point Power Plant (Section 3.1.3). Target organisms were removed from all samples and enumerated.

The proportion lost (p_L) between the intake and discharge was estimated for each target organism taxon:

$$\hat{p}_L = \frac{\hat{I} - \hat{D}}{\hat{I}} \tag{3-10}$$

where

$\hat{I}$ = average intake density

$\hat{D}$ = average discharge density.

Average intake densities were computed as follows:

$$\hat{I} = \frac{1}{n} \sum_{i=1}^{n} I_i \tag{3-11}$$

where

n = number of trials

$$I_i = \frac{\sum_{j=1}^{m} y_{ij}}{\sum_{j=1}^{m} v_{ij}} \tag{3-12}$$

y_{ij} = number of target organisms in sample j collected during trial i

v_{ij} = volume of sample j collected during trial i

m = number of samples at intake (or discharge) per trial.

Similarly, average discharge densities were computed as follows:

$$\hat{D} = \frac{1}{n} \sum_{i=1}^{n} D_i \tag{3-13}$$

where D_i is computed as in Equation 3-12.

Working within the framework for ratio estimates presented by Cochran (1977), the variance of $\hat{p}_L$ was estimated as

$$\hat{Var}(\hat{p}_L) = \frac{1}{\hat{I}^2}\left[\hat{Var}(\hat{D}) - 2(1 - \hat{p}_L)\, Cov(\hat{I},\hat{D}) + (1 - \hat{p}_L)^2\, \hat{Var}(\hat{I})\right] \tag{3-14}$$

where

$$\hat{Var}(\hat{D}) = \frac{1}{n^2} \sum_{i=1}^{n} \frac{m}{\left(\sum_{j=1}^{m} v_{ij}\right)^2} \frac{\sum_{j=1}^{m} (y_{ij} - v_{ij} D_i)^2}{m - 1} \tag{3-15}$$

$$\hat{Var}(\hat{I}) = \frac{1}{n^2} \sum_{i=1}^{n} \frac{m}{\left(\sum_{j=1}^{m} v_{ij}\right)^2} \frac{\sum_{j=1}^{m} (y_{ij} - v_{ij} I_i)^2}{m - 1} \tag{3-16}$$

$$Cov(\hat{I},\hat{D}) = \frac{1}{n(n-1)} \sum_{i=1}^{n} (\hat{I}_i - \hat{I})(\hat{D}_i - \hat{D}). \tag{3-17}$$

The proportion lost (p_L) was estimated separately for each of the two sampling days for each target taxon. The resulting two estimates of p_L were statistically compared

using the Z-test for comparison of proportions (Ostle and Mensing 1975). When the two estimates were found not to be significantly different ($\alpha = 0.05$), the data for the two sampling days were pooled, yielding single estimates of p_L and its variance. Next, the null hypothesis that $p_L = 0$ was statistically tested. The null hypothesis was rejected in favor of $p_L > 0$ when

$$\hat{p}_L \geq 1.65\ \widehat{S.E.}(\hat{p}_L) \tag{3-18}$$

where

$$\widehat{S.E.}(\hat{p}_L) = \sqrt{\hat{Var}(\hat{p}_L)}\ . \tag{3-19}$$

Rejecting the null hypothesis implied that the proportion lost was statistically significant ($\alpha = 0.05$); that is, that significant losses of organisms were occurring during cooling system passage.

When statistically significant proportions lost were obtained, the estimates of total numbers entrained ($\hat{E}$) (see Equation 3-4) were corrected to account for organisms lost during cooling system passage upstream of the point of entrainment abundance sampling. Equation 3-4 was modified as follows:

$$\hat{E}' = f\hat{E} \tag{3-20}$$

where

$$f = \frac{1}{1 - \hat{p}_L} = \text{correction factor} \tag{3-21}$$

$\hat{E}'$ = corrected estimate of total numbers entrained.

The variance of $\hat{E}'$ was estimated as

$$\hat{Var}(\hat{E}') = \frac{1}{(1 - \hat{p}_L)^2}\left[\hat{Var}(\hat{E}) + \left(\frac{\hat{E}}{1 - \hat{p}_L}\right)^2 \hat{Var}(\hat{p}_L)\right]\ . \tag{3-22}$$

3.1.2.2.2 Results of Mass Balance Study

Mean intake densities considerably exceeded mean discharge densities for all target organism taxa examined, indicating a high proportion of organisms lost during cooling system passage (Table 3-2).

Estimates of the proportion lost (p_L) were computed for each target taxon and sampling date (Table 3-3). The estimates ranged from 0.51 to 0.82. Proportions lost did not vary significantly ($\alpha = 0.05$) between sampling dates.

The data for the two sampling dates were combined, yielding pooled estimates of the proportion lost (Table 3-3). The pooled estimates of p_L for fish larvae, fish eggs, brachyuran larvae, and anomuran larvae are 0.76, 0.53, 0.74, and 0.67, respectively.

The pooled estimates of p_L for brachyuran and anomuran larvae were statistically compared using the Z-test for differences in proportions (Ostle and Mensing 1975) and were found not to be significantly different ($\alpha = 0.05$). Consequently, the data for the two taxa were pooled, yielding a single estimate of p_L for entrained macroinvertebrates, 0.70.

Since the intake was sampled at a point 107 m (350 ft) downstream from the traveling screens in the west intake tunnel, any losses of entrained organisms that might have occurred between the screens and the sampling point were not measured. Consequently, if losses were occurring in the intake tunnel, p_L may have been underestimated to some extent. Sampling closer to the screens was desirable but was precluded by lack of suitable access points for sampling. Sampling in front of the screens was not considered because of likely spatial variability in organism densities over the intake cross-section.

The estimates of p_L were used to correct entrainment densities and estimates of total numbers entrained reported in Sections 3.1.3 and 3.1.4. The computed correction factors derived by Equation 3-21 were 4.2, 2.1, and 3.4 for fish larvae, fish eggs, and macroinvertebrates, respectively. The estimates of total numbers entrained based on discharge sampling were multiplied by the correction factors to yield estimates of the total numbers of organisms entering the cooling water intake structures.

TABLE 3-2 MEAN DENSITIES OF TARGET ORGANISMS IN THE INTAKE AND DISCHARGE OF UNIT 3 OF THE HUNTERS POINT POWER PLANT

Taxon	Mean Density[a] (no./m^3)					
	Sampling Day 1		Sampling Day 2		Combined Sampling Days	
	Intake	Discharge	Intake	Discharge	Intake	Discharge
Fish larvae	0.27	0.07	0.84	0.20	0.55	0.13
Fish eggs	0.48	0.23	0.72	0.32	0.60	0.28
Brachyura larvae	1.82	0.34	1.03	0.39	1.42	0.36
Anomura larvae	2.83	0.91	1.43	0.47	2.13	0.69
Invertebrates combined[b]	--	--	--	--	1.78	0.53

(a) Mean density computed using Equations 3-11 and 3-13.
(b) Includes both brachyuran and anomuran larvae.

Note: (--) indicates that the value was not computed.

TABLE 3-3 ESTIMATES OF THE PROPORTION LOST DURING COOLING SYSTEM PASSAGE ($\hat{p}_L$) AT UNIT 3 OF THE HUNTERS POINT POWER PLANT

Taxon	Sampling Day 1		Sampling Day 2		Combined Sampling Days	
	p_L (a)	S.E. ($\hat{p}_L$) (b)	p_L	S.E. ($\hat{p}_L$)	p_L	S.E. ($\hat{p}_L$)
Fish larvae	0.75	0.09	0.76	0.06	0.76	0.05
Fish eggs	0.51	0.15	0.55	0.11	0.53	0.15
Brachyuran larvae	0.82	0.09	0.62	0.09	0.74	0.07
Anomuran larvae	0.68	0.10	0.67	0.04	0.67	0.08
Invertebrates combined (c)	--	--	--	--	0.70	0.05

(a) Estimated proportion lost (Equation 3-10).
(b) Approximate standard error of p_L (Equation 3-19).
(c) Includes both brachyuran and anomuran larvae.

Note: (--) indicates that the value was not computed.

The correction factors calculated at Unit 3 were applied to Units 2 and 4 as well. The Unit 2 cooling water system is very similar to the Unit 3 system in all respects, and consequently the proportions lost through the two systems are likely to be the same. The Unit 4 system differs from Units 2 and 3, but it is similar to the Potrero Power Plant Unit 3, where no through-plant losses of entrained organisms have been observed (PGandE 1980). Therefore, the proportions lost through Unit 4 are likely to be less than those at Units 2 and 3, and thus, applying the Unit 3 results to Unit 4 should overestimate total numbers entrained.

3.1.3 General Characteristics of Entrainment

Approximately 20 taxa of ichthyoplankton were entrained at the Hunters Point Power Plant Unit 3 during the one-year study (20 April 1978 - 16 April 1979). Gobies and Pacific herring together constituted 91 percent of the 108 million fish larvae and juveniles estimated to have been entrained at Units 2 and 3 and at Unit 4 (Table 3-4). Goby larvae were entrained in the greatest numbers (68 million), constituting 63 percent of the total fish larvae and juveniles entrained. Pacific herring were second in abundance: an estimated 30 million were entrained, constituting 28 percent of the total. Other larvae, entrained in much lower numbers, included northern anchovy (2.8 million), plainfin midshipman (1.3 million), staghorn sculpin (0.61 million), unidentified sculpins (0.49 million), surf smelt (0.31 million), white croaker (0.30 million), silversides (0.19 million), bay pipefish (0.08 million), and striped bass (0.06 million). In addition, 3.8 million unidentified and other fish larvae and juveniles were estimated to have been entrained, 3.5 percent of the total number.

Fish larvae and juveniles were entrained throughout the year, the greatest densities occurring in February (Figure 3-3). Mean daily densities over the year, computed as the average of the densities for the eight 3-hour samples collected on each sampling date, ranged from $0.008/m^3$ to over $8.0/m^3$.

Of the 268 million fish eggs estimated to have been entrained at Units 2 and 3 and Unit 4 during the study period, 59 million (22 percent) were northern anchovy (Table 3-4). An estimated 0.06 million (less than 0.1 percent) were silversides. Fish eggs were entrained throughout the year, with greatest densities ($3.4/m^3$) in August (Figure 3-4). The rest were not identified below class Osteichthyes (bony fishes).

TABLE 3-4 ESTIMATED NUMBERS (millions) OF SELECTED ICHTHYOPLANKTON ENTRAINED AT THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979[a]

Taxon		Estimated Number						
		Units 2 & 3		Unit 4		Units 2, 3, & 4		
Common Name	Scientific Name	Total Number Entrained[b]	Standard Error[c]	Total Number Entrained	Standard Error	Total Number Entrained	Standard Error	Percentage Composition
Fish Larvae and Juveniles								
Total gobies[d]	Gobiidae	33.93	12.70	33.60	12.52	67.53	24.48	62.7
Bay goby	*Lepidogobius lepidus*	0.88	0.26	0.96	0.29	1.85	0.53	1.7
Arrow goby	*Clevelandia ios*	0.22	0.08	0.26	0.09	0.48	0.16	0.5
Yellowfin goby	*Acanthogobius flavimanus*	0.03	0.02	0.04	0.02	0.07	0.04	<0.1
Chameleon goby	*Tridentiger trigonocephalus*	0.02	*	0.02	*	0.05	0.02	<0.1
Unidentified gobies	Gobiidae	32.78	12.55	32.31	12.36	65.09	24.17	60.5
Pacific herring	*Clupea harengus pallasi*	15.86	4.74	14.20	4.38	30.06	8.85	27.9
Northern anchovy	*Engraulis mordax*	1.53	0.72	1.29	0.57	2.81	1.25	2.6
Plainfin midshipman	*Porichthys notatus*	0.74	0.22	0.60	0.20	1.34	0.40	1.2
Staghorn sculpin	*Leptocottus armatus*	0.30	0.11	0.31	0.11	0.61	0.22	0.6
Unidentified sculpins	Cottidae	0.29	0.12	0.20	0.10	0.49	0.21	0.5
White croaker	*Genyonemus lineatus*	0.15	0.05	0.15	0.05	0.30	0.10	0.3
Surf smelt	*Hypomesus pretiosus*	0.16	0.06	0.15	0.06	0.31	0.12	0.3
Silversides	Atherinidae	0.10	0.05	0.10	0.05	0.19	0.09	0.2
Smelts	Osmeridae	0.01	0.01	0.01	0.01	0.03	0.03	<0.1
Pipefish	*Syngnathus* sp.	0.01	0.01	0.01	0.01	0.02	0.02	<0.1
Bay pipefish	*Syngnathus leptorhynchus*	0.04	0.03	0.04	0.02	0.08	0.05	<0.1
Striped bass	*Morone saxatilis*	0.02	0.02	0.04	0.04	0.06	0.06	<0.1
Cabezon	*Scorpaenichthys marmoratus*	0.02	0.02	0.02	0.02	0.04	0.04	<0.1
English sole	*Parophrys vetulus*	0.01	0.01	0.01	0.01	0.03	0.03	<0.1
Osteichthyes - unidentified		1.91	0.57	1.83	0.55	3.74	1.08	3.5
TOTAL		55.10	17.59	52.54	17.02	107.64	33.60	
Fish Eggs								
Northern anchovy	*Engraulis mordax*	31.52	11.88	27.66	10.27	59.18	21.49	22.1
Silversides	Atherinidae	0.03	0.02	0.03	0.01	0.06	0.03	<0.1
Osteichthyes - unidentified		115.25	37.27	93.77	30.15	209.03	65.47	77.9
TOTAL		146.81	47.85	121.46	39.41	268.26	84.76	

(a) Estimates based on actual operating conditions.
(b) Computed using Equations 3-4 and 3-20.
(c) Computed using Equations 3-5 and 3-22.
(d) Includes identified and unidentified gobies.
Note: (*) indicates less than 10,000 organisms.

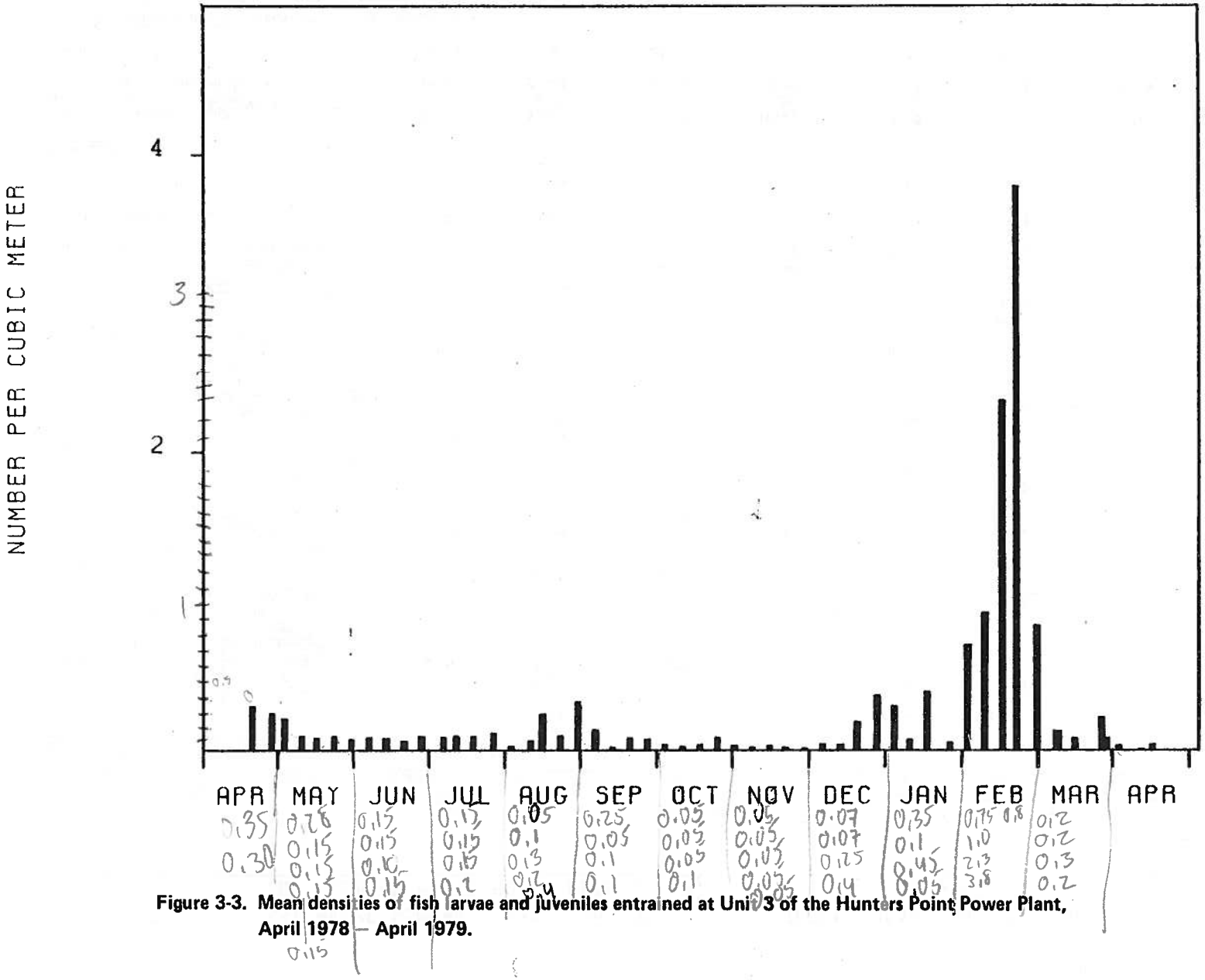


Figure 3-3. Mean densities of fish larvae and juveniles entrained at Unit 3 of the Hunters Point Power Plant, April 1978 – April 1979.

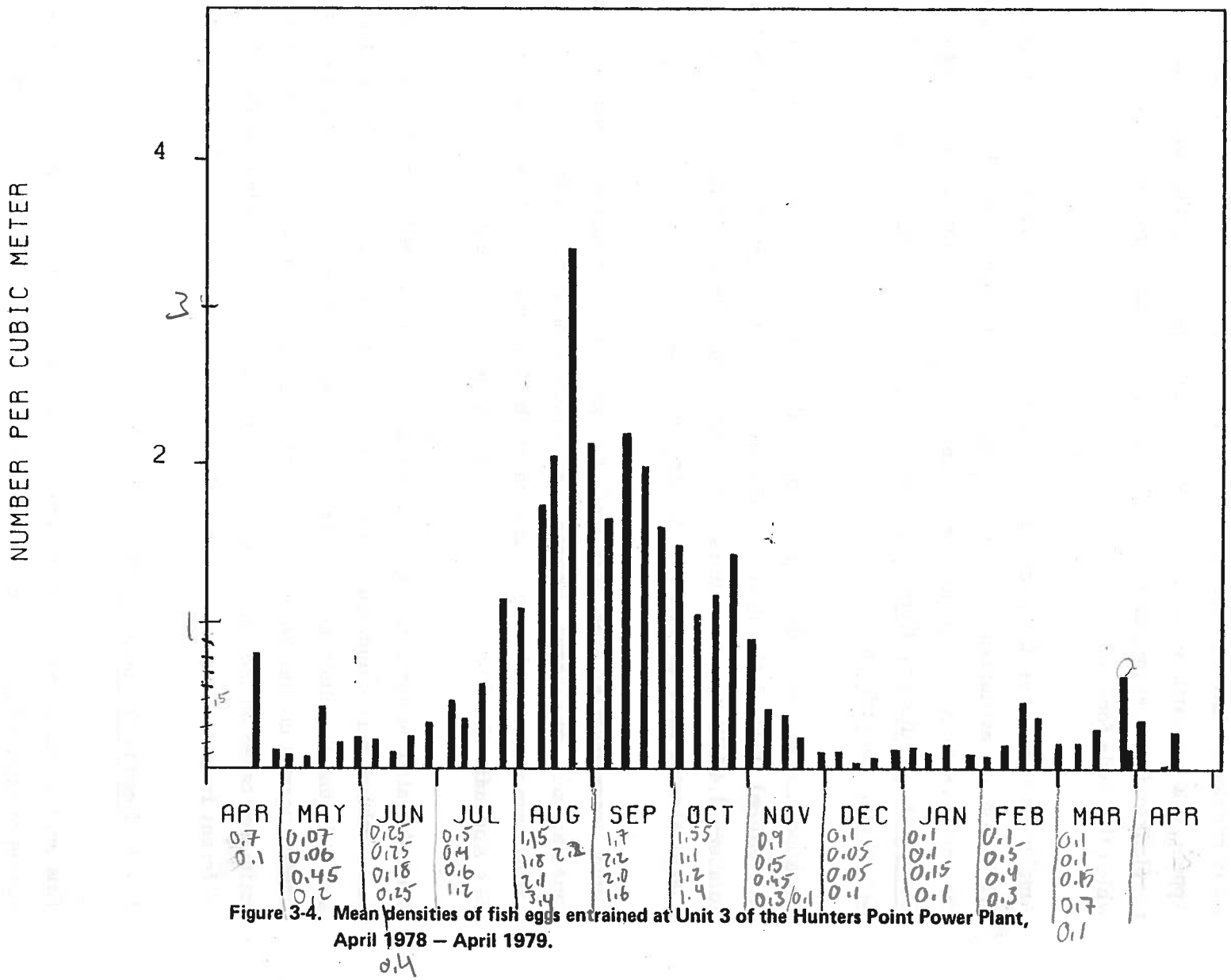


Figure 3-4. Mean densities of fish eggs entrained at Unit 3 of the Hunters Point Power Plant, April 1978 – April 1979.

Fish eggs, larvae, and juveniles were entrained predominantly at night (Table 3-5).

Many species of invertebrates were entrained at the Hunters Point Power Plant (see Appendix E for listings). A variety of holoplanktonic, meroplanktonic, and generally nonplanktonic invertebrates were collected in addition to the macroinvertebrates on which the study focused.

Amphipods were the most abundantly entrained macroinvertebrates (Table 3-6); 4.1 billion are estimated to have been entrained at Units 2 and 3 and Unit 4 during the one-year study. Amphipod species entrained in large numbers were Jassa falcata, Corophium insidiosum, Corophium spp., Caprella equilibra, Stenothoe valida, and Corophium acherusicum .

Decapod larvae were the second most abundantly entrained macroinvertebrates (1.8 billion) (Table 3-6). True crab (Brachyura) larvae were entrained in the greatest numbers (1.4 billion). Anomurans were next in abundance (372 million). True shrimps (Caridea) were the least abundantly entrained decapods.

Other macroinvertebrates entrained (in order of decreasing abundance) include tanaidaceans, cumaceans, isopods, and opossum shrimp. Arrow worms (Chaetognatha), were entrained in low numbers at the Hunters Point Power Plant (9 million) (See Appendix E). They are not discussed further in this section.

The estimated numbers of the entrained ichthyoplankton and macroinvertebrates discussed above were computed on the basis of actual cooling water flows at Units 2, 3, and 4 during the study period. Estimates were also computed on the basis of continuous normal cooling water flows (Section 2.1.3.2; Appendix E, Table E.1-1). The estimates based on the continuous normal flows are only slightly (less than 5 percent) different from those based on actual flows.

3.1.4 Results for Selected Taxa

This section discusses the entrainment abundance results for each species or taxon having relatively high entrainment or having potential economic importance.

TABLE 3-5 DIEL DISTRIBUTION OF ENTRAINMENT OF SELECTED ICHTHYOPLANKTON AND MACROINVERTEBRATES AT UNIT 3 OF THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979

Taxon		Sampling Period Start Time							
		0600	0900	1200	1500	1800	2100	2400	0300
Common Name	Scientific Name	Percentage of Total Numbers Collected							
Fish Larvae and Juveniles									
Pacific herring	*Clupea harengus pallasi*	17	8	3	5	8	21	18	19
Gobies	Gobiidae	12	4	2	2	14	33	17	17
Northern anchovy	*Engraulis mordax*	0	8	7	41	11	12	14	9
Plainfin midshipman	*Porichthys notatus*	7	0	0	0	12	21	36	25
Staghorn sculpin	*Leptocottus armatus*	10	4	0	5	8	46	18	9
White croaker	*Genyonemus lineatus*	8	8	0	0	17	18	41	8
Fish Eggs									
Northern anchovy	*Engraulis mordax*	9	15	14	13	10	14	11	15
Unidentified		2	2	2	8	26	41	11	7
Macroinvertebrates									
Amphipods	Amphipoda	8	20	13	13	10	16	8	13
Decapods	Decapoda								
True crabs	Brachyura								
Spider crabs	Majidae	2	10	7	21	25	30	2	2
Cancer crabs	Cancridae	2	4	19	13	7	33	9	13
Pebble crabs	Xanthidae	5	5	4	5	42	32	0	7
Pea crabs	Pinnotheridae	5	7	20	20	21	15	6	7
Shore crabs	Grapsidae	4	5	5	5	7	50	18	7

TABLE 3-5 (CONT.)

Taxon		Sampling Period Start Time							
		0600	0900	1200	1500	1800	2100	2400	0300
Common Name	Scientific Name	Percentage of Total Numbers Collected							
Anomurans	Anomura	6	3	2	1	1	7	16	64
True shrimp	Caridea	1	4	4	8	4	41	23	13
Tanaids	Tanaidacea	9	19	12	12	9	16	9	13
Cumaceans	Cumacea	11	4	2	7	14	23	12	27
Isopods	Isopoda	8	11	4	11	13	23	14	16
Opossum shrimp	Mysidacea	5	14	4	11	4	23	10	27

TABLE 3-6 ESTIMATED NUMBERS (millions) OF SELECTED[a] INVERTEBRATES ENTRAINED AT THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979[b]

Taxon		Estimated Number					
		Units 2 & 3		Unit 4		Units 2, 3, & 4	
Common Name	Scientific Name	Total Number Entrained[c]	Standard Error[d]	Total Number Entrained	Standard Error	Total Number Entrained	Standard Error
Amphipods	Amphipoda	2,160.00	430.39	1,922.05	385.60	4,082.05	781.47
	Corophium spp.	293.69	61.62	252.33	56.98	546.03	114.31
	C. acherusicum	38.49	9.86	34.64	10.15	73.12	19.34
	C. insidiosum	675.87	130.79	644.47	129.15	1,320.34	248.96
	Jassa falcata	829.86	203.59	771.98	180.52	1,601.84	371.57
	Stenothoe valida	164.22	49.38	77.85	21.51	242.08	53.05
	Caprella equilibra	43.62	10.18	43.93	10.82	87.55	20.25
Decapods	Decapoda	973.45	228.05	824.03	190.80	1,797.48	406.14
True crabs	Brachyura	765.72	194.57	624.73	153.99	1,390.45	338.38
Spider crabs	Majidae	28.55	7.48	20.71	5.40	49.26	12.46
Cancer crabs	Cancridae	113.27	29.45	85.94	25.42	199.21	53.01
Pebble crabs	Xanthidae	11.98	2.99	10.71	2.54	22.69	5.34
Pea crabs	Pinnotheridae	119.50	27.40	107.95	26.72	227.45	52.28
Shore crabs	Grapsidae	423.17	141.62	342.69	108.31	765.86	243.21
Anomurans	Anomura	188.59	50.67	183.08	53.03	371.67	100.44
Blue mud shrimp	*Upogebia pugettensis*	180.73	50.06	175.15	52.35	355.88	99.19
True shrimps	Caridea	17.32	3.84	14.55	3.23	31.87	6.84
Tanaids	Tanaidacea	113.96	21.14	95.74	18.10	209.70	37.46
	Leptochelia dubia	104.91	19.32	87.15	16.31	192.06	34.00
Cumaceans	Cumacea	79.51	16.12	64.02	13.04	143.53	27.60
	Cumella vulgaris	76.15	15.61	60.60	12.56	136.75	26.60
Isopods	Isopoda	21.60	5.53	24.33	7.01	45.94	12.09
	Epicaridea	16.02	4.56	19.63	6.31	35.64	10.45
Opossum shrimp	Mysidacea	11.74	3.27	9.30	2.46	21.05	5.48

decapods

See p. 3-32

(a) See Appendix E for data for other taxa collected.
(b) Estimates based on actual operating conditions.
(c) Computed using Equations 3-4 and 3-20.
(d) Computed using Equations 3-5 and 3-22.

3.1.4.1 Gobies (Gobiidae)

Gobies were the most abundantly entrained larval and juvenile fish; an estimated 68 million were entrained, constituting 63 percent of the total numbers of fish larvae and juveniles entrained (Table 3-4). No goby larvae were identified to the species level with certainty, because of incomplete descriptions of larval characteristics and overlapping taxonomic characteristics between species. However, at least seven species are known to inhabit the San Francisco Bay (Aplin 1967; Miller and Lea 1972, 1976; Moyle 1976), and juveniles of at least four species were entrained: arrow goby, bay goby, chameleon goby, and yellowfin goby. Goby eggs were not identified, but because the eggs are demersal and are often laid in burrows (Weisel 1947; Prasad 1959; Moyle 1976), they are probably not entrained in large numbers at the Hunters Point Power Plant. Goby larvae and juveniles were entrained throughout the year, but were most abundant (up to $3.2/m^3$) during February and early March (Figure 3-5). Goby larvae and juveniles were entrained predominantly at night: 19 percent during the day (0600-1800 hours) and 81 percent at night (1800-0600 hours) (Table 3-5). Entrained gobies ranged in length from 2 to 72 mm (Table 3-7); mean length was 6.2 mm, and most were less than 8 mm long.

3.1.4.2 Pacific Herring (Clupea harengus pallasi)

Pacific herring was the second most abundantly entrained larval and juvenile fish taxon: an estimated 30 million were entrained, representing 28 percent of the total numbers entrained (Table 3-4). Larvae and yolk-sac larvae were entrained from November through March, and a few juveniles were entrained in May and July (Figure 3-6). Peak larval densities (up to $0.8/m^3$) occurred during February, coincidentally with the major spawning of herring (Thomas and Dahlstrom 1979). Larvae were entrained predominantly at night: 34 percent were entrained during the day and 66 percent during the night (Table 3-5). The larvae and juveniles ranged in size (total length) from 4 to 48 mm (Table 3-7); mean length was 7.7 mm. Pacific herring eggs were not entrained; they are adhesive and attach to the substrate (Frey 1971).

3.1.4.3 Northern Anchovy (Engraulis mordax)

An estimated 59 million northern anchovy eggs were entrained, constituting 22 percent of the ichthyoplankton eggs entrained (Table 3-4). They were entrained nearly

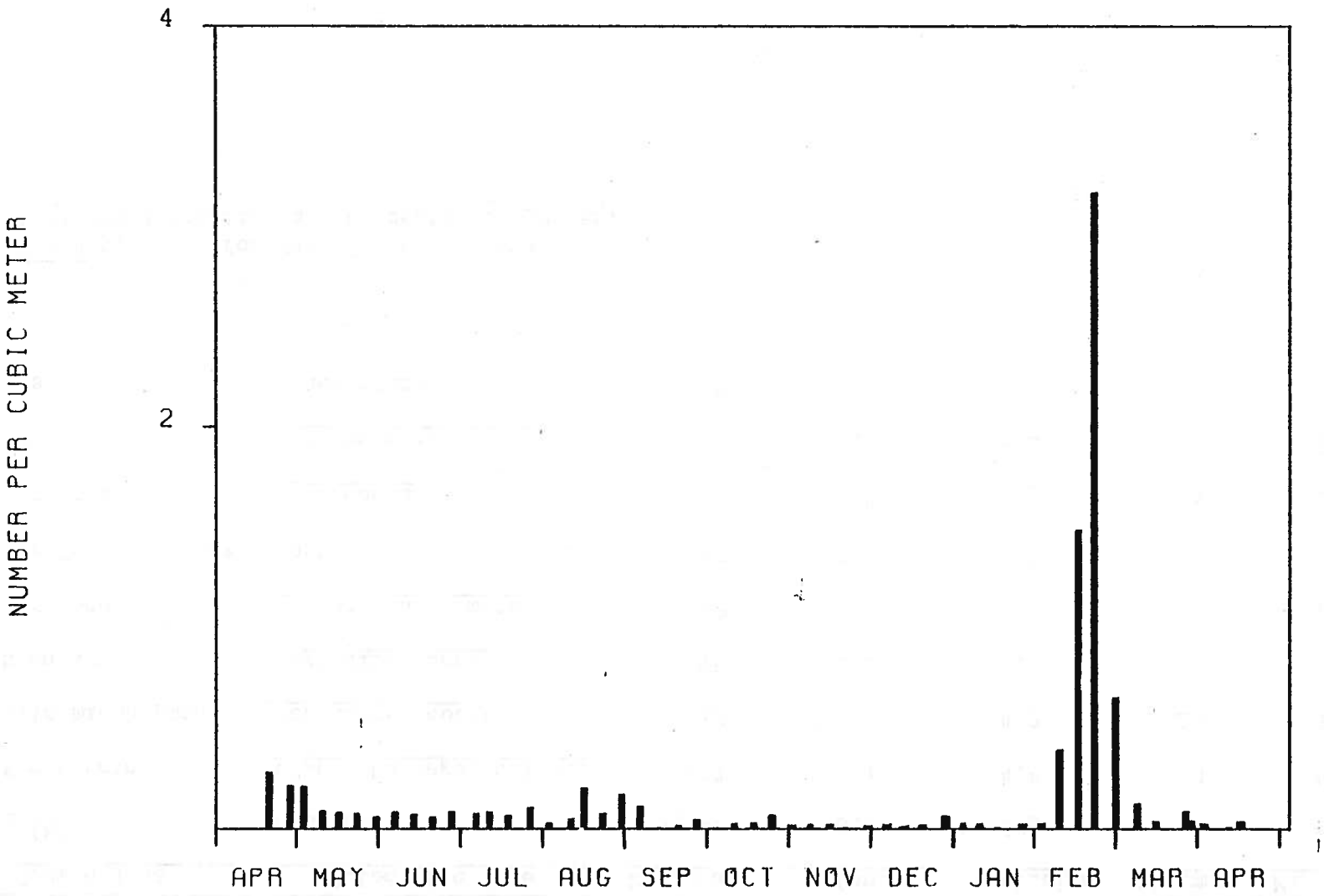


Figure 3-5. Mean densities of goby larvae and juveniles entrained at Unit 3 of the Hunters Point Power Plant, April 1978 – April 1979.

TABLE 3-7 LENGTH STATISTICS FOR SELECTED[a] ICHTHYOPLANKTON TAXA ENTRAINED AT THE HUNTERS POINT POWER PLANT UNIT 3

Taxon		Number Measured	Mean Length (mm)	Standard Deviation	Size Range (mm)	
Common Name	Scientific Name				Minimum	Maximum
Gobies[b]	Gobiidae	1,349	6.2	6.3	2	72
Pacific herring	*Clupea harengus pallasi*	637	7.7	4.4	4	48
Plainfin midshipman	*Porichthys notatus*	52	32.0	4.9	25	50
Northern anchovy	*Engraulis mordax*	45	29.5	23.1	6	82
Staghorn sculpin	*Leptocottus armatus*	22	6.7	2.5	4	12
Unidentified sculpins	Cottidae	17	5.9	1.7	4	9
White croaker	*Genyonemus lineatus*	12	9.4	4.7	5	21
Surf smelt	*Hypomesus pretiosus*	9	44.1	5.8	35	52
Silversides	Atherinidae	8	5.9	0.4	5	6

(a) See Appendix E for data for other taxa.
(b) Includes identified and unidentified gobies.

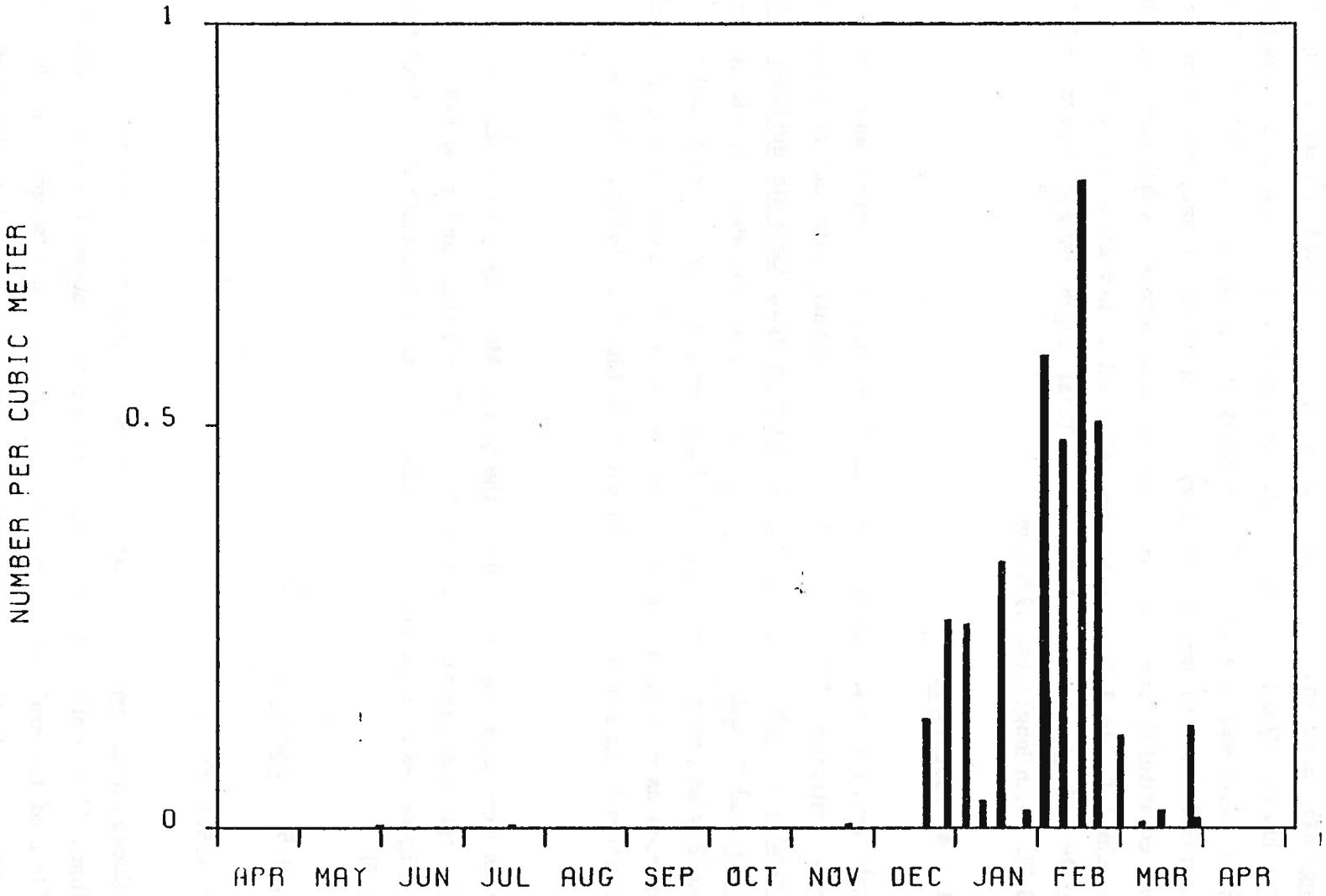


Figure 3-6. Mean densities of Pacific herring larvae and juveniles entrained at Unit 3 of the Hunters Point Power Plant, April 1978 – April 1979.

year-round, except for the period from mid-November through mid-February (Figure 3-7). Eggs were most abundant in March and April (up to $0.64/m^3$) and in August and September (up to $1.7/m^3$), coinciding with the winter-spring and fall spawning periods (Frey 1971). Eggs were entrained about equally during the day and night (Table 3-5). An estimated 2.8 million northern anchovy yolk-sac larvae, larvae, and juveniles were entrained, constituting only 2.6 percent of the total number of fish larvae and juveniles entrained (Table 3-4). They were entrained in low densities (up to $0.14/m^3$) sporadically throughout most of the year. Total lengths ranged from 6 to 82 mm (Table 3-7). Mean length was 29.5 mm.

3.1.4.4 Amphipods

Amphipods were the most abundantly entrained macroinvertebrates: an estimated 4.1 billion were entrained (Table 3-6). The most abundantly entrained amphipods were *Jassa falcata*, *Corophium insidiosum*, *Corophium* spp., *Caprella equilibra*, *Stenothoe valida*, and *Corophium acherusicum*. These taxa are widely distributed in San Francisco Bay and other wave-protected bays along the Pacific coast, and they have been reported as very abundant in surveys of the benthic community in the vicinity of the Hunters Point Power Plant (PGandE 1973; Liu et al. 1975; Brown and Caldwell 1975).

Amphipods were entrained throughout the year. Mean daily densities were greater during the spring and summer months (up to $29.8/m^3$) than during the fall and winter months (Figure 3-8). Amphipods were entrained fairly uniformly throughout the day (Table 3-5).

3.1.4.5 Decapods

3.1.4.5.1 Crabs

Of the decapods the true crabs (Brachyura) were entrained in the greatest numbers (1.4 billion). Five families of true crabs were entrained during the study period (Table 3-6). Most of the crabs entrained were in the zoeal life stage. The shore crabs (Grapsidae) were entrained in the greatest numbers (766 million) (Table 3-6). Pea crabs (Pinnotheridae) and *Cancer* crabs (Cancridae) were also abundant; an estimated 277 million pea crab and 199 million *Cancer* crab zoeae and megalopae were entrained

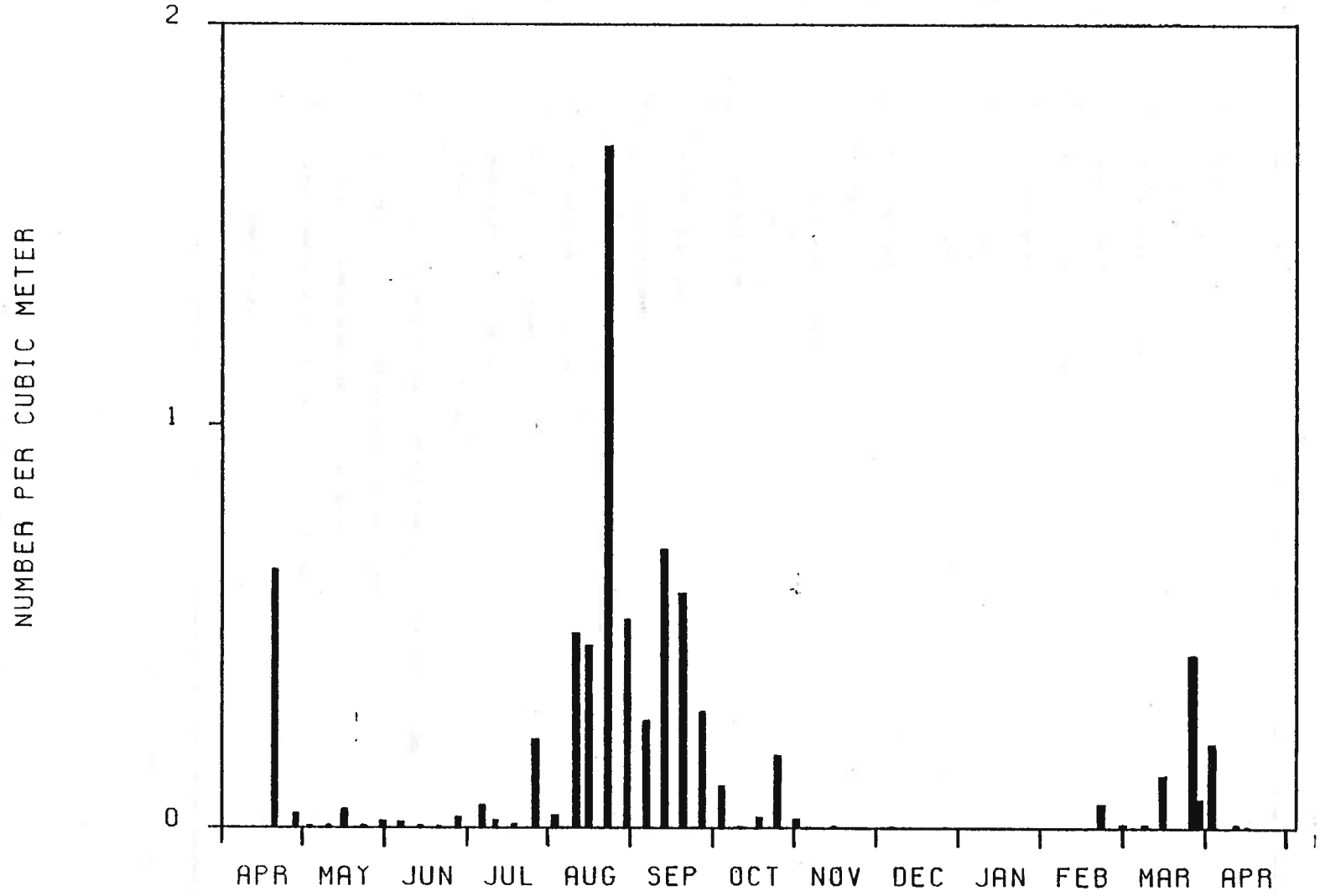


Figure 3-7. Mean densities of northern anchovy eggs entrained at Unit 3 of the Hunters Point Power Plant, April 1978 – April 1979.

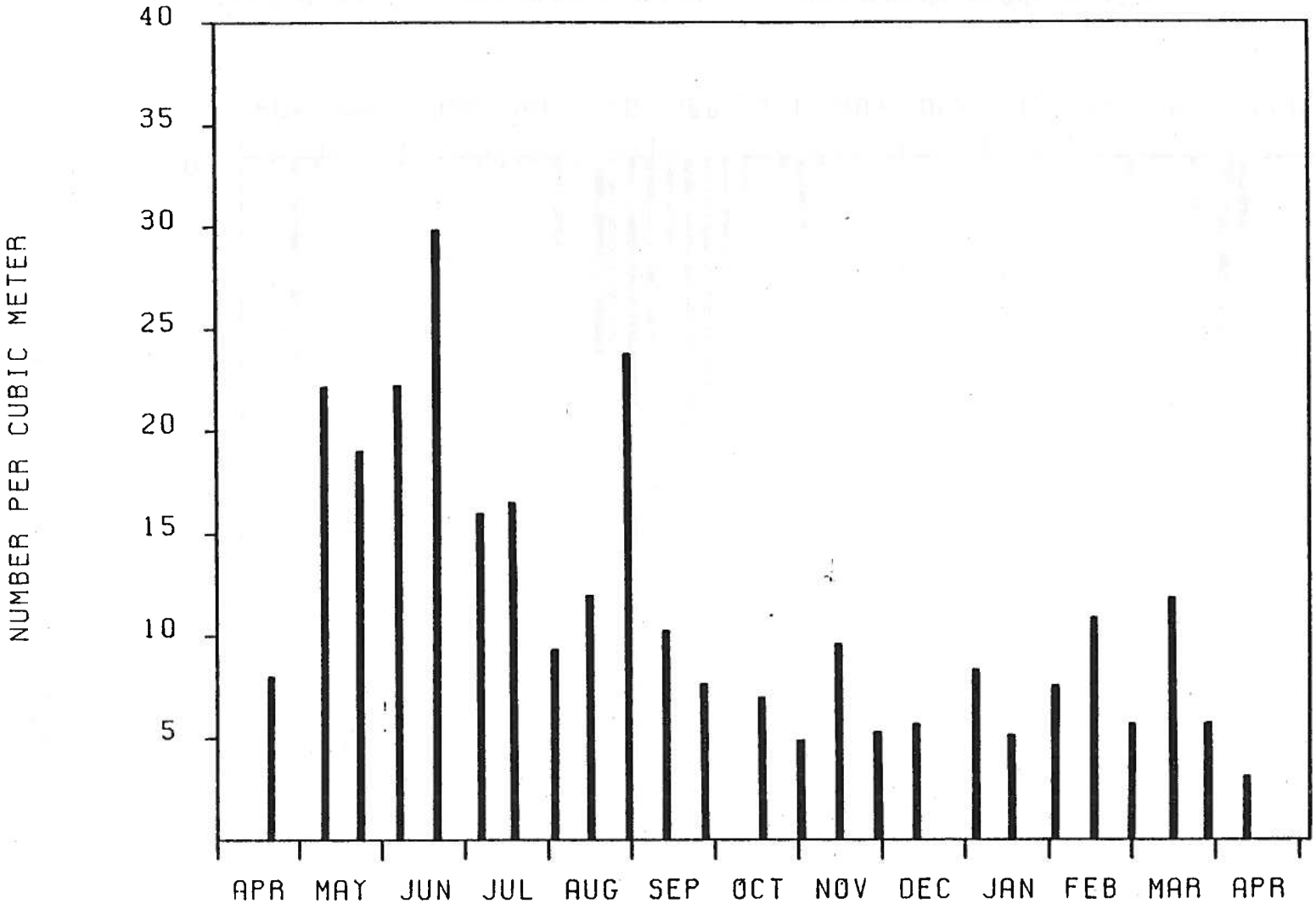


Figure 3-8. Mean densities of amphipods entrained at Unit 3 of the Hunters Point Power Plant, April 1978 – April 1979.

during the study period (Table 3-6). Three species of Cancer crabs were identified: C. antennarius, C. gracilis, and C. productus. Dungeness crab (C. magister) zoeae and megalopae were not entrained.

Shore crabs, mainly Hemigrapsis oregonensis and Pachygrapsis crassipes, were entrained predominantly during midsummer: mean daily densities of up to 17.9/m^3 were observed in mid-August. Pea crabs (Pinnotheridae) were entrained throughout the year but in greatest densities in February-March and June-August (up to 2.5/m^3). Cancer crabs were entrained throughout the year; densities ranged from zero in June to 1.9-2.1/m^3 in September and March (Figure 3-9). Spider crabs (Majidae) were entrained mainly during the summer months (up to 0.82/m^3), and pebble crabs (Xanthidae) were entrained sporadically, with densities not exceeding 0.22/m^3.

All crabs except pea crabs were entrained predominantly at night; pea crabs were entrained equally during the day and night (Table 3-5).

3.1.4.5.2 Anomurans

Anomurans were the next most abundant decapods entrained (372 million) (Table 3-6). The blue mud shrimp, Upogebia pugettensis, was the most abundantly entrained anomuran (356 million). Mean daily densities of U. pugettensis larvae and juveniles were high during the winter months (up to 8.4/m^3), but decreased to zero during the late spring and summer (Figure 3-10). This shrimp reproduces in winter, and juveniles settle out of the water column in late spring (Ricketts and Calvin 1968). Eighty-eight percent were entrained at night and 12 percent during the day (Table 3-5).

3.1.4.5.3 True Shrimps

The carideans, or true shrimps, were the least abundant decapods entrained at the Hunters Point Power Plant (32 million) (Table 3-6). Species entrained included Palaemon macrodactylus and Crangon spp. Carideans were entrained practically throughout the year; densities ranged from zero to 0.45/m^3. Eighty-two percent were entrained at night and 18 percent during the day (Table 3-5).

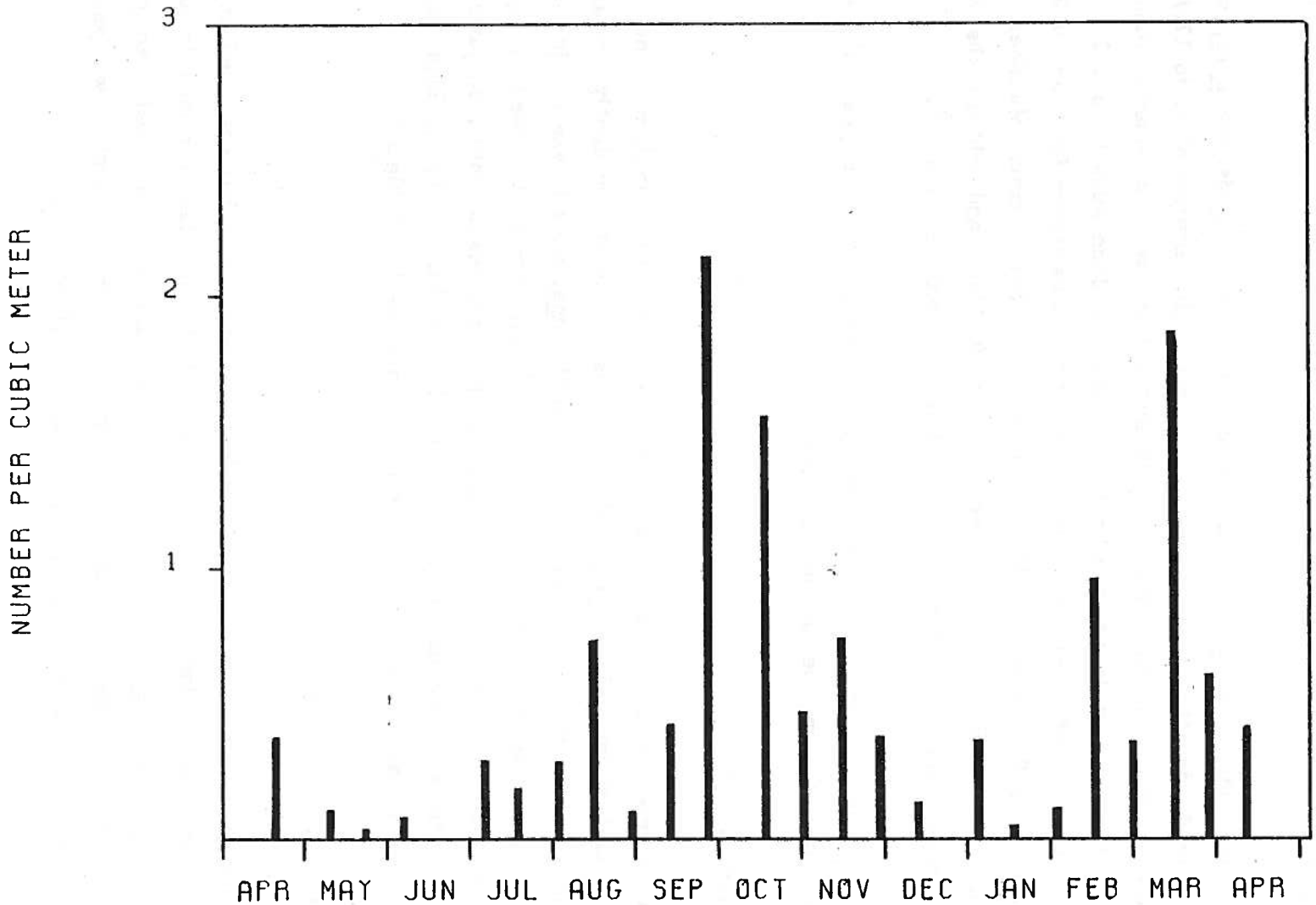


Figure 3-9. Mean densities of Cancer spp. crabs entrained at Unit 3 of the Hunters Point Power Plant, April 1978 – April 1979.

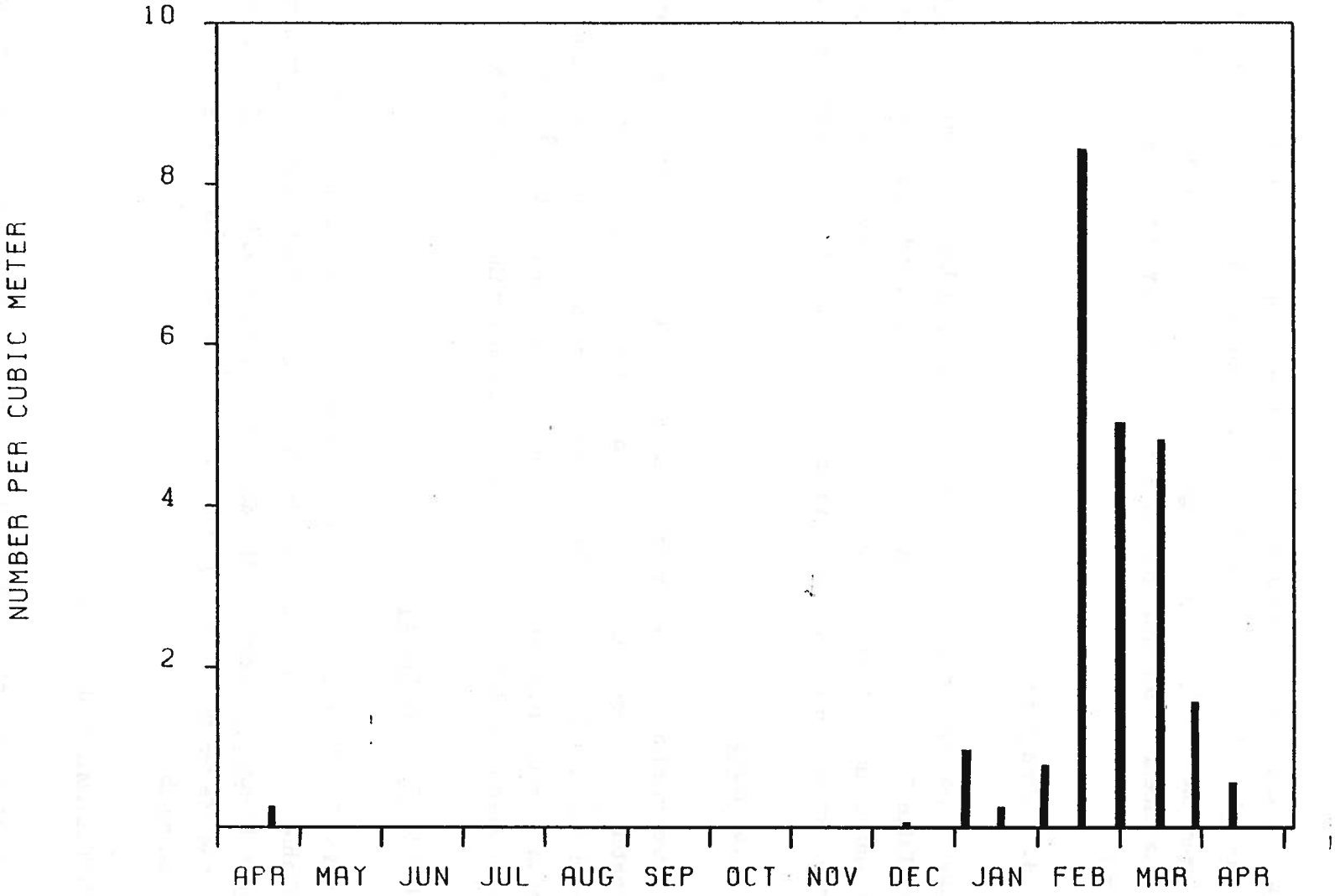


Figure 3-10. Mean densities of Upogebia pugettensis entrained at Unit 3 of the Hunters Point Power Plant, April 1978 – April 1979.

3.1.4.6 Tanaidaceans

An estimated 210 million tanaidaceans were entrained, 192 million of which were *Leptochelia dubia* (Table 3-6). Tanaidaceans were entrained fairly uniformly throughout the year; mean daily densities ranged from $0.14/m^3$ in February to $1.03/m^3$ in June. Tanaidaceans were entrained with equal frequency during the day and night (Table 3-5).

3.1.4.7 Cumaceans

An estimated 144 million cumaceans were entrained, including 137 million *Cumella vulgaris* (Table 3-6). Cumaceans were entrained in greatest densities from August through March (up to $1.1/m^3$). Densities declined to as low as $0.08/m^3$ in April. Seventy-six percent were entrained at night and 24 percent during the day (Table 3-5).

3.1.4.8 Isopods

Isopods were entrained in lower numbers than most other macroinvertebrate groups: an estimated 46 million were entrained, 36 million of which were of the parasitic suborder Epicaridea (Table 3-6). Isopods were entrained practically throughout the year; mean daily densities ranged from zero in late August to $0.82/m^3$ in May. Sixty-six percent were entrained at night and 34 percent during the day (Table 3-5).

3.1.4.9 Opossum Shrimp

An estimated 21 million opossum shrimp (Mysidacea) were entrained during the one-year study (Table 3-6). The more abundantly entrained species were *Acanthomysis macropis* and *Neomysis mercedis*. Mysidaceans were entrained in low densities throughout the year (fewer than $0.24/m^3$). Sixty-six percent were entrained at night and 34 percent during the day (Table 3-5).

3.2 ENTRAINMENT SURVIVAL

In this section the potential survival of fish eggs and larvae and macroinvertebrates entrained into the cooling water systems of the Hunters Point Power Plant is assessed.

3.2.1 Introduction

Entrainment survival is a function of (1) the proportion of organisms entering the intake that complete cooling system passage, and (2) of the proportion of those organisms completing passage that survive. Organisms may be lost during cooling system passage, possibly by being preyed upon by fouling organisms lining intake structures or cooling system conduits. The proportion lost (i.e., not completing passage) is designated as p_L. A proportion of the organisms completing passage may not survive the combined physical, thermal, and biocidal stresses of entrainment; this proportion is designated as p_e. The overall proportion of entrained organisms not surviving entrainment (p_N) is a function of both p_L and p_e:

$$p_N = p_L + (1 - p_L)\, p_e \qquad (3\text{-}23)$$

That is, the overall proportion not surviving entrainment equals the proportion not completing passage plus that part of the proportion completing passage that does not survive.

The proportion lost (p_L) was estimated in Section 3.1.2.2 on the basis of the results of the intake-discharge mass balance study. Estimates of p_L for fish larvae, fish eggs, and macroinvertebrates reported are 0.76, 0.53, and 0.70, respectively. These results indicate that up to three-fourths of the organisms entrained do not complete cooling system passage. This is probably the result of predation by fouling organisms living on the walls of the cooling water system conduits.

In Section 3.2.2, the proportion of those organisms completing passage that do not survive (p_e) is estimated on the basis of the results of pertinent laboratory and field studies reviewed in Appendix B. Studies reviewed include entrainment survival studies conducted at the neighboring Potrero Power Plant, other PGandE plants, and plants outside the PGandE system. A single estimate of p_e is provided in Section 3.2.2 for fish larvae, fish eggs, and macroinvertebrates. The estimates of p_L and p_e are substituted into Equation 3-23 to compute the overall proportion not surviving entrainment.

In Section 3.3, the overall proportion not surviving entrainment is used in estimating total entrainment losses of fish larvae, fish eggs, and macroinvertebrates at the Hunters Point Power Plant.

3.2.2 Estimating Entrainment Survival at the Hunters Point Power Plant

Entrainment survival is influenced by physical, thermal, and chemical (biocidal) stresses potentially experienced by entrained organisms during cooling water system passage.

Entrained organisms appear to be tolerant of the physical stresses associated with condenser passage, based on the results of condenser-simulator studies reported in Appendix B. The only physical stress that has been isolated and quantified in the laboratory is pressure. Pressure increases at the circulating water pump are not expected to cause significant entrainment mortality, but pressure decreases greater than one atmosphere (about 15 psi) across the condensers may damage entrained organisms. At the Hunters Point Power Plant, pressure decreases across the condensers are small (5.4 to 5.7 psi) (Section 2.1.2), even compared to those reported at many other power plants where high survival of some entrained species has been demonstrated. Pressure decreases at the Hunters Point Power Plant are therefore not expected to cause significant entrainment mortality.

The laboratory thermal tolerance studies reviewed in Appendix B indicate that most species of fish and macroinvertebrate tested are capable of tolerating short exposures to temperatures less than 30 C (86 F), although thermal tolerance varies widely among species and among life stages within species. Some species are capable of tolerating short exposures to temperatures as high as 40 C (104 F). At the Hunters Point Power Plant, discharge temperatures rarely exceed 30 C (86 F). Over 98 percent of the discharge temperatures recorded from April 1978 to April 1979 were lower than 30 C (86 F) at Units 2, 3, and 4 (Sections 2.1.3.2.1 and 2.1.3.2.2). Temperatures over 30 C (86 F) generally occurred only between June and August, a period of minimal entrainment of larval fish. Periods of exposure to maximum temperatures within the cooling water system are short (1-3 minutes) (Table 2-1). In the discharge plume, temperatures drop rapidly to within 4-7 C (7-13 F) of ambient, but thereafter decay slowly (Section 2.1.3.2.1). Temperatures remain 3-5 C (5-9 F) above ambient for at least 60 minutes from the time of discharge, thereby extending the period of exposure to elevated temperature. However, given the low initial discharge temperatures, the extended thermal decay is not expected to be a significant cause of entrainment mortality at the Hunters Point Power Plant.

Entrainment survival may be reduced during periods of condenser chlorination. At the Hunters Point Power Plant the condensers of each unit are presently chlorinated once a day for 30-minutes. During these periods, total residual chlorine (TRC) concentrations at the condenser inlet are maintained at approximately 0.4 mg/liter (Sections 2.1.2.1 and 2.1.2.2). Concentrations in the cooling water are reduced by dechlorination to 0.0 mg/liter residual chlorine prior to discharge. The most sensitive marine organisms have been estimated to be tolerant of 0.34 mg/liter TRC when exposure duration is limited to 5 minutes (Appendix B). As exposure duration increases to 60 minutes, the maximum concentration tolerated drops to 0.14 mg/liter. On the basis of these estimates, some of the more sensitive marine organisms entrained at the Hunters Point Power Plant may not survive the chlorine exposures. However, given the low chlorine residuals, the short exposure times, and the infrequency of chlorination, 2 percent of the time, the overall effect on marine organisms is considered minimal.

Field studies of entrainment survival (summarized in Appendix B) demonstrate that at discharge temperatures below 30 C survival may be as high as 100 percent. Survival has been shown to vary widely among species. The most sensitive larval fish families include Clupeidae, Engraulidae, Atherinidae, and Ammodytidae. Survival of macroinvertebrates is generally higher than that of fish larvae.

At other PGandE plants, entrainment survival has been shown to be high when discharge temperatures remain below 30 C. Survival of striped bass larvae and juveniles averaged 61 percent at the Pittsburg Power Plant and 80 percent at the Contra Costa Power Plant. Survival of the opossum shrimp Neomysis mercedis averaged 90 percent at Pittsburg and 72 percent at Contra Costa, and survival of gammaridean amphipods averaged 96 percent at Pittsburg and 95 percent at Contra Costa (Ecological Analysts, unpublished data). Survival of Pacific herring, a sensitive clupeid species, averaged 79 percent at the Potrero Power Plant (PGandE 1980), considerably higher than the values observed for clupeids at plants outside the PGandE system.

Based on these results and on the conclusions drawn from the laboratory studies discussed above and in Appendix B, it was concluded that entrainment survival of organisms completing passage through the Hunters Point Power Plant is high--on the order of 75 percent or higher. For purposes of estimating total entrainment losses, 75 percent survival of organisms completing cooling system passage has been assumed,

which translates to an estimate of p_e, the proportion not surviving, equal to 0.25 (i.e., 25 percent mortality).

Substituting the estimates of p_L, the proportion lost during cooling system passage, from Section 3.1.2.2 and the above estimate of p_e (0.25) into Equation 3-23, and expressing the result in terms of percentage survival, overall entrainment survival at the Hunters Point Power Plant for fish larvae, fish eggs, and macroinvertebrates is estimated at 18, 35, and 23 percent, respectively. Despite the expected high (75 percent) survival of organisms completing cooling system passage, the high proportions lost due to cropping by predation in the system result in low overall survival estimates.

3.3 ESTIMATION OF TOTAL ENTRAINMENT LOSSES AT THE HUNTERS POINT POWER PLANT

Total entrainment losses of ichthyoplankton and macroinvertebrates at Hunters Point Power Plant were estimated by multiplying the estimates of total numbers entrained (Section 3.1) by the net proportions not surviving entrainment (Section 3.2).

An estimated 88 million fish larvae and juveniles and 174 million fish eggs were lost to entrainment during the one-year study (April 1978 - April 1979) (Table 3-8). Macroinvertebrate losses were estimated to be 3.1 billion amphipods, 1.4 billion decapods, 161 million tanaids, 111 million cumaceans, 35 million isopods, and 16 million mysids (Table 3-9).

3.4 ENTRAINMENT SUMMARY

Densities of entrained ichthyoplankton and macroinvertebrates were monitored at the Hunters Point Power Plant Unit 3 for a period of one year (20 April 1978 - 16 April 1979). Cooling water was sampled from the well-mixed discharge, and corrections were made for through-plant losses of entrained organisms. These losses were attributed to predation by fouling organisms lining cooling system conduits.

The most abundant fish larvae and juveniles entrained were gobies and Pacific herring. Northern anchovy, plainfin midshipman, staghorn and other sculpins, surf smelt, white

TABLE 3-8 ESTIMATED ANNUAL ENTRAINMENT LOSSES (millions) OF ICHTHYOPLANKTON AT THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979[a]

Taxon		Estimated Loss		
Common Name	Scientific Name	Units 2 & 3	Unit 4	Total
Fish Larvae and Juveniles				
Total gobies	Gobiidae	27.82	27.55	55.37
Bay goby	*Lepidogobius lepidus*	0.72	0.79	1.52
Arrow goby	*Clevelandia ios*	0.18	0.21	0.39
Yellowfin goby	*Acanthogobius flavimanus*	0.02	0.03	0.06
Chameleon goby	*Tridentiger trigonocephalus*	0.02	0.02	0.04
Unidentified gobies	Gobiidae	26.88	26.49	53.37
Pacific herring	*Clupea harengus pallasi*	13.01	11.64	24.65
Northern anchovy	*Engraulis mordax*	1.25	1.06	2.30
Plainfin midshipman	*Porichthys notatus*	0.61	0.49	1.10
Staghorn sculpin	*Leptocottus armatus*	0.25	0.25	0.50
Unidentified sculpins	Cottidae	0.24	0.16	0.40
White croaker	*Genyonemus lineatus*	0.12	0.12	0.25
Surf smelt	*Hypomesus pretiosus*	0.13	0.12	0.25
Silversides	*Atherinidae*	0.08	0.08	0.16
Bay pipefish	*Syngnathus leptorhynchus*	0.03	0.03	0.07
Striped bass	*Morone saxatilis*	0.02	0.03	0.05
Cabezon	*Scorpaenichthys marmoratus*	0.02	0.02	0.03
Smelts	Osmeridae	0.01	0.01	0.02
Pipefish	*Syngnathus* sp.	0.01	0.01	0.02
English sole	*Parophrys vetulus*	0.01	0.01	0.02
Osteichthyes - unidentified		1.57	1.50	3.07
Total		45.18	43.08	88.26

(a) Estimates are based on actual operating conditions and 82 percent entrainment mortality for ichthyoplankton; 65 percent entrainment mortality for fish eggs.

Note: There may be discrepancies in column totals that are due to rounding.

TABLE 3-8 (CONT.)

Taxon		Estimated Loss		
Common Name	Scientific Name	Units 2 & 3	Unit 4	Total
Fish Eggs				
Northern anchovy	*Engraulis mordax*	20.49	17.98	38.47
Silversides	Atherinidae	0.02	0.02	0.04
Osteichthyes - unidentified		74.91	60.95	135.87
Total		95.43	78.95	174.37

TABLE 3-9 ESTIMATED ANNUAL ENTRAINMENT LOSSES (millions) OF SELECTED[a] INVERTEBRATES AT THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979[b]

Taxon		Estimated Loss		
Common Name	Scientific Name	Units 2 & 3	Unit 4	Total
Amphipods	Amphipoda	1,663.20	1,479.98	3,143.18
	Corophium spp.	226.14	194.29	420.44
	C. acherusicum	29.64	26.67	56.30
	C. insidiosum	520.42	496.24	1,016.66
	Jassa falcata	638.99	594.42	1,233.42
	Stenothoe valida	126.45	59.94	186.40
	Caprella equilibra	33.59	33.83	67.41
Decapods	Decapoda	749.56	634.50	1,384.06
True crabs	Brachyura	589.60	481.04	1,070.65
Spider crabs	Majidae	21.98	15.95	37.93
Cancer crabs	Cancridae	87.22	66.17	153.39
Pebble crabs	Xanthidae	9.22	8.25	17.47
Pea crabs	Pinnotheridae	92.02	83.12	175.14
Shore crabs	Grapsidae	325.84	263.87	589.71
Anomurans	Anomura	145.21	140.97	286.19
Blue mud shrimp	*Upogebia pugettensis*	139.16	134.87	274.03
True shrimps	Caridea	13.34	11.20	24.54
Tanaids	Tanaidacea	87.75	73.72	161.47
	Leptochelia dubia	80.78	67.11	147.89

Includes dungeness

(a) See Appendix E for data for other taxa collected.
(b) Estimates based on actual operating conditions and 77 percent entrainment mortality.

NOTE: There may be discrepancies in column totals that are due to rounding.

TABLE 3-9 (CONT.)

Taxon		Estimated Loss		
Common Name	Scientific Name	Units 2 & 3	Unit 4	Total
Cumaceans	Cumacea	61.22	49.30	110.52
	Cumella vulgaris	58.64	46.66	105.30
Isopods	Isopoda	16.63	18.73	35.37
	Epicaridea	12.34	15.12	27.44
Opossum shrimp	Mysidae	9.04	7.16	16.21

croaker, silversides, and other species were entrained in much lower numbers. A total of 108 million fish larvae and juveniles are estimated to have been entrained at Units 2, 3, and 4 during the study period. A total of 268 million fish eggs are estimated to have been entrained, 22 percent of which were those of northern anchovy.

A variety of invertebrates were entrained, the majority of which were copepods, barnacle larvae, and other small zooplankton. Major macroinvertebrates entrained, in order of decreasing abundance, were amphipods (4.1 billion), decapod larvae (1.8 billion), tanaidaceans (210 million), cumaceans (144 million), isopods (46 million), and mysidaceans (21 million).

Estimated overall entrainment survival for fish larvae, fish eggs, and macroinvertebrates at the Hunters Point Power Plant is 18, 35, and 23 percent, respectively. Overall survival is low because of significant through-plant losses of entrained organisms. Actual survival of the small proportions of organisms completing cooling system passage was estimated to be high (75 percent), based on the results of pertinent laboratory and field studies.

Total entrainment losses of ichthyoplankton and macroinvertebrates were estimated based on the total numbers entrained during the one-year study and the estimated proportions surviving entrainment. An estimated 88 million fish larvae and juveniles and 174 million fish eggs were lost to entrainment. Macroinvertebrate entrainment losses were estimated at 3.1 billion amphipods, 1.4 billion decapods, 161 million tanaidaceans, 111 million cumaceans, 35 million isopods, and 16 million mysidaceans.

3.5 REFERENCES

Aplin, J. A. 1967. Biological survey of San Francisco Bay, 1963-1966. Calif. Dep. Fish Game, Mar. Resour. Oper., MRO Ref. 67-4. 131 pp.

Brown and Caldwell (BC). 1975. A predesign report on marine waste disposal. Volume IV. Prepared for City and County of San Francisco. BC, San Francisco.

Cochran, W. G. 1977. Sampling techniques. 3rd ed. Wiley, New York. 428 pp.

Frey, H. W., ed. 1971. California's living marine resources and their utilization. California Department of Fish and Game. 148 pp.

Liu, D. H. W., K. D. Martin, and C. R. Norwood. 1975. San Francisco Bay benthic community study: technical evaluation. Prepared for U.S. Army Engineer District, San Francisco, Corps of Engineers. Contract DACW 07-74-C-0005. SRI Project LSU-2894. Stanford Research Institute, Menlo Park, Calif. 244 pp.

Miller, D. J. and R. N. Lea. 1972, 1976. Guide to the coastal marine fishes of California. Calif. Dep. Fish Game, Fish Bull. 157. 249 pp.

Moyle, P. B. 1976. Inland fishes of California. University of California Press, Berkeley. 405 pp.

Ostle, B. and R. W. Mensing. 1975. Statistics in research. 3rd ed. Iowa State University Press, Ames. 596 pp.

Pacific Gas and Electric Company (PGandE). 1973. An evaluation of the effect of cooling water discharges on the beneficial uses of receiving waters at Hunters Point Power Plant. PGandE, San Francisco.

Pacific Gas and Electric Company (PGandE). 1977. Hunters Point Power Plant cooling water intake report and 316(b) study plan. Revised edition. Submitted to California Regional Water Quality Control Board, San Francisco Bay Region. PGandE, San Francisco.

Pacific Gas and Electric Company (PGandE). 1980. Potrero Power Plant cooling water intake structures 316(b) demonstration. Prepared by Ecological Analysts, Inc. PGandE, San Francisco.

Prasad, R. R. 1959. Reproduction in Clevelandia ios (Jordan and Gilbert), with an account of the embryonic and larval development. Proc. Natl. Inst. Sci. India, Part B, Biol. Sci. 25B(1):12-30.

Ricketts, E. F. and J. Calvin. 1968. Between Pacific tides. 4th ed. Revised by J. W. Hedgpeth. Stanford University Press, Stanford, Calif. 614 pp.

Thomas, D. H. and W. A. Dahlstrom. [1979]. Summary of the 1978-1979 California herring season. Draft. California Department of Fish and Game, Menlo Park. 6 pp.

Weisel, G. F., Jr. 1947. Breeding behavior and early development of the mudsucker, a gobiid fish of California. Copeia 1947(2):77-85.

Yamane, T. 1967. Elementary sampling theory. Prentice-Hall, Englewood Cliffs, N.J. 405 pp.

Chapter 4

Impingement

4.1 Impingement Abundance

4.2 Impingement Survival

4.3 Estimation of Total Impingement Losses at the Hunters Point Power Plant

4.4 Impingement Summary

4.5 References

CHAPTER 4: IMPINGEMENT

Impingement and entrainment (Chapter 3) are the two principal ways in which cooling water intakes can adversely impact aquatic organisms. Impingement occurs when an organism is held against the intake screens used to remove debris from the cooling water. The damage incurred by fish and macroinvertebrates impinged on intake screens depends on species, life stage, and size. The extent of impingement damage is also directly related to intake water velocities, duration of impingement, and techniques of handling impinged organisms and returning them to the water body. Factors contributing to the abundance and survival of impinged organisms have been the subject of numerous reports and reviews (Jensen 1974, 1976, 1978; Grimes 1975; Hanson et al. 1977; Uziel 1978; Oak Ridge National Laboratory and Atomic Industrial Forum, Inc. 1979). In addition, considerable effort has been directed recently toward improving the design of cooling water intake systems to minimize the number of organisms impinged and to maximize the survival of organisms that are impinged.

A major objective of the 316(b) program for the Hunters Point Power Plant is to estimate the numbers of juvenile and adult fish and macroinvertebrates impinged. The study plan (PGandE 1977) describes studies designed to provide quantitative information on the number and species composition of impinged organisms (impingement abundance).

Two studies were designed to provide a quantitative basis for estimating the total number of fish and macroinvertebrates lost to local populations as a result of impingement. The first, impingement abundance, was designed to provide estimates of the total numbers of organisms impinged on intake screens of the Hunters Point Power Plant Units 2 and 3 and Unit 4. The second, impingement survival, conducted at the Moss Landing Power Plant, was designed to provide a generic basis for extrapolating species-specific estimates of the proportion of organisms surviving impingement. The results of the two studies are combined to estimate the total numbers of organisms lost to impingement at the Hunters Point Power Plant.

Study design, methods, and results of the impingement abundance and survival studies are presented in the rest of this chapter. The impingement abundance study is described in Section 4.1, and a detailed listing of the supporting data base is presented

in the accompanying impingement data summary (Section E.2, Appendix E). The impingement survival study is described in Section 4.2. Finally, the total numbers of selected fish and macroinvertebrates lost to local populations are estimated in Section 4.3.

These estimates, along with similar estimates of entrainment losses in Chapter 3, provide the foundation for Chapter 5, an assessment of the impact of cooling water system operations on the aquatic populations of San Francisco Bay. These results also provide site- and species-specific information necessary to evaluate the potential effectiveness of intake modifications for minimizing the impact of impingement and for determining the best intake technology available for the units of the Hunters Point Power Plant (Chapter 6).

4.1 IMPINGEMENT ABUNDANCE

The impingement abundance study was designed to provide a quantitative basis for estimating the number of each species of fish and macroinvertebrate impinged on the Units 2 and 3 and Unit 4 intake screens. The study was designed to:

1. determine the species composition of the organisms impinged,
2. determine the lengths and weights of impinged organisms,
3. determine the diel and seasonal patterns of impingement,
4. examine the relationship between impingement and cooling water system operational parameters,
5. determine the sex ratios and degree of gonadal maturity for selected fish species, and
6. determine whether or not any significant impingement occurred on intake bar racks.

In the impingement abundance study, the numbers and sizes of fish and macroinvertebrates impinged on the Units 2 and 3 and Unit 4 intake screens were determined from weekly sampling. Sample collections were periodically isolated into 3-hour time intervals within a 24-hour sampling period to determine if a diel pattern in impingement existed. The experimental design permitted detection of seasonal and diel patterns in the number, size, and species composition of impinged organisms. In addition, the

experimental design provided a framework for correlating impingement with varying plant operational parameters.

In addition to the routine impingement abundance collections, a series of experiments were performed to document the collection and processing efficiency of the impingement sampling techniques. The methodology and results of these studies are presented in Section 4.1.1.2.

4.1.1 Methods and Materials

The following sections present methods used (1) for weekly impingement abundance sampling and (2) for the special studies used to document sampling efficiency.

4.1.1.1 Impingement Abundance Methods

Impingement of fish and macroinvertebrates on vertical traveling intake screens was measured during one 24-hour period each week from 10 May 1978 through 30 April 1979. Impinged organisms were collected from the screenwash sluiceways of the Units 2 and 3 and Unit 4 intakes. To facilitate comparisons, the two intakes were sampled simultaneously. During one sampling period in each month from August 1978 to April 1979, eight discrete 3-hour samples were collected to characterize the diel pattern in impingement abundance; during the remainder of the year 24-hour composite samples were collected.

Before each sampling period all screens were rotated and washed to remove previously impinged organisms and debris. The screens then remained stationary for 2-3/4 hours and were then rotated for 15 minutes while impinged organisms were washed into a collection device. This cycle of stationary period and rotation was repeated through the 24-hour sampling period. Samples were collected from the screenwash sluiceways in containers lined with 1/4-in. (6.4-mm) steel or nylon mesh.

Impinged fish and macroinvertebrates collected in the screenwash sluiceways were sorted by hand from the detritus. Fish were identified to species, counted, and measured at the site. Fork length was measured for up to 50 individuals of each species in each 3-hour sample. With the exception of jellyfish, which were counted in the field,

macroinvertebrates were preserved in 10 percent formalin and were counted, identified, and weighed later in the laboratory. Carapace width was measured to the nearest millimeter for Cancer spp. Composite weights to the nearest 0.1 gram were recorded for all species.

Bar racks were inspected occasionally throughout the study to determine if impingement was occurring.

Gonads of the most abundantly impinged fish species were periodically examined to assess spawning condition. The sex and degree of gonadal maturity of northern anchovy and plainfin midshipman were determined for a subsample of impinged individuals. Each fish was dissected and the condition of the gonads classified as undeveloped (undifferentiated tissue of testes or ovaries), developing (ovary integrity maintained, eggs compact and adhesive), mature (eggs and sperm uncompact and not adhesive), or spent (concave abdominal region and urogenital area swollen and red).

Estimates of the numbers of each fish and macroinvertebrate species impinged were based on the assumption that all organisms impinged during a sampling period were collected. Estimates of the total numbers of animals impinged were based on a stratified sampling design. The one-year sampling period was divided into 26 two-week strata, each having at least two sampling days. The annual impingement abundance estimate, $\hat{I}$, is an estimate of the total numbers of organisms impinged on the intake screens during the year of study. The general equation for this estimate is:

$$\hat{I} = \sum_{i=1}^{26} N_i \bar{y}_i \qquad (4\text{-}1)$$

where

i = the ordinal number of a given two-week interval in the one-year sampling period

N_i = the total number of days the plant was in operation during interval i.

$\bar{y}_i$, the mean number of impinged organisms observed during interval i, is calculated as:

$$\bar{y}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} y_{ij} \tag{4-2}$$

where

j = the ordinal number of a given impingement sample

n_i = the number of impingement samples taken in interval i

y_{ij} = the number of impinged organisms collected during sample j of interval i.

The variance of the annual estimate, $\hat{Var}(\hat{I})$, has been calculated as:

$$\hat{Var}(\hat{I}) = \sum_{i=1}^{26} \frac{N_i(N_i - n_i)s_i^2}{n_i} \tag{4-3}$$

where

$$s_i^2 = \frac{1}{(n_i - 1)} \sum_{j=1}^{n_i} (y_{ij} - \bar{y}_i)^2.$$

The 95 percent confidence interval for the annual impingement estimate for a given taxon is equal to $\hat{I} \pm 1.96\ \widehat{S.E.}(\hat{I})$, in which the standard error is the square root of the variance: $\widehat{S.E.}(\hat{I}) = \sqrt{\hat{Var}(\hat{I})}$.

Standard errors are reported for the estimated annual impingement for each species. The assumption of normality that forms the basis for the 95 percent confidence interval is valid for species with relatively large impingement rates, but is not valid for species that are rarely impinged. A confidence interval extending below zero indicates that the assumption of normality may not be appropriate.

4.1.1.2 Collection and Processing Efficiency

All sample collection and processing operations were subject to a strict quality assurance program. The efficiency of the impingement abundance sample-collection techniques was determined by two experiments. In the first test, 1,100 marked dead fish were released into the Units 2 and 3 intake between the bar racks and the traveling screens. The fish were impinged and washed into the screenwash sluiceway and into the impingement abundance collection nets. Eighty-seven percent of the released fish were recovered. In the second test, marked dead fish were released directly into the screenwash sluiceway during screen rotation and cleaning. There was 95 percent recovery of 152 fish released at the Units 2 and 3 intake, and 100 percent recovery of 149 fish released at Unit 4. It was concluded from these studies that the small bias associated with the collection techniques was acceptable for the purpose of estimating the total numbers of fish and macroinvertebrates impinged at the Units 2 and 3 and Unit 4 intakes.

The sample processing efficiency of the crews working at the Hunters Point Power Plant was checked on six occasions to determine the number of fish and macroinvertebrates not separated from detrital material. After routine sorting of an impingement sample, a second group re-sorted the detrital material. Sixty-four fish were counted in the routine sorting of six samples and none were found in the re-sort, a sorting efficiency of 100 percent. Sorting efficiency for macroinvertebrates was 97 percent: 477 animals were counted in routine sorting procedures and 17 were found in the re-sort.

The efficiency of taxonomic identification for fish and macroinvertebrates was routinely monitored as part of the quality assurance program. No impingement samples were found to be deficient.

4.1.2 General Characteristics of Impingement

Annual impingement estimates for the most abundantly impinged species are presented in Table 4-1 for Units 2 and 3 and Unit 4 on the basis of actual cooling system operation from May 1978 through April 1979. The estimated annual impingement of fish was 85,099 individuals at Units 2 and 3 and 31,446 individuals at Unit 4, for a total of 116,545 fish. Forty-six species of fish were collected at the Units 2 and 3

intake, and 40 at Unit 4. The nine most abundant species constituted over 91.7 percent of the fish collected at both intakes: northern anchovy (64.3 percent), Pacific herring (10.3 percent), plainfin midshipman (6.6 percent), white surfperch (2.5 percent), shiner surfperch (2.2 percent), surf smelt (1.8 percent), pile surfperch (1.5 percent), walleye surfperch (1.4 percent), and white croaker (1.2 percent) (Table 4-2).

Species composition was generally similar between fish impinged at Units 2 and 3 and Unit 4 (Table 4-2). Northern anchovy, the most abundant fish impinged at both intakes, represented 66.0 percent of the impinged fish at Units 2 and 3 and 59.6 percent of the impinged fish at Unit 4. Eight species of fish collected at Units 2 and 3 were not present in collections from Unit 4; three species collected at Unit 4 were not collected at Units 2 and 3.

The total estimated annual impingement of macroinvertebrates for the study year was 66,511 individuals at Units 2 and 3 and 40,653 individuals at Unit 4 (Table 4-1). Jellyfish (Cnidaria) were the most abundant macroinvertebrates impinged, representing 95 percent of the macroinvertebrates counted at Units 2 and 3 and at Unit 4. Several species of jellyfish were impinged during the study, but the most abundant was Polyorchis penicillatus. Aside from jellyfish, 3,091 macroinvertebrates are estimated to have been impinged at the Units 2 and 3 intake and 2,062 at Unit 4 between May 1978 and April 1979. Twenty-nine species of macroinvertebrates were collected at the Units 2 and 3 intake and 21 at Unit 4. Excluding jellyfish, 9 species constituted over 90.8 percent of the macroinvertebrate impingement catch (Table 4-2). Of those, Crangon nigricauda, Hemigrapsus oregonensis, and Cancer antennarius were the most commonly impinged, representing 24.3, 15.8, and 15.5 percent (Table 4-2) of the total catch during these studies.

The estimated numbers of impinged fish and macroinvertebrates discussed above were computed on the basis of actual days of cooling system operation at Units 2 and 3, and Unit 4 during the study period. Estimates were also computed on the basis of continuous cooling system operation (Section 2.1.3.2; Table E.2-1, Appendix E). The estimates based on continuous operation are only slightly (<5 percent) different from those based on actual flows.

TABLE 4-2 NUMBERS, WEIGHTS, AND PERCENTAGES OF SELECTED FISHES AND MACROINVERTEBRATES COLLECTED AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, MAY 1978 - APRIL 1979

Taxon		Units 2 and 3		Unit 4		Totals			
Common Name	Scientific Name	Number	Percent	Number	Percent	Number	Percent	Weight (kg)	Percent
Fish									
Northern anchovy	*Engraulis mordax*	8,123	66.0	2,743	59.6	10,866	64.3	31.6	19.0
Pacific herring	*Clupea harengus pallasi*	1,086	8.8	651	14.1	1,737	10.3	3.3	2.0
Plainfin midshipman	*Porichthys notatus*	872	7.0	251	5.4	1,123	6.6	20.1	12.1
White surfperch	*Phanerodon furcatus*	300	2.4	118	2.6	418	2.5	11.6	7.0
Surf smelt	*Hypomesus pretiosus*	251	2.0	45	1.0	296	1.8	1.1	0.6
Shiner surfperch	*Cymatogaster aggregata*	211	1.7	167	3.6	378	2.2	2.2	1.3
Walleye surfperch	*Hyperprosopon argenteum*	159	1.2	70	1.5	229	1.4	2.4	1.4
Pile surfperch	*Damalichthys vacca*	155	1.2	98	2.1	253	1.5	4.3	2.6
White croaker	*Genyonemus lineatus*	80	0.6	117	2.5	197	1.2	2.2	1.3
Other fish		1,056	8.5	346	7.5	1,402	8.3	87.3	52.6
Total fish		12,293		4,606		16,899		166.1	
Macroinvertebrates									
Blacktail shrimp	*Crangon nigricauda*	102	22.8	81	26.6	183	24.3	0.2	0.8
Shore crab	*Hemigrapsus oregonensis*	64	14.3	55	18.0	119	15.8	0.4	1.7
Rock crab	*Cancer antennarius*	70	15.6	47	15.4	117	15.5	10.9	45.8
Bay shrimp	*Crangon franciscorum*	40	8.9	12	3.9	52	6.9	0.1	0.4
Fish lice	*Lironeca vulgaris*	37	8.3	11	3.9	48	6.5		0
Spider crab	*Pyromaia tuberculata*	37	8.3	22	7.2	59	7.8	0.1	0.4
Red rock crab	*Cancer productus*	35	7.8	17	5.6	52	6.9	9.7	40.8
Skeleton shrimp	*Caprella equilibra*	17	3.8	28	9.2	45	6.0		0
Dungeness crab	*Cancer magister*	7	1.6	1	0.3	8	1.0	1.9	8.0
Other macroinvertebrates		39	8.7	29	9.8	68	9.2	0.5	2.1
Subtotal macroinvertebrates		448		303		751		23.8	
Jellyfish	Cnidaria	9,062		5,514		14,576			
Total macroinvertebrates		9,510		5,817		15,327			

Note: There may be slight discrepancies in column totals that are due to rounding.

To facilitate comparisons between the two intakes, the average daily number of organisms impinged at the Units 2 and 3 and Unit 4 intakes was divided by the average daily cooling water volume and adjusted to organisms impinged per million cubic meters of cooling water to yield a standard density of impinged organisms. The average density of fish impinged on Units 2 and 3 intake screens was $455/10^6$ m^3, compared to $174/10^6$ m^3 impinged on Unit 4 intake screens (Table 4-3). Average densities of impinged macroinvertebrates (excluding Cnidaria) were similar at the two intakes: $17/10^6$ m^3 at Units 2 and 3, and $11/10^6$ m^3 at Unit 4.

Differences in impingement of fish between Units 2 and 3 and Unit 4 result from differences in configuration and in location in the intake basin of the two cooling water intake structures (Figure 2-4). The greater number of intake screens associated with the Units 2 and 3 intake (six, as against two at Unit 4) results in a greater cross-sectional area for impingement to occur and may lead to higher impingement rates. In addition, the Units 2 and 3 intake is at the end of the intake basin and is perpendicular to the net flow, while the Unit 4 intake is parallel to the net flow. Impingeable organisms which may pass the Unit 4 intake have a greater potential to be impinged at the Units 2 and 3 intake because of its location in the intake basin, possibly leading to higher impingement rates.

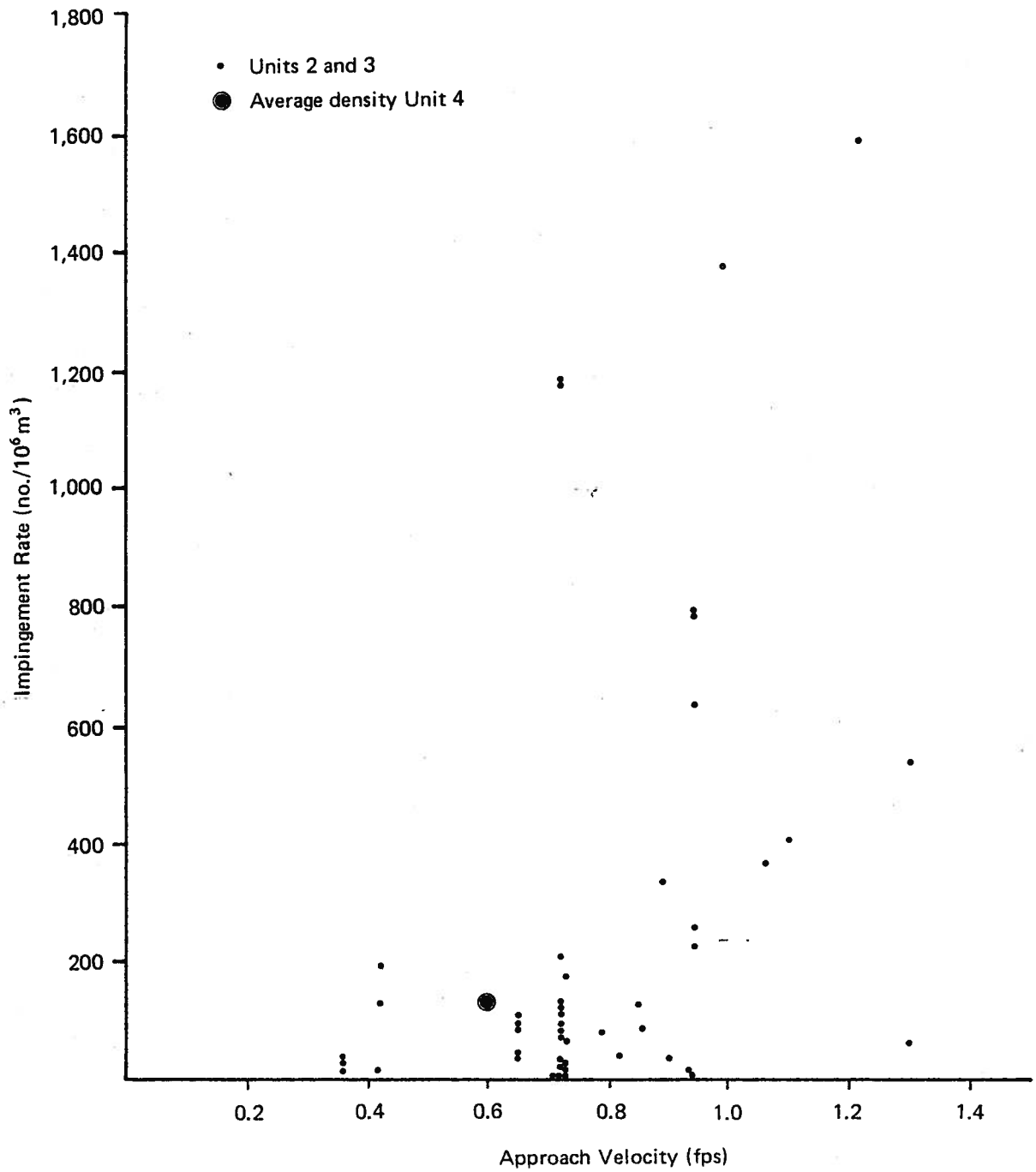
Differences in circulating water pump operation between the two intakes is an additional factor which may have contributed to differences in the rates of impingement. Under normal conditions of circulating water pump operation, average approach velocities at the two intakes are similar (Appendix A). At the Units 2 and 3 intake, however, additional pumps are occasionally brought into operation, resulting in increased approach velocities at the intake (see Section A.1.3). Figure 4-1 illustrates the relationship between the density of impinged northern anchovy and the average water velocity (calculated on the basis of circulating water pump operation) at the Units 2 and 3 and Unit 4 intakes. Impingement rates of northern anchovy are similar at the two intakes when they are operated at approach velocities typical of normal circulating water pump operation (0.6-0.7 fps; 18-21 cm/sec). Impingement of northern anchovy, however, increased markedly as approach velocity to the Units 2 and 3 intake structure increased. Higher rates of impingement during periods of increased circulating water pump operation account for part of the higher number of northern anchovy impinged at the Units 2 and 3 intake during the study period. The pattern of increased rates of impingement at higher approach velocities observed for northern

TABLE 4-3 COMPARISON OF THE NUMBERS AND AVERAGE DENSITIES OF FISHES AND MACROINVERTEBRATES IMPINGED AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, MAY 1978 - APRIL 1979

	Units 2 and 3	Unit 4
Total Number		
Fish	85,099	31,446
Macroinvertebrates[a]	3,091	2,062
Daily Mean Number		
Fish	241	96
Macroinvertebrates[a]	9	6
Density[b]		
Fish	455	174
Macroinvertebrates[a]	17	11

(a) Excluding Cnidaria.
(b) Average number of organisms per 10^6 m^3 of cooling water flow.

Note: Average daily cooling water volume for Units 2 and 3 was 5.34×10^5 m^3; for Unit 4, 5.53×10^5 m^3.



Velocities calculated from circulating water pump operation.

Figure 4-1. Variation of northern anchovy impingement with intake approach velocity at the Hunters Point Power Plant.

anchovy (Figure 4-1) is typical of that found for other species of fish impinged at Units 2 and 3. Impingement rates for macroinvertebrates were not directly related to intake approach velocities.

The size distributions for the most abundant fish species and Cancer spp. impinged are presented in Table 4-4. Impinged fish ranged in size from a 24-mm (0.9-in.) northern anchovy to a 928-mm (36.5-in.) brown smoothhound. Cancer spp. ranged in carapace width from an 11-mm (0.4-in.) C. antennarius to a 155-mm (6.1-in.) C. magister. The carapace widths of 8 C. magister, the Dungeness crab, ranged from 85 to 155 mm (3.3-6.1 in.), with an average of 119 mm (4.7 in.).

Impingement of fish was highest in summer and late fall (Figure 4-2). The maximum daily impingement rate (1,515/day for the units combined) occurred on 14 November 1978, with northern anchovy accounting for 94 percent of the catch. The minimum daily impingement rate (5/day for the units combined) occurred on 16 March 1979.

Macroinvertebrate impingement was greatest from December to March; large numbers of impinged Polyorchis penicillatus (Cnidaria) accounted for 97.6 percent of the total macroinvertebrate catch during this period. Excluding Cnidaria, the maximum daily impingement rate (114/day for the units combined) occurred on 1 March 1979; the minimum daily impingement rate (2/day for the units combined) occurred on 10 May 1978 (Figure 4-3).

Results of the diel impingement studies reveal a nocturnal peak in both fish and macroinvertebrate impingement at the Units 2 and 3 and Unit 4 intakes. In the course of nine 24-hour sampling periods (2,591 fish total), 784 fish were collected between 0600 and 1800 hours (daytime), representing 30.3 percent of the total catch, and 1,807 fish were collected between 1800 and 0600 hours (night), representing 69.7 percent. Results of diel studies for impinged macroinvertebrates (excluding Cnidaria) also indicate a nocturnal peak in abundance at both intakes. Of macroinvertebrates impinged (122 individuals) 69.7 percent were collected from 1800 to 0600 hours (night) and 30.3 percent were collected from 0600 to 1800 hours (daytime).

Routine inspection of the bar racks associated with the Units 2 and 3 and Unit 4 intake structures indicated that no impingement of fish or macroinvertebrates was occurring there during the one-year study.

TABLE 4-4 SUMMARY OF THE LENGTHS OF SELECTED FISHES AND *CANCER* SPP. CRABS COLLECTED IN IMPINGEMENT SAMPLES AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, MAY 1978 - APRIL 1979

Taxon		Number Measured	Mean Length[a] (mm)	Standard Deviation	Size Range	
Common Name	Scientific Name				Minimum (mm)	Maximum (mm)
Fish						
Northern anchovy	*Engraulis mordax*	3,615	76.6	11.2	24	200
Pacific herring	*Clupea harengus pallasi*	1,015	59.3	14.7	33	295
Plainfin midshipman	*Porichthys notatus*	965	100.4	63.6	25	322
White surfperch	*Phanerodon furcatus*	418	113.6	38.4	52	264
Surf smelt	*Hypomesus pretiosus*	277	84.5	24.7	34	173
Shiner surfperch	*Cymatogaster aggregata*	370	68.5	15.2	38	147
Walleye surfperch	*Hyperprosopon argenteum*	229	77.7	24.0	24	270
Pile surfperch	*Damalichthys vacca*	253	89.6	29.9	50	329
White croaker	*Genyonemus lineatus*	197	80.3	36.9	37	311
Macroinvertebrates						
Rock crab	*Cancer antennarius*	113	73.8	17.2	11	106
Slender crab	*Cancer gracilis*	1	61.0		61	61
Dungeness crab	*Cancer magister*	8	119.5	25.6	85	155
Red rock crab	*Cancer productus*	52	105.5	17.9	70	146
Yellow crab	*Cancer anthonyi*	2	95.5	0.7	95	96

(a) Fork length of fish measured to 1 mm; carapace width of *Cancer* spp. measured to 1 mm.

Note: A complete length summary for most abundantly impinged species is given in Appendix E.2.

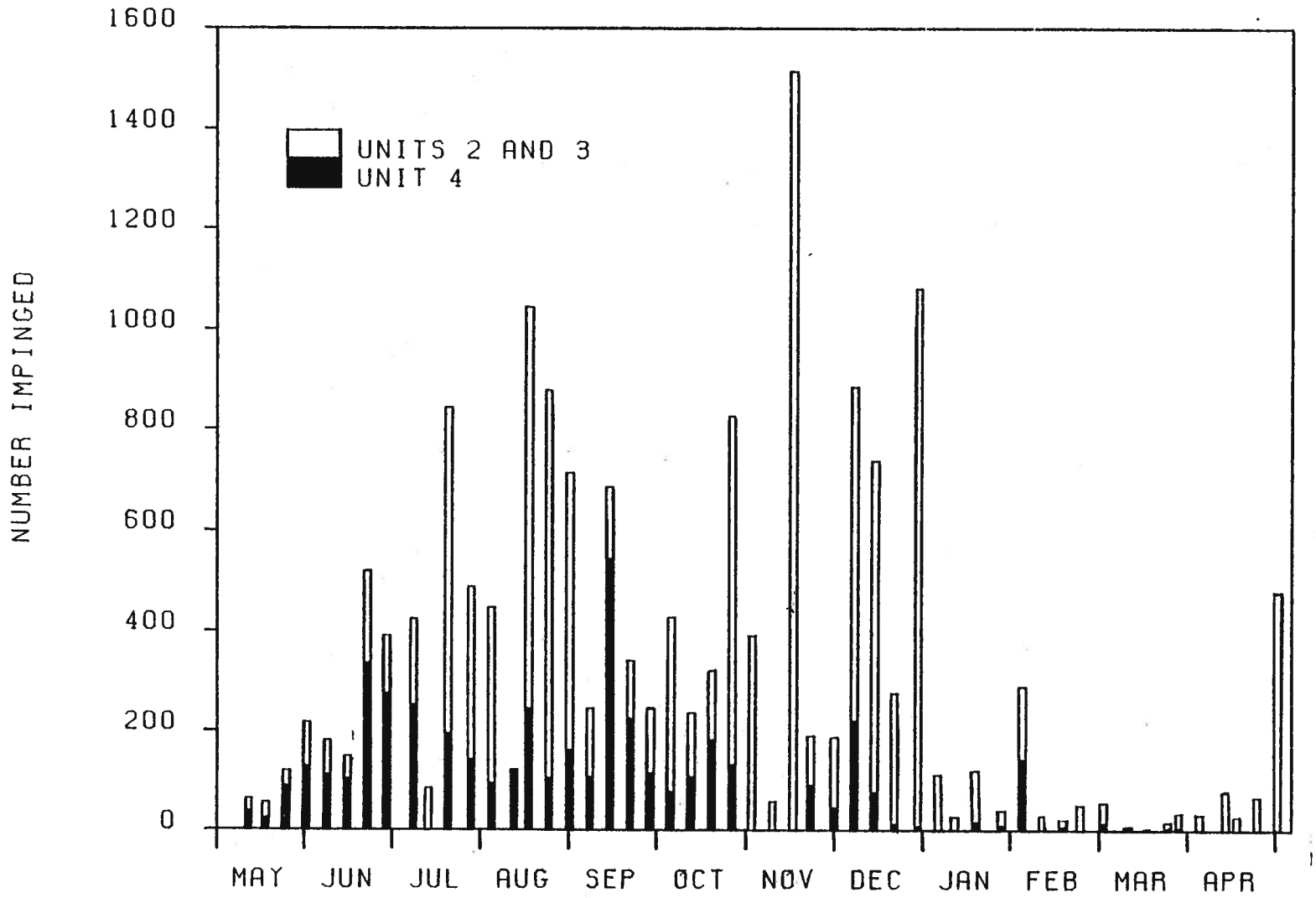


Figure 4-2. Numbers of impinged fish collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, May 1978 – April 1979.

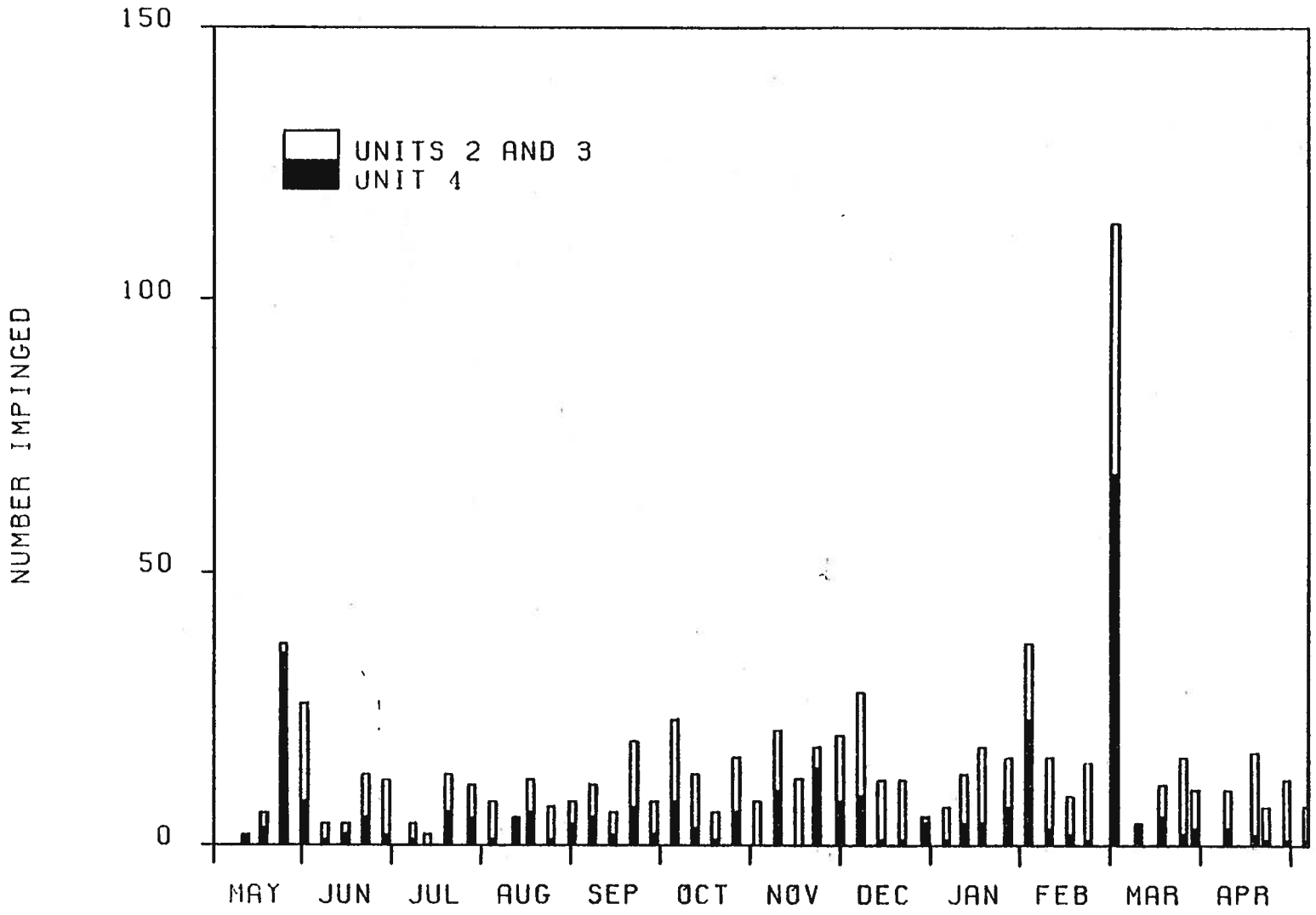


Figure 4-3. Numbers of impinged macroinvertebrates (excluding Cnidaria) collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, May 1978 – April 1979.

4.1.3 Results for Selected Taxa

The four most abundant species of fish selected for discussion, in order of the total numbers collected, are northern anchovy, Pacific herring, plainfin midshipman, and white surfperch. Crabs of the genus Cancer and shrimp of the genus Crangon are also discussed, with primary emphasis on Cancer antennarius and Crangon nigricauda, the two most abundantly impinged macroinvertebrates (excluding Cnidaria). Discussions are based on results and observations made during the weekly impingement abundance and monthly diel collections. The numbers and percentages reported are those estimated to have been impinged under actual cooling system operation during the year of study.

4.1.3.1 Northern Anchovy (Engraulis mordax)

Northern anchovy, the only species of Engraulidae (anchovies) collected, constituted 64.3 percent of all fish collected (Table 4-2). Over 75 percent of the northern anchovy, 56,256 individuals with a combined weight of 156.2 kg (343.6 lb), were estimated to have been impinged on the Units 2 and 3 intake screens, and 18,678 northern anchovy with a combined weight of 61.7 kg (135.7 lb) were estimated to have been impinged on the Unit 4 intake screens. Northern anchovy were collected throughout the year (Figure 4-4), with impingement peaks during late summer (August-September) and late fall (November-December) 1978.

The size distribution of northern anchovy collected each month on the Units 2 and 3 and Unit 4 intake screens is shown in Figure 4-5. The fish ranged in length from 24 to 200 mm (0.9-7.9 in.) (Table 4-4). The mean fork length computed for each month ranged from 71 to 83 mm (2.8-3.2 in.) over the study year.

The summer and fall impingement peaks were dominated by fish 65-85 mm (2.6-3.3 in.) long. Growth rate studies of laboratory-reared northern anchovy (Sakagawa and Kimura 1976) indicate that 70-mm (2.8-in.) northern anchovy are approximately three months old. On the basis of this estimated growth rate, northern anchovy impinged during the summer and fall peaks would appear to have been spawned in April-May and August-September, respectively.

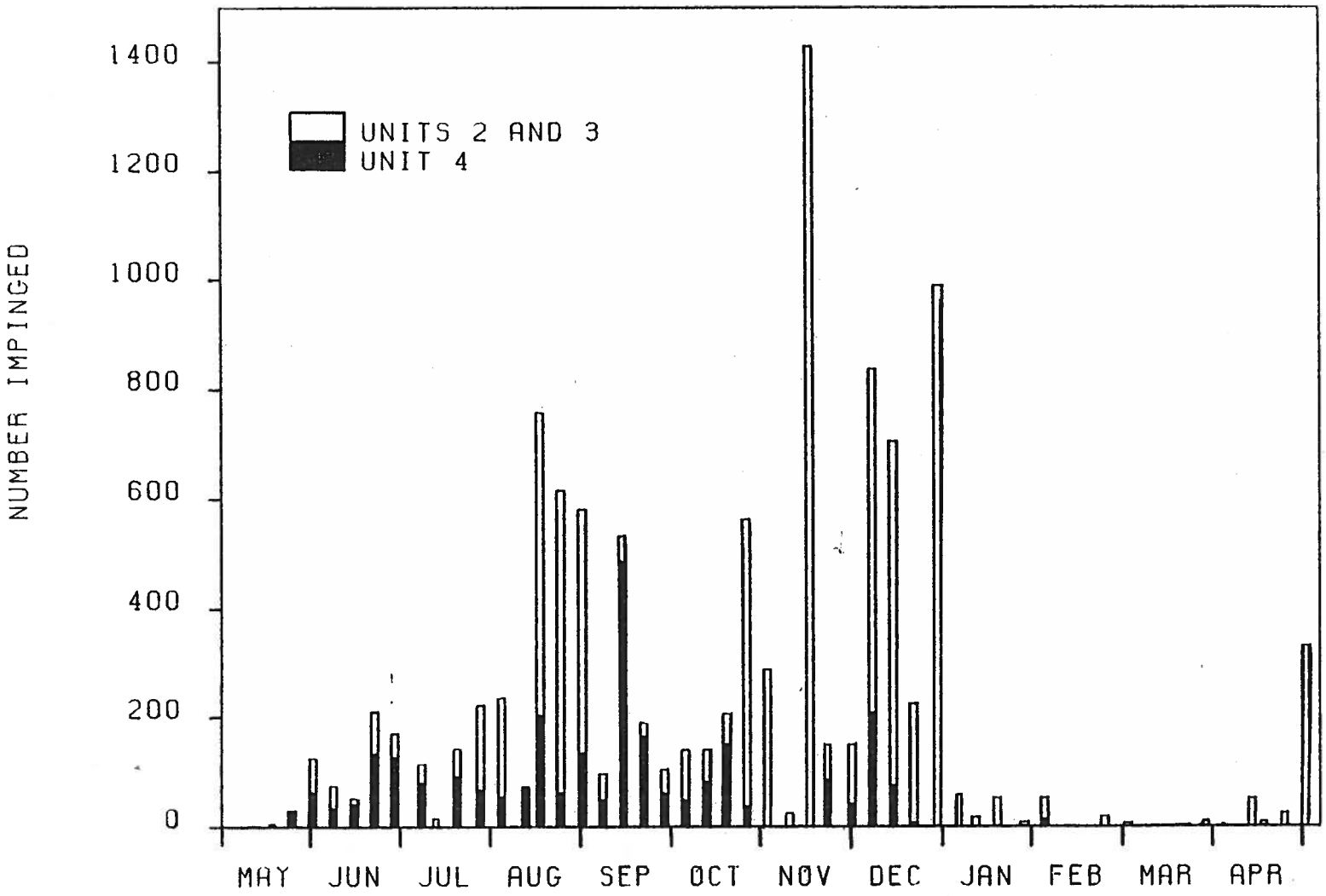


Figure 4-4. Numbers of impinged northern anchovy collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, May 1978 – April 1979.

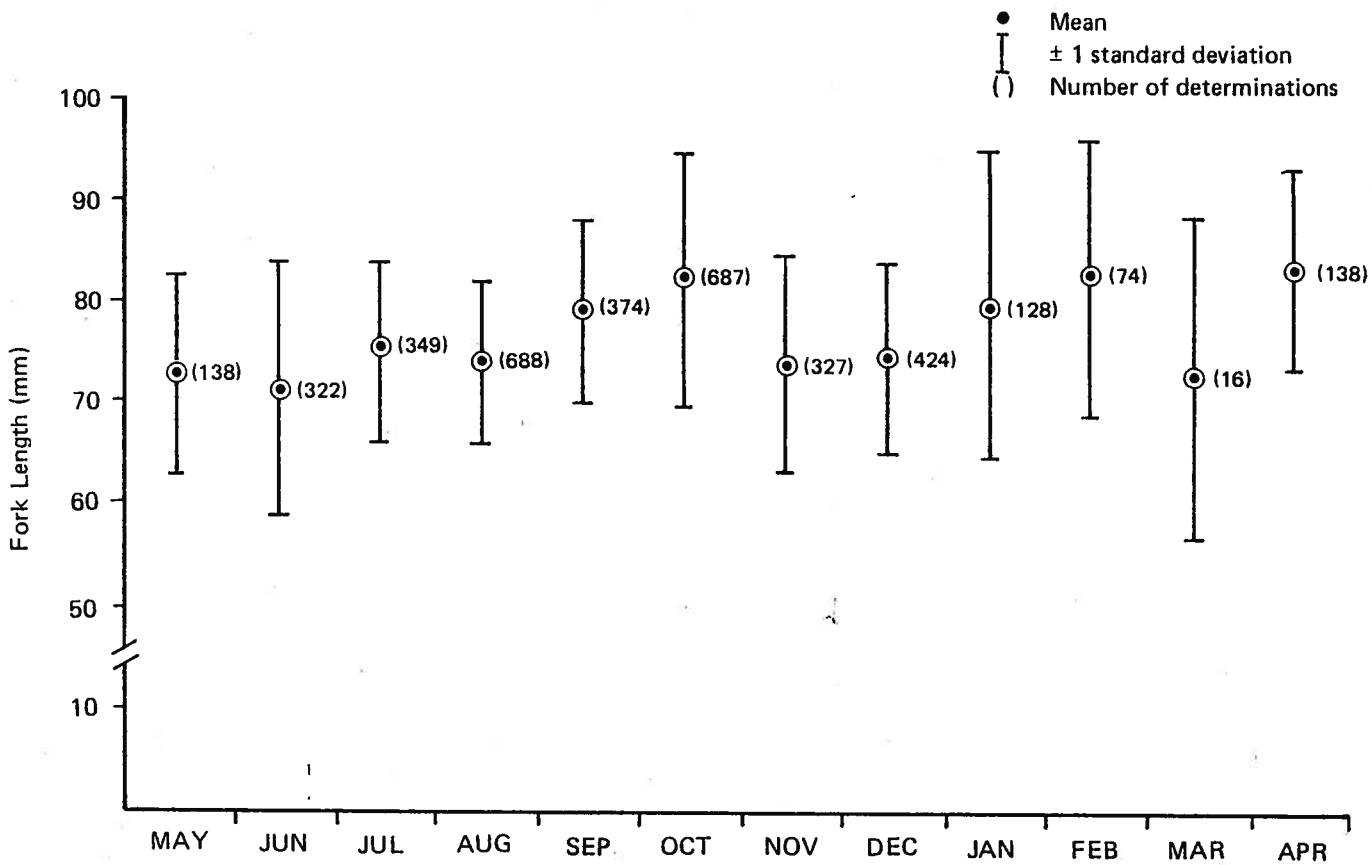


Figure 4-5. Fork lengths of impinged northern anchovy collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, May 1978 – April 1979.

Sixty-nine adult northern anchovy collected from June through October were examined to determine their gonadal condition and sex ratios (Table 4-5). Seventy-four percent had developing gonads and 23 percent had fully developed gonads. The high incidence of developing and mature gonadal condition during this period coincides with peak abundances of northern anchovy eggs entrained at the Hunters Point Power Plant. Seventy-two percent of the northern anchovy examined were female, 25 percent were male, and the sex of about 3 percent was impossible to determine.

4.1.3.2 Pacific Herring (Clupea harengus pallasi)

Pacific herring was the second most abundantly impinged fish species, and the most abundant member of the family Clupeidae, representing 10.3 percent of all fish impinged (Table 4-2). The annual estimated impingement of Pacific herring was 7,545 individuals (12.5 kg [27.5 lb]) impinged on Units 2 and 3 intake screens and 4,513 individuals (10.6 kg [23.3 lb]) impinged on the Unit 4 intake screens. Pacific herring were impinged throughout the year (Figure 4-6), but were most abundant from June through August 1978. Impinged Pacific herring were predominantly juveniles with monthly mean lengths ranging from 56 to 61 mm (2.2-2.4 in.) (Appendix E.2). The decrease in juvenile Pacific herring impingement in September (Figure 4-6) may be related to an autumnal offshore migration pattern as observed by Hourston (1958) in Barkley Sound, British Columbia.

4.1.3.3 Plainfin Midshipman (Porichthys notatus)

Plainfin midshipman was the third most abundant species of fish impinged and the only member of the family Batrachoididae, representing 6.6 percent of all fish collected (Table 4-2). The annual estimated impingement of plainfin midshipman for the study year was 6,061 individuals with a combined weight of 90.7 kg (199.5 lb) on Units 2 and 3 intake screens and 1,659 individuals with a combined weight of 47.6 kg (104.7 lb) on the Unit 4 intake screens. Impingement was greatest in July and in late September and early October (Figure 4-7). The highest rate of midshipman impingement observed on the Units 2 and 3 and Unit 4 intake screens was 224/day, on 3 October 1978.

TABLE 4-5 GONADAL CONDITION OF A SUBSAMPLE OF NORTHERN ANCHOVY AND PLAINFIN MIDSHIPMAN IMPINGED AT THE HUNTERS POINT POWER PLANT, MAY 1978 - APRIL 1979

	Northern Anchovy (Engraulis mordax)	Plainfin Midshipman (Porichthys notatus)
Period of Observation	JUL-OCT	MAY-OCT
Number Examined	69	72
Sex		
Male	17	31
Female	50	41
Undetermined	2	0
Gonadal Condition		
Undeveloped	2	0
Developing	51	38
Mature	16	34
Spent	0	0

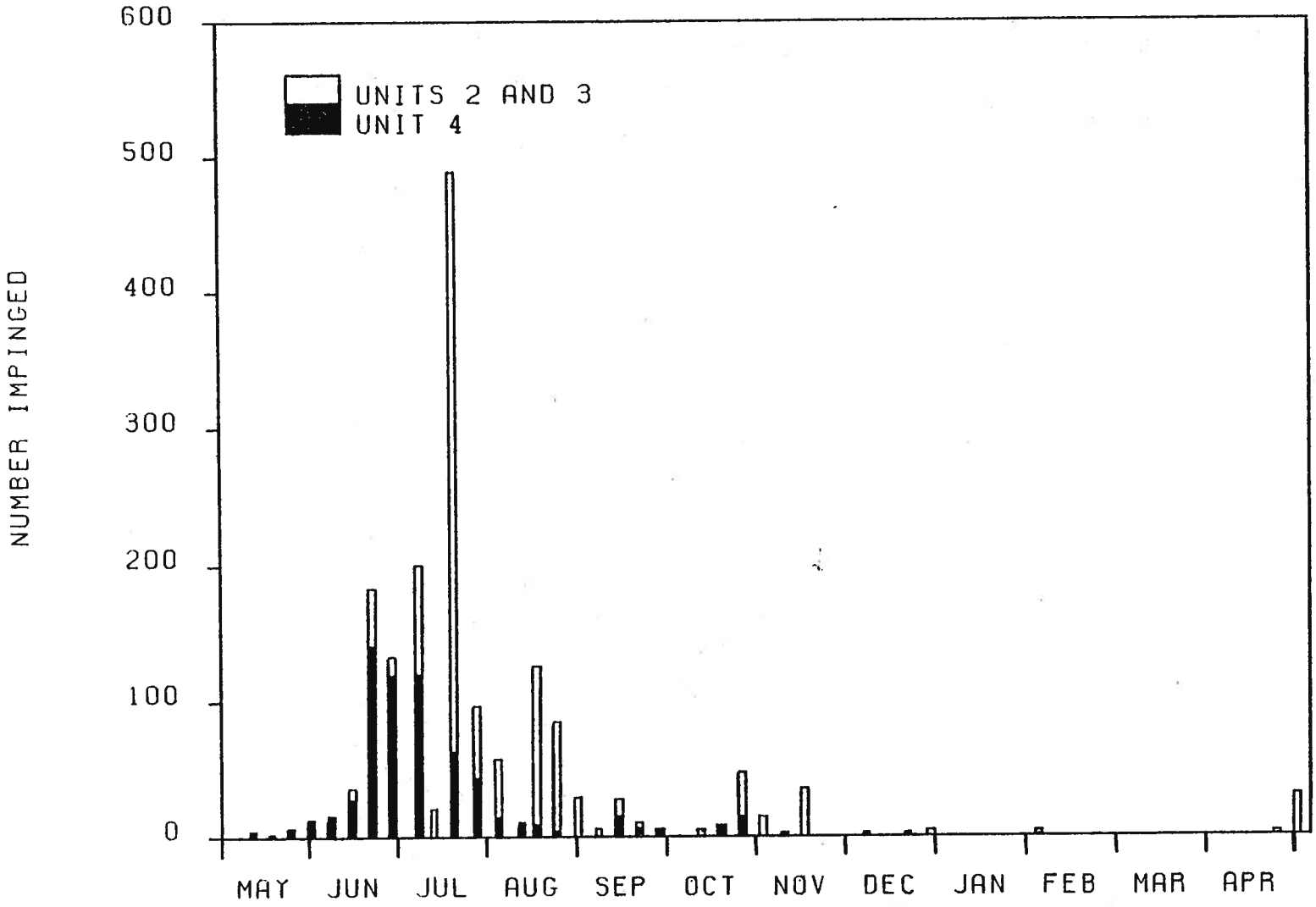


Figure 4-6. Numbers of impinged Pacific herring collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, May 1978 – April 1979.

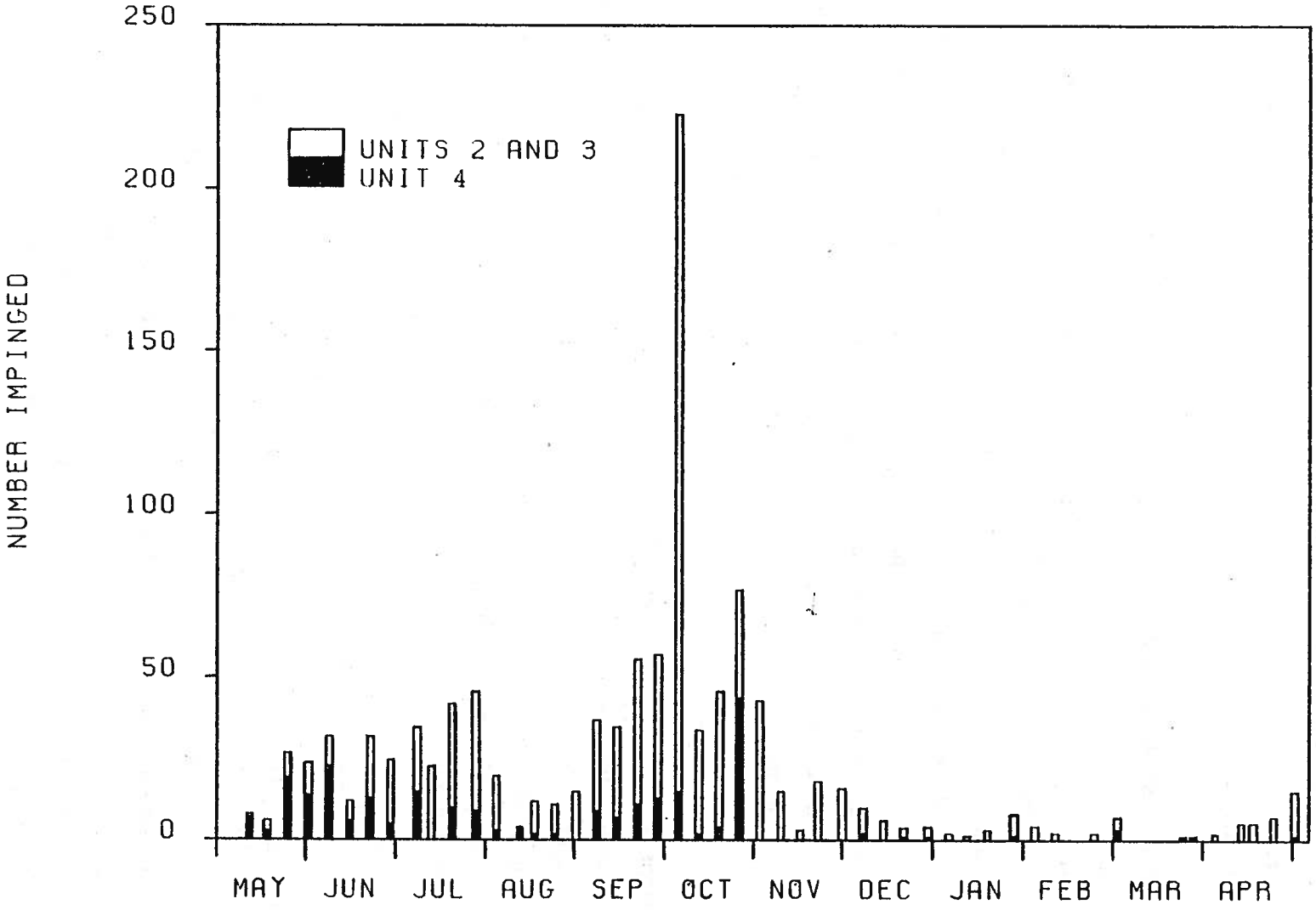


Figure 4-7. Numbers of impinged plainfin midshipman collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, May 1978 – April 1979.

Plainfin midshipman were examined between May and October to determine their gonadal maturation. All 72 individuals examined either had developing gonads (53 percent) or were mature (47 percent). Over half of the individuals examined were collected from May to July.

The observed seasonal pattern in midshipman impingement may reflect the onshore spawning migration of adults from late May to early July (Arora 1948) and the recruitment of young into a size range susceptible to impingement in September. During May, June, and July, adult fish with either developing or mature gonads dominated the numbers of impinged midshipman (Table 4-5); those months coincide with the period of the reported onshore spawning migration (Hart 1973) and the early peak of plainfin midshipman impingement. The late peak in midshipman impingement from September to December was dominated by juveniles ranging in mean length from 56 to 79 mm (2.2-2.5 in.) (Figure 4-8). The midshipman impinged from December to April were predominantly young of the year that had not yet migrated offshore into deeper waters.

Observations during eight 24-hour diel collections from Units 2 and 3 and Unit 4 intake screens indicate that the highest rate of impingement of plainfin midshipman occurs at night (Figure 4-9). The observed diel trend in plainfin midshipman impingement is supported by observations by Arora (1948) who reported that juvenile plainfin midshipman are negatively phototaxic: that they dig into bottom sediments during the day and rise at night to feed.

4.1.3.4 White Surfperch (Phanerodon furcatus)

White surfperch, the most abundant species of the family Embiotocidae collected, constituted 2.5 percent of all fish impinged (Table 4-2). The annual estimated impingement of white surfperch was 2,092 individuals (61.4 kg [135.1 lb]) on Units 2 and 3 intake screens and 779 (18.2 kg [40.0 lb]) on Unit 4 intake screens. Although white surfperch were impinged throughout the year, 83 percent were collected from July to October (Figure 4-10). These fish were predominantly juveniles or yearlings, with monthly mean lengths ranging from 101 to 126 mm (4.0-5.0 in.) (Table E.2-3).

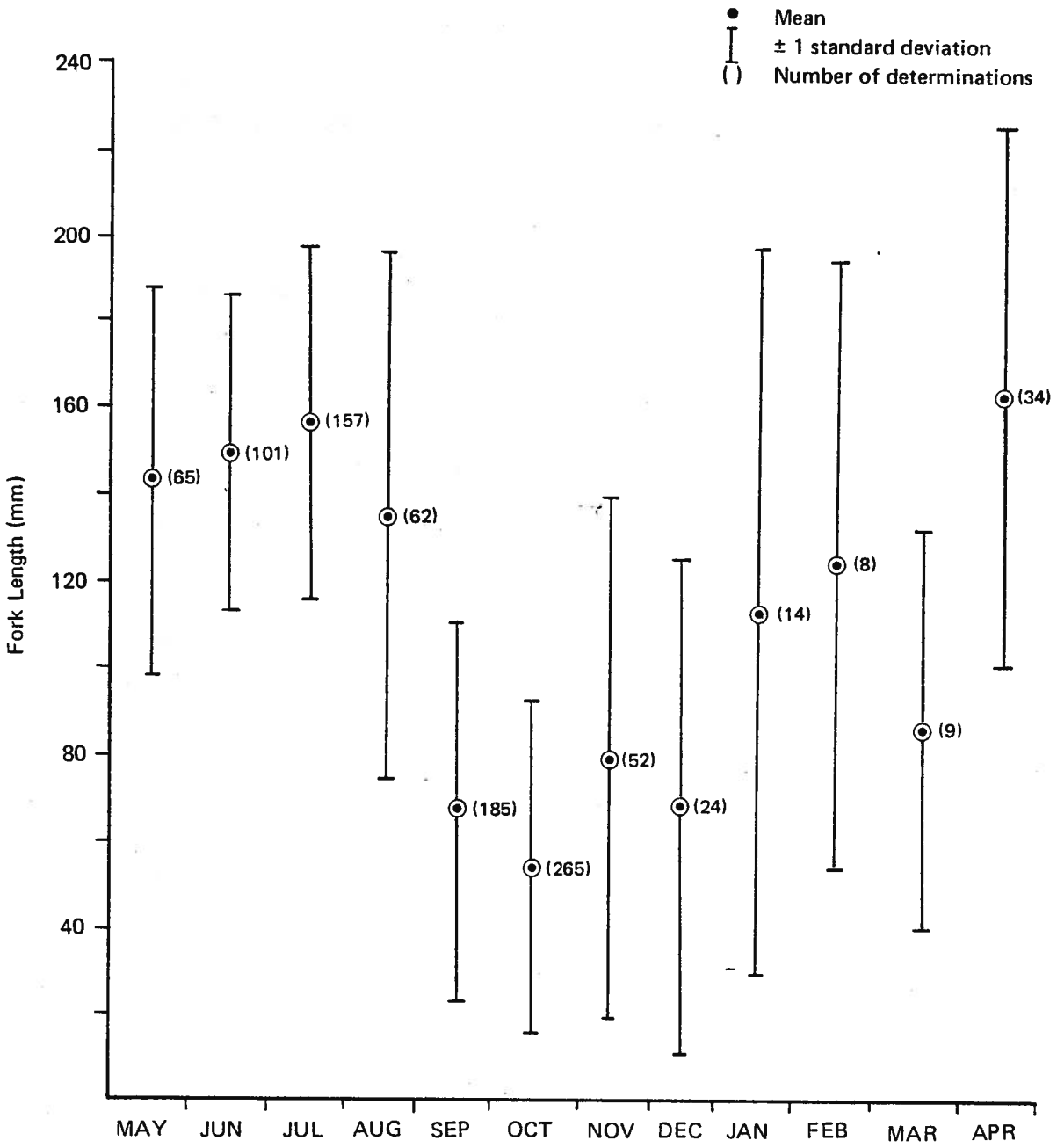


Figure 4-8. Fork lengths of impinged plainfin midshipman collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, May 1978 – April 1979.

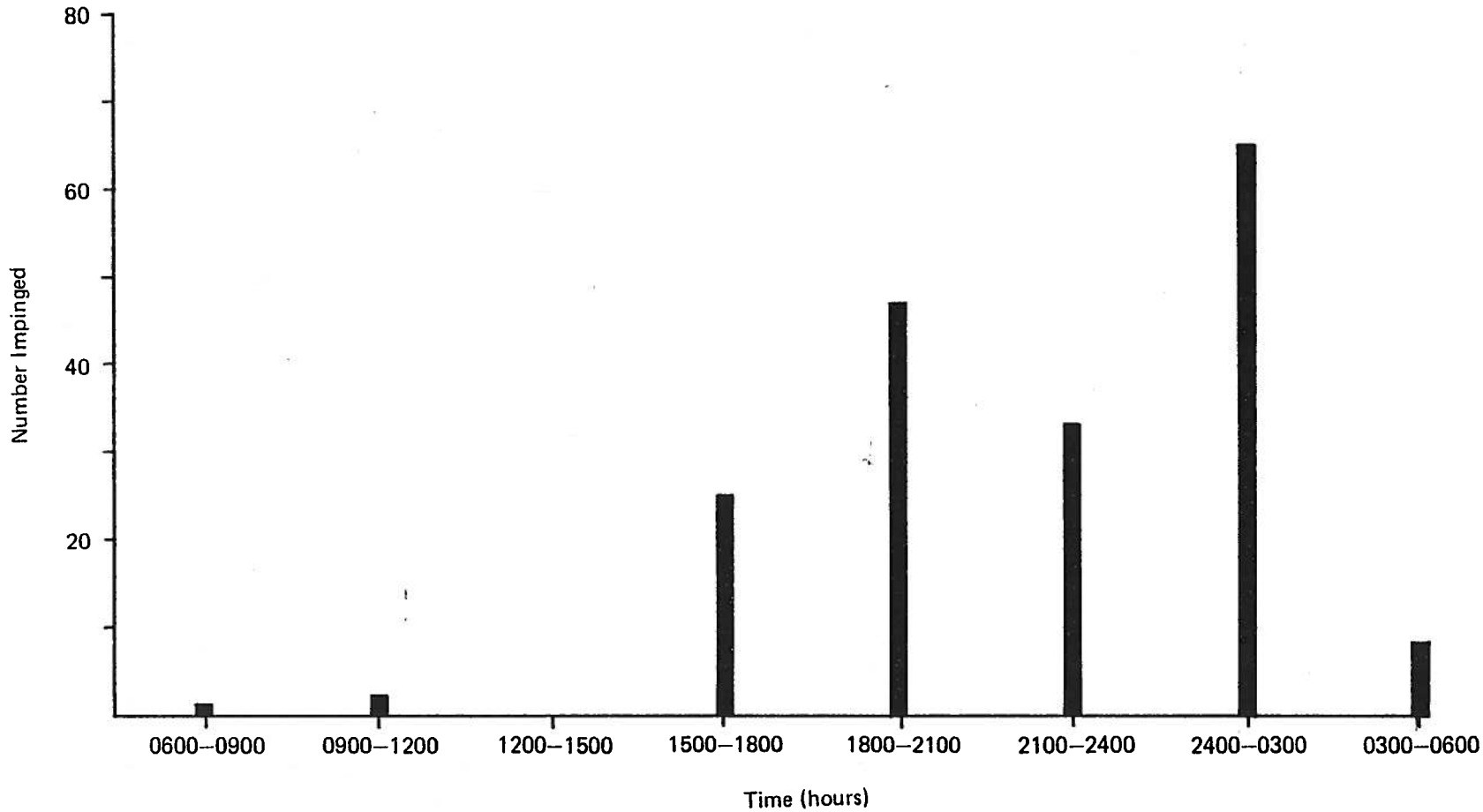


Figure 4-9. Diel variation in numbers of impinged plainfin midshipman collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, August 1978 – April 1979.

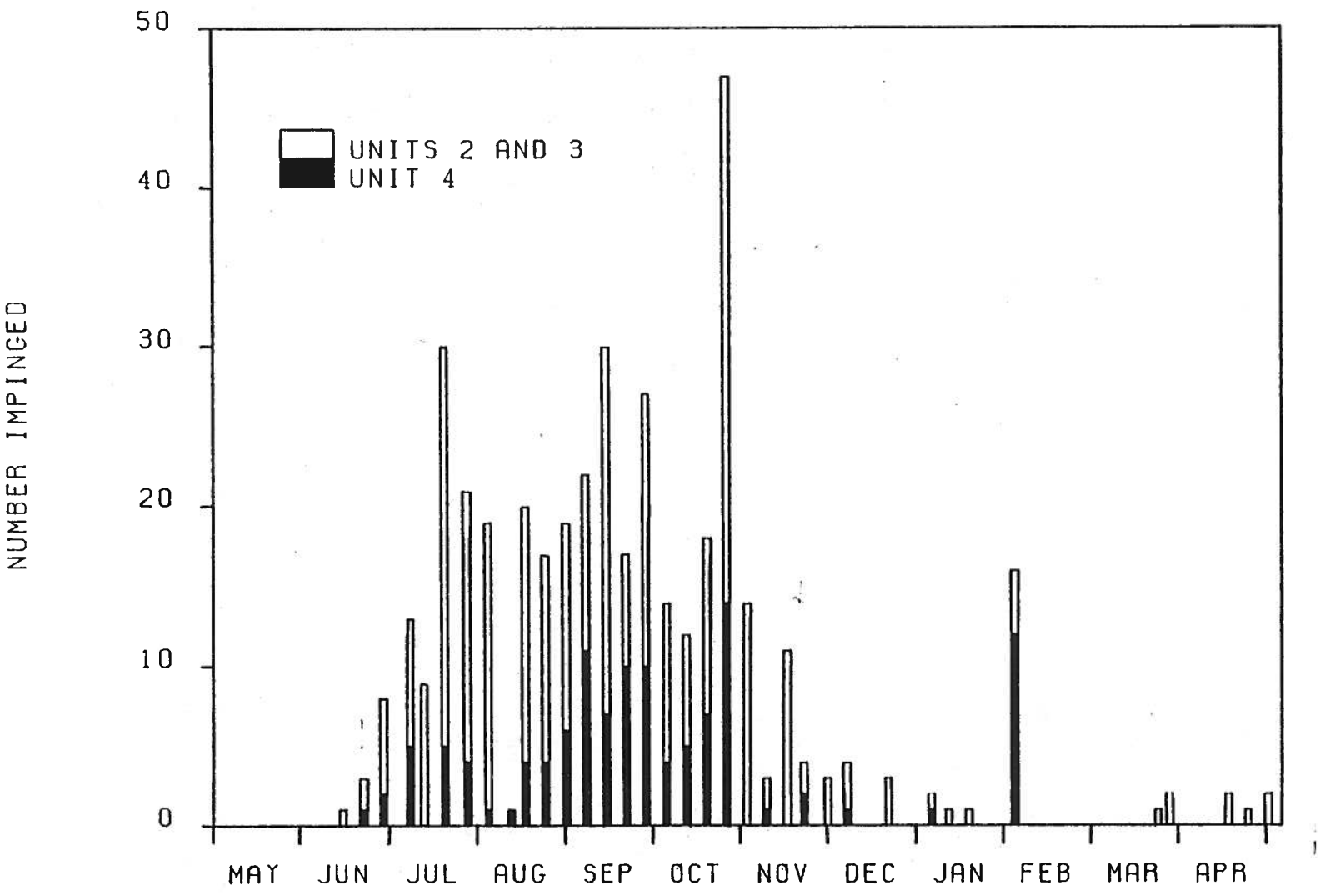


Figure 4-10. Numbers of impinged white surfperch collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, May 1978 – April 1979.

4.1.3.5 Crabs

Five species of the genus Cancer (family Cancridae) were collected, representing 23.9 percent of all macroinvertebrates (excluding Cnidaria) impinged. Cancer antennarius was the most abundant, followed by C. productus, C. magister, C. anthonyi, and C. gracilis. In addition, one species of the genus Hemigrapsus was collected.

Cancer antennarius, the rock crab, was the third most abundant macroinvertebrate impinged, accounting for 15.5 percent of all macroinvertebrates collected (excluding Cnidaria) (Table 4-2). Of the estimated 798 C. antennarius impinged, 60.5 percent (483 individuals; 43.2 kg [95.0 lb]) were impinged on Units 2 and 3 intake screens and 39.5 percent (315 individuals; 32.3 kg [71.1 lb]) on the Unit 4 intake screens. Cancer antennarius were impinged throughout the year (Figure 4-11). Maximum impingement rates occurred in midwinter (10/day for the units combined, on 25 January 1979). The majority of impinged C. antennarius were juveniles, and the average carapace width was 73.8 mm (2.9 in.) (Table 4-4).

Cancer productus, the red rock crab, was the seventh most abundant macroinvertebrate impinged, representing 6.9 percent of the total catch (excluding Cnidaria). Of the total estimated annual impingement, 67.4 percent (238 individuals; 45.7 kg [100.5 lb]) were impinged on the Units 2 and 3 intake screens, and 33.6 percent (115 individuals; 19.2 kg [42.2 lb]) were impinged on the Unit 4 intake screens. The average carapace width was 105.5 mm (4.2 in.) (Table 4-4).

Cancer magister (the Dungeness crab), C. anthonyi (the yellow crab), and C. gracilis (the slender crab), are all considered to be relatively uncommon in San Francisco Bay (D. Chivers, Calif. Acad. Sci., 1978, personal communication). Fifty-six C. magister were estimated to have been impinged over the study year, representing 1.1 percent of the impinged macroinvertebrates (excluding Cnidaria). Cancer magister carapace widths averaged 119.5 mm (4.7 in.) and ranged from 85 to 155 mm (3.3-6.1 in.). The estimated annual impingement of C. anthonyi and C. gracilis was 12 and 7 individuals, respectively.

Hemigrapsus oregonensis, the shore crab (family Grapsidae), was the second most abundantly impinged macroinvertebrate, representing 15.8 percent of the total catch

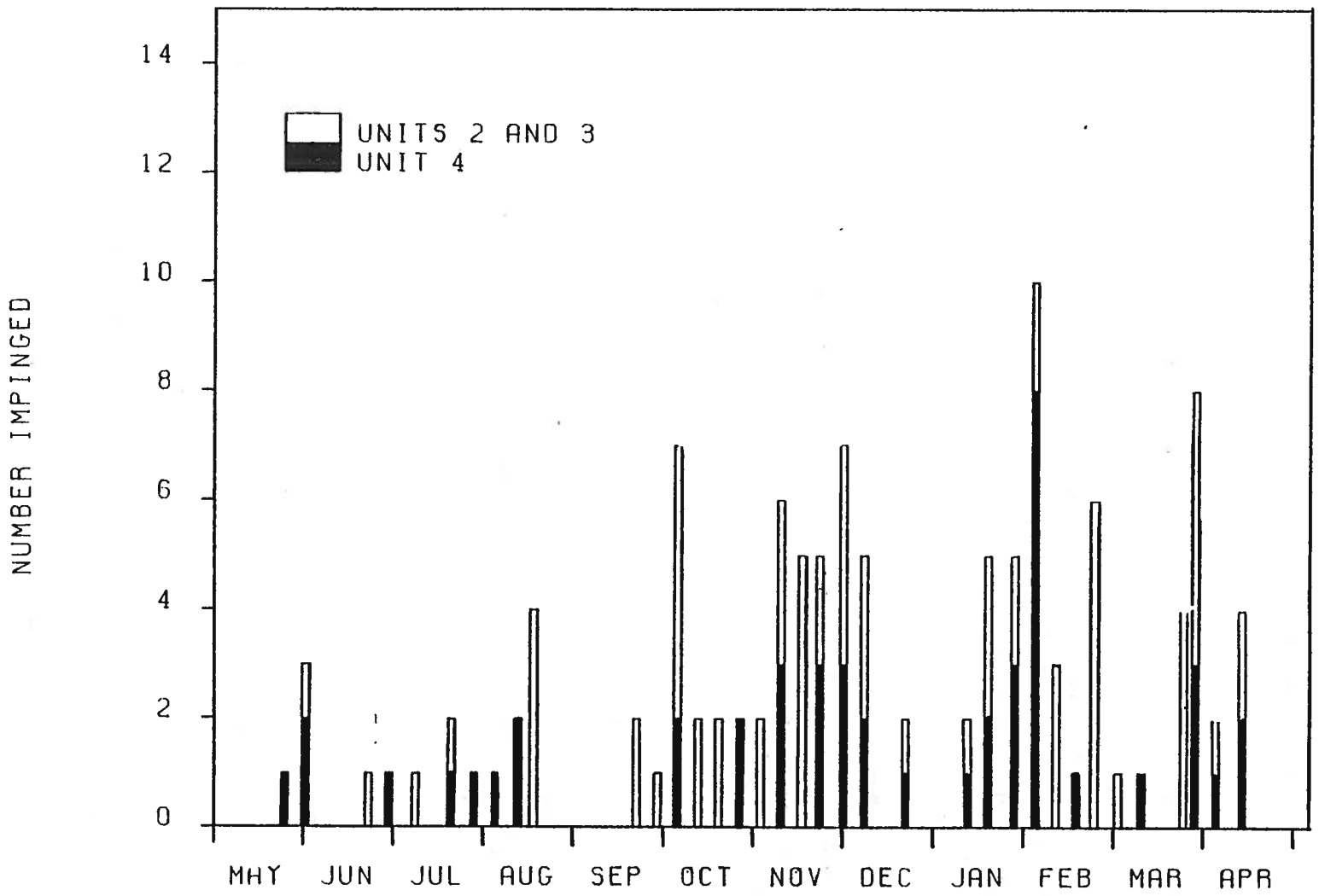


Figure 4-11. Numbers of impinged Cancer antennarius collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, May 1978 – April 1979.

(excluding Cnidaria). Of the total estimated annual impingement, 55.0 percent (446 individuals; 1.7 kg [3.7 lb]) were impinged on the Units 2 and 3 intake screens and 45.0 percent (365 individuals; 1.1 kg [2.4 lb]) were impinged on the Unit 4 intake screens.

4.1.3.6 Shrimps

Crangon nigricauda was the most abundant macroinvertebrate impinged, representing 24.3 percent of the impinged macroinvertebrates (excluding Cnidaria) (Table 4-2). Of the total estimated annual impingement of C. nigricauda, 55.5 percent (697 individuals; 0.8 kg [1.8 lb]) were impinged at Units 2 and 3, and 44.5 percent (560 individuals; 0.4 kg [0.9 lb]) were estimated to have been impinged at Unit 4. Although C. nigricauda were impinged throughout the year, 76 percent of the overall catch was impinged from December to March (Figure 4-12). Krygier and Horton (1975) report that C. nigricauda abundance varies inversely with temperature and directly with salinity in Yaquina Bay, Oregon. The seasonal distribution of impinged C. nigricauda may be related to its increased abundance in San Francisco Bay in winter.

Crangon franciscorum was the fourth most abundant macroinvertebrate impinged, representing 7.0 percent of the impinged macroinvertebrates (excluding Cnidaria) (Table 4-2). Of the total estimated annual impingement of C. franciscorum, 76.8 percent (278 individuals; 0.5 kg [1.1 lb]) were impinged at Units 2 and 3 and 23.2 percent (84 individuals; 0.2 kg [0.4 lb]) were estimated to have been impinged at Unit 4.

4.2 IMPINGEMENT SURVIVAL

To evaluate the potential for survival of impinged organisms, generic survival studies were conducted at the Moss Landing Power Plant. The studies were designed to:

1. estimate the initial and latent survival of fish and macroinvertebrates impinged on intake screens under a routine screenwash operational cycle, and
2. examine the relationship between initial and latent impingement survival and various alternative screenwash operational cycles.

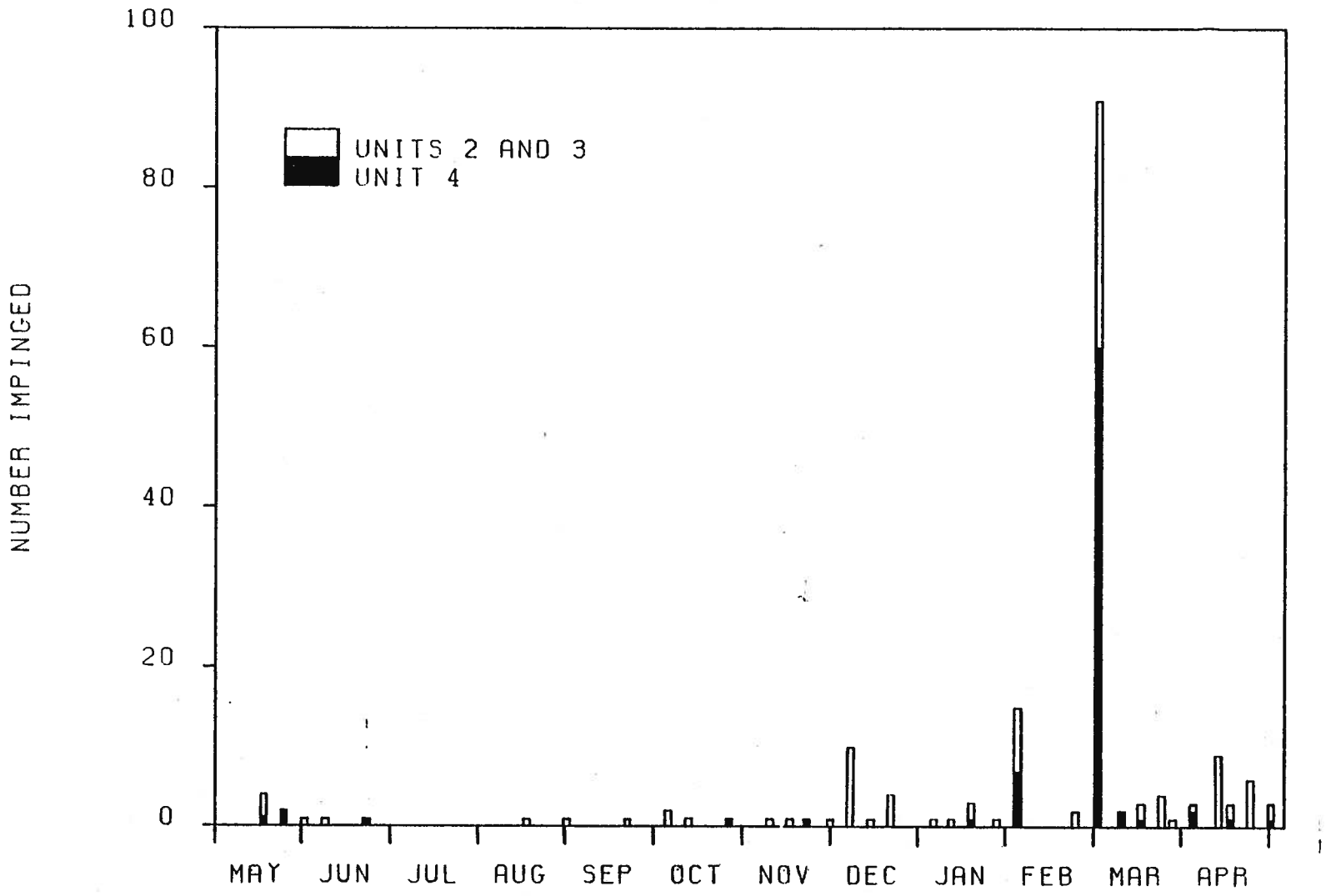


Figure 4-12. Numbers of impinged *Crangon nigricauda* collected at Units 2 and 3 and Unit 4 of the Hunters Point Power Plant, May 1978 – April 1979.

Impingement survival studies conducted at the Moss Landing Power Plant were considered to be applicable to the Hunters Point Power Plant because:

1. the species of impinged fish and macroinvertebrates are similar (estimates) of impingement survival at Moss Landing are available for surfperches, northern anchovy, Pacific herring, plainfin midshipman, and Cancer spp.);
2. both power plants are sited in marine environments;
3. both power plants utilize vertical traveling intake screens equipped with 3/8-in. (9.5-mm) square mesh screens; and
4. average water velocities through the intake screens at the Hunters Point Power Plant Units 2 and 3 and Unit 4 are similar to those at the Moss Landing Power Plant Units 6 and 7, where the studies were conducted.

The impingement survival study was designed to estimate the species-specific proportion of fish and macroinvertebrates not surviving impingement. Impingement survival was determined for three modes of cooling water intake screen operation: continuous screen rotation, 1-hour intermittent rotation, and 3-hour intermittent rotation. The proportion of organisms lost as a result of impingement was estimated from the numbers of each species which were alive and dead immediately following removal from the intake screens and at 96 hours after impingement. Control samples were collected to account for mortality from sampling and other natural causes not related to impingement. The experimental design provided an opportunity to determine the relationship between the duration of impingement (i.e., intake screen rotation frequency) and the initial and latent survival of those species impinged in greatest abundance.

4.2.1 Methods and Materials

Organisms were collected from the screenwash sluiceway using 1/4-in. (6.4-mm) mesh nets following rotation and cleaning of the intake screens at the Moss Landing Power Plant. They were placed in an ambient temperature water bath, and fish and macroinvertebrates were sorted from the detrital material. Dead organisms (those that showed no opercular movement and no response to gentle probing) were removed from the sample, identified to species, and counted, and fork length was measured for fish or carapace width for crabs of the genus Cancer. Organisms that were alive after

impingement were held in an ambient water flow-through holding system for 96 hours to determine latent survival. Organisms that had not been impinged were used as controls to determine the effect of sample collection, processing, and holding on survival. Control organisms were collected with beach seines or otter trawls from the vicinity of the plant. Controls were held for 2-4 days to recover from the stress of collection and were then treated identically to impinged organisms collected alive.

The proportion of organisms not surviving impingement was calculated and corrected for control mortality by employing the following equation:

$$p_s = \frac{p_e - p_c}{1 - p_c} \tag{4-4}$$

where

p_s = corrected proportion of organisms not surviving impingement
p_e = experimental proportion of organisms not surviving impingement
p_c = control proportion of organisms not surviving collection, processing, and holding.

Initial and latent survival of impinged organisms were determined for three intake screen operating modes:

1. a 3-hour intermittent screen rotation cycle in which the intake screens were stationary for 2-3/4 hours and were then rotated and cleaned for 15 minutes (an operating cycle typical of that used during impingement abundance sample collections),
2. a 1-hour intermittent screen rotation cycle in which the intake screens were stationary for 45 minutes and were then rotated and cleaned for 15 minutes, and
3. a continuous screen rotation cycle.

The screen rotation cycle limited the length of time an impinged organism was held against the intake screen.

4.2.2 Results

The initial and latent survival estimates of impinged organisms, adjusted for control mortality, are summarized in Table 4-6. Impingement survival estimates were computed for three operational modes at Moss Landing Units 6 and 7 (through-screen velocity of 1.5 fps [46 cm/sec]). These results are considered to be representative of impingement survival at the Hunters Point Power Plant Units 2 and 3 and Unit 4 intakes, which have similar through-screen velocities. The results of impingement survival studies conducted at Moss Landing Units 1-5 (design through-screen velocity of 2.4 fps [73 cm/sec]) are presented for comparison.

Initial and latent impingement survival of surfperches (Embiotocidae) following a 3-hour screen rotation cycle were low, 37 and 6 percent respectively. During a 1-hour rotational cycle, however, the observed long-term survival of impinged surfperch increased to 41 percent, and it further increased to 83 percent for continuous intake screen rotation. Decreasing the duration of impingement by increasing the frequency of intake screenwash and rotation is expected to increase the survival of impinged surfperch.

Northern anchovy impingement survival was characteristically low. Initial and latent survival of 2,643 anchovy observed after a 3-hour screenwash cycle were 16 and 2 percent, and survival was not improved by decreasing the duration of impingement.

Impingement survival of plainfin midshipman was high. No initial or latent impingement mortality was observed for 64 midshipman impinged during a 3-hour screen rotation cycle. Alteration of screen operation to decrease the duration of impingement is not expected to influence either the initial or latent impingement survival of plainfin midshipman.

Both initial and latent impingement survival of crabs (Cancer spp.) at Units 6 and 7 of the Moss Landing Power Plant appear to be high, although the number of crabs observed was small. Observations made during impingement abundance collections at the Hunters Point Power Plant and at Units 1-5 of the Moss Landing Power Plant also suggested that initial survival of impinged crabs is high.

TABLE 4-6 PERCENTAGE SURVIVAL OF FISHES AND CANCER CRABS COLLECTED IN IMPINGEMENT SAMPLES AT THE MOSS LANDING POWER PLANT IN THREE SCREENWASH OPERATIONAL MODES, 1978-1979

Taxon		Size Range (mm)	Screen Operational Mode											
			3-Hour Intermittent			1-Hour Intermittent			Continuous			Control		
				Survival (%)			Survival (%)			Survival (%)			Survival (%)	
Common Name	Scientific Name		No.	Initial	96-Hour	No.	Initial	96-Hour	No.	Initial	96-Hour	No.	Initial	96-Hour
			Units 6 and 7											
Surfperches	Embiotocidae	39-125	19	37	6	27	81	41	12	92	83	41	100	81
Northern anchovy	*Engraulis mordax*	70-134	2,690	16	2	239	27	0	108	17	0	59	100	49
Plainfin midshipman	*Porichthys notatus*		64	100	100	0			0			50	100	100
Crabs	*Cancer* spp.	50-80	10	100	80	5	80	80	7	86	43	46	100	100
			Units 1-5											
Surfperches	Embiotocidae	68-120	310	11	1	163	23	0	46	46	5	41	100	81
Northern anchovy	*Engraulis mordax*	75-115	2,414	17	0	490	23	0	319	32	0	59	100	49
Pacific herring	*Clupea harengus pallasi*	55-107	163	4	0	94	14	0	19	42	0	0		
Crabs	*Cancer* spp.	15-80	16	44	38	23	83	65	51	80	76	46	100	100

Note: Survival percentage has been corrected to account for control mortality (Section 4.2.1).

4.2.3 Discussion

Impingement survival data collected for northern anchovy and Pacific herring indicate that initial and latent survival of these species is low. Plainfin midshipman and crabs are able to survive impingement on intake screens. Impingement survival for either the sensitive species such as herring and anchovy or the hardy species such as plainfin midshipman does not appear to be enhanced substantially by increasing the frequency of screen rotation and cleaning and hence decreasing the maximum duration of impingement. Survival of surfperches, however, was enhanced substantially by increasing the frequency of screen rotations. Available impingement survival data for rockfish and sole are inadequate to determine the relationship between impingement survival and intake screen operation for these species.

Initial and long-term observations reflect the survival of organisms removed from the intake screens. Survival estimates presented in Section 4.2.2 do not, however, include effects associated with transit through the screenwash sluiceway or of the return of impinged organisms to the thermal discharge. Therefore, impingement survival study results represent the potential for organisms to survive when removed from the intake screens, and not necessarily the survival of organisms returned to the receiving water body.

4.3 ESTIMATION OF TOTAL IMPINGEMENT LOSSES AT THE HUNTERS POINT POWER PLANT

Estimates of total numbers of selected fish and macroinvertebrates lost to impingement at Hunters Point Power Plant Units 2 and 3 and Unit 4 during the one-year study (May 1978 - April 1979) are summarized in Table 4-7. Estimated losses were calculated based on the assumption of 100 percent impingement mortality, and on the impingement survival rates presented in Section 4.2. The estimates were based on the number of cooling system operating days occurring during the study period. On the assumption of 100 percent mortality, annual impingement losses for fish were 116,545 individuals. Based on impingement survival rates presented in Section 4.2, annual impingement losses for fish were estimated to be 106,784. Total annual impingement losses for macroinvertebrates (excluding jellyfish) were 5,153 individuals assuming 100 percent mortality and 4,138 assuming a survival rate of 80 percent for *Cancer* spp.

TABLE 4-7 ESTIMATED IMPINGEMENT MORTALITY OF SELECTED FISHES AND MACROINVERTEBRATES AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, MAY 1978 - APRIL 1979

Taxon		Total Number (Assuming No Survival)	96-Hour Survival (%)	Number (Assuming Survival)		
Common Name	Scientific Name			Units 2 and 3	Unit 4	Total
Fish						
Northern anchovy	*Engraulis mordax*	74,934	2	55,131	18,313	73,444
Pacific herring	*Clupea harengus pallasi*	12,058	0	7,545	4,513	12,058
Other fish		9,592	0	7,209	2,383	9,592
Plainfin midshipman	*Porichthys notatus*	7,720	100	0	0	0
White surfperch	*Phanerodon furcatus*	2,871	6	1,966	732	2,698
Shiner surfperch	*Cymatogaster aggregata*	2,612	6	1,390	1,067	2,457
Surf smelt	*Hypomesus pretiosus*	2,012	0	1,705	307	2,012
Pile surfperch	*Hyperprosopon argenteum*	1,599	6	1,024	459	1,483
Walleye surfperch	*Damalichthys vacca*	1,767	6	1,018	643	1,661
White croaker	*Genyonemus lineatus*	1,379	0	560	819	1,379
Total fish		116,545				106,784
Macroinvertebrates						
Blacktail shrimp	*Crangon nigricauda*	1,257	0	697	560	1,257
Shore crab	*Hemigrapsus oregonensis*	811	0	446	365	811
Rock crab	*Cancer antennarius*	798	80	97	63	160
Other macroinvertebrates		469	80	54	40	94
Spider crab	*Pyromaia tuberculata*	403	0	256	147	403
Bay shrimp	*Crangon franciscorum*	362	0	278	84	362
Red rock crab	*Cancer productus*	353	0	238	115	353
Fish louse	*Lironeca vulgaris*	331	0	254	77	331
Skeleton shrimp	*Caprella equilibra*	315	0	119	196	315
Dungeness crab	*Cancer magister*	56	0	49	7	56
Subtotal macroinvertebrates		5,153				4,138
Jellyfish	Cnidaria	101,994	0	63,421	38,573	101,994
Total macroinvertebrates		107,146				106,132

In Chapter 5, the estimates based on 100 percent mortality for all species are used in assessing the impact of impingement on aquatic populations.

4.4 IMPINGEMENT SUMMARY

The abundance of impinged fish and macroinvertebrates was monitored at the Hunters Point Power Plant Units 2 and 3 and Unit 4 intake screens for a period of one year (May 1978 - April 1979). Impinged organisms were collected in the screenwash sluiceways of each intake.

The most abundant fishes impinged were northern anchovy, Pacific herring, plainfin midshipman, white surfperch, surf smelt, shiner surfperch, walleye surfperch, pile surfperch, and white croaker, accounting for 91.7 percent of the total catch at the two intakes. Northern anchovy was the most abundant species collected at both intakes, representing 64.1 percent of the total catch. Total estimated annual impingement, under actual cooling system operating conditions at the Hunters Point Power Plant, is 116,545 fish: 85,099 at Units 2 and 3 and 31,446 at Unit 4.

The most abundant macroinvertebrates impinged were jellyfish (Cnidaria), the shrimp Crangon nigricauda, and the crab Cancer antennarius. The total annual impingement of macroinvertebrates at the Hunters Point Power Plant is approximately 107,000: 66,500 at Units 2 and 3 and 40,500 at Unit 4 under actual cooling system operating conditions. Excluding jellyfish, the estimated total annual impingement of macroinvertebrates is 3,091 at Units 2 and 3 and 2,062 at Unit 4.

The initial and latent survival of impinged organisms was examined at the Moss Landing Power Plant and extrapolated to estimate the potential for impingement survival at the Hunters Point Power Plant. Initial and latent survival of impinged northern anchovy and Pacific herring was low. Impingement survival was enhanced for surfperches by decreasing the duration of impingement through use of various intake screen operational modes. Plainfin midshipman and crabs are able to survive impingement.

Total impingement losses of fish and macroinvertebrates were estimated based on actual and continuous normal cooling system operating days at Units 2 and 3 and Unit 4. Total losses were computed on the assumption of 100 percent impingement mortality for all species (used in Chapter 5) and also on species-specific results of the impingement survival study.

4.5 REFERENCES

Arora, H. L. 1948. Observations on the habits and early life history of the batrachoid fish, Porichthys notatus Girard. Copeia 1948(2):89-93.

Chivers, D. 1978. Personal communication. California Academy of Sciences, San Francisco.

Grimes, C. B. 1975. Entrapment of fishes on intake water screens at a steam electric generating station. Chesapeake Sci. 16(3):172-177.

Hanson, C. H., J. R. White, and H. W. Li. 1977. Entrapment and impingement of fishes by power plant cooling-water intakes: an overview. U.S. Natl. Mar. Fish. Serv., Mar. Fish. Rev. 39(10):7-17.

Hart, J. L. 1973. Pacific fishes of Canada. Bull. Fish. Res. Board Can. 180. 740 pp.

Hourston, A. S. 1958. Population studies on juvenile herring in Barkley Sound, British Columbia. J. Fish. Res. Board Can. 15(5):909-960.

Jensen, L. D., ed. 1974. Proceedings of the Second Workshop on Entrainment and Intake Screening. February 5-9, 1973, Baltimore, Md. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif. 347 pp.

Jensen, L. D., ed. 1976. Third National Workshop on Entrainment & Impingement. February 24, 1976, New York, N.Y. Ecological Analysts, Melville, N.Y. 425 pp.

Jensen, L. D., ed. 1978. Fourth National Workshop on Entrainment and Impingement. December 5, 1977, Chicago, Ill. Ecological Analysts, Melville, N.Y. 424 pp.

Krygier, E. E. and H. F. Horton. 1975. Distribution, reproduction, and growth of Crangon nigricauda and Crangon franciscorum in Yaquina Bay, Oregon. Northwest Sci. 49(4):216-240.

Oak Ridge National Laboratory and Atomic Industrial Forum, Inc. 1979. Impingement: an annotated bibliography. Interim report. EPRI EA-1050, ORNL/EIS-135. Electric Power Research Institute, Palo Alto, Calif. 193 pp.

Pacific Gas and Electric Company (PGandE). 1977. Hunters Point Power Plant cooling water intake report and 316(b) study plan. Revised edition. Submitted to California Regional Water Quality Control Board, San Francisco Bay Region. PGandE, San Francisco.

Sakagawa, G. T. and M. Kimura. 1976. Growth of laboratory-reared northern anchovy, Engraulis mordax, from southern California. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 74(2):271-279.

Uziel, M. S. 1978. Impingement. J. Water Pollut. Control Fed. 50(6):1553-1567.

Chapter 5

Impact Assessment

5.1 Introduction

5.2 Impact Assessment for Selected Organism Groups

5.3 Summary and Conclusions

5.4 References

CHAPTER 5: IMPACT ASSESSMENT

5.1 INTRODUCTION

This chapter assesses the impact of entrainment and impingement losses on populations of fishes and macroinvertebrates of the source water body, San Francisco Bay and adjacent coastal waters. The impacts on individual species resulting from entrainment (Chapter 3) and impingement (Chapter 4) mortality are evaluated by comparing the numbers lost and available information on their distribution, abundance, behavior, and life histories. Based on guidance material provided by California Regional Water Quality Board, San Francisco Bay Region (letter to B. W. Shackelford, 13 July 1977), the potential impact of the plant was considered to be low (PGandE 1977), and hence the principal concern has been to determine if unexpectedly high numbers of any fish or invertebrate species were entrained or impinged. Key species were identified for which enough data were available to develop estimates of the total population in the Bay for direct comparison with the numbers lost at the plant.

Based on entrainment and impingement surveys at the Hunters Point Power Plant during the one year of study, no unusually high losses of any species were observed, and no rare or endangered species were collected. The most abundant organisms lost at the power plant are abundant and widely distributed in San Francisco Bay and nearby coastal waters, and none are found only in the vicinity of the power plant. Because the cooling water flow (1.1×10^6 m^3/day) amounts to less than 0.2 percent of the tidal inflow to the Bay (680×10^6 m^3/day), no significant or detectable difference in organism abundance in the Bay is expected to result from power plant effects. Most of the organisms entrained or impinged were immature stages of species with high reproductive potentials resulting from either large numbers of eggs per female or short generation times. Organisms that do not survive entrainment or impingement are returned to the Bay, where they remain available as food for other invertebrates and fish. Many of the species collected are benthic, and are entrained and impinged only when moving into the water column occasionally for feeding or dispersal. The potential for power plant impacts on these species is minimal.

The Pacific herring and northern anchovy were selected for detailed impact assessment because of their high abundance in entrainment and impingement samples, their

commercial importance, and the availability of quantitative data regarding populations in the Bay. Sufficient information is available for these species concerning their population dynamics and adult abundance to assess the potential effect of the power plant losses on the populations in the Bay and nearby coastal waters. The losses at the plant were found to be small when compared to the numbers taken in a commercial net fishery that is carefully managed by the California Department of Fish and Game.

In the remainder of this chapter, details pertaining to the above conclusions for individual species or organism groups are presented.

5.2 IMPACT ASSESSMENT FOR SELECTED ORGANISM GROUPS

Chapter 1 presents the key organism groups that were selected for detailed study at the Hunters Point Power Plant, and reviews the study plan (PGandE 1977) rationale for selection. This portion of the impact assessment discusses each of the selected macroinvertebrate and fish groups, and relates entrainment and impingement losses to relevant life history, behavioral, and population distribution data.

5.2.1 Macroinvertebrates

The macroinvertebrate groups selected as key organism groups for this study were jellyfish (Cnidaria), arrow worms (Chaetognatha), and several taxa of higher crustaceans (Malacostraca): mysids (Mysidacea), cumaceans (Cumacea), tanaidaceans (Tanaidacea), isopods (Isopoda), amphipods (Amphipoda), and shrimps and crabs (Decapoda). Many of these forms are important elements in the aquatic community food webs, and some groups are valuable as commercial shellfish.

5.2.1.1 Jellyfish

Jellyfish (Cnidaria) are gelatinous, bell- to saucer-shaped, planktonic animals that feed in competition with other consumers on small crustaceans and other planktonic forms. Coastal forms do not appear to have specific predators, although scavenging birds commonly feed on them when they are stranded on beaches. They have no known commercial or sport value.

Several species were impinged at the Hunters Point Power Plant during the monitoring program, but the most abundant was Polyorchis penicillatus. This coastal form is distributed from Alaska to Baja California and is particularly common in bays, where great swarms are sometimes present (J. Rees, Lawrence Berkeley Lab., 1979, personal communication). Little information is available on the biology of this animal. The impingement cropping estimate for jellyfish under actual cooling system operation (May 1978 - April 1979) was 101,994 organisms. They were the most abundant aquatic organisms impinged at the Hunters Point Power Plant.

The impact of the plant on jellyfish populations is considered minimal because they are abundant in the Bay and widely distributed along the coast, they are not considered an important element of the aquatic food chain, and they are of no commercial or sport fishery value.

5.2.1.2 Mysids and Cumaceans

These animals are small crustaceans with shrimplike body forms. Females carry a relatively small number of embryos in a brood pouch, but short generation times can result in the production of large numbers of young. Mysids are planktonic forms that feed on small plankton and detritus; cumaceans inhabit the surface layers of bottom sediments, sometimes migrating into the water column at night. Although the biology of most species is poorly known, available evidence suggests that they are widely distributed in inshore coastal areas.

Four species of mysids were entrained at the Hunters Point Power Plant. Acanthomysis macropsis and Neomysis mercedis were most common (Table 5-1). Acanthomysis macropsis is a marine form that is widely distributed in south and central San Francisco Bay and San Pablo Bay (Tattersall 1932). The estimated number of A. macropsis lost from the population due to entrainment was 4.4 million animals. Neomysis mercedis is an estuarine species that occurs in the brackish portions of San Francisco Bay in enormous numbers (Orsi and Knutson 1979). It is relatively uncommon in the vicinity of the Hunters Point Power Plant. The estimated entrainment loss of N. mercedis was 6.3 million organisms. The estimated loss of all mysids was 16.2 million.

Five species of cumaceans were entrained at the plant. The most common species was Cumella vulgaris (105 million) (Table 5-1), which is widely distributed in the intertidal

TABLE 5-1 ESTIMATED MORTALITY OF SELECTED MYSIDACEA, CUMACEA, TANAIDACEA, AND ISOPODA AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, 1978-1979

Taxon	Number	
	Entrainment[a]	Impingement
Mysidacea		
Acanthomysis macropsis	4,400,000	0
Neomysis mercedis	6,300,000	0
Neomysis kadiakensis	1,900,000	0
Neomysis rayii	1,700,000	0
Cumacea		
Cumella vulgaris	105,300,000	0
Eudorella pacifica	1,200,000	0
Lamprops spp.	1,700,000	0
Other Cumacea	1,800,000	0
Tanaidacea		
Leptochelia dubia	147,900,000	0
Other Tanaidacea	13,600,000	0
Isopoda		
Epicaridea	27,400,000	0
Other Isopoda	8,000,000	0

(a) Estimates are based on actual cooling water flows and 77 percent overall entrainment loss (see Sections 3.1.2.2 and 3.2.2 and Table 3-9).

and subtidal portions of south and central San Francisco Bay and San Pablo Bay (Jones 1961). Cumaceans are predominantly benthic and are susceptible to entrainment only at night. The estimated total entrainment loss of cumaceans was 110 million animals.

The entrainment and population impact of the plant resulting from losses of mysids and cumaceans is minimal, because they are widely distributed in the Bay and coastal waters and have high reproductive capacity.

5.2.1.3 Tanaidaceans and Isopods

These animals are small, compact, flattened forms. Like the mysids and other lower malacostracans, their fecundities are relatively low, but production is often high because of short generation times. Tanaidaceans are a small group of tiny, cryptic crustaceans that live in bottom sediments, but may sometimes be found in the water column. Isopods, however, are a diverse group that may be important as intermediate links in aquatic food webs. Although predominantly benthic, they are often found swimming free in the water column. Most species of tanaidaceans and isopods found in San Francisco Bay are widely distributed along the coast in inshore areas.

Five species of tanaidaceans were entrained at the Hunters Point Power Plant. The most common, *Leptochelia dubia* (Table 5-1), is widely distributed in the intertidal and subtidal portions of south and central San Francisco Bay and San Pablo Bay, where it burrows to depths of two feet or more (Jones 1961). The estimated entrainment loss was 148 million *L. dubia*, for a total of 162 million tanaidaceans.

Ten species of isopods were entrained at the plant. The estimated entrainment loss of isopods was 35 million organisms.

The ecological impact of the plant resulting from losses of tanaidaceans and isopods is small, because they are abundant and widely distributed in the Bay, they are predominantly benthic forms, and they have a high reproductive capacity.

5.2.1.4 Amphipods

These animals are a diverse and abundant group of shrimplike crustaceans that occur in nearly all marine habitats. Most are bottom-dwelling forms that periodically (daily

and seasonally) migrate into the water column for breeding, feeding, and dispersal. Fecundities are relatively low, in general, but short generation times often result in the production of large numbers of individuals, particularly in summer and fall populations. Most amphipods are microphagous, feeding on suspended and deposited detritus. They are an important link in the food chain because they are extremely abundant and provide food for many higher animal forms, including fishes, invertebrates, and shorebirds.

Thirty-two taxa of inshore coastal amphipods were entrained at the Hunters Point Power Plant during the monitoring program. Some of these are distributed all along the outer coast, but most are found only in the low intertidal and subtidal regions of wave-protected areas. Here, many of them are associated with soft sediments or with the fouling community present on pilings and piers. Some of the San Francisco Bay species are natives that have broad geographical distributions in temperate northeastern Pacific waters. However, a number of other species have been introduced by man from their native ranges; these may be found in bays and estuaries throughout the world. The most common species entrained at the Hunters Point Power Plant were Corophium insidiosum, Jassa falcata, Stenothoe valida, and Caprella equilibra (Table 5-2).

Corophium insidiosum, a tube-dwelling amphipod, was probably introduced along with eastern oysters into San Francisco Bay (Bousfield 1973; Smith and Carlton 1975). It is widely distributed in San Francisco Bay (Shoemaker 1949; Liu 1973; Liu et al. 1975), extending as far up the estuary as the PGandE Pittsburg Power Plant (Ecological Analysts, unpublished data). It may be particularly abundant in fouling communities (Barnard 1961). Graham and Gay (1945) reported densities up to 155,000/m^2 on settling plates in the Oakland Estuary. Most of the amphipods identified only as Corophium spp. (420 million) were probably C. insidiosum. The estimated entrainment loss was 1,017 million C. insidiosum, and the total loss of all Corophium spp. amphipods was 1,500 million.

Jassa falcata also lives in tubes and is often associated with fouling communities (Reish and Barnard 1967). It is likely to be widely distributed and common in San Francisco Bay, but again, specific information is limited. The estimated annual entrainment mortality was 1,233 million organisms.

TABLE 5-2 ESTIMATED MORTALITY OF SELECTED AMPHIPODA AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, 1978-1979

Taxon	Number	
	Entrainment[a]	Impingement[b]
Corophium insidiosum	1,016,700,000	0
Other *Corophium* spp.	483,600,000	0
Jassa falcata	1,233,400,000	0
Stenothoe valida	186,400,000	0
Caprella equilibra	67,400,000	315
Other Caprellidea	71,700,000	98

(a) Estimates are based on actual cooling water flows and 77 percent overall entrainment loss (see Sections 3.1.2.2 and 3.2.2 and Table 3-9).
(b) Estimates are based on actual cooling water flows and 100 percent impingement mortality (see Table 4-7).

Stenothoe valida does not live in tubes, but is often associated with fouling hydroids (Barnard and Reish 1959). It, too, is probably widely distributed and common in San Francisco Bay. The estimated annual entrainment mortality was 186 million animals.

Caprella equilibra is a "skeleton shrimp." These odd amphipods cling to other animals, such as hydroids and bryozoans, that are part of the fouling community. Caprella equilibra is widely distributed and quite common in San Francisco Bay, but no specific information is available for this species. Estimated entrainment mortality was 67 million C. equilibra and 72 million other Caprella spp.

Although the estimated numbers of amphipods lost to entrainment are in the hundreds of millions, the impact of these losses on their populations and the indirect impact on the aquatic community is minimal, because they are exceedingly abundant and widely distributed in the Bay, they are predominantly benthic, and they have a high reproductive capacity.

5.2.1.5 Shrimps

The most common species of decapod shrimp collected in this study were Crangon franciscorum, C. nigricauda, Palaemon macrodactylus, and Upogebia pugettensis (Table 5-3). The two species of the genus Crangon are collectively referred to here as bay shrimps. Crangon franciscorum is geographically distributed from Alaska to San Diego, California (Schmitt 1921), and C. nigricauda has been recorded from British Columbia to Baja California (Rathbun 1904). Both of these shrimps are shallow-burrowing and swimming forms that live in subtidal regions to depths of about 50 m (165 ft). They are widely distributed in San Francisco Bay (Schmitt 1921; Israel 1936). Crangon franciscorum is most abundant in San Pablo Bay and its distribution extends up into the western Delta region; C. nigricauda is most commonly encountered in San Pablo Bay, becoming less common in the central Bay and in the estuary (Ecological Analysts, unpublished data). Natural predators of bay shrimps include a variety of fishes.

The life history features of the two species are similar. Adults migrate toward the ocean as the spawning season approaches, and the embryos hatch in high-salinity regions (Israel 1936; Siegfried et al. 1978). Later, larvae or juveniles are transported

TABLE 5-3 ESTIMATED MORTALITY OF SELECTED DECAPOD SHRIMPS AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, 1978-1979

Taxon	Number	
	Entrainment[a]	Impingement[b]
Upogebia pugettensis	274,000,000	70
Palaemon macrodactylus	700,000	42
Crangon nigricauda	500,000	1,257
Crangon franciscorum	2,400,000	362
Crangon spp.	3,700,000	0
Other Caridea	17,300,000	0

(a) Estimates are based on actual cooling water flows and 77 percent overall entrainment loss (see Sections 3.1.2.2 and 3.2.2 and Table 3-9).

(b) Estimates are based on actual cooling water flows and 100 percent impingement mortality (see Table 4-7 and Table E.2-1, Appendix E).

back into lower-salinity regions. Spawning occurs at the end of the first year, and large females may spawn twice in one season.

Crangon franciscorum spawns from December to June; C. nigricauda from April to September (Israel 1936). Fecundities are directly proportional to female size. In San Francisco Bay, C. franciscorum and C. nigricauda females average 60 and 45 mm in length, respectively. Average-sized C. franciscorum females carry about 4,000 embryos; C. nigricauda females carry about 3,700 embryos (Krygier and Horton 1975). Females of both species grow larger than males and live somewhat longer, about 18 months.

Bay shrimp, especially C. franciscorum, have been fished commercially in the San Francisco Bay area since about 1869 (Frey 1971). Peak landings at the turn of the century were about 2.9 million kg (6.5 million pounds) (Skinner 1962), but the annual catch for 1973-1976 averaged only 34,500 kg (83,700 pounds) (McAllister 1975, 1976; Pinkas 1977; W. Dahlstrom, Calif. Dep. Fish Game, 1979, personal communication). At present the fishery is limited by market demand rather than the size of the stock (Frey 1971; W. Dahlstrom, Calif. Dep. Fish Game, 1979, personal communication). Most of the shrimp landed since 1965 have been used as bait for striped bass and sturgeon sport fishing, but historically the shrimp were caught for human consumption. Most of the fishery is located in San Pablo Bay, but there is some activity in the south Bay near Alviso. Before 1940, the fishery was active near the Hunters Point Power Plant.

Juvenile and adult bay shrimp were impinged. Annual impingement loss estimates for C. franciscorum and C. nigricauda are 362 and 1,257 animals, respectively. About 6.6 million shrimp identifiable as bay shrimps were lost to entrainment (Table 5-3). These included 2.4 million C. franciscorum and 0.5 million C. nigricauda. Smaller shrimp larvae collected in entrainment samples at the plant could only be identified as Caridea. These were larvae of shrimps in the following families: Hippolytidae, Alpheidae, Crangonidae, and Palaemonidae. These families include several species of the genera Heptacarpus, Betaeus, and Crangon, and the species Palaemon macrodactylus. Altogether, between 5 and 10 species were represented. The number lost to combined entrainment mortality was about 17.3 million. The proportion of bay shrimps is not known.

Palaemon macrodactylus is a nonburrowing, subtidal shrimp that was accidentally introduced to San Francisco Bay from Japan or Korea in 1954 (Newman 1963). Although not found along the outer coast, it is widely distributed in San Francisco Bay, extending up the estuary past Antioch (Ecological Analysts, unpublished data). It is most abundant in the low-salinity areas of the San Francisco Bay - Delta system (Newman 1963; Ganssle 1966), where densities of juveniles and adults may exceed $10/m^3$ (Siegfried et al. 1978). The spawning season is from April to October (Little 1969). Fish are the most important natural predators of this shrimp. A commercial fishery existed in the 1950s (Newman 1963), but there is no fishery for this shrimp today.

Palaemon macrodactylus juveniles and adults were both entrained and impinged at the Hunters Point Power Plant. An estimated 670,000 organisms are lost to entrainment annually; the impingement loss estimate is 42 animals.

Upogebia pugettensis is a thalassinid shrimp found in the low intertidal and shallow subtidal regions of bays and estuaries from southeastern Alaska to San Quintin Bay, Baja California (Rathbun 1904). It excavates a relatively permanent Y-shaped burrow that may extend several feet into the sediment (Thompson 1972). The distribution and abundance of this shrimp in the San Francisco Bay system are poorly known because of its sedentary burrowing habits. It is probably fairly common where mud or sandy-mud sediments prevail. The species cannot tolerate salinities below about 10 percent (3 ppt) seawater in the laboratory (Thompson and Pritchard 1969), so it probably does not occur in the lower-salinity areas of the San Francisco Bay system. According to Thompson (1972), embryo-bearing females are found in the winter and spring. Larvae are free in the water for about two weeks before settling to the substrate and are vulnerable to entrainment at that time. Natural predators include fish and Cancer spp. crabs. A small sport fishery for this shrimp in San Francisco Bay (near Candlestick Park and Alameda) involves collection of the shrimp as bait for striped bass and sturgeon fishing.

The number of U. pugettensis larvae lost to entrainment during the study period was 274 million larvae. Only 70 juveniles and adults were impinged. Except for U. pugettensis, the estimated numbers of decapod shrimp lost to combined entrainment and impingement impacts at the Hunters Point Power Plant was low. The impact of the plant on the decapod shrimp populations and the indirect impact on the

community are minimal, because they are abundant and widely distributed in the San Francisco Bay system. The center of distribution of Crangon spp. is located in San Pablo Bay and Suisun Bay. Upogebia pugettensis is probably abundant in the south Bay and in the area of the Hunters Point Power Plant, but it is a burrowing shrimp, and individuals are vulnerable to entrainment for only two weeks during the larval stage before they settle to the substrate. The decapod shrimp entrained were predominantly larvae, and each adult female produces several thousand embryos.

5.2.1.6 Crabs

Eight species of crabs were impinged at the Hunters Point Power Plant, and larvae and juveniles of some of these were also entrained. Most of these crabs occur along the outer coast as well as in bays. Except for the grapsids, which may be found throughout the intertidal zone, the crabs discussed here occur mainly at low intertidal and subtidal depths. The most common species collected in this study were Cancer spp. crabs and Hemigrapsus oregonensis (Table 5-4).

The Dungeness crab, Cancer magister, has been reported from Unalaska, Alaska, to Magdalena Bay, Baja California (Schmitt 1921), but it is rare south of Point Conception, California. Adults live in sandy subtidal regions to depths of 50 fathoms (90 m), and juveniles occur in shallow wave-protected areas having sand or mud bottoms. Juveniles are widely distributed in San Francisco Bay, particularly in the channels (Schmitt 1921; Ecological Analysts, unpublished data; S. Hatfield, Calif. Dep. Fish Game, 1979, personal communication). Because juvenile C. magister seem to tolerate salinities less than 10 ppt, they are sometimes found in the brackish areas of the Bay system, extending as far up the estuary as Port Chicago (S. Hatfield, Calif. Dep. Fish Game, 1979, personal communication). Larvae (zoeae and megalopae) are uncommon in the Bay. Both larvae and adults are common offshore in the Gulf of the Farallones, but the Bay appears to be a nursery area for juveniles that later migrate offshore.

The life history features of the Dungeness crab are well known (Frey 1971). Reproduction begins in the spring when hard-shelled males mate with freshly molted females. Females extrude embryos in the fall and carry them until they hatch in the winter. Brood sizes range from 700,000 to 2,500,000 offspring, depending on female size. The newly hatched larvae pass through five zoeal and one megalop stage before

TABLE 5-4 ESTIMATED MORTALITY OF SELECTED DECAPOD CRABS AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, 1978-1979

Taxon	Number	
	Entrainment[a]	Impingement[b]
Majidae		
Majidae unid.	37,900,000	0
Pyromaia tuberculata	0	403
Cancridae		
Cancer spp.[c]	45,200,000	0
Cancer antennarius	1,700,000	798
Cancer productus	106,100,000	353
Cancer gracilis	300,000	7
Cancer magister	0	56
Cancer anthonyi	0	12
Xanthidae	17,500,000	0
Pinnotheridae	175,100,000	0
Grapsidae		
Grapsidae unid.	700,000	0
Hemigrapsus oregonensis	251,900,000	811
Pachygrapsus crassipes	264,600,000	24
Hemigrapsus spp.	72,500,000	0

(a) Estimates are based on actual cooling water flows and 77 percent overall entrainment loss (see Sections 3.1.2.2 and 3.2.2 and Table 3-9).

(b) Estimates are based on actual cooling water flows and 100 percent impingement mortality for all species (see Table 4-7 and Table E.2-1, Appendix E).

(c) More than 99 percent of cancrid Stage I zoeae, identified as *Cancer* sp. 1, were either *C. antennarius* or *C. gracilis* (P. Riley, Calif. Dep. Fish. Game, 1979, unpublished taxonomic key).

metamorphosing into juvenile crabs. From three to five months are required to complete the larval stages: juveniles appear on the bottom in late spring and early summer. Maturity is reached about 18 months after metamorphosis. Maximum age is about six years.

The Dungeness crab has been the focus of a commercial fishery in the San Francisco area since 1870 (Skinner 1962; Frey 1971). The fishery, which is restricted to males, reached its peak in the 1956-1957 season, when 4,450 tons (4,000 metric tons) were caught offshore. However, the fishery declined drastically in 1961-1962 and has not exceeded 700 tons (600 metric tons) per season since that time. Very few Dungeness crabs of legal size are taken in the crab sport fishery in San Francisco Bay. Natural predators of Dungeness crabs include fish, octopi, and other crabs. The larvae of C. magister are uncommon in San Francisco Bay, and none were observed in the entrainment samples taken in this study: none of the zoeae or megalopae identified only as Cancer spp. were C. magister.

The impingement loss estimate for C. magister was only 56 individuals. This number represents only about 2-1/4 percent of the impingement cropping estimate for all Cancer spp. crabs. The tendency of C. magister to frequent channels and to move up into brackish areas of the Bay system may account for the low numbers impinged at the Hunters Point Power Plant.

Two species of Cancer crabs are collectively referred to here as rock crabs. These are the red crab, Cancer productus, distributed from Kodiak, Alaska, to Laguna Beach, California (Rathbun 1930), and the rock crab, C. antennarius, which is recorded from Coos Bay, Oregon, to Todos Santos Island, Baja California (Nations 1975). These crabs live in the low intertidal and shallow subtidal regions of bays and wave-protected rocky areas. They are widely distributed in south and central San Francisco Bay and San Pablo Bay, but do not occur in the more estuarine parts of the Bay system (Schmitt 1921; S. Hatfield, Calif. Dep. Fish Game, 1979, personal communication). Abundance appears to be highest in the central Bay. The crabs can be found in a variety of habitats, but are particularly common around rocks and pilings. Embryo-bearing females have been collected from November to January, and zoeae and megalopae are present in San Francisco Bay in the late winter and spring. Rock crab larvae provide food for a variety of fishes. Juveniles and adults are prey to fish, octopi, birds, and other Cancer spp. crabs. Although rock crabs are not important

commercially in the Bay area, they support a sizable sport fishery (Frey 1971). They are taken around fishing piers with baited nets and traps.

Approximately 106 million Cancer productus zoeae were entrained at the Hunters Point Power Plant, but no megalopae were recorded for this species. About 1.7 million C. antennarius zoeae and megalopae were also entrained. In addition, many of the zoeae identifiable only as Cancer spp. were probably C. antennarius. Well-established fecundity estimates are not available for rock crabs. However, one estimate is that each female produces 500,000 first-stage zoeae per year (W. Dahlstrom, Calif. Dep. Fish Game, 1979, personal communication).

The estimated impingement mortality for Cancer productus was 353 animals. The estimate for C. antennarius was 798. These crabs were almost all juveniles. Intake structures and their fouling assemblages provide habitat for rock crabs, and some of the crabs impinged may have been residents of the intakes rather than of nearby natural habitats.

Hemigrapsus oregonensis is an intertidal and subtidal grapsid crab that occurs in harbors and bays. Its recorded range is from Prince William Sound, Alaska, to San Quintin Bay, Baja California (Rathbun 1918; Kuris 1971). Hemigrapsus oregonensis is widely distributed and abundant in south and central San Francisco Bay and San Pablo Bay (Schmitt 1921; Ecological Analysts, unpublished data). Fecundity varies from 1,200 to 25,000 brooded embryos per female, depending on the size of the crab (Kuris 1971). Most females have several broods each year. The most important natural predators of this crab are birds, fish, larger crabs, and octopi.

The estimated number of grapsid zoeae and megalopae exposed to entrainment mortality was 590 million. The impingement loss estimate for juvenile and adult H. oregonensis was 811 animals.

Pyromaia tuberculata is a small spider crab living at subtidal depths to 45 fathoms (80 m) in wave-protected areas, particularly in harbors and bays (Schmitt 1921). Its recorded range is from Tomales Bay, California to Panama (Garth 1958), so San Francisco Bay is near the northern limit of its range. In San Francisco Bay, Pyromaia spp. appear to be most common on soft-bottom deposits and wharf pilings in the central

Bay, although they have also been collected in San Pablo Bay and the south Bay (Liu 1973; Liu et al. 1975).

Larvae identified only as Majidae were probably Pyromaia tuberculata, although at least two other majids were also present in the area. The estimated entrainment loss of majid larvae was 38 million organisms. The impingement loss estimate for adult P. tuberculata was 403 animals.

Crab larvae identifiable only as Xanthidae and Pinnotheridae were also entrained at the plant. Several species could have contributed to the category Xanthidae. No pinnotherids were taken in the impingement samples. The estimated numbers lost to combined entrainment mortalities were 17 million Xanthidae and 175 million Pinnotheridae. Little is known about the life history or ecological function of these crabs in San Francisco Bay.

The estimated number of crabs lost due to impingement at the Hunters Point Power Plant is very low. The number of crab larvae entrained is larger; however the direct impact of entrainment on crab populations and the indirect impact on the aquatic community is minimal, because most of the crabs entrained were in the larval zoeal stage, and female crabs produce several thousand to several million zoeae per brood. The crab of greatest economic importance, Cancer magister, was not entrained, and only 56 juveniles were impinged. Crabs are abundant and widely distributed in the Bay and along the outer coast.

5.2.1.7 Arrow Worms

Arrow worms (Chaetognatha) are a small group of torpedo-shaped, planktonic animals. Active and predatory, they feed mainly on small crustaceans and larval fish. Temperate species produce several broods each year, and each brood may consist of several hundred embryos. The only species entrained at the Hunters Point Power Plant in this study was Sagitta euneritica. This species is found in the upper layers of coastal waters from Washington to Central America (Alvarino 1965). In the California region, they may be present in large numbers (thousands per cubic meter). The estimated total number lost to entrainment was 7 million organisms. The impact is minimal, because they are abundant in the Bay and in coastal waters.

5.2.2 Fish

The major groups of fish in the San Francisco Bay system are the anadromous fishes, marine inshore fishes, marine pelagic fishes, and freshwater fishes (Section 2.3.4). The anadromous fishes include striped bass, sturgeon, American shad, salmon, and steelhead. The marine inshore species are a diverse fauna including flatfishes, rockfishes, surfperches, croakers, gobies, and sculpins (cottids). The marine pelagic bait and forage fishes include Pacific herring, northern anchovy, topsmelt, jacksmelt, and true smelts (Osmeridae). The freshwater fishes are confined to the upper estuary and are not discussed in this report.

5.2.2.1 Anadromous Fishes

Anadromous fishes are considered by the SWRCB (1975) to be the most important fish in the Bay system. The most important species include striped bass, king salmon, steelhead trout, green sturgeon, white sturgeon, and American shad. Of the anadromous fishes, salmon, steelhead, and American shad reside as adults in the ocean and use the Bay only to migrate to upper rivers of the system to spawn (Section 2.3.4). Young of these species migrate down to the ocean through the Bay. Only 33 king salmon, 7 American shad, and 7 steelhead were estimated to have been impinged at the Hunters Point Power Plant.

Adult and juvenile striped bass and sturgeon are known to reside in the Bay near Hunters Point, but the majority reside in the northern Bay. Only 42 striped bass and no white sturgeon are estimated to have been impinged during the study; thus these species are apparently not vulnerable to the intakes of the plant.

5.2.2.2 Flatfishes (Pleuronectiformes)

The flatfishes common to the Bay are the English sole, starry flounder, and sanddabs. Flatfishes were entrained and impinged in low numbers at the Hunters Point Power Plant (Table 5-5). Some of the unidentified fish eggs (Osteichthyes eggs) may have been flatfish eggs, which are pelagic, but aside from the starry flounder, flatfishes spawn in offshore ocean waters, and the Bay is used only by juveniles, as a nursery area. Fecundity is generally high. English sole females release from 150,000 to 2 million pelagic eggs (Harry 1959); therefore, even if a majority of the unidentified

TABLE 5-5 ESTIMATED MORTALITY OF FLATFISHES (PLEURONECTIFORMES) AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, 1978-1979

Taxon		Number	
Common Name	Scientific Name	Entrainment[a]	Impingement[b]
English Sole	*Parophrys vetulus*	24,600	1,129
Speckled sanddab	*Citharichthys stigmaeus*	0	680
California tonguefish	*Symphurus atricauda*	0	164
Diamond turbot	*Hypsosetta guttulata*	0	91
Starry flounder	*Platichthys stellatus*	0	19

(a) Estimates are based on actual cooling water flows and 82 percent overall entrainment loss (see Sections 3.1.2.2 and 3.2.2 and Table 3-9).
(b) Estimates are based on actual cooling water flows and 100 percent impingement mortality (see Table 4-7 and Table E.2-1, Appendix E).

fish eggs were flatfish eggs, the total would only represent the production of a few hundred females.

The impact of the plant on populations of flatfishes is minimal, because of the low numbers of animals either entrained and/or impinged at the plant. Since juvenile flatfish are abundant in the Bay and in the area of the plant, they would appear to be able to avoid being impinged on the intake screens. Since low numbers of larvae were entrained, the planktonic eggs and larvae are probably concentrated in offshore coastal waters.

5.2.2.3 Rockfishes (Sebastes spp.)

Rockfishes are marine inshore (neritic) fishes, many species of which are found along the Pacific coast and in San Francisco Bay. They sustain important sport and commercial fisheries outside the Bay. Only the brown rockfish, black rockfish, bocaccio, and unidentified rockfish were impinged (523, 201, 105, and 84, respectively). All of these were juveniles. No rockfish larvae were entrained.

The impact of these losses on rockfish populations in the Bay or outside the Bay is minimal, because the numbers involved are low in comparison to the numbers found from the south Bay to San Pablo Bay (Ganssle 1966; Aplin 1967). Recent studies by the National Marine Fisheries Service at Tiburon (T. Echeverria, Natl. Mar. Fish. Serv., 1979, personal communication) indicate that many brown rockfish use the Bay as a nursery area. The brown rockfish is not a major component of the commercial fishery (Miller and Hardwick 1973; Fitch and Lavenberg 1975).

5.2.2.4 Sculpins (Cottidae)

The sculpins, or cottids, are bottom-dwelling fishes of marine inshore waters. The staghorn sculpin is abundant and widely distributed in the Bay system (Ganssle 1966; Aplin 1967; Moyle 1976). Staghorn sculpin support a small baitfish fishery (McAllister 1975, 1976; Pinkas 1977, 1979); they are also often caught by sport fisherman, but are usually not kept. Only 150 staghorn sculpin were estimated to have been impinged at the Hunters Point Power Plant during the one-year survey. About 500,000 staghorn sculpin larvae were lost to entrainment. Cabezon were also entrained or impinged, in low numbers (Table 5-6). The cabezon is considered a sport fish and is caught

TABLE 5-6 ESTIMATED MORTALITY OF SCULPINS (COTTIDAE) AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, 1978-1979

Taxon		Number	
Common Name	Scientific Name	Entrainment[a]	Impingement[b]
Staghorn sculpin	*Leptocottus armatus*	500,000	150
Sculpin larvae	Cottidae	400,000	0
Cabezon	*Scorpaenichthys marmoratus*	30,000	0

(a) Estimates are based on actual cooling water flows and 82 percent overall entrainment loss (see Sections 3.1.2.2 and 3.2.2 and Table 3-9).

(b) Estimates are based on actual cooling water flows and 100 percent impingement mortality (see Table E.2-1, Appendix E).

in small numbers in the San Francisco Bay region; however, the species is far more abundant in southern California waters (O'Connell 1953; Frey 1971).

The impact of the plant on the sculpin populations in the Bay is minimal because the numbers entrained and impinged are low. The largest impact was due to the entrainment of larvae, which are pelagic and active swimmers (Moyle 1976; Jones 1962). The impact of these losses is low because staghorn sculpin eggs are demersal and clustered (Jones 1962) and not subject to entrainment; and the late larvae and juveniles concentrate in estuarine portions of the Bay system (Jones 1962). The number of cabezon lost to entrainment, 30,000, is small: each female produces from 37,000 to 100,000 eggs and may spawn more than once per season (O'Connell 1953).

5.2.2.5 Surfperches (Embiotocidae)

Surfperches, common along the Pacific coast and in San Francisco Bay, are unusual in that they bear live young. They are a commonly caught sport and commercial fish. The sport species are the barred, shiner, redtail, and walleye. The major species in the San Francisco Bay region commercial catch are redtail, white, black, pile, and rubberlip surfperch (Frey 1971). No surfperch were entrained; these fish are born as juveniles. The numbers of surfperch lost due to impingement is presented in Table 5-7. Most were juveniles. The impact of the plant on the populations in the Bay is minimal, because the numbers lost are low in comparison to their abundance and wide distribution.

5.2.2.6 White Croaker

Three croakers (Sciaenidae) may occur in San Francisco Bay—white croaker, queenfish, and white seabass. The white croaker was the only species collected in this study. The queenfish and white seabass are more common in southern California waters.

White croaker are marine inshore bottom-dwelling fish found along the California coast and in the Bay system from the south Bay to Carquinez Strait (Ganssle 1966; Aplin 1967). A modest commercial fishery for croaker exists statewide: annual landings ranged from 115 to 290 tons (100 to 260 metric tons) statewide and 15-25 tons (13-23 metric tons) in the San Francisco Bay region from 1973 to 1976. The annual statewide sport catch is estimated at 670,000 fish (Frey 1971).

TABLE 5-7 ESTIMATED MORTALITY OF SURFPERCHES (EMBIOTOCIDAE) AT UNITS 2 AND 3 AND UNIT 4 OF THE HUNTERS POINT POWER PLANT, 1978-1979

Taxon		Number	
Common Name	Scientific Name	Entrainment	Impingement[a]
White surfperch	*Phanerodon furcatus*	0	2,871
Shiner surfperch	*Cymatogaster aggregata*	0	2,612
Pile surfperch	*Damalichthys vacca*	0	1,767
Walleye surfperch	*Hyperprosopon argenteum*	0	1,599
Rubberlip surfperch	*Rhacochilus toxotes*	0	233
Dwarf surfperch	*Micrometrus minimus*	0	161
Black surfperch	*Embiotoca jacksoni*	0	40
Striped surfperch	*Embiotoca lateralis*	0	39

(a) Estimates are based on actual cooling water flows and 100 percent impingement mortality (see Table 4-7 and Table E.2-1, Appendix E).

habitat and food (Brittan et al. 1970; Moyle 1976). The impact on the goby populations is minimal, because of their overall abundance and wide distribution in the Bay.

5.2.2.8 Smelts and Silversides (Osmeridae and Atherinidae)

The smelts and silversides are important forage fishes for larger predator fishes in coastal waters (Frey 1971). Two species of silversides and five species of smelt are found in the Bay system. The silversides (topsmelt and jacksmelt) are considered sport fish and are commonly caught in the Bay (Frey 1971).

The number impinged at the intakes of the Hunters Point Power Plant in the one-year survey was very low. The topsmelt population had the highest number of animals impinged (628). The entrainment losses of smelt larvae (Osmeridae) were also low (270,000); since the larvae are planktonic, they must not occur in large numbers near the Hunters Point Power Plant. Entrainment loss of silversides (Atherinidae) was also low (155,800 animals), given their fecundity (20,000-30,000 eggs per female) (Ecological Analysts, unpublished data) and wide distribution and abundance in the Bay. The impact of the plant on smelt and silverside populations is minimal, because they are abundant and widely distributed in the Bay.

5.2.2.9 Pacific Herring

The Pacific herring is a planktivorous, pelagic schooling species found in the Pacific Ocean from Baja California to Alaska (Miller and Lea 1972, 1976). Its population is made up of many genetically separate subpopulations in this range, including the San Francisco Bay area (Frey 1971; Spratt 1976).

The San Francisco Bay spawning stock of Pacific herring, the largest subpopulation in the southern range, has recently been estimated at 20,000 tons (18,000 metric tons) (Spratt 1976). Several spawning runs enter San Francisco Bay between December and March. The Bay spawning stock supports a considerable fishery, which varies from year to year depending on the demand. In recent years there has been a high demand from the Japanese market for roe. Other high-demand periods occurred from 1916 to 1928, when they were harvested for reduction to fish meal, and from 1947 to 1962, when they were used as a partial replacement for the sardine fishery (Hardwick 1973). Recent catches in the San Francisco Bay region ranged from 1,000 to 5,500 tons

(900-5,000 metric tons) annually, 80-90 percent of the statewide total. Most of this catch originates in San Francisco Bay, but up to 500 tons (450 metric tons) may come from Tomales Bay (Spratt 1976).

Pacific herring are vulnerable to the intakes of the power plant during the spawning migration of adults and as young before they migrate to the ocean. Since the eggs are demersal and adhesive, they have little probability of being entrained in the plant's cooling water system. However, the planktonic larvae were entrained at estimated annual rate of 30 million individuals (Table 3-4) during the one-year study. Entrainment survival studies indicated that about 82 percent of these (24.6 million) did not survive (Table 3-15). In addition, an estimated 12,058 juvenile and adult Pacific herring were impinged on the intake screens during the year (Table 4-1).

An equivalent adult model was used to assess the significance of these losses. The model utilizes population mortality rates calculated from field data or available in the literature to equate the cropped larvae and juveniles to adult fish. Details of the analyses are presented in Appendix C. The annual estimated equivalent adults (age 2 years) amounted to 603,125 fish (Table 5-8). At an average weight per fish of 0.0708 kg, this would amount to 42,695 kg or 42.7 metric tons (47.6 tons), equivalent to 0.2 percent of the San Francisco Bay spawning stock, estimated at 18,000 metric tons (20,000 tons), and 1.6 percent of the average annual cropping of Pacific herring from San Francisco Bay by the commercial fishery during the last six years (2,600 metric tons; 2,900 tons) (Calif. Dep. Fish Game, unpublished data).

5.2.2.10 Northern Anchovy

The northern anchovy is also a planktivorous, pelagic schooling species found in the Pacific Ocean from Baja California to Alaska (Miller and Lea 1972, 1976). Its population consists of many genetically separate subpopulations in this range (Frey 1971; Spratt 1976), including one in the area that encompasses San Francisco Bay.

Vrooman and Smith (1971) estimated the annual spawning biomass of the central stock of northern anchovy (between San Francisco and Cape San Lazaro, Baja, California) at 5.0-8.1 million tons (4.5-7.3 million metric tons) from 1962 to 1966. In this period the mean total biomass was 6.1 million tons (5.5 million metric tons). The mean biomass of the subpopulation north of Point Conception was estimated at 0.26 million tons

TABLE 5-8 EQUIVALENT ADULT LOSSES OF NORTHERN ANCHOVY AND PACIFIC HERRING AT THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979

Source of Loss	Northern Anchovy		Pacific Herring	
	Number Lost	Equivalent Adult Loss	Number Lost	Equivalent Adult Loss
Entrainment of eggs[a]	38,470,000	7,554	0	0
Entrainment of larvae and juveniles[a]	2,300,000	101,242	24,650,000	595,619
Impingement of juveniles and adults[b]	74,934	74,934	12,058	7,506
Total		183,730		603,125

(a) Estimates are based on actual cooling water flows and 82 percent overall entrainment loss (see Sections 3.1.2.2 and 3.2.2 and Table 3-9).

(b) Estimates are based on actual cooling water flows and 100 percent impingement mortality (see Table 4-7).

(0.24 million metric tons), 4.2 percent of the total 5-year mean. The size of the central spawning stock has been low for the past several years, and is estimated at 860,000 tons (780,000 metric tons) for the 1979-1980 season; the northern subpopulation remains a small fraction of this stock (J. Hunter, Natl. Mar. Fish Serv., 1979, personal communication).

The northern anchovy fishery has become highly intensive and, as a result of the dramatic decline of the sardine, is the largest (in biomass) commercial fishery in California. The anchovy catch is canned, reduced to oil and meal, or sold as bait fish (Frey 1971). During the years 1973-1976 the statewide commercial catch ranged from nearly 50,000 to 150,000 tons (45,000-136,000 metric tons) annually. The allowable catch for the 1979-1980 season has been set at 120,000 tons (109,000 metric tons). The San Francisco Bay region catch ranged from 250 to nearly 520 tons (230-450 metric tons) annually during the period 1973-1976, representing less than 0.2 percent of the spawning biomass of the northern subpopulation.

Northern anchovy eggs and larvae are planktonic and thus susceptible to entrainment. An estimated 59 million eggs and 2.8 million larvae were entrained (Table 3-4) and an estimated 74,934 anchovy juveniles were impinged (Table 4-1) during the one-year study (April 1978 - April 1979). Entrainment survival and mass balance studies indicated that about 65 percent of the eggs (38 million) and 82 percent of the larvae (2.3 million) entrained did not complete cooling system transit alive (Table 3-8). The significance of this cropping was assessed using the equivalent adult model. The computed annual equivalent adults (age 1 year) for the eggs, larvae, and adults cropped by the Hunters Point Power Plant was 183,730 fish (Table 5-8). At an average age-1 weight of 0.0185 kg/fish, this amounts to 3.4 metric tons (3.6 tons). This amounts to less than a thousandth of one percent of the estimated central zone spawning stock of 780,000 metric tons (860,000 tons) for the 1979-1980 season, or 0.8-1.5 percent of the annual commercial catch in the San Francisco Bay region (230-450 metric tons) during the years 1973-1976.

5.3 SUMMARY AND CONCLUSIONS

The numbers of fish and macroinvertebrates impinged on the intake screens of the Hunters Point Power Plant are extremely low, given that the organism groups impinged are common in San Francisco Bay and in the area of the plant. The numbers

of fish and macroinvertebrates lost to entrainment are also considered low, because only the early life stages, which are generally abundant and widely distributed, are affected. The 38.5 million eggs and 2.3 million larvae of northern anchovy lost to combined entrainment impacts represent only about 109,000 adults; the 24.6 million Pacific herring larvae lost to entrainment represent about 595,000 adults. The reason for this is based on the ecological assimilative capacity of the species, in that most of the species of fish and invertebrates entrained have very high reproductive potentials (either in terms of numbers of young produced or frequency of reproduction) and the young have very high natural mortality rates. The numbers lost to entrainment and the equivalent adults are also only a small fraction of the total population in San Francisco Bay because the Hunters Point Power Plant uses only a very small portion of the water of the Bay. Young Pacific herring and anchovy are especially abundant throughout the Bay. Most of the other young fish and macroinvertebrates entrained in large numbers are also abundant throughout the Bay, and it is unlikely that the effect on their populations would be any greater than the effect on the populations of Pacific herring and northern anchovy.

On the basis of life history reviews of the key species of fishes and macroinvertebrates, many have behavioral, reproductive, and migrational patterns that minimize their entrainment and impingement at the plant. Only certain life stages of the young (usually larvae) are planktonic and susceptible to entrainment. Many species are large enough to avoid entrainment and impingement by the time they move into San Francisco Bay (e.g., Cancer magister and the flatfishes).

In sum, the ecological roles or trophic functions of key organism groups affected by the Hunters Point Power Plant are not expected to be significantly affected by the continued operation of the plant. The transfer of energy through predator-prey relationships in the trophic structure of the aquatic community is not, and cannot, be affected by the relatively small mortalities that occur at the plant. Most life stages of the entrained key organism groups feed on lower trophic forms such as phytoplankton and microzooplankton, and they, in turn, are prey to adults of their species and to a wide array of other species of fish and invertebrates. Since the effect on the species populations, discussed in the previous sections, is considered to be minimal, changes in these ecological roles or functions due to entrainment and impingement losses at the Hunters Point Power Plant are insignificant and undetectable in the populations.

The commercial and sport fisheries in San Francisco Bay, including those near the plant, are not adversely affected by the plant. Since the effect of the plant is estimated to be small compared to commercial fisheries, the effect on these fisheries from losses should be minimal. The bay shrimp fishery in San Francisco Bay, although considered small, is still far larger than the numbers of bay shrimp entrained at the plant. With respect to striped bass, rockfish, and sturgeon populations that sustain significant sport fisheries in the Bay, as well as the anadromous king salmon, steelhead trout, and American shad that are also considered by the SWRCB (1975) to be important species in the Bay, there is virtually no direct effect caused by the continued operation of the Hunters Point Power Plant (Section 2.3). The indirect effect on these groups through loss of their prey is also expected to be minimal, since their prey are abundant and widely distributed throughout the Bay. Moreover, the fisheries are located in the more northern areas of the Bay.

Lesser sport fisheries for the silversides (topsmelt and jacksmelt), white croaker, flatfish, rockfish, and surfperch exist in San Francisco Bay and near the Hunters Point Power Plant (Section 2.3). Since the numbers of these species cropped by the plant are low, the population and community effect (both direct and indirect) would be undetectable.

5.4 REFERENCES

Alvarino, A. 1965. Chaetognaths. Oceanogr. Mar. Biol. Annu. Rev. 3:115-194.

Aplin, J. A. 1967. Biological survey of San Francisco Bay, 1963-1966. Calif. Dep. Fish Game, Mar. Resour. Oper., MRO Ref. 67-4. 131 pp.

Barnard, J. L. 1961. Relationship of Californian amphipod faunas in Newport Bay and in the open sea. Pac. Nat. 2(4):166-186.

Barnard, J. L. and D. J. Reish. 1959. Ecology of Amphipoda and Polychaeta of Newport Bay, California. Allan Hancock Found. Publ., Occas. Pap. 21. 106 pp.

Bousfield, E. L. 1973. Shallow-water gammaridean Amphipoda of New England. Cornell University Press, Ithaca. 312 pp.

Brittan, M. R., A. B. Albrecht, and J. B. Hopkirk. 1963. An oriental goby collected in the San Joaquin River Delta near Stockton, California. Calif. Fish Game 49(4):302-304.

Brittan, M. R., J. D. Hopkirk, J. D. Conners, and M. Martin. 1970. Explosive spread of the oriental goby Acanthogobius flavimanus in the San Francisco Bay-Delta region of California. Proc. Calif. Acad. Sci. 38(11):207-214.

California State Water Resources Control Board (SWRCB). 1975. Water Quality Control Plan, San Francisco Bay Basin (2). SWRCB, Regional Water Quality Control Board, San Francisco Bay Region, Oakland. 2 vols.

Dahlstrom, W. 1979. Personal communication. California Department of Fish and Game, Menlo Park.

Echeverria, T. 1979. Personal communication. U.S. National Marine Fisheries Service, Tiburon, Calif.

Ecological Analysts, Inc. (EA). 1978. Impact of the cooling water intake at the Indian River Power Plant: a §316(b) evaluation. Prepared for Delmarva Power and Light Co. EA, Towson, Md. 2 vols.

Fitch, J. E. and R. J. Lavenberg. 1975. Tidepool and nearshore fishes of California. California Natural History Guides, No. 38. University of California Press, Berkeley. 156 pp.

Frey, H. W., ed. 1971. California's living marine resources and their utilization. California Department of Fish and Game. 148 pp.

Ganssle, D. 1966. Fishes and decapods of San Pablo and Suisun Bays, in Ecological studies of the Sacramento-San Joaquin Estuary. Part 1 (D. W. Kelley, comp.), pp. 64-94. Calif. Dep. Fish Game, Fish Bull. 133.

Garth, J. S. 1958. Brachyura of the Pacific coast of America: Oxyrhyncha. Allan Hancock Pac. Exped. 21(1-2). 854 pp.

Graham, H. W. and H. Gay. 1945. Season of attachment and growth of sedentary marine organisms at Oakland, California. Ecology 26(4):375-386.

Hardwick, J. E. 1973. Biomass estimates of spawning herring, Clupea harengus pallasi, herring eggs, and associated vegetation in Tomales Bay. Calif. Fish Game 59(1):36-61.

Harry, G. Y., Jr. 1959. Time of spawning, length at maturity, and fecundity of the English, petrale, and Dover soles (Parophrys vetulus, Eopsetta jordani, and Microstomus pacificus, respectively). Oreg. Fish Comm. Res. Briefs 7(1):5-13.

Hart, J. L. 1973. Pacific fishes of Canada. Bull. Fish. Res. Board Can. 180. 740 pp.

Hatfield, S. 1979. Personal communication. California Department of Fish and Game, Menlo Park.

Hunter, J. 1979. Personal communication. U.S. National Marine Fisheries Service, La Jolla, Calif.

Israel, H. R. 1936. A contribution toward the life histories of two California shrimps, Crago franciscorum (Stimpson) and Crago nigricauda (Stimpson). Calif. Dep. Fish Game, Fish Bull. 46. 28 pp.

Jones, A. C. 1962. The biology of the euryhaline fish Leptocottus armatus armatus Girard (Cottidae). Univ. Calif. Publ. Zool. 67(4):321-367.

Jones, M. L. 1961. A quantitative evaluation of the benthic fauna off Point Richmond, California. Univ. Calif. Publ. Zool. 67(3):219-320.

Krygier, E. E. and H. F. Horton. 1975. Distribution, reproduction, and growth of Crangon nigricauda and Crangon franciscorum in Yaquina Bay, Oregon. Northwest Sci. 49(4):216-240.

Kuris, A. M. 1971. Population interactions between a shore crab and two symbionts. Ph.D. dissertation, University of California, Berkeley. 477 pp.

Little, G. 1969. The larval development of the shrimp, Palaemon macrodactylus Rathbun, reared in the laboratory, and the effect of eyestalk extirpation on development. Crustaceana 17(1):69-87.

Liu, D. H. W. 1973. A preliminary survey of benthic communities in selected areas in San Francisco Bay. Prepared for U.S. Army Engineer District, San Francisco, Corps of Engineers. Contract DACW 07-73-C-0059. SRI Project LSU-2496. Stanford Research Institute, Menlo Park, Calif. 122 pp.

Liu, D. H. W., K. D. Martin, and C. R. Norwood. 1975. San Francisco Bay benthic community study: technical evaluation. Prepared for U.S. Army Engineer District, San Francisco, Corps of Engineers. Contract DACW 07-74-C-0005. SRI Project LSU-2894. Stanford Research Institute, Menlo Park, Calif. 244 pp.

McAllister, R. 1975, 1976. California marine fish landings for 1973 (1974). Calif. Dep. Fish Game, Fish Bull. 163. 53 pp.

Miller, D. J. and R. N. Lea. 1972, 1976. Guide to the coastal marine fishes of California. Calif. Dep. Fish Game, Fish Bull. 157. 249 pp.

Miller, D. J. and J. E. Hardwick. 1973. The status of the rockfish resource and its management. Calif. Dep. Fish Game, Mar. Resour. Tech. Rep. 17. 33 pp.

Moyle, P. B. 1976. Inland fishes of California. University of California Press, Berkeley. 405 pp.

Nations, J. D. 1975. The genus Cancer (Crustacea: Brachyura): systematics, biogeography and fossil record. Nat. Hist. Mus. Los Angeles City, Sci. Bull. 23. 104 pp.

Newman, W. A. 1963. On the introduction of an edible oriental shrimp (Caridea, Palaemonidae) to San Francisco Bay. Crustaceana 5(2):119-132.

O'Connell, C. P. 1953. The life history of the cabezon, Scorpaenichthys marmoratus (Ayres). Calif. Dep. Fish Game, Fish Bull. 93. 76 pp.

Orsi, J. J. and A. C. Knutson, Jr. 1979. The role of mysid shrimp in the Sacramento-San Joaquin Estuary and factors affecting their abundance and distribution, in San Francisco Bay: the urbanized estuary (T. J. Conomos, ed.), pp. 401-408. American Association for the Advancement of Science, Pacific Division, San Francisco.

Pacific Gas and Electric Company (PGandE). 1977. Hunters Point Power Plant cooling water intake report and 316(b) study plan. Revised edition. Submitted to California Regional Water Quality Control Board, San Francisco Bay Region. PGandE, San Francisco.

Pinkas, L. 1977. California marine fish landings for 1975. Calif. Dep. Fish Game, Fish Bull. 168. 55 pp.

Pinkas, L. 1979. California marine fish landings for 1976. Preliminary, unpublished data.

Rathbun, M. J. 1904. Decapod crustaceans of the northwest coast of North America. Harriman Alaska Exped. 10:1-210.

Rathbun, M. J. 1918. The grapsoid crabs of America. U.S. Natl. Mus. Bull. 97. 461 pp.

Rathbun, M. J. 1930. The cancroid crabs of America of the families Euryalidae, Portunidae, Atelecyclidae, Cancridae and Xanthidae. U.S. Natl. Mus. Bull. 152. 609 pp.

Rees, J. 1979. Personal communication. Lawrence Berkeley Laboratory, Berkeley, Calif.

Reish, D. J. and J. L. Barnard. 1967. The benthic Polychaeta and Amphipoda of Morro Bay, California. Proc. U.S. Natl. Mus. 120(3565):1-26.

Riley, P. 1979. Unpublished taxonomic key. California Department of Fish and Game, Menlo Park.

Schmitt, W. L. 1921. The marine decapod Crustacea of California. Univ. Calif. Publ. Zool. 23. 470 pp.

Shoemaker, C. R. 1949. The amphipod genus Corophium on the west coast of America. J. Wash. Acad. Sci. 39(2):66-82.

Siegfried, C. A., A. W. Knight, and M. E. Kopache. 1978. Ecological studies in the western Sacramento-San Joaquin Delta during a dry year. Univ. Calif., Davis, Water Sci. Eng. Pap. 4506. 121 pp.

Skinner, J. E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay area. Calif. Dep. Fish Game, Water Projects Branch Rep. 1. 226 pp.

Smith, R. I. and J. T. Carlton. 1975. Light's manual: intertidal invertebrates of the central California coast. 3rd ed. University of California Press, Berkeley. 716 pp.

Spratt, J. D. 1976. The Pacific herring resource of Tomales and San Francisco Bays: its size and structure. Calif. Dep. Fish Game, Mar. Resour. Tech. Rep. 33. 44 pp.

Tattersall, W. M. 1932. Contributions to a knowledge of the Mysidacea of California. II. The Mysidacea collected during the survey of San Francisco Bay by the U.S.S. "Albatross" in 1914. Univ. Calif. Publ. Zool. 37(14):315-347.

Thompson, L. C. and A. W. Pritchard. 1969. Osmoregulatory capacities of Callianassa and Upogebia (Crustacea: Thalassinidea). Biol. Bull. 136(1):114-129.

Thompson, R. K. 1972. Functional morphology of the hind-gut gland of Upogebia pugettensis (Crustacea, Thalassinidea) and its role in burrow construction. Ph.D. dissertation, University of California, Berkeley. 202 pp.

Vrooman, A. M. and P. E. Smith. 1971. Biomass of the subpopulations of northern anchovy Engraulis mordax Girard. Calif. Coop. Oceanic Fish. Invest. Rep. 15:49-51.

Chapter 6

Evaluation of Alternative Intake Technologies

6.1 Demonstrated Operation Criterion

6.2 Biological Benefit Criterion

6.3 Feasibility Analysis

6.4 Conclusions and Recommendations

6.5 References

CHAPTER 6: EVALUATION OF ALTERNATIVE INTAKE TECHNOLOGIES

The purpose of this chapter is to evaluate alternative intake technologies for the Units 2 and 3 and Unit 4 cooling water structures. A hierarchical evaluation system was developed to assess which alternative intake technologies would reduce biological losses and be feasible for application to the cooling water systems of the Hunters Point Power Plant. Alternative intake technologies were evaluated on the basis of the following four criteria:

1. the alternative technology is available and proven (i.e., it has demonstrated operability and reliability at a cooling water intake having a similar size and environmental setting to that at the Hunters Point Power Plant);
2. implementation of the alternative technology will result in a reduction in the loss of aquatic organisms from the present operating conditions;
3. implementation of the alternative technology is feasible at the Hunters Point Power Plant site, based on site-specific considerations of engineering, operations, and reliability; and
4. the total economic cost of the alternative technology is proportionate to the environmental benefits anticipated.

These criteria were applied to all alternatives considered for application at the Hunters Point Power Plant. All intake technologies that were considered to be available and proven for application at the plant (Criterion 1) were given a biological evaluation (Criterion 2). Feasibility analyses (Criteria 3 and 4) were carried out for alternatives that would reduce biological losses. The process is illustrated in Figure 6-1. The chapter ends with a discussion of and judgment as to the best intake technology available for the Units 2 and 3 and Unit 4 cooling water structures at the Hunters Point Power Plant.

Intake technologies are reviewed in Appendix D. Evaluation of whether or not an intake technology is available and will minimize impacts requires site-specific analyses which are presented in this chapter. The design and operation of the cooling water systems of Units 2 and 3 and Unit 4 are described in Chapter 2, along with a discussion of the

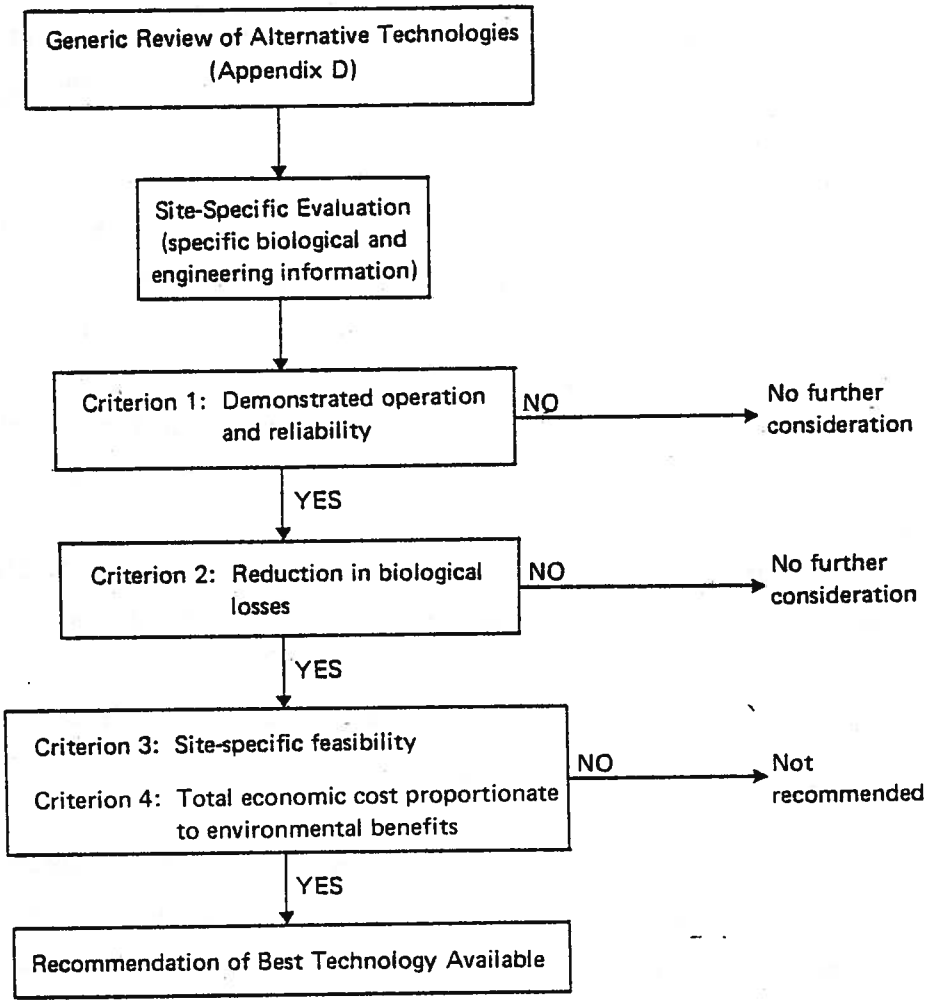


Figure 6-1. Schematic representation of the procedure used to evaluate alternative intake technologies for the Hunters Point Power Plant.

physical and biological characteristics of the source water body. Chapters 3 and 4 present the results and interpretation of entrainment and impingement studies necessary to assess the magnitude and significance of biological losses, and those losses are discussed in Chapter 5. Data from Chapters 2, 3, 4, and 5 provide the site-specific framework for evaluating the engineering feasibility and potential biological effectiveness of each intake technology considered.

6.1 DEMONSTRATED OPERATION CRITERION

Intake technologies that were determined to be proven and available for consideration at the Hunters Point Power Plant (Table 6-1) include onshore, offshore, and recessed intake locations and configurations, once-through cooling water systems, light, sound, bubble screens, and velocity caps. Drum screens, centerflow screens, and vertical traveling screens were also determined to be appropriate for further consideration. Fish return systems, including sluiceways, fish pump systems, and vertical traveling screen modifications, and operational modifications such as curtailment, alternative biofouling programs, cooling system structural modifications, circulating water pump volume reduction, temperature regulation, and maintenance dredging of the intake area are also considered to be proven and available technologies. A brief discussion of the alternatives presented in Appendix D that failed to satisfy the first evaluation criterion, and hence are not considered further in the analysis, is presented in the following sections.

6.1.1 Cooling Water System

A survey of operating experience with saltwater closed-cycle cooling systems prepared for the Utility Water Act Group (Stone & Webster Engineering Corporation 1978) concluded that there are no known operating or proposed electric generating facilities in the United States that use seawater makeup closed-cycle cooling systems. Seawater is characterized by salinities in the range of 26-36 ppt. Salinities at the Hunters Point site are within this range during most of the year (Section A.2, Appendix A). The only power generating facility in the world that uses seawater makeup in a closed-cycle cooling system with cooling towers is the Fleetwood Power Station in England, a small peaking plant (three 32-MWe units) with a low capacity factor (Stone & Webster Engineering Corporation 1978). The units are cooled by two natural draft cooling towers that have a circulating water flow rate of 67 cfs (1.9 m^3/sec).

TABLE 6-1 OPERATIONAL FEASIBILITY OF INTAKE TECHNOLOGIES AND OPERATIONAL ALTERNATIVES CONSIDERED FOR THE HUNTERS POINT POWER PLANT

Intake Technologies	Operation Demonstrated	Operation Not Demonstrated
Cooling Water System	Once-through	Closed-cycle
Intake Location	Offshore Onshore	
Intake Configuration	Shoreline Recessed	
Behavioral Barrier	Light Sound Bubble screen Velocity cap	Velocity gradient Electrical barrier Louvers Chemicals Magnetic field Chains and cables
Physical Barrier	Drum screen Centerflow screen Vertical traveling screen	Media filter Porous dike Radial well Stationary screen Horizontal traveling screen Angled screen - louver Caisson
Fish Collection, Removal, and Conveyance Systems	Vertical traveling screen modifications Gravity sluiceway Fish pump	
Operational Alternatives		
Maintenance and Operational Modifications	Dredging Circulating water pump volume reduction Curtailment Alternative biofouling control Cooling system modifications Temperature regulation	

Salinity of the cooling water makeup at the Fleetwood Power Station typically ranges from 26 to 27 ppt. The circulating water is normally concentrated 1.2-1.5 times. Operational problems associated with corrosion and material deterioration have been reported.

It was concluded, based on information presented in the Stone & Webster Engineering Corporation (1978) survey of power plants which presently use cooling towers, that seawater closed-cycle cooling systems do not satisfy the criterion of demonstrated operation, and thus they are not considered to be a proven and available alternative technology for use at the Hunters Point Power Plant.

6.1.2 Behavioral Barriers

Velocity gradients, magnetic and chemical barriers, and chain and cable barriers have not been used in power plant intake structures, and are considered to be in an experimental stage of development (Cannon et al. 1979). Electric barriers have been used with limited success in fresh water, but because of low electrical resistance, no application of electric fish barriers has been made in salt or brackish waters. Louvers have been used effectively at several large agricultural water diversions, but the application of louvers to power plant cooling water intakes has not been attempted. Louvers do not provide a positive barrier either to entrained organisms or to debris that could block the condenser tube system and lead to reduced operating reliability and increased maintenance. Velocity gradients, electric barriers, louvers, magnetic barriers, chemicals, and chain and cable barriers are not considered to be available and proven technologies for the Hunters Point Power Plant.

6.1.3 Physical Barriers

Media filters such as rapid sand filters, porous dikes, and radial well intakes have never been used to provide power plant cooling water from a marine source. Prototype tests have been conducted that have identified biofouling accumulation and sedimentation as two major constraints in the application of media filters in the marine environment. In the absence of demonstrated performance capabilities and operational reliability in a once-through cooling system, media filters are not considered to be an available technology for the Hunters Point Power Plant.

Stationary screens, such as perforated plate and pipe systems and cylindrical wedge-wire screens, were also eliminated from consideration. Fixed-screen intake systems do not have either demonstrated performance capability or operational reliability in once-through cooling system applications. Biofouling accumulations have been identified as a factor that would substantially decrease the operational reliability of fixed-screen intake structures sited in a marine environment.

Horizontal traveling screens were not considered to be an available technology for the Hunters Point Power Plant because of a lack of demonstrated operational reliability (Farr and Prentice 1974).

An angled screen - louver intake structure and a caisson intake design were not considered to be available technologies for the Hunters Point Power Plant because of a lack of demonstrated performance. One U.S. utility has an angled traveling screen - louver intake structure under construction, but no data are currently available for either the operating reliability or the biological effectiveness. A caisson intake design has been proposed for use at a marine site (California Public Utilities Commission 1978), but construction has not yet begun.

6.2 BIOLOGICAL BENEFIT CRITERION

Each technology that satisfied the demonstrated operation criterion (Table 6-1) was evaluated to determine whether or not it would reduce the entrainment and impingement losses reported in Chapters 3 and 4. Results of the evaluation are summarized in the following sections.

6.2.1 Intake Location

Alternative intake locations for the generating units at the Hunters Point Power Plant include submerged offshore, shoreline, and approach channel locations. The existing intake location and configuration is the standard technology against which each alternative is compared.

6.2.1.1 Offshore Intake Location

The effectiveness of an offshore intake in reducing entrainment depends, to a large degree, on the existence of vertical stratification of entrainable organisms in the water column at the point of water withdrawal. In such a system, a reduction in entrainment is achieved by locating the submerged intake at a depth where the density of entrainable organisms is lowest. In the area of the Hunters Point Power Plant, entrainable organisms are expected to be distributed in approximately equal densities throughout the water column as a result of tidal mixing and shallow depths in the immediate area of the plant (Section 2.2). Thus, a submerged intake system could not be expected to result in reduced entrainment rates at the Hunters Point Power Plant.

For reducing the number of impinged organisms, the effectiveness of a submerged offshore intake depends on locating the intake in an area where such impingeable organisms are not abundant. Many of the dominant groups of fish and invertebrates (e.g., the surfperches, flounders, plainfin midshipman, rockfishes, crabs, and shrimps) are typically found in association with an offshore bottom habitat, and many of the typically pelagic fish species, such as northern anchovy and Pacific herring, are commonly found in large schools which move throughout the water column, often concentrating near the bottom substrates during the daytime (Hart 1973). Thus, use of a submerged offshore intake system might result in higher rates of impingement than those observed at existing shoreline intake screens. Therefore, an offshore intake location is not considered to be an acceptable alternative to a shoreline intake location for the Hunters Point Power Plant.

6.2.1.2 Shoreline Intake Location

Extensive filling and development of the shore zone in the area (Section 2.2.2) has markedly altered the shoreline topography and also the relationship between the Hunters Point Power Plant cooling water intake structures and the source water body. The present cooling water intakes are classified as shoreline intake structures in the Hunters Point Power Plant NPDES permit (No. CA0005649) but include some features of a recessed intake. In addition, the general similarity of the shorezone habitat throughout the site suggests that entrainment and impingement would not be substantially different between available shoreline locations. Fisheries collections

indicate that the abundance and species composition of impingeable fishes are similar throughout the local shorezone area surrounding the Hunters Point Power Plant (PGandE 1973). No reasonable alternative shoreline intake location has been identified that would be advantageous for reducing entrainment or impingement losses.

6.2.2 Intake Configuration

The present recessed intake configuration of the plant has a restricted forebay which may form a zone of entrapment. There is no information available to determine the degree of entrapment that may have resulted from changes in overall intake configuration at the Hunters Point Power Plant or to determine the reduction in impingement that could be expected if the intake configuration were changed. In addition, the extensive filling and shoreline development in the area has eliminated available alternative shoreline intake locations. Because of these facts, and because of the relatively small numbers of fish and macroinvertebrates impinged and the low impact of these losses, no further investigation of alternative intake configurations is warranted.

6.2.3 Behavioral Barriers

Light, sound, air bubbles, and a velocity cap were evaluated to determine their potential effectiveness for reducing biological losses at the Hunters Point Power Plant. The velocity cap was not considered further, since its applicability is restricted to offshore intakes, which are not considered to be an acceptable alternative for use at the Hunters Point Power Plant (Section 6.2.1).

Light, sound, and air bubble screens have not proven successful in reducing the numbers of fish impinged at power plant intakes. In addition, such barriers are not expected to reduce the numbers of entrained organisms or the impingement rates of macroinvertebrates. Behavioral barriers are not considered to represent an effective alternative for reducing entrainment or impingement at the Hunters Point Power Plant.

6.2.4 Physical Barriers

The applicability of drum screens, centerflow screens, and vertical traveling screens for reducing biological losses associated with entrainment and impingement at the Hunters Point Power Plant is evaluated in the following sections.

6.2.4.1 Drum Screens

Drum screens are not considered to be biologically effective, based on the limited data available (Eicher 1974), and are not expected to reduce the numbers of organisms entrained or impinged at the Hunters Point Power Plant cooling water intake structure. There is no information available to suggest that survival of organisms impinged on drum screens would be substantially different from impingement survival on conventional vertical traveling screens. In the absence of any predicted biological advantages, drum screens are not considered to be an acceptable alternative intake technology applicable to the Hunters Point Power Plant.

6.2.4.2 Centerflow Traveling Screens

Centerflow traveling screens are not expected to offer any major biological advantages over conventional or modified vertical traveling screens (Cada et al. 1979). The number of organisms impinged on centerflow screens is not expected to be reduced, and significantly increased impingement survival has not been satisfactorily demonstrated for these systems. To date, no studies of long-term survival of fish impinged on centerflow screens have been conducted.

Centerflow traveling screens equipped with 1.0-mm (0.04-in.) mesh would minimize the entrainment of fish eggs and larval fish at the Hunters Point Power Plant. Laboratory studies of various screen types suggest that the entrainment of larval fish can be virtually eliminated by use of 0.5-mm (0.02-in.) intake screen mesh (Tomljanovich et al. 1978). Impingement survival, however, is species-specific: under laboratory conditions, survival rates of larval fish 48 hours after a 16-minute impingement ranged from less than 1 percent for striped bass to 96 percent for bluegill and smallmouth bass (Table 6-2) (Tomljanovich et al. 1978). Survival of larval fish impinged on fine-mesh intake screens may be no higher, or even lower, than the survival of larval fish passing through a cooling water system (Cada et al. 1979). In addition, survival of larval fish impinged on a fine-mesh intake screen that is operated in an intermittent screenwash mode or is subject to high detrital loads may be extremely low (Tomljanovich et al. 1977).

TABLE 6-2 MEAN SURVIVAL (%) OF LARVAL FISH IMPINGED ON A SIMULATED FINE-MESH CENTERFLOW SCREEN UNDER LABORATORY CONDITIONS

Taxon		Impingement Survival[a]		Control Survival
Common Name	Scientific Name	Initial	48-hr	(48-hr)
Jewelfish	*Hemichromis bimaculatus*	43	30	100
Threadfin shad	*Dorosoma petenense*	55	20	98
Golden shiner/ Fathead minnow	*Notemigonus crysoleucas* *Pimephales promelas*	89	79	99
White sucker	*Catostomus commersoni*	74	36	100
Channel catfish	*Ictalurus punctatus*	97	88	99.5
Striped bass	*Morone saxatilis*	7	1	44
Bluegill	*Lepomis macrochirus*	96	96	99
Smallmouth bass	*Micropterus dolomieui*	100	96	100
Largemouth bass	*Micropterus salmoides*	70	52	93
Walleye	*Stizostedion vitreum*	9	2	71

(a) 16-minute impingement duration; screen mesh sizes 0.5, 1.0, 1.3, 1.8, and 2.5 mm combined; test velocities 15, 31, and 46 cm/sec combined.

Source: Tomljanovich et al. 1978.

No specific information concerning the impingement survival of marine ichthyoplankton such as Pacific herring and goby larvae and northern anchovy eggs and larvae impinged on fine-mesh centerflow screens is available elsewhere to provide a direct comparison with the survival of entrained larvae. Impingement survival of Pacific herring and northern anchovy is expected to be similar to that of Clupeiformes impinged on fine-mesh vertical traveling screens (<1 percent) (Table 6-3). In the absence of a demonstrated potential for increasing the initial and long-term survival of organisms impinged or entrained at the existing cooling water system, centerflow screens are not considered to represent an acceptable alternative intake technology for use at the Hunters Point Power Plant.

6.2.4.3 Vertical Traveling Screens

Conventional vertical traveling screens with 3/8-in. (9.5-mm) mesh are presently in operation at the Hunters Point Power Plant Units 2 and 3 and Unit 4 cooling water intakes. The vertical traveling screen is the standard technology against which each alternative screening technology considered in this analysis is compared.

6.2.5 Fish Collection, Removal, and Conveyance Systems

6.2.5.1 Vertical Traveling Screen Fish Buckets and Accessories

Several modifications to conventional vertical traveling screens have been considered in recent years in an attempt to increase their biological effectiveness (White and Brehmer 1976). Such modifications to the intake screens (Figure 6-2) have been aimed at reducing the mortality of impinged organisms through the installation of the following features:

1. watertight fish collection buckets along the base of each screen panel to prevent repeated impingement of organisms and to provide a holding area for organisms during screen rotation,
2. a low-pressure wash system to remove impinged organisms from the screen, reducing the stress and abrasion that results from exposure to the high-pressure spraywash required for the removal of debris,

TABLE 6-3 INITIAL AND 96-HOUR SURVIVAL OF LARVAL AND JUVENILE CLUPEIFORMES IMPINGED ON A CONTINUOUSLY ROTATING FINE-MESH VERTICAL TRAVELING SCREEN AT THE INDIAN POINT GENERATING STATION

Taxon		Mean Length (mm)	Number Collected	Impingement Survival(%)	
Common Name	Scientific Name			Initial	96-hr[a]
Blueback herring	*Alosa aestivalis*	48	234	77	1
American shad	*Alosa sapidissima*	55	23	87	0
Alewife	*Alosa pseudoharengus*	60	7	86	0
	Alosa spp.	8	62	0	0
Bay anchovy	*Anchoa mitchilli*	18	65	0	0

(a) 96-hour survival (%)

$$= \frac{\text{number live + stunned at the end of 96 hours}}{\text{initial number live + stunned tested for latent effects}} .$$

Source: Ecological Analysts 1979.

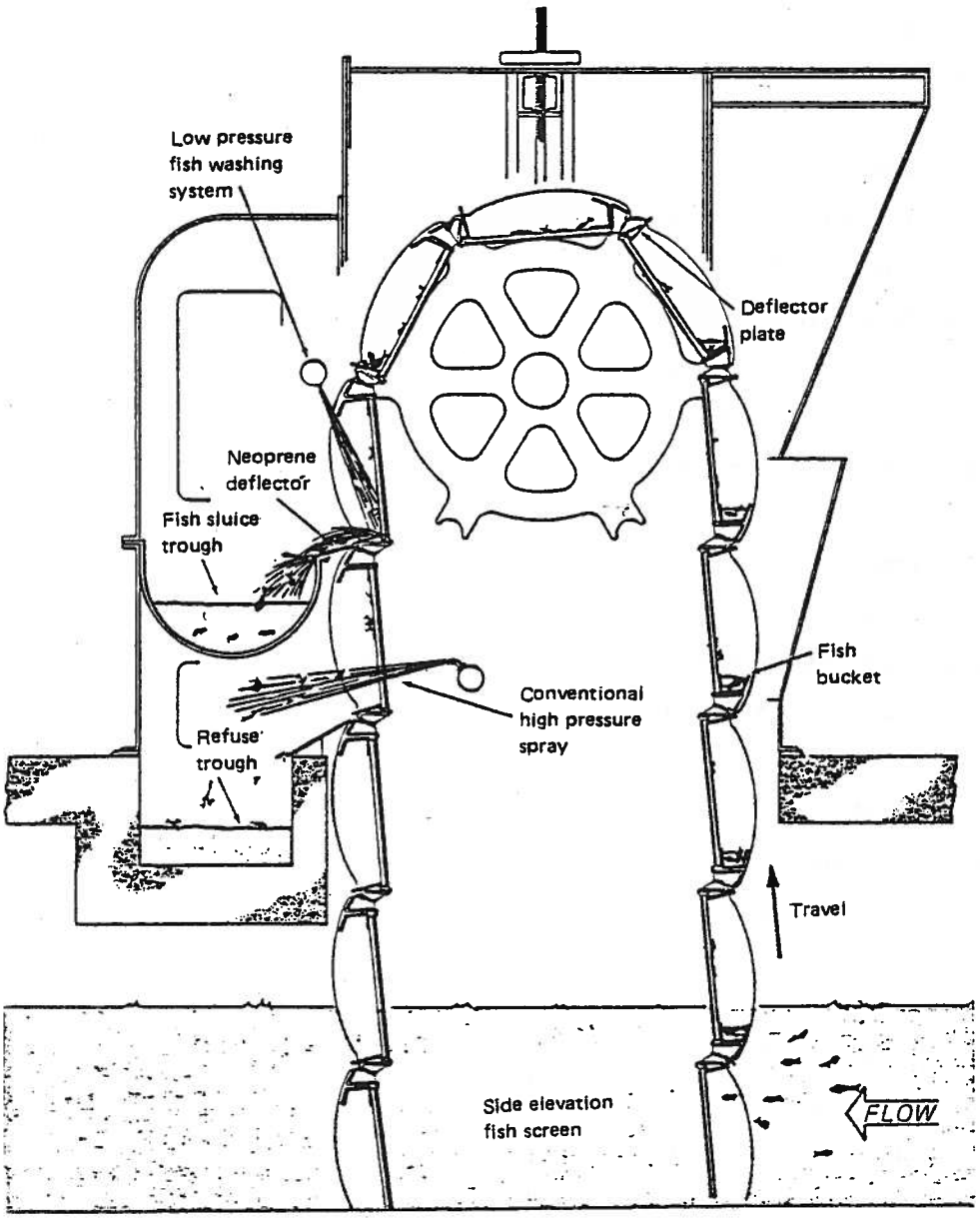


Figure 6-2. Ristroph modified traveling screen with fish buckets, a modified spray water system, and a sluiceway for fish. (Courtesy of Envirex.)

3. a second sluiceway - fish return system to transport organisms removed from the screen by the low-pressure spraywash back to the receiving water body, and
4. heavy-duty bearings and motors to permit continuous rotation and screen cleaning, minimizing the time an organism is retained on the screen.

Operational modifications to vertical traveling screens such as the use of continuous screen rotation have been identified as alternatives that may increase the biological effectiveness of conventional vertical traveling screens. Continuous screen rotation did not result in consistently improved impingement survival of marine organisms examined at the Moss Landing Power Plant (Section 4.2). In addition, no consistent relationships were found between latent survival of fish species impinged on the Hudson River and screen operational modes (King et al. 1978).

Among impinged fish at the Moss Landing Power Plant, species such as plainfin midshipman and rockfish appeared to have high survival, but fragile species such as northern anchovy and Pacific herring had low survival. Although available data are incomplete, neither the high impingement survival rates of the hardy species nor the lower rates of the fragile species are expected to be increased by the addition of fish buckets, low-pressure spraywashes, and continuous rotation of screening surfaces. Installation of modified traveling screens would not, therefore, be expected to reduce the total number of organisms not surviving impingement at the cooling water intake.

The present intake screen rotation schedule employed at the Hunters Point Power Plant (Section 2.1) causes fish to remain impinged for up to eight hours. Survival of impinged organisms under this intake screen operating mode is expected to be negligible. It is anticipated that a reduction in maximum impingement duration from eight hours to three hours would permit survival of hardy species, but there does not appear to be any further significant biological advantage to the use of continuous screen rotation. Decreasing the maximum duration of impingement to three hours would result in a reduction in the total number of fish lost annually from approximately 117,000 to 107,000 based on results of impingement survival studies (Table 4-8). The loss of impinged macroinvertebrates would be decreased from approximately 107,000 to 106,000.

Vertical traveling screens have recently been modified to include fine-mesh screen material. Vertical traveling screens equipped with 0.5- to 1.0-mm (0.02- to 0.04-in.) screen mesh would substantially reduce, if not eliminate, the entrainment of most of the ichthyoplankton and macroinvertebrates found at the Hunters Point Power Plant. Fine-mesh vertical traveling screens are not considered to be a proven technology, based on the absence of long-term operating experience at a power plant intake. In addition, it has not been demonstrated that the survival of either eggs or larval fish impinged on fine-mesh screens would equal or exceed their survival if they were entrained through a once-through cooling system (Section 6.2.4.2). Net survival of ichthyoplankton eggs and larvae and macroinvertebrates entrained through the once-through cooling systems of the Hunters Point Power Plant is estimated to be 35, 18, and 23 percent (Section 3.2.2). In the absence of a demonstrated potential for increasing the survival of egg and larval fish, it cannot be concluded that use of fine-mesh traveling screens would reduce the combined impact of entrainment and impingement at the Hunters Point Power Plant.

In summary, modified vertical traveling screens, including fish buckets, continuous rotation, fine-mesh screen material, etc., do not represent an alternative technology that would reduce the loss of aquatic organisms resulting from entrainment and impingement at the Hunters Point Power Plant. It is expected, however, that increasing the frequency of screen rotation from 8-hour intervals to 3-hour intervals would result in a slight reduction in the mortality of impinged organisms.

6.2.5.2 Fish Return Conveyance Systems

A modification of the gravity-sluiceway return system that would eliminate the return of organisms impinged at Units 2 and 3 and Unit 4 to the discharge was examined as an alternative. Survival of hardy species such as plainfin midshipman would not be expected to be substantially improved by use of a modified sluiceway, since the duration of exposure to elevated temperatures in the discharge is expected to be short, and since discharge temperatures are less than 30 C (86 F), the upper lethal temperature for many species, over 98 percent of the time (Section 2.1.3.2.2). Impingement survival of fragile species such as northern anchovy is low (Section 4.2), and modification of the sluiceway would not contribute substantially to improved

survival for these species. It is unlikely that modification of the screenwash sluiceway return system for Units 2 and 3 and Unit 4 would result in a measurable improvement in impingement survival. In the absence of a demonstrated potential for increasing impingement survival, modification of the screenwash sluiceway return system is not considered further.

6.2.6 Intake Maintenance and Operational Modifications

Operational modifications and maintenance which may reduce entrainment and impingement losses include: maintenance dredging of the cooling water intakes, circulating water pump volume reduction, seasonal curtailment of cooling system operation, use of alternative biofouling schemes, cooling system structural modifications, and through-plant temperature regulation.

6.2.6.1 Maintenance Dredging

Sediment accumulation within the area of a cooling water intake structure may reduce the open area of the intake, resulting in increased water velocities. Increased velocities approaching the intake structure will, in many cases, result in increased rates of impingement.

Measurements made in the intake structures of Hunters Point Power Plant Units 2 and 3 and Unit 4 indicate that sediment accumulation is minor and has not affected intake water velocities (Section 2.1.3.2.2). No further consideration of maintenance dredging is warranted.

6.2.6.2 Circulating Water Pump Volume Reduction

Seasonal reduction in the number of circulating water pumps in operation has been suggested as an alternative operational strategy for reducing cooling water volumes and intake approach velocities, and hence reducing the number of organisms entrained and impinged. Short-term regulation of circulating water pump operation would be most effective biologically if cooling water flows were reduced when the unit was operating in a spinning reserve mode with low delta-T, or when the unit was out of service. This operational alternative would result in reduced numbers of organisms being entrained while maintaining high survival of those which were entrained.

Data presented in Chapter 4 indicate that the rate of impingement would not be reduced substantially by reducing circulating water pump operation, and hence approach water velocities (approximately 0.7 fps; 21 cm/sec), below that typical of normal operation (Section 2.1.3.2.1). Occasionally circulating water pumps are operated in excess of the normal operating mode at Units 2 and 3, resulting in increased rates of impingement (Figure 4-1). Reduction in normal circulating water pump operation for Units 2, 3, or 4 is not expected to reduce the loss of impinged fish and macroinvertebrates substantially.

Reducing the frequency of circulating water pump operation in excess of the normal operating mode for Units 2 and 3 (see Section 2.1.2.1) would reduce the loss of impinged organisms. Reduction in circulating water pump operation when the units are in spinning reserve or out of service would also result in a reduction in the numbers of organisms lost as a result of entrainment or impingement. A reduction in circulating water pump operation under these conditions will be considered further in the feasibility analysis (Section 6.3).

6.2.6.3 Seasonal Curtailment

Systematic seasonal curtailment of cooling system operation would reduce the numbers of organisms lost due to entrainment and impingement. The amount of the reduction would depend on the length of time operation was curtailed and the density of organisms during the period of curtailment. Based on entrainment and impingement data collected at the Hunters Point Power Plant from April 1978 to April 1979 (Chapters 3 and 4), two peak periods of abundance, December through February and August through October, have been selected as potential periods of curtailment. The estimated percentages by which the number of Pacific herring, northern anchovy, and gobies entrained and of northern anchovy, Pacific herring, and plainfin midshipman impinged would have been reduced as a result of curtailment in those two peak periods are presented in Table 6-4. Systematic seasonal curtailment of cooling system operation would result in a reduction in the numbers of organisms entrained and impinged and is therefore considered to be an alternative technology for cost and engineering consideration at the Hunters Point Power Plant.

TABLE 6-4 ESTIMATED REDUCTION (%) IN THE NUMBERS OF FISH ENTRAINED OR IMPINGED ANNUALLY AT THE HUNTERS POINT POWER PLANT THAT WOULD RESULT FROM SEASONAL CURTAILMENT IN COOLING SYSTEM OPERATION

Taxon			Period of Curtailment			
			December-February		August-October	
Common Name	Scientific Name	Life Stage	Units 2 and 3	Unit 4	Units 2 and 3	Unit 4
Entrainment						
Pacific herring	*Clupea harengus pallasi*	Larvae	86	87	0	0
Northern anchovy	*Engraulis mordax*	Eggs	1	1	80	75
Northern anchovy	*Engraulis mordax*	Larvae	12	13	59	51
Gobies	Gobiidae	Larvae	67	65	13	10
Impingement						
Northern anchovy	*Engraulis mordax*	Juvenile-Adult	7	1	33	57
Pacific herring	*Clupea harengus pallasi*	Juvenile-Adult	1	0	30	13
Plainfin midshipman	*Porichthys notatus*	Juvenile-Adult	3	2	61	43

6.2.6.4 Alternative Biofouling Schemes

The biofouling control procedure currently used at the Hunters Point Power Plant consists of intermittent chlorination (Chapter 2). The mortality of entrained organisms as a result of the present antibiofouling program is unknown. However, no alternative antibiofouling program has yet been identified that meets the objective of achieving satisfactory biofouling control in a marine environment while reducing the direct mortality to entrained organisms.

Because of the high proportion of entrained organisms not completing passage through the cooling water systems (Section 3.3), presumably due to predation from biofouling organisms, it would be advantageous to implement a more effective fouling control program.

6.2.6.5 Cooling System Modifications

Structural modification of cooling system components to reduce the mortality of entrained organisms is not effective at the present time. Insufficient quantitative data are available to isolate specific sources of mortality within a cooling water system. Design parameters for specifying pressure regimes, circulating water pump design and operation, tolerable shear stresses, and cooling system designs for minimizing mechanical abrasion have not been developed. In addition, the survival of entrained organisms at the Hunters Point Power Plant is expected to be high (Section 3.2), and therefore such modifications are not warranted.

6.2.6.6 Discharge Temperature Regulation

Discharge temperatures are relatively low at the Hunters Point Power Plant throughout the year, remaining below 30 C (86 F) over 98 percent of the time (Section 2.1.3.2). Exposures to discharge temperatures below 30 C for short periods during cooling system transit are generally considered to be nonlethal to entrained organisms (Appendix B). Therefore, thermal stresses are not expected to be a significant cause of mortality to entrained fish or invertebrates at any time of the year (Section 3.2). Discharge temperature regulation is not expected to result in a reduction of the number of organisms lost to entrainment through the Hunters Point Power Plant cooling systems.

6.2.7 Conclusions: Biological Effects

Based on results of the biological evaluation (Section 6.2.), the following was concluded:

1. there is no reasonable alternative intake location that would reduce entrainment and impingement losses;
2. behavioral barriers are not expected to reduce numbers of organisms exposed to either entrainment or impingement;
3. conventional vertical traveling screens are acceptable, and entrainment and impingement losses would not be substantially reduced by use of drum screens, centerflow traveling screens, or modified vertical traveling screens;
4. a screen mesh size of 3/8 in. (9.5 mm) is acceptable, because survival of ichthyoplankton (fish eggs and larvae) impinged on fine-mesh screens is not expected to exceed the survival of organisms entrained through the Hunters Point Power Plant cooling system;
5. sediment accumulation in the intakes is minor, and therefore consideration of maintenance dredging is not warranted; and
6. cooling system structural modifications and discharge temperature regulation are not expected to substantially reduce the mortality of entrained organisms.

The following alternative intake technologies will reduce entrainment and/or impingement losses at the Hunters Point Power Plant and were therefore selected for feasibility analysis:

1. increased rotation frequency of the existing vertical traveling screens,
2. seasonal curtailment of cooling system operation for each unit,
3. short-term reductions in circulating water pump operation, and
4. application of an alternative biofouling scheme to minimize cropping of entrained organisms.

6.3 FEASIBILITY ANALYSIS

Each alternative technology that satisfied the biological reduction criterion (Section 6.2) and differed in design or operation from that presently in use at the Hunters Point Power Plant was evaluated with regard to engineering feasibility, operation, and reliability. In addition, the total economic cost in 1980 dollars associated with various alternatives was estimated. Cost estimates reflect direct capital costs and indirect costs (e.g., the loss of generating capacity) whenever possible.

6.3.1 Increased Intake Screen Rotation Frequency

Modification to the Units 2 and 3 intake screens to provide automatic screen rotation and cleaning at 3-hour intervals would involve the installation of timers and relays requiring rewiring of the present control systems. At the present time the intake screens are not automated. Estimated total capital cost of the modification to the existing screen control system is approximately $25,000. Unit 4 intake screens currently have automatic controls and would require no structural or electrical modifications.

Increasing intake screen rotation frequency from eight hours to three hours would result in increased maintenance requirements, the degree of which cannot be quantified from available information. Increasing intake screen rotation frequency is expected to reduce the loss of impinged fish by approximately 9 percent (Section 6.2.5.1), with hardy species such as plainfin midshipman representing the majority of the reduction (Table 4-8). The reduction in loss of macroinvertebrates is expected to be approximately 1 percent. Increasing the frequency of intake screen rotation will contribute to a reduction in the numbers of fish and macroinvertebrates lost as a result of impingement, but the benefit of implementation for reducing overall biological impact would probably be minimal.

6.3.2 Curtailment of Cooling System Operation

Seasonal curtailment of cooling system operation at the Hunters Point Power Plant is infeasible because of the high demand for electrical energy in the San Francisco load center and the limited surplus electrical energy available to replace it from other sources. Because the capacity of transmission lines into the San Francisco load

center is limited, curtailment would have a substantial impact on the reliability of service to the city of San Francisco. The present San Francisco operating criteria require that 50 percent of the demand for electrical power (city load) be supplied by city generating units (Hunters Point and Potrero power plants) and that the remaining 50 percent of city load be available in spinning reserve or fast-start units within the city. Operation of the Hunters Point Power Plant is required to satisfy these two operating criteria. The present operation of Units 2 and 3 and Unit 4 is primarily to meet base load demand. Supposing that an alternative energy source were available to meet demands, the estimated replacement cost of lost generation resulting from curtailment of Units 2 and 3 and Unit 4 from December through February and from August through October would be that summarized in Table 6-5. Curtailment during these two periods would result in reduced biological losses resulting from both entrainment and impingement.

An alternative curtailment strategy would be to schedule maintenance outages to coincide with periods of greatest biological loss. Maintenance outages for unit overhauls are scheduled on the basis of 50,000 hours of operation—approximately five years between scheduled overhauls. An overhaul of Unit 2 or 3 would require approximately four weeks for each unit. An overhaul of Unit 4 would require an outage of approximately eight weeks. Scheduled maintenance outages for overhauls are determined on a yearly basis and require coordination between projected system generating requirements and manpower availability. Because of the infrequency of major scheduled maintenance outages and the uncertainties of maintenance scheduling, curtailment based on maintenance outages is an ineffective method of reducing biological losses at the Hunters Point Power Plant.

Daily curtailment of cooling system operation (e.g., at night or when load is low) was also considered as an alternative approach for reducing biological loss. Curtailment of circulating water pump operation at either Units 2 and 3 or Unit 4 would result in the draining of the unit condenser and cooling water system. The time required to prime and restart the circulating water pumps and fill the conduits and condenser before the unit could begin generation would be excessive for either system. Daily curtailment of cooling system operation is therefore considered to be infeasible for the Hunters Point Power Plant, on the basis of present San Francisco operating criteria.

TABLE 6-5 ESTIMATED COST OF REPLACEMENT ENERGY THAT WOULD BE NEEDED FOR TWO PERIODS OF CURTAILMENT OF PLANT OPERATION AT THE HUNTERS POINT POWER PLANT

Period of Curtailment	Cost of Replacement Energy ($/MWh)[a]	Hours per Month	Unit 2		Unit 3		Unit 4	
			Capacity Factor[b] (%)	Energy Replacement Cost ($)	Capacity Factor (%)	Energy Replacement Cost ($)	Capacity Factor (%)	Energy Replacement Cost ($)
December	57	744	65.7	3,065,000	65.4	3,051,000	80.9	5,832,000
January	57	744	54.4	2,538,000	55.3	2,580,000	77.7	5,602,000
February	57	672	37.3	1,572,000	38.8	1,635,000	73.6	4,793,000
Total		2,160		7,175,000		7,266,000		16,227,000
August	57	744	36.7	1,712,000	30.6	1,427,000	80.2	5,782,000
September	57	720	29.5	1,332,000	0.0	0	61.9	4,319,000
October	57	744	57.1	2,664,000	42.6	1,987,000	68.7	4,953,000
Total		2,208		5,708,000		3,414,000		15,054,000

(a) Energy replacement cost is based on actual annual average power pool replacement costs (1980 dollars) and does not necessarily reflect present costs or the costs of a guaranteed energy replacement capacity through construction of new facilities. Cost estimates do not include potential savings associated with reduced operating and maintenance expenses.

(b) Monthly capacity factors based on May 1978 - April 1979 data summarized in Table 2-2.

Curtailment of cooling system operation would result in a reduction of both entrainment and impingement losses that would depend on the abundance of organisms present during the period of curtailment and the duration of the outage. The cost of energy replacement and the reliability of electrical service to the San Francisco load center during the period of curtailment also depend on the season and on the duration of unit outage. The lack of available alternative power sources to meet present demands and inadequate transmission into the San Francisco load center precludes consideration of curtailment of power generation as a method of reducing entrainment and impingement losses at the Hunters Point Power Plant.

6.3.3 Reduction in Circulating Water Pump Operation

A reduction in the number of circulating water pumps in operation (Section 2.1.2) has been suggested as an operational strategy for reducing cooling water volume and intake approach velocities, and hence the rates of entrainment and impingement. The normal circulating water pump operation at Units 2 and 3 is the minimum level necessary to sustain unit generation. Under normal operation one main and one auxiliary house unit pump are operated to supply cooling water to each unit. Reduction in circulating water pump operation below this level would result in removing the unit from service. Minimizing the higher-than-normal pumping rates would reduce approach velocities and would result in a reduced impingement rate (Section 4.1.2). The frequency and duration of this pumping at higher-than-normal rates are minimized whenever operating conditions permit. Based on the relatively small numbers of fish and macroinvertebrates impinged and the generating penalty and operational inefficiency, no further consideration of reduced pump operation as an approach to reducing biological losses at Units 2 and 3 is warranted.

Reduction in circulating water pump operation (from two pumps to one) associated with the Unit 4 once-through cooling system would be expected to result in a 50 percent reduction in full load capability. There would be increased temperature differentials through the condenser system (delta-T) and thus reduced turbine cycle thermal efficiency. These operational constraints severely limit the performance efficiency of a generating unit. Reducing circulating water pump operation would reduce approach velocity and would be expected to result in a reduced impingement rate, but the degree of reduction cannot be quantified. A reduction in cooling water volume by 50 percent, as a result of operating one pump, is expected to reduce the number of entrained

organisms by 50 percent, but the associated increase in delta-T might reduce the overall survival of those organisms that were entrained. Based on the relatively small numbers of fish and macroinvertebrates impinged, and the generating penalty and operational inefficiency that would accompany reduced circulating water pump operation, no further investigation of reduced pump operation as an approach to reducing biological losses at Unit 4 is warranted.

Reducing the number of circulating water pumps in operation when generating loads are low or a unit is being operated in a spinning reserve mode (e.g., Units 2 and 3) or when a unit is out of service may not only reduce biological losses, but may also reduce the cost required to operate one or more circulating water pumps. To permit rapid response to energy demands, units in a spinning reserve mode are operated at at low or minimum loads but kept fully operational and capable of an immediate increase in load by maintaining the circulating water system in service at the full-load rate. If the circulating water pumps were taken out of service, the condenser and conduits would drain. The time required to refill the cooling system would not permit fulfillment of the requirements of spinning reserve operation. Consistent with system load demand, less efficient units are taken out of service (generation) for fuel conservation outages. In this case the circulating water pumps may or may not be left in service, depending on the length of the fuel conservation outage. Normally, if an extended outage is expected the circulating water pumps are shut down to conserve energy. For anticipated short outages of a day or so, the circulating water pumps are usually not taken out of service. A fuel conservation outage is intended to be an outage in which the unit is kept fully capable of returning to service on short notice. If maintenance is to be performed on a unit that is on fuel conservation which in any way jeopardizes the unit's return to service or its capability, the outage is changed to a maintenance outage.

During periods when a unit is removed from service, either for fuel conservation or for maintenance, one or more of the circulating water pumps can be shut down, depending on the nature and expected length of the outage. Reducing circulating water pump operation when units are out of service for extended periods is a standard operating procedure at the Hunters Point Power Plant.

6.3.4 Alternative Biofouling Schemes

Entrainment data indicate that there is a loss of organisms within the cooling system that is possibly due to predation by fouling organisms lining the cooling system conduits. It may be that alternative fouling control procedures would result in a higher probability of safe passage of entrained organisms through the system. Chlorine (0.4 mg/liter) is currently used to control slime (condenser biofouling). Increased chlorination, accompanied by dechlorination (Section 2.1.2), might result in a net reduction in the loss of entrained organisms due to biofouling organisms in the intake tunnels of the Hunters Point Power Plant. Increasing the dosage rate, frequency, and duration of chlorination, however, is directly opposed to current regulatory guidelines and standards for the minimization of chlorination.

Reinstatement of heat treatment procedures (Sections 2.1.2.1. and 2.1.2.2) at Units 2 and 3 and at Unit 4 is a possible supplement to chlorination for the control of mussels in the intake tunnels. Thermal shock treatment was discontinued at the Hunters Point Power Plant in 1975. Reinstatement of thermal shock treatment would require modification of cooling system components such as gates, valves, and pumps. Although the biological impact of the system as presently operated is low, thermal shock treatment would reduce cropping of entrained organisms by fouling organisms in the cooling water system. It would also reduce maintenance requirements associated with the manual removal of fouling organisms from the condensers. The use of thermal shock treatment is recommended. PGandE is presently investigating the maintenance requirements for reimplementing thermal shock treatment at all units.

6.4 CONCLUSIONS AND RECOMMENDATIONS

The impact of entrainment and impingement at the Hunters Point Power Plant on adult populations of fish and invertebrates was judged to be minimal in these studies (Chapter 5). A reduction in the number of organisms entrained or impinged would not result in a detectable reduction in biological impact on the aquatic community. In addition, very few striped bass, steelhead, salmon, sturgeon, or American shad were entrained or impinged, indicating that the plant site is outside the main migratory path, spawning grounds, and nursery areas of these important commercial and sport species. The organisms entrained and impinged were predominantly marine species that are common along the Pacific Coast. For these reasons, it was concluded that the

impact of the Hunters Point Power Plant is minimal, and the evaluation presented here of alternative intake technologies is based in part on this conclusion.

The judgment of the best technology available for each cooling system at the Hunters Point Power Plant is based on a consideration of the low impact of entrainment and impingement on the local aquatic community, biological effectiveness of various technologies for further reducing entrainment and impingement losses, engineering feasibility, and cost-effectiveness, as outlined in the guidance manual (U.S. EPA 1977). The costs and engineering constraints of each alternative must be considered in relation to the benefits to be gained from a reduction in loss of aquatic organisms. The analysis is summarized in Table 6-6.

6.4.1 Best Technology Available--Units 2 and 3

It was concluded that the best available intake technology for Units 2 and 3 consists of the following:

- the existing once-through cooling water system,
- the existing intake configuration,
- the existing conventional vertical traveling intake screens with 3/8-in. (9.5-mm) mesh,
- continued use of intermittent (8-hour) screen rotation,
- continued use of intermittent chlorination to control condenser biofouling,
- continued use of the existing debris- and fish-return system to return organisms to San Francisco Bay, and
- use of thermal shock treatment to control biofouling organisms.

Reducing the number of circulating water pumps in operation when Units 2 and 3 are out of service for extended periods is possible, but the benefit of implementation for reducing biological impact would be minimal (Chapter 5). Additional modifications to the Units 2 and 3 intake to reduce impingement and entrainment are not warranted because of the low biological impact of the existing system.

TABLE 6-6 SUMMARY OF THE EVALUATION OF INTAKE TECHNOLOGIES AND OPERATIONAL ALTERNATIVES CONSIDERED FOR THE HUNTERS POINT POWER PLANT

	Demonstrated (Meets Criterion 1)	Biological Benefit (Meets Criterion 2)	Recommended (Meets Criteria 3 and 4)
Intake Technologies			
Cooling Water Systems			
Closed-cycle	No	--	--
Once-through[a]	Yes	--	Yes
Intake Locations			
Offshore	Yes	No	--
Onshore[a]	Yes	--	Yes
Intake Configurations			
Shoreline	Yes	No	--
Recessed[a]	Yes	--	Yes
Behavioral Barriers			
Velocity gradient	No	--	--
Electrical barrier	No	--	--
Louvers	No	--	--
Chemicals	No	--	--
Magnetic field	No	--	--
Chains and cables	No	--	--
Light	Yes	No	--
Sound	Yes	No	--
Bubble screen	Yes	No	--
Velocity cap	Yes	No	--
Physical Barriers			
Media filter	No	--	--
Porous dike	No	--	--
Radial well	No	--	--
Stationary screen	No	--	--
Horizontal traveling screen	No	--	--
Angled screen - louver	No	--	--
Caisson	No	--	--
Drum screen	Yes	No	--
Centerflow screen	Yes	No	--
Vertical traveling screen[a]	Yes	--	Yes
Fish Collection, Removal, and Conveyance Systems			
Vertical traveling screen modifications	Yes	No	--
Gravity sluiceway[a]	Yes	--	Yes
Fish pumps	Yes	No	--
Operational Alternatives			
Maintenance			
Dredging			
Units 2 and 3	Yes	No	--
Unit 4	Yes	No	--
Operational Modifications			
Circulating water pump volume reduction	Yes	Yes	No
Curtailment	Yes	Yes	No
Alternative biofouling control	Yes	Yes	Yes
Cooling system modifications	Yes	No	--
Temperature regulation	Yes	No	--

(a) Existing structure or operation at Units 2, 3, and 4.

6.4.2 Best Technology Available--Unit 4

It is concluded from the preceding evaluations that the best available intake technology for Unit 4 consists of the following:

- the existing once-through cooling water system,
- the existing intake structure,
- the existing conventional vertical traveling intake screens with 3/8-in. (9.5-mm) mesh,
- continued use of intermittent (8-hour) screen rotation,
- continued use of intermittent chlorination to control condenser biofouling,
- continued use of the existing debris- and fish-return system to return organisms to San Francisco Bay, and
- use of thermal shock treatment to control biofouling organisms.

6.5 REFERENCES

Cada, G. F., J. B. Cannon, and D. W. Lee. 1979. Alternative screening devices at Indian Point Units 2 and 3, Bowline Point, and Roseton generating stations. Testimony prepared for Hudson River NPDES case before the U.S. Environmental Protection Agency, Region II. EPA Docket No. C/II-WP-77-01. 29 pp.

California Public Utilities Commission. 1978. Decision against Application 57626. Joint Western LNG Terminal Associates, Pacific Gas and Electric Company, and Pacific Lighting Service application to construct and operate LNG terminal at Point Conception. Filed 14 October 1977. Interim order no. 89177. Decision date 31 July 1978.

Cannon, J. B., G. F. Cada, K. K. Campbell, D. W. Lee, and A. T. Szluha. 1979. Fish protection at steam-electric power plants: alternative screening devices. Prepared for the U.S. Nuclear Regulatory Commission, Division of Site Safety & Environmental Analysis, and the U.S. Environmental Protection Agency, Region II. Contract No. W-7405-eng-26. Oak Ridge National Laboratory, Oak Ridge, Tenn. 138 pp.

Ecological Analysts, Inc. (EA). 1979. Evaluation of the effectiveness of a continuously operating fine mesh traveling screen for reducing ichthyoplankton entrainment at the Indian Point Generating Station. Prepared for Central Hudson Gas & Electric Corporation, Consolidated Edison Company of New York, Inc., Orange and Rockland Utilities, Inc., and Power Authority of the State of New York. EA, Middletown, N.Y.

Eicher, G. J. 1974. Adaptation of hydro fish facilities to steam-electric stations, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 273-276. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Envirosphere Company (EC). 1978. Chlorine toxicity in marine ecosystems: an evaluation of the Mattice and Zittel model for deriving toxicity thresholds and a proposed alternative. Prepared for Edison Electric Institute. EC, New York.

Farr, W. E. and E. F. Prentice. 1974. Mechanical operation of horizontal traveling screen model VII, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 215-222. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Hart, J. L. 1973. Pacific fishes of Canada. Bull. Fish. Res. Board Can. 180. 740 pp.

King, L. R., J. B. Hutchison, Jr., and T. G. Huggins. 1978. Impingement survival studies on white perch, striped bass, and Atlantic tomcod at three Hudson River power plants, in Fourth National Workshop on Entrainment and Impingement (L. D. Jensen, ed.), pp. 217-233. Ecological Analysts, Melville, N.Y.

Pacific Gas and Electric Company (PGandE). 1973. An evaluation of the effect of cooling water discharges on the beneficial uses of receiving waters at Hunters Point Power Plant. PGandE, San Francisco.

Stone & Webster Engineering Corporation. 1978. Ocean-sited plants. Prepared for the Utility Water Act Group. 2 vols.

Tomljanovich, D. A., J. H. Heuer, and C. W. Voigtlander. 1977. Investigations on the protection of fish larvae at water intakes using fine-mesh screening. Tennessee Valley Authority, Div. For. Fish. Wildl. Dev., Tech. Note B22. 53 pp.

Tomljanovich, D. A., J. H. Heuer, and C. W. Voigtlander. 1978. Investigations on the protection of fish larvae at water intakes using fine-mesh screening, in Larval exclusion systems for power plant cooling water intakes. Proceedings of the workshop held at Shelter Island Inn, San Diego, California, February 7-8, 1978 (R. K. Sharma and J. B. Palmer, eds.), pp. 125-139. NUREG/CP-002, ANL/ES-66. Argonne National Laboratory, Argonne, Ill.

U.S. Environmental Protection Agency (U.S. EPA). 1977. Guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment: section 316(b) P.L. 92-500. Draft. U.S. EPA, Office of Water Enforcement, Permits Division, Industrial Permits Branch, Washington, D.C. 59 pp.

White, J. C., Jr. and M. L. Brehmer. 1976. Eighteen-month evaluation of the Ristroph traveling fish screens, in Third National Workshop on Entrainment & Impingement (L. D. Jensen, ed.), pp. 367-380. Ecological Analysts, Melville, N.Y.

Appendix A

Intake Velocity and Water Quality Studies

A.1 Intake Velocity Studies

A.2 Water Quality Data

A.3 References

APPENDIX A: INTAKE VELOCITY AND WATER QUALITY STUDIES

A.1 INTAKE VELOCITY STUDIES

This section summarizes a study of intake velocities at the Hunters Point Power Plant Units 2 and 3 and Unit 4 cooling water intakes which are reported in Technical Report 420-79.102 of the Department of Engineering Research of Pacific Gas and Electric Company (PGandE 1979). The measurements were made in support of biological field surveys conducted at the Hunters Point Power Plant between April 1978 and April 1979.

Intake velocities at the face of a cooling water intake directly influence impingement of fish on the traveling screens, and thus constitute an important factor affecting the biological impact of the cooling water intake. Because operating characteristics of the intake system change over time as a result of factors such as sediment accumulation in the intake area, wear and reduced performance of the circulating water pumps, and accumulation of biofouling organisms in the cooling water system, the use of design intake velocities in the intake evaluation cannot be justified without confirmation by direct measurement of the approach velocities at each intake.

The objective of the study was to determine the velocity regime at the face of both intakes over a wide range of tidal stages. Velocity measurements were made at the Hunters Point Power Plant Units 2 and 3 and Unit 4 intakes between January and April 1979. Methods and results of this study are presented below.

A.1.1 Methods and Materials

Velocity measurements of a vertical cross-section of the Units 2 and 3 intake system were made approximately 1.5 ft (0.5 m) in front of the four traveling screens in the center of the intake (Figure 2-7, Section 2.1). Measurements were not made in front of the end screens, because no access to the forebay areas was available. At the Unit 4 intake, velocity measurements were made approximately 1.5 ft (0.5 m) behind the curtain walls of the two forebays immediately in front of the bar racks (Figure 2-9, Section 2.1). A two-dimensional grid pattern was established parallel to the face of each intake structure in order to measure velocities at the same

positions during each velocity survey. At the Units 2 and 3 intake, the grid consisted of three vertical transects, one at the center of the forebay and the other two located 4.9 ft (1.5 m) on either side of the center transect; vertical spacing of observations was set at 1.6-ft (0.5-m) increments. At Unit 4 the grid in each forebay consisted of five vertical transects spaced at 3.3-ft (1-m) increments across the forebay curtain wall. Vertical spacing of observations on all transects was set at increments of 3.3 ft (1 m).

Water velocities were measured at several tidal elevations and were timed to coincide with slack water periods to minimize the effect of tide-induced currents and water level changes. Measurements at the Units 2 and 3 and Unit 4 intakes were made at the two tidal stages (spring higher high and spring lower low) that represent the extremes in tidal elevation and at four intermediate tidal stages (spring lower high, neap higher high, neap lower high, and neap lower low). Velocity data collected at the Unit 4 intake at neap lower low and spring lower high tidal stages, reported in PGandE (1979), are not included in this discussion, because velocity measurements were not made in one of the two intake forebays.

Velocity was measured with a Marsh-McBirney Model 527 current meter. The unit operates on the Faraday principle of electromagnetic induction and measures the vector components of the water velocity parallel to two perpendicular axes (X and Y). The sensor contains a compass which records the orientation of the probe's housing relative to magnetic north. The velocity and direction of the water current are calculated from the meter's output by the following equations:

$$V^1 = \sqrt{X^2 + Y^2}$$

$$\theta = \tan^{-1} (X/Y), \text{ if } Y \geq 0$$

$$\theta = \tan^{-1} (X/Y) + 180^\circ, \text{ if } Y < 0$$

$$\theta_n = \theta + \theta_c$$

where

X = Cartesian component of velocity from the X axis

Y = Cartesian component of velocity from the Y axis

V^1 = current velocity in fps

θ = angle theta, referenced to Y', or vertical axis

θ_c = relative position of probe housing with respect to magnetic north

θ_n = current direction, referenced to magnetic north.

To measure the velocities, the probe was lowered, free hanging, to the bottom grid point of a vertical transect. The probe weighs 19 lb (8.6 kg) and can hang freely in current velocities well above those observed at the intake without significantly affecting the velocity readings. The electronic readout was regularly monitored to avoid systematic and gross errors induced by metallic interference, submerged debris, or probe damage. The probe was raised from grid point to grid point until it reached the top of the intake opening, where it was moved to the next vertical transect in the grid pattern, and the cycle was repeated. The tidal elevation was recorded at the beginning and end of an intake survey, in order to account for change in tidal elevation that might have occurred during the measurement period. Soundings of both intake areas were made with a lead line and a recording fathometer to determine the amount of sediment accumulation.

A.1.2 Data Analysis

Velocity data collected with the Marsh-McBirney current meters were corrected for calibration differences, which had been determined by measuring the meter's response in a stream of known current velocities. The correction formula developed for the instruments used in this study (PGand E 1979) was

$$V_c = 1.07V_1 + 0.04$$

where

V_c = calibrated velocity (fps)

V_1 = uncalibrated velocity (fps).

Velocity profiles of the intakes were constructed by mapping corrected velocity data from each survey on a two-dimensional grid representing the intake cross-section and then interpolating the velocity isobars around the measured values by standard cartographic techniques. An arithmetic mean was computed for each survey.

A.1.3 Results

Five of the six velocity surveys at the Units 2 and 3 intake were conducted under normal circulating water pump operation (see Section 2.1.2.1; cooling water flow = 218.2 cfs [6.18 m^3/sec]). The remaining survey was conducted with all circulating water pumps in operation (cooling water flow = 396.4 cfs [11.22 m^3/sec]). Under normal pump operation, intake velocities (Figures A-1 and A-2) ranged from 0.2 to 1.4 fps (6-43 cm/sec) and averaged 0.8 fps (24 cm/sec) at spring higher high tide. At spring lower low tide the intake velocity range was nearly the same, 0.2-1.3 fps (6-40 cm/sec), and the average velocity was 0.9 fps (27 cm/sec). Intake velocities were markedly higher during the survey when all circulating water pumps were in operation: they ranged from 0.1 to 3.0 fps (3-91 cm/sec) and averaged 1.3 fps (40 cm/sec). Highest velocities occurred in the forebays serving the east intake tunnel, since under conditions of maximum operation, three of the four main circulating water pumps draw from this tunnel. Under normal operation only one of the three main circulating water pumps located on the east intake tunnel is operating. Increased operation of the main circulating water pumps results in increased flow through, and intake velocities to, the three forebays which service the east intake tunnel.

No appreciable accumulation of sediment was observed in the forebays serving the east intake tunnel. A sediment layer approximately 1.5 ft (0.4 m) deep was observed in the forebays serving the west intake tunnel. This accumulation of sediment is probably due to the lower volume of water flowing through these forebays compared to the volume that flows through the east intake tunnel forebays. The lower volume results in lower water velocities, which permit more sediment to settle out in the forebays.

Intake velocities at the Unit 4 intake ranged from 0.1 to 0.9 fps (3-27 cm/sec), with no significant shift in range between highest and lowest tides (Figure A-3). Average intake velocities ranged from 0.5 to 0.7 fps (15-21 cm/sec) (Figure A-2).

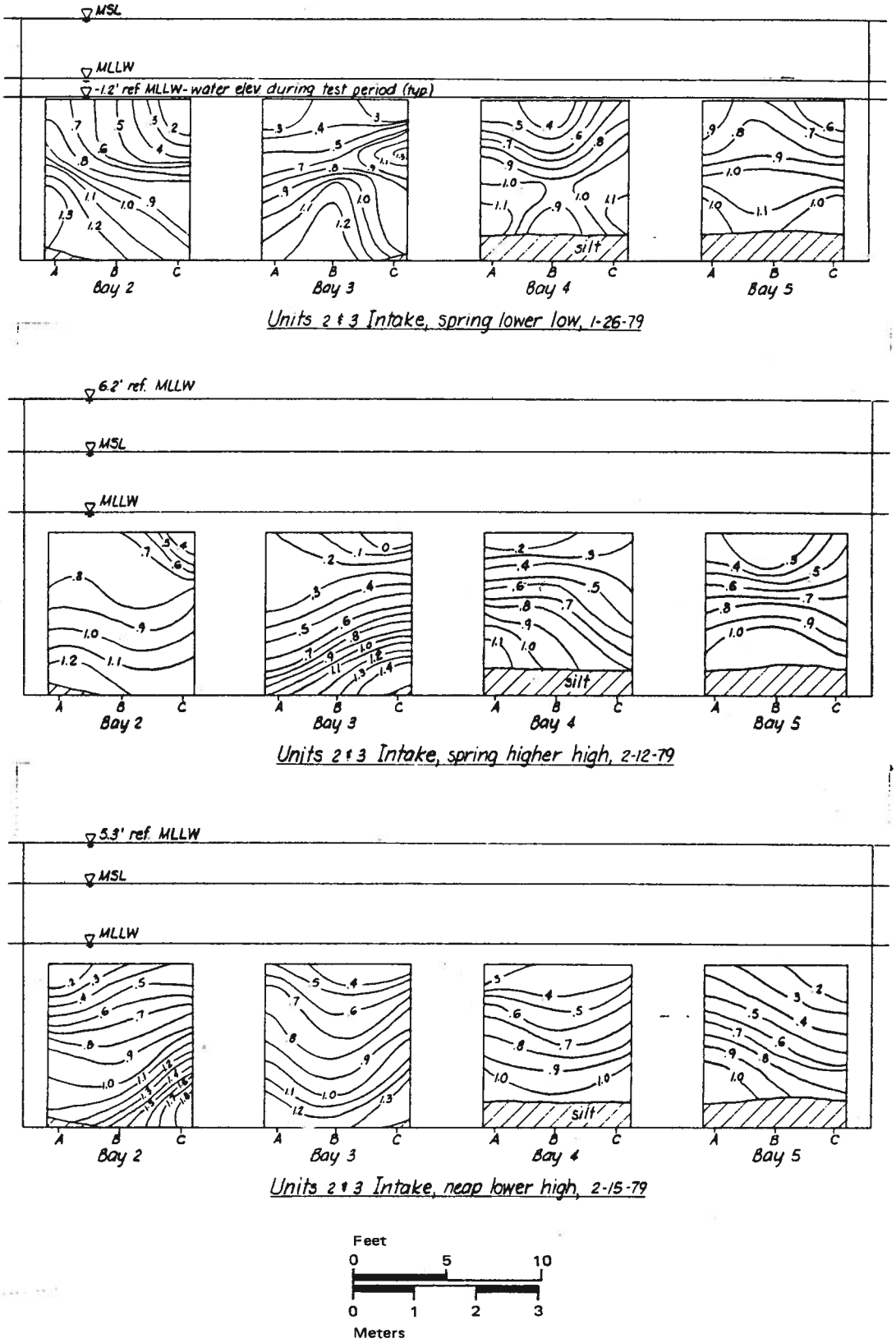
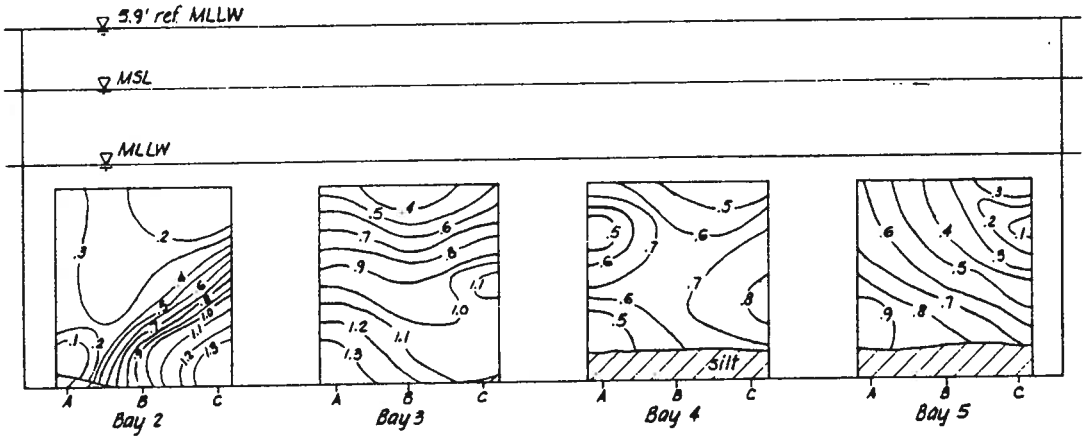
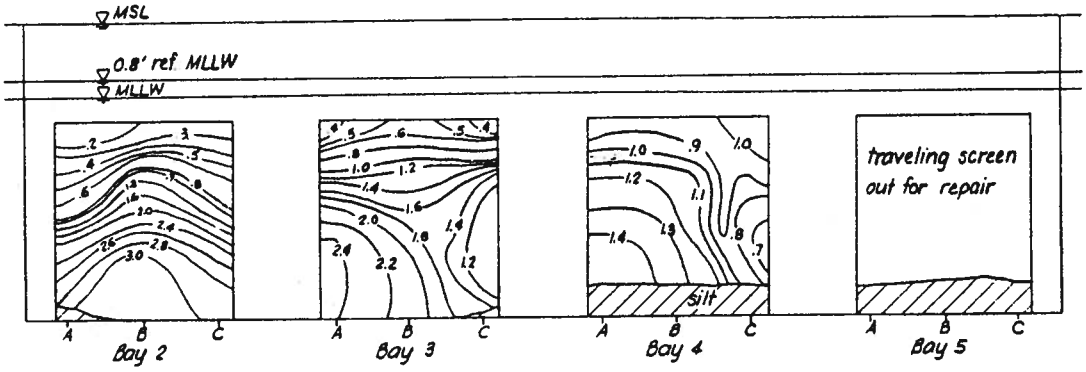


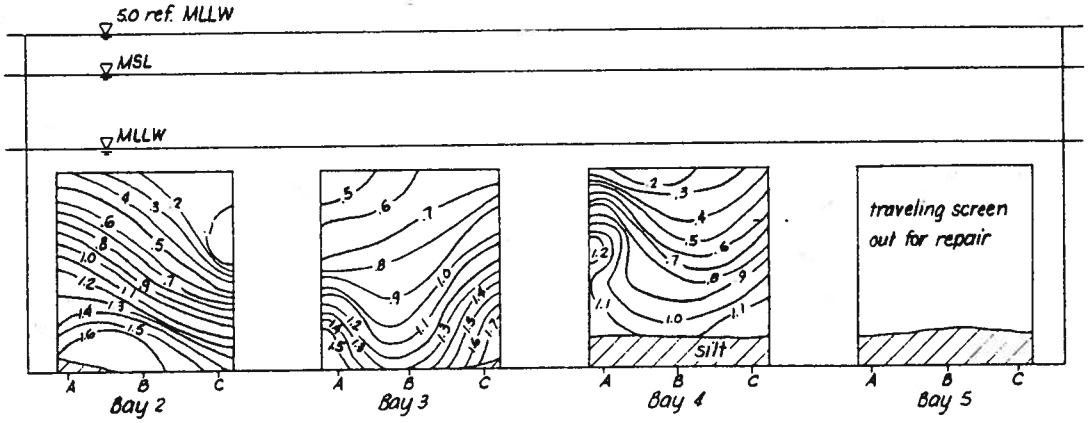
Figure A-1. Intake velocity (fps) profiles at the Units 2 and 3 intake of the Hunters Point Power Plant, 1979. (From PGandE 1979.)



Units 2 & 3 Intake, neap higher low, 3-12-79



Units 2 & 3 Intake, neap lower low, 5-4-79



Units 2 & 3 Intake, spring lower high, 5-11-79

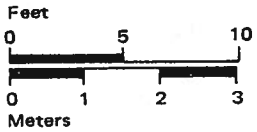
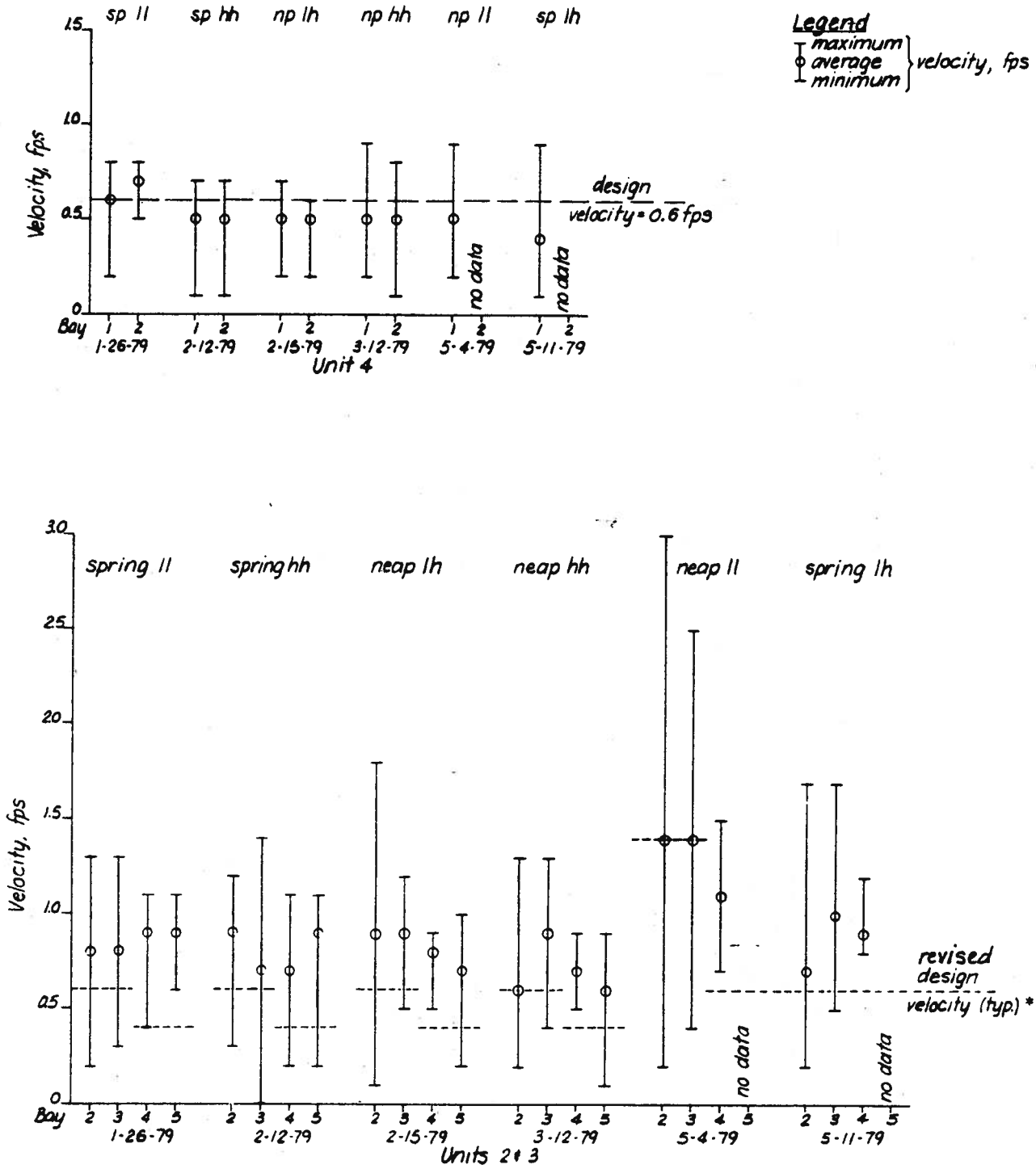


Figure A-1. (Cont.)



* Calculated values based on intake cross-section and CWP flows.

Figure A-2. Ranges and means of intake velocities (fps) at the Units 2 and 3 and Unit 4 intakes of the Hunters Point Power Plant, 1979. (From PGandE 1979.)

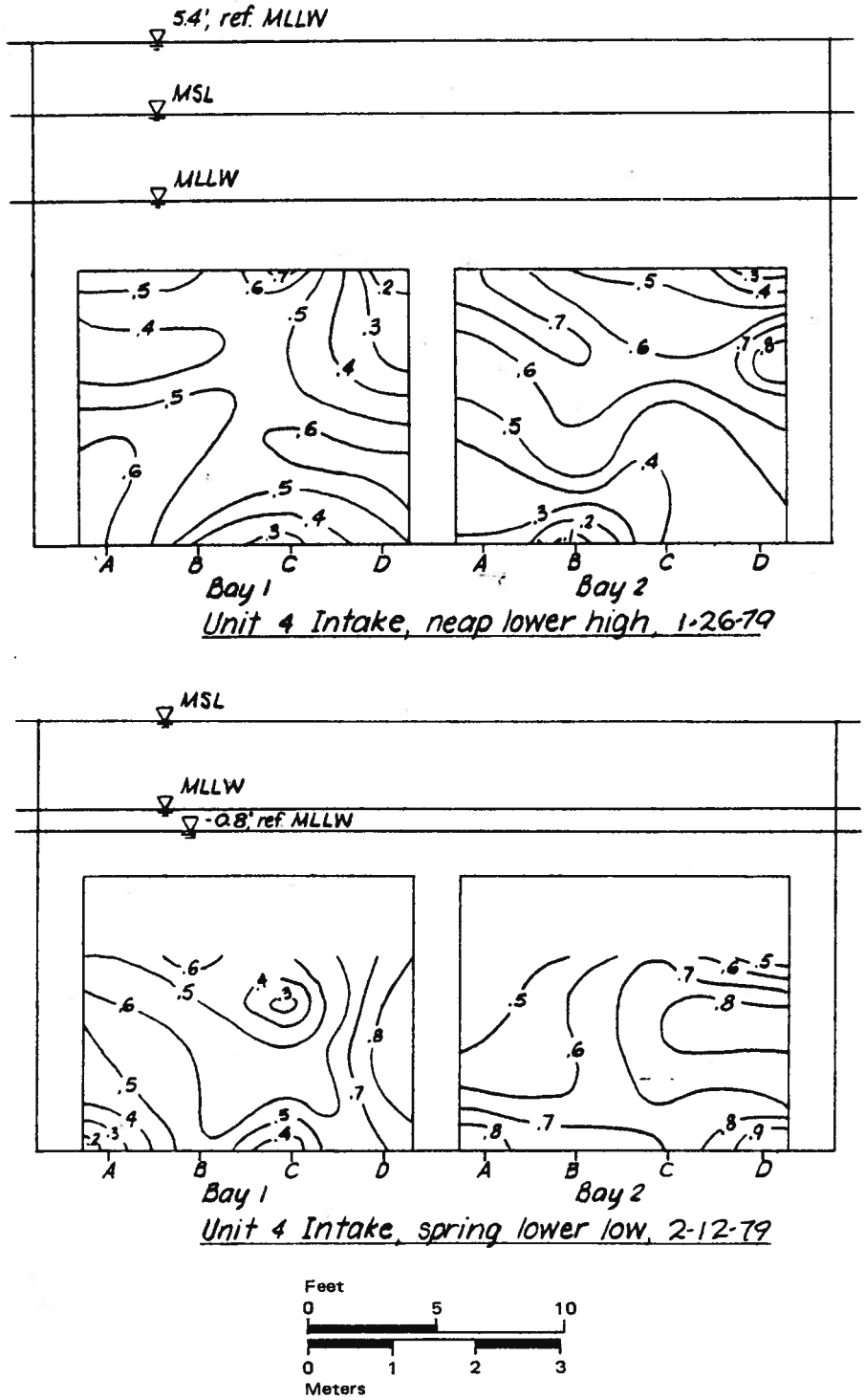
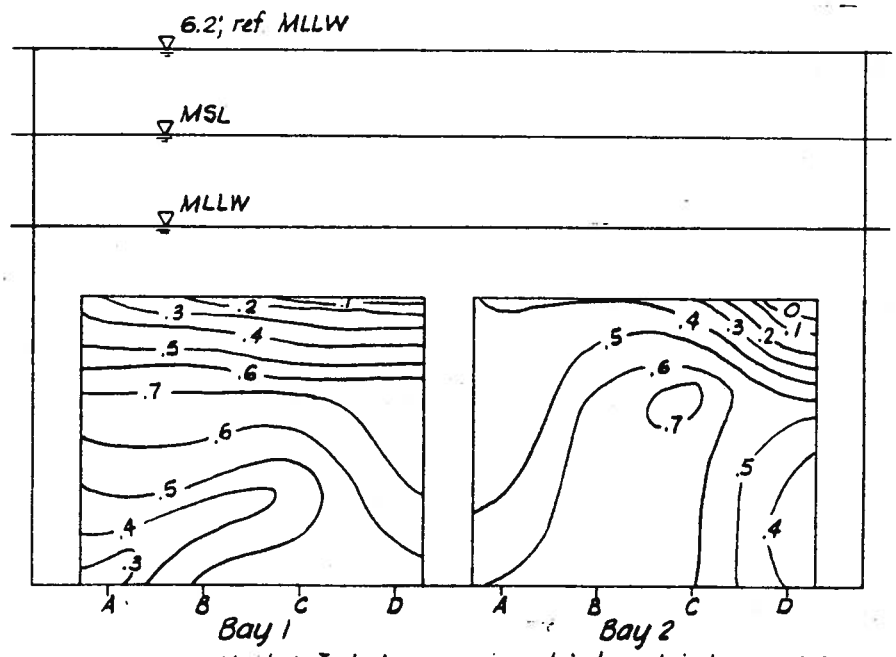
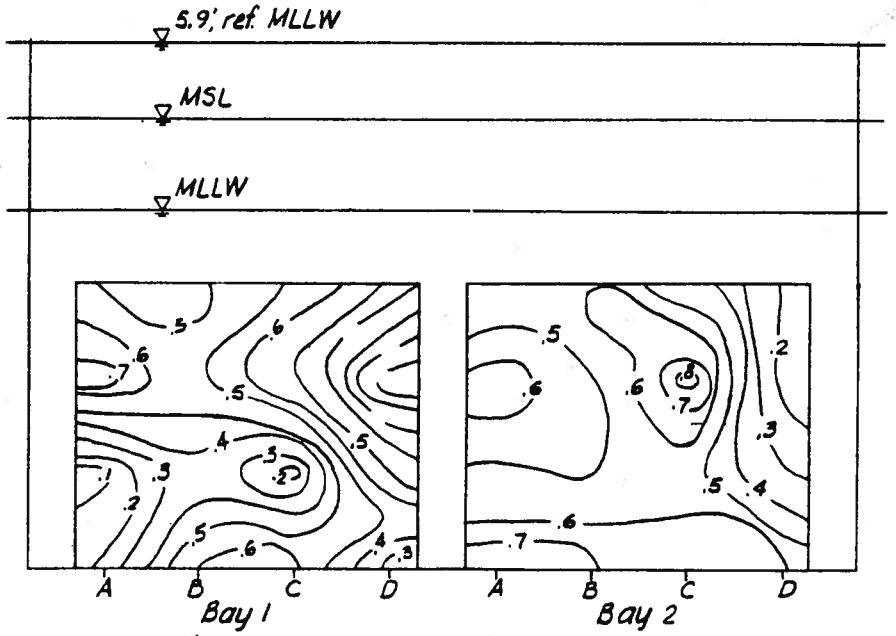


Figure A-3. Intake velocity (fps) profiles at the Unit 4 intake of the Hunters Point Power Plant, 1979. (From PGandE 1979.)



Unit 4 Intake, spring higher high, 2-15-79



Unit 4 Intake, neap higher high, 3-12-79

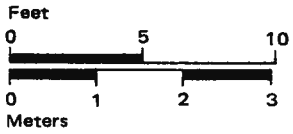


Figure A-3. (Cont.)

No tidal relationship was apparent. The average velocity measured at the intake is in close agreement with the 0.6-fps (18-cm/sec) design velocity reported by PGandE (1973). No significant accumulation of sediment was detected in the Unit 4 intake forebay.

A.2 WATER QUALITY DATA

Water temperature, conductivity, and dissolved oxygen concentration were measured during each impingement and entrainment survey. Intake and discharge temperatures of Units 2 and 3 and Unit 4 cooling water flows were continuously recorded. The data provided background information on the seasonal changes in physical and chemical characteristics of the cooling water.

A.2.1 Methods and Materials

Martek Mark V water quality analyzers were used to collect temperature, conductivity, and dissolved oxygen data during all biological surveys of the Hunters Point Power Plant cooling water system between May 1978 and April 1979. These instruments provided data of sufficient accuracy for the purposes of the 316(b) studies. Manufacturer's specifications for each parameter are listed in Table A-1. Backup systems available in the event of unit failures consisted of calibrated mercury thermometers, fixing reagents for preserving samples for subsequent laboratory determination of dissolved oxygen, and portable conductivity meters.

Use of the water quality analyzers is based on a standard operating procedure and operator training program. Each analyzer was calibrated and maintained on a weekly or biweekly basis. The calibration procedures for each parameter are described in Section A.2.3.

Water temperatures were continuously recorded from April 1978 to April 1979 by Foxboro Model 12R Temperature Recorders. These instruments have a temperature range of 30-110 F (-1.1 - 43.3 C), and are equipped with 7-day clock-driven recording charts.

TABLE A-1 MANUFACTURERS' ACCURACY SPECIFICATIONS FOR WATER QUALITY INSTRUMENTS USED AT THE HUNTERS POINT POWER PLANT, 1978-1979

Instrument	Parameter	Probe Type	Accuracy
Martek Mark V	Temperature	Thermolinear array mounted in stainless steel tube	±0.1 C
	Conductivity	Platinized nickle electrode; automatic temperature compensated to 25 C	±1.0 mmho[a]
	Dissolved Oxygen	Polarographic gold/silver electrode system; automatic temperature compensation	±0.05 mg/liter
Foxboro Model 12R	Temperature	Temperature sensitive bulb connected by capillary tube to measuring element inside recorder housing	±0.5% of full scale

(a) Accuracy of unit equipped with probe having cell constant of 20K; translates to approximately ±0.7 ppt salinity.

A.2.2 Sampling Locations

Water quality measurements were made with Martek water quality analyzers in the Unit 4 intake forebays between the bar racks and the curtain wall approximately 1.6 ft (0.5 m) below the surface. Water quality was not measured at the Units 2 and 3 intake because both Units 2 and 3 and Unit 4 withdraw cooling water from a common intake basin where differences in water quality between the two intakes are expected to be negligible.

Foxboro temperature sensors were located as follows:

1. the Unit 4 intake structure directly in front of the curtain wall approximately 3.3 ft (1.0 m) below mean sea level (MSL),
2. the Unit 2 discharge structure approximately 4.9 ft (1.5 m) below MSL,
3. the Unit 3 discharge channel upstream of the outfall weir approximately 3.3 ft (1.0 m) below the water surface, and
4. the Unit 4 discharge conduit approximately 50 ft (12.7 m) upstream of the submerged discharge structure.

The Unit 4 intake station monitored the temperature of the cooling water flow before it entered the intake structure. The data obtained at this station were used to represent intake temperatures for all three generating units. On several occasions extreme low tides caused the water level to fall below the intake sensor for short periods of time. These data have been eliminated from the data set and the problem was remedied by relocating the sensors 1.0 m (3.3 ft) below their previous level.

A.2.3 Instrument Calibration and Correction Factors

A.2.3.1 Martek Calibration

Water quality analyzers were calibrated on a weekly or biweekly basis, depending on the frequency of use and the stability of the individual unit. The calibration procedures for each parameter are briefly described below, and formulas used to convert conductivity to salinity and to correct dissolved oxygen measurements to ambient salinity are presented.

Temperature

A two-point temperature calibration procedure was employed to ensure accuracy of the sensor. The sensor was placed in an ice bath and the temperature readout was adjusted to correspond to the actual temperature, as measured with a thermometer traceable to a NBS standard (± 0.1 C). The sensor was then placed in a water bath maintained at approximately 40 C (104 F) and further adjustments were made to the readout circuit if the unit's output did not agree with the actual temperature of the water bath. Calibration adjustments were made at both temperatures until all instrument readings agreed with the standard without further adjustment.

Conductivity

Calibration of the unit consisted of first electronically zeroing the system with the sensor out of water, then immersing the sensor in a solution of known conductivity (approximately 35.0 millimhos at 25 C) and adjusting the readout to agree with the standard. Conductivity of the standard solution was measured with a YSI Model 31 conductivity bridge (accuracy ± 1 percent of reading, resolution better than 0.5 percent) and was occasionally checked by volumetric silver-nitrate titration (Strickland and Parsons 1972).

Conductivity is automatically compensated for temperature to 25 C, so direct comparison of readings taken at different temperatures is possible without manipulation. However, in marine environments it may be desirable to report salinity instead of conductivity. Salinity is related to conductivity by the following:

$$S\ (\text{ppt}) = \frac{0.4738}{C_{25}^{-1.07} - 0.00075} + 0.03$$

where

C_{25} = specific conductance at 25 C in millimhos.

Dissolved Oxygen

Calibration of the dissolved oxygen system consisted of electronically zeroing the internal readout circuit and then immersing the sensor in fresh water with a dissolved oxygen concentration determined by a Winkler titration (APHA et al. 1976). The water quality analyzer was adjusted to bring the unit into agreement with the standard.

The response of a polarographic membrane electrode used for measuring dissolved oxygen is affected by the salinity of the water in which it is being used. Since salinities often varied in the course of a 24-hour survey, it was not practical to maintain the instrument to read actual dissolved oxygen concentration at all times. Instead, the unit was calibrated in fresh water, and readings obtained at higher salinities were corrected according to an empirical formula developed by Pijanowski (1973):

$$DO_A = DO_i(P_{ij})$$

where

DO_A = actual DO (ppm)
DO_i = instrument DO reading (ppm)
P_{ij} = correction factor.

P_{ij} was calculated as follows:

$$P_{ij} = 0.9987e^{-0.001[S/(0.1455 + 0.001255T)]}$$

where

S = salinity (ppt) at which DO was measured
T = temperature (C) at which DO was measured

The use of the conversion formula for the Martek dissolved oxygen meter was verified in laboratory tests over a range of salinities of 14-36 ppt. This range brackets the

salinities observed during the study period. Good agreement of the observed and calculated correction factor values was obtained over the entire salinity range, and therefore the correction factor P_{ij} was used without modification.

A.2.3.2 Foxboro Calibration

The Foxboro recorders were calibrated before installation and recalibrated at 2-month intervals for the duration of the study period. Calibration consisted of removing the sensor bulb from the cooling water flow and comparing its reading to the reading of a NBS-traceable thermometer (± 0.1 C) in an ice bath (temperature approximately 32 F; 0 C) and in a warm water bath (temperature approximately 110 F; 41 C). Adjustments were made if the recorder reading differed from the actual temperature by more than 1.0 F (0.5 C).

A.2.4 Data Analysis

A.2.4.1 Verification of Martek Data

Data collected with the water quality analyzers were evaluated on the basis of calibration results obtained upon return of the units to the laboratory after a period of use in the field. A certain amount of drift is inherent in these instruments, and it is primarily on the basis of the amount of relative variation between calibrations that data are rejected. Instrument error was calculated from the results of calibration as follows:

$$\text{Error (percent)} = \frac{V_i - V_s}{V_s} \times 100$$

where

V_i = instrument reading in a standard solution
V_s = actual value of the standard.

Relative variation (RV) between calibrations was calculated as follows:

$$RV = \text{Error at } T_2 - \text{Error at } T_1$$

where

Error at T_2 is calibration error after field sampling, and

Error at T_1 is calibration error immediately following the previous calibration and is assumed to be zero.

Calibration errors for temperature, conductivity, and dissolved oxygen in excess of plus or minus 2.5, 5.0, and 15.0 percent, respectively, were interpreted as instrument failures for the period prior to recalibration, and data for parameters whose calibration error exceeded these limits were eliminated from the data file. In general, the calibration errors were much lower than the rejection limits for all three parameters.

Relative variations of water quality analyzers are presented in Figure A-4 for all sampling days in which acceptable data for each parameter were obtained. On the basis of relative variation between calibrations 0, 7, and 10 days of data were eliminated from the data base for temperature, conductivity, and dissolved oxygen, respectively.

A.2.4.2 Verification of Foxboro Data

The temperature response of a Foxboro recorder was compared to a precision thermometer over the full temperature range of the unit. Foxboro response was linear over the full range with no significant deviation in the middle of the range (Table A-2), so no adjustments were required for temperature response.

Calibration of the units used at the Hunters Point Power Plant maintained an accuracy within ±1 F (0.5 C) during the study period, so compensation of recorded temperatures was unnecessary for the purposes of the study.

A.2.5 Data Summary Tables

Tables A-3 through A-6 summarize the results of conductivity (reported as salinity), dissolved oxygen, and intake and discharge temperature measurements taken at the Hunters Point Power Plant.

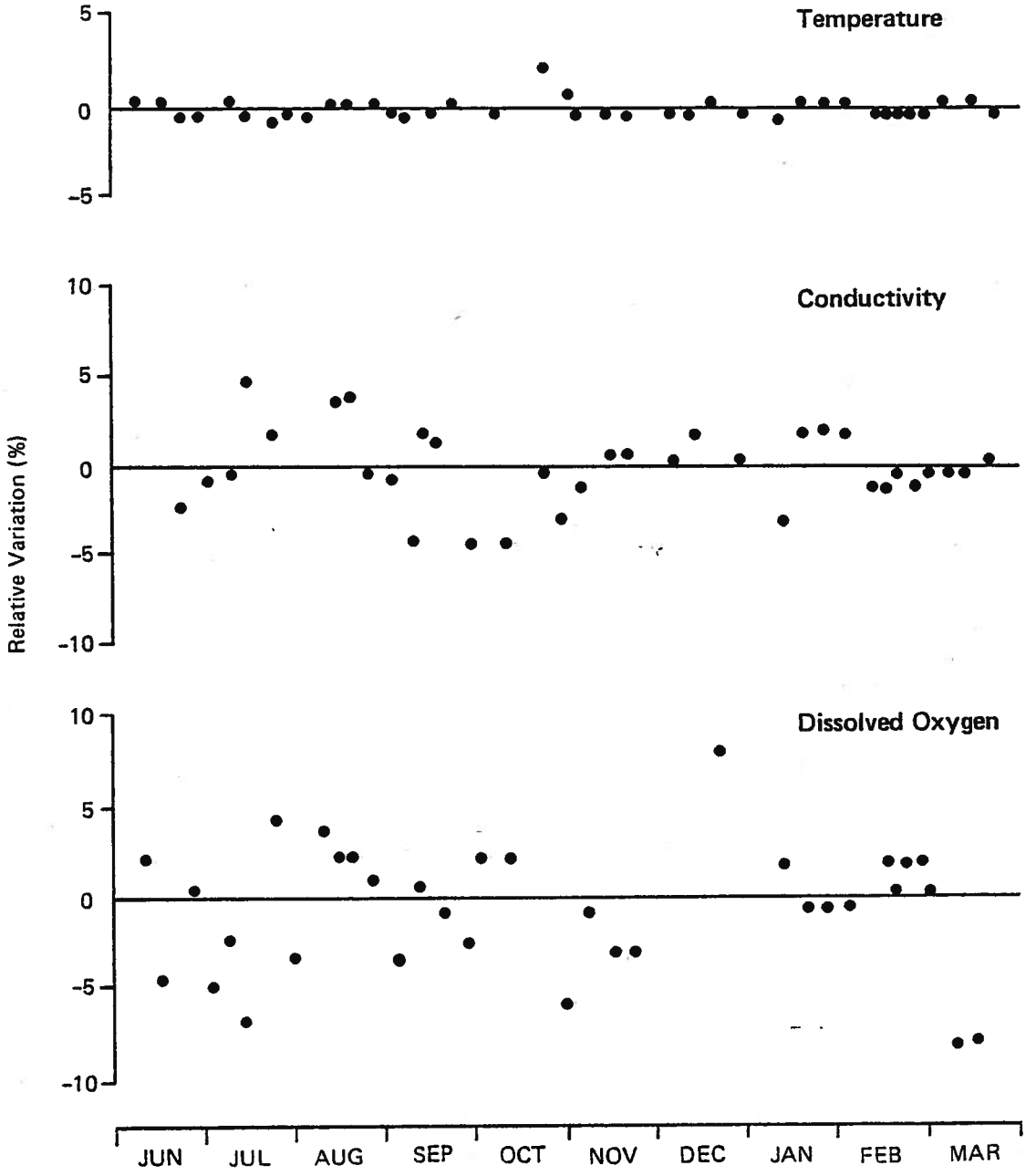


Figure A-4. Relative variation between calibrations of water quality analyzers used at the Hunters Point Power Plant, 1978–1979.

TABLE A-2 COMPARISON[a] OF TEMPERATURE MEASUREMENTS OBTAINED WITH A FOXBORO RECORDER CALIBRATED AT 32.2 AND 106.0 F AND A CALIBRATED PRECISION THERMOMETER

Temperature Recorded (F)		Difference (F)
Foxboro Recorder[b]	Thermometer[c]	
106.0	106.0	0.0
101.0	101.2	-0.2
96.6	96.6	0.0
93.0	92.8	+0.2
89.5	89.4	+0.1
86.6	86.6	0.0
84.0	84.0	0.0
81.5	81.5	0.0
79.3	79.2	+0.1
77.5	77.2	+0.3
76.3	76.2	+0.1
75.0	75.0	0.0
73.5	73.4	+0.1
72.7	72.5	+0.2
72.0	72.0	0.0
70.0	69.8	+0.2
67.5	67.5	0.0
66.5	66.5	0.0
65.3	65.2	+0.1
63.6	63.6	0.0
60.2	60.2	0.0
55.5	55.5	0.0
50.3	50.2	+0.1
44.6	44.6	0.0
39.3	39.2	+0.1
33.2	33.4	-0.2

(a) Test carried out by E. Petroske, 28 and 31 December 1979.
(b) No. FO 01; calibrated by E. Petroske on 21 December 1979.
(c) No. NR-2; calibrated by T. W. Holmbeck in August 1979 at the Department of Engineering Research, Pacific Gas and Electric Company.

TABLE A-3 MONTHLY MEANS AND RANGES OF SALINITY MEASUREMENTS (ppt) TAKEN AT THE HUNTERS POINT POWER PLANT UNIT 4 INTAKE STRUCTURE, MAY 1978 - APRIL 1979

Month	Year	Mean (ppt)	Range (ppt) Min.	Range (ppt) Max.	Number of Observations
MAY	78	25.0	22.8	25.7	8
JUN	78	29.8	28.0	31.1	16
JUL	78	32.0	29.4	33.7	17
AUG	78	30.5	27.7	31.9	23
SEP	78	30.9	28.9	32.8	24
OCT	78	29.5	27.1	32.9	38
NOV	78	29.1	26.3	31.7	32
DEC	78	31.0	27.7	33.0	12
JAN	79	26.5	23.7	30.4	26
FEB	79	24.6	23.1	26.4	31
MAR	79	22.9	18.5	26.5	38
APR	79	24.7	22.1	27.7	20
Summary		27.7	18.5	33.7	285

Note: Means are weighted by the number of monthly observations.

TABLE A-4 MONTHLY MEANS AND RANGES OF DISSOLVED OXYGEN MEASUREMENTS (mg/liter) TAKEN AT THE HUNTERS POINT POWER PLANT UNIT 4 INTAKE STRUCTURE, MAY 1978 - APRIL 1979

Month	Year	Mean (mg/l)	Range (mg/l) Min.	Range (mg/l) Max.	Number of Observations
MAY	78	7.9	7.4	8.5	8
JUN	78	8.2	7.0	9.2	22
JUL	78	7.4	6.4	8.7	16
AUG	78	7.4	6.4	8.5	36
SEP	78	6.5	6.1	7.4	24
OCT	78	7.1	6.4	9.2	22
NOV	78	6.7	6.4	7.4	10
DEC	78	7.4	6.6	8.3	30
JAN	79	7.0	6.7	7.6	15
FEB	79	7.8	7.1	8.9	17
MAR	79	8.2	5.1	9.3	38
APR	79	7.6	6.8	9.2	20
Summary		7.5	5.1	9.9	259

Note: Means are weighted by the number of monthly observations.

TABLE A-5 MONTHLY MEANS AND RANGES OF INTAKE AND DISCHARGE TEMPERATURES (F) AT THE HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979

	Intake		Discharge					
	Unit 4		Unit 2		Unit 3		Unit 4	
Period	Mean	Range	Mean	Range	Mean	Range	Mean	Range
APR 78	58.8	57-61	--	--	67.0	61-80	65.2	57-73
MAY 78	59.0	57-62	--	--	69.6	59-86	65.6	57-76
JUN 78	60.0	58-63	71.8	58-88	70.3	58-88	72.1	59-83
JUL 78	61.7	60-64	70.1	60-97	75.0	64-90	73.6	60-84
AUG 78	63.5	60-66	73.4	64-88	71.8	62-90	78.5	62-86
SEP 78	64.1	60-66	73.9	64-86	64.9	61-68	76.8	65-85
OCT 78	61.4	60-65	76.2	65-87	72.2	60-86	76.4	61-85
NOV 78	55.0	53-65	74.6	60-86	74.1	61-86	72.3	56-85
DEC 78	48.7	47-50	64.3	53-78	63.5	52-77	69.3	57-77
JAN 79	49.4	47-51	66.1	54-77	65.1	53-77	68.6	50-82
FEB 79	51.4	49-52	64.0	53-76	64.8	54-77	67.4	57-75
MAR 79	54.9	53-58	58.4	55-75	68.1	58-84	64.6	50-76
APR 79	57.5	57-59	67.3	57-85	67.3	57-85	73.6	61-92
Summary	57.3	47-66	69.1	53-97	68.7	52-90	71.1	50-96

Note: (--) indicates unit out of service for entire month.

TABLE A-6 SUMMARY OF THE INTAKE AND DISCHARGE TEMPERATURES AT THE HUNTERS POINT POWER PLANT UNITS 2 AND 3 AND UNIT 4, APRIL 1978 - APRIL 1979

Computer Code	Definition
Loc	HPIS02A1 = Unit 4 intake HPDU02A1 = Unit 2 discharge HPDS02A1 = Unit 3 discharge HPDU04A1 = Unit 4 discharge
Frequency Bar Chart Midpoint Temp.	Observed temperature (F).
Freq	Frequency of observations recorded for each temperature.
Cum. Freq	Cumulative frequency of temperature observations.
Percent	Percentage of observations represented by each temperature based on frequency of occurrence.
Cum. Percent	Cumulative percentage represented by each temperature.

LOCATION=HPIS02A1

Unit 4 Intake

MIDPOINT TEMP		FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
	*	0	0	0.00	0.00
45	*	0	0	0.00	0.00
46	*	6	6	0.28	0.28
47	**	52	58	2.41	2.69
48	**********	78	136	3.61	6.30
49	**********	96	232	4.45	10.75
50	**********	40	272	1.85	12.60
51	**********	71	343	3.29	15.89
52	**********	15	358	0.70	16.59
53	******	101	459	4.68	21.27
54	**********	44	503	2.04	23.31
55	**********	31	534	1.44	24.75
56	**********	144	678	6.67	31.42
57	**********	231	909	10.70	42.12
58	**********	221	1130	10.24	52.36
59	**********	191	1321	8.85	61.21
60	**********	214	1535	9.92	71.13
61	**********	155	1690	7.18	78.31
62	**********	150	1840	6.95	85.26
63	**********	179	2019	8.29	93.56
64	**********	114	2133	5.28	98.84
65	**********	25	2158	1.16	100.00
66	**********	0	2158	0.00	100.00
67	*	0	2158	0.00	100.00
68	*	0	2158	0.00	100.00
69	*	0	2158	0.00	100.00
70	*	0	2158	0.00	100.00
71	*				

LOCATION=HPDU02A1

Unit 2 Discharge

MIDPOINT TEMP		FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
	^	0	0	0.00	0.00
50	^	0	0	0.00	0.00
51	^	0	0	0.00	0.00
52	^	8	8	0.40	0.40
53	^****	11	19	0.55	0.95
54	^******	11	30	0.55	1.50
55	^******	24	54	1.20	2.71
56	^**********	62	116	3.11	5.82
57	^**********	50	166	2.51	8.32
58	^**********	12	178	0.60	8.93
59	^******	38	216	1.91	10.83
60	^**********	54	270	2.71	13.54
61	^**********	54	324	2.71	16.25
62	^**********	63	387	3.16	19.41
63	^**********	44	431	2.21	21.61
64	^**********	55	486	2.76	24.37
65	^**********	74	560	3.71	28.08
66	^**********	114	674	5.72	33.80
67	^**********	94	768	4.71	38.52
68	^**********	95	863	4.76	43.28
69	^**********	107	970	5.37	48.65
70	^**********	87	1057	4.36	53.01
71	^**********	83	1140	4.16	57.17
72	^**********	102	1242	5.12	62.29
73	^**********	57	1299	2.86	65.15
74	^**********	86	1385	4.31	69.46
75	^**********	111	1496	5.57	75.03
76	^**********	115	1611	5.77	80.79
77	^**********	55	1666	2.76	83.55
78	^**********	51	1717	2.56	86.11
79	^**********	54	1771	2.71	88.82
80	^**********	51	1822	2.56	91.37
81	^**********	44	1866	2.21	93.58
82	^**********	49	1915	2.46	96.04
83	^**********	24	1939	1.20	97.24
84	^**********	18	1957	0.90	98.14
85	^*********	13	1970	0.65	98.80
86	^*******	12	1982	0.60	99.40
87	^******	6	1988	0.30	99.70
88	^***	2	1990	0.10	99.80
89	^*	1	1991	0.05	99.85
90	^*	0	1991	0.00	99.85
91	^	1	1992	0.05	99.90
92	^*	1	1993	0.05	99.95
93	^*	0	1993	0.00	99.95
94	^	0	1993	0.00	99.95
95	^	0	1993	0.00	99.95
96	^	1	1994	0.05	100.00
97	^*	0	1994	0.00	100.00
98	^	0	1994	0.00	100.00
99	^	0	1994	0.00	100.00
100	^				

LOCATION=HPDS02A1

Unit 3 Discharge

MTDPOINT

TEMP		FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
	^				
45	^	0	0	0.00	0.00
46	^	0	0	0.00	0.00
47	^	0	0	0.00	0.00
48	^	0	0	0.00	0.00
49	^	0	0	0.00	0.00
50	^	0	0	0.00	0.00
51	^	0	0	0.00	0.00
52	^	2	2	0.06	0.06
53	^*	3	5	0.09	0.15
54	^********	40	45	1.17	1.32
55	^*****	25	70	0.73	2.06
56	^**	8	78	0.23	2.29
57	^**********	96	174	2.82	5.11
58	^**********	82	256	2.41	7.52
59	^**********	70	326	2.06	9.57
60	^**********	64	390	1.88	11.45
61	^**********	116	506	3.41	14.86
62	^**********	141	647	4.14	19.00
63	^**********	158	805	4.64	23.64
64	^**********	219	1024	6.43	30.07
65	^**********	262	1286	7.69	37.77
66	^**********	247	1533	7.25	45.02
67	^**********	217	1750	6.37	51.40
68	^**********	108	1858	3.17	54.57
69	^**********	94	1952	2.76	57.33
70	^**********	115	2067	3.38	60.70
71	^**********	123	2190	3.61	64.32
72	^**********	171	2361	5.02	69.34
73	^**********	194	2555	5.70	75.04
74	^**********	154	2709	4.52	79.56
75	^**********	115	2824	3.38	82.94
76	^**********	130	2954	3.82	86.75
77	^**********	75	3029	2.20	88.96
78	^**********	68	3097	2.00	90.95
79	^**********	53	3150	1.56	92.51
80	^********	40	3190	1.17	93.69
81	^********	38	3228	1.12	94.80
82	^*****	27	3255	0.79	95.59
83	^*****	24	3279	0.70	96.30
84	^******	32	3311	0.94	97.24
85	^******	32	3343	0.94	98.18
86	^*****	25	3368	0.73	98.91
87	^**	12	3380	0.35	99.27
88	^***	17	3397	0.50	99.77
89	^*	6	3403	0.18	99.94
90	^	2	3405	0.06	100.00
91	^	0	3405	0.00	100.00
92	^	0	3405	0.00	100.00

LOCATION=HPBU04A1

Unit 4 Discharge

MIDPOINT TEMP		FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
	*	0	0	0.00	0.00
45	*	0	0	0.00	0.00
46	*	0	0	0.00	0.00
47	*	0	0	0.00	0.00
48	*	0	0	0.00	0.00
49	*	9	9	0.33	0.33
50	*****	11	20	0.40	0.73
51	******	7	27	0.25	0.98
52	****	2	29	0.07	1.05
53	*	2	31	0.07	1.13
54	*	3	34	0.11	1.24
55	**	9	43	0.33	1.56
56	*****	24	67	0.87	2.43
57	**********	51	118	1.85	4.29
58	**********	39	157	1.42	5.70
59	**********	92	249	3.34	9.05
60	**********	76	325	2.76	11.81
61	**********	81	406	2.94	14.75
62	**********	71	477	2.58	17.33
63	**********	77	554	2.80	20.13
64	**********	66	620	2.40	22.53
65	**********	99	719	3.60	26.13
66	**********	83	802	3.02	29.14
67	**********	99	901	3.60	32.74
68	**********	105	1006	3.82	36.56
69	**********	94	1100	3.42	39.97
70	**********	114	1214	4.14	44.11
71	**********	163	1377	5.92	50.04
72	**********	142	1519	5.16	55.20
73	**********	167	1686	6.07	61.26
74	**********	156	1842	5.67	66.93
75	**********	127	1969	4.61	71.55
76	**********	110	2079	4.00	75.55
77	**********	98	2177	3.56	79.11
78	**********	88	2265	3.20	82.30
79	**********	124	2389	4.51	86.81
80	**********	78	2467	2.83	89.64
81	**********	106	2573	3.85	93.50
82	**********	70	2643	2.54	96.04
83	**********	52	2695	1.89	97.93
84	**********	12	2707	0.44	98.36
85	******	7	2714	0.25	98.62
86	****	2	2716	0.07	98.69
87	*	4	2720	0.15	98.84
88	**	8	2728	0.29	99.13
89	****	8	2736	0.29	99.42
90	****	9	2745	0.33	99.75
91	*****	3	2748	0.11	99.85
92	**	1	2749	0.04	99.89
93	*	0	2749	0.00	99.89
94	*	2	2751	0.07	99.96
95	*	1	2752	0.04	100.00
96	*				

A.3 REFERENCES

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1976. Standard methods for the examination of water and wastewater. 14th ed. APHA, Washington, D.C. 1193 pp.

Pacific Gas and Electric Company (PGandE). 1973. An evaluation of the effect of cooling water discharges on the beneficial uses of receiving waters at Hunters Point Power Plant. PGandE, San Francisco.

Pacific Gas and Electric Company (PGandE). 1979. Hunters Point Power Plant Units 2 and 3 and Unit 4 intake velocity studies. PGandE, Dep. Eng. Res., Rep. 420-79.102. San Ramon, Calif.

Pijanowski, B. S. 1973. Salinity corrections for dissolved oxygen measurements. Environ. Sci. Technol. 7(10):957-958.

Strickland, J. D. H. and T. R. Parsons. 1972. A practical handbook of seawater analysis. 2nd ed. Bull. Fish. Res. Board Can. 167. 310 pp.

Appendix B

Review of Laboratory and Field Entrainment Survival Studies

B.1 Introduction

B.2 Review of Laboratory Studies Pertinent to Entrainment Survival

B.3 Review of Field Studies Pertinent to Entrainment Survival

B.4 Summary and Conclusions

B.5 References

APPENDIX B: REVIEW OF LABORATORY AND FIELD ENTRAINMENT SURVIVAL STUDIES

B.1 INTRODUCTION

Steam electric generating stations drawing cooling water from a water body entrain a variety of aquatic organisms into the cooling water flow. Plankton and weak-swimming nekton capable of passing through intake screens are carried along with the cooling water through the plant and are subjected to a variety of thermal, physical, and chemical (biocidal) stresses. Upon reaching the circulating water pumps, entrained organisms are exposed to pressure increases, velocity shear forces, physical buffeting, and abrasion. Passing through the condensers, organisms are subjected to rapid temperature increases and pressure decreases as well. They may also be exposed to chlorine during cooling system passage, if this biocide is used to prevent fouling of condenser tube surfaces. In once-through cooling systems, entrained organisms are returned to the source water body, where they are subjected to rapidly decreasing temperatures.

Entrainment survival at power plants was initially thought to be low or negligible, based on the results of several early field studies (Marcy 1971, 1973; Carpenter et al. 1974). Consequently, fine-mesh screening was proposed as a mechanism for preventing entrainment of the larger plankton and weak-swimming nekton. However, recent studies have shown entrainment survival of a variety of aquatic organisms to be high under many plant operating conditions, suggesting that exclusion by means of fine-mesh screening may not be the best means of minimizing impact on aquatic organisms.

The purpose of this review of the results of laboratory and field studies pertinent to entrainment survival is to form a basis for estimating survival at power plants for which no site-specific data exist and to supplement the results of limited site-specific survival studies. The review is applicable to power plants with once-through cooling systems (entrainment survival at power plants with closed-cycle cooling is assumed to be negligible). The review demonstrates that high entrainment survival of a variety of aquatic organisms is likely, and specifies the plant operating conditions under which high survival can be expected.

B.2 REVIEW OF LABORATORY STUDIES PERTINENT TO ENTRAINMENT SURVIVAL

Physical, thermal, and chemical (biocidal) stresses potentially influence entrainment survival. The effects of these stresses have been isolated in laboratory studies.

B.2.1 Physical Stresses

Physical stresses include mechanical buffeting, abrasion, and collision; velocity shear forces; and changes in hydrostatic pressure. Entrained organisms are subjected to physical stresses throughout the cooling system, although such stresses may be greatest in the circulating water pumps and condensers.

Although the separate effects of most physical stresses have not been isolated in the laboratory, the effects of the combined physical stresses associated with passage of entrained organisms through actual or simulated condenser tubes have been quantified by several investigators (Section B.2.1.1), and the effects of rapid changes in hydrostatic pressure and velocity shear forces have been specifically studied (Sections B.2.1.2 and B.2.1.3, respectively).

B.2.1.1 Condenser Passage Experiments

Condenser passage experiments provide data on the effects of physical stresses on entrained organisms, although they do not allow distinguishing the effects of the various individual physical stresses.

Kerr (1953) passed 100 live young king salmon and striped bass through a condenser tube of PGandE's Contra Costa Power Plant operating at full load. Young salmon (34-61 mm in length) withstood condenser passage and an 8.9 C (16 F) temperature rise of 3-1/2 to 5 minutes with no fatalities after a 10-day observation period. Young striped bass (21-46 mm in length) suffered only 6 percent mortality after a 5-day observation period.

Coutant and Kedl (1975) passed young striped bass and larvae of five other species of fish through an experimental condenser tube designed to simulate the physical forces, such as pressure (reductions of one-half atmosphere from acclimation pressure), turbulence, and shear, associated with actual power plant condensers. Mortalities of

organisms passed through the condenser simulator at velocities of 7-19 fps (213-579 cm/sec) were no greater than mortalities of controls. When temperature stress was added (6-minute exposures), resulting mortality was comparable to that observed in laboratory thermal tolerance studies (6-minute exposures), indicating independence of physical and thermal stresses. The authors concluded that physical damage to larvae of most species due to passage through a typical power plant condenser tube is minimal (<5 percent mortality).

Another condenser simulator study was conducted at New York University (NYU 1979). The investigators concluded that "the mechanical effects of condenser tube passage alone had little or no effect on survival of striped bass yolk-sac larvae and larvae...." In addition, the study showed that "the combined effects of increased temperature, condenser tube passage, and biocide (chlorine) application was essentially additive for striped bass. . . ."

B.2.1.2 Changes in Hydrostatic Pressure

Changes in hydrostatic pressure within the cooling water system may stress entrained organisms. Pressure increases occur at the circulating water pumps, and pressure decreases occur across the condenser tubes. Increases and decreases are usually on the order of one atmosphere (14.7 psi) or less.

Sudden increases in pressure of up to 250 psi above atmospheric pressure for 15 minutes had no significant effect on the development and survival of eggs and larvae of striped bass (determined 24 hours after exposure) (NYU 1974a). Striped bass juveniles tolerated pressure increases of up to 495 psi above atmospheric pressure for 12 minutes (NYU 1975). Such pressure increases are far greater than those found in once-through cooling systems.

Results of NYU (1974a, 1975) studies indicated that striped bass eggs, larvae, and juveniles were more sensitive to decreases than increases in pressure. Sudden pressure drops, either from atmospheric pressure to subatmospheric pressure or from greater than atmospheric pressure to atmospheric pressure, often resulted in significantly lower survival of test organisms than of control organisms. Pressure decreases tested ranged from 8.7 to 30 psi. Survival of striped bass eggs and larvae was reduced by 0-13 percent after exposure to pressure decreases of up to 13 psi from atmospheric

pressure (survival measured 24 hours after exposure). Survival of juveniles was reduced by 71 percent after a 13 psi decrease from atmospheric pressure. Pressure decreases from 30 psi above atmospheric pressure back to atmospheric pressure reduced survival of striped bass larvae by 33-88 percent, but had no effect on juveniles.

The macroinvertebrates Gammarus spp. and Neomysis americana were also tested at NYU (1975), and were found to be tolerant of both decreases and increases in pressure. Neither taxon showed significantly reduced survival after exposure to a pressure decrease from an acclimation pressure of 44.7 psia to 1.5 psia for 15 seconds followed by a pressure increase to 35-510 psia for 12 minutes. Survival, measured 24 hours after exposure, was reduced by only 5-9 percent. Survival of Gammarus spp. exposed to a pressure decrease from 44.7 to 1.5 psia for 15 seconds was reduced by 2 percent.

The NYU (1974a, 1975) pressure studies indicate that pressure decreases are more likely than pressure increases to affect entrained organisms adversely. Pressure decreases in excess of one atmosphere (about 15 psi) may be expected to cause substantial entrainment mortality. Pressure decreases are less tolerable to organisms than increases because of a tendency for gas cavities, such as vacuoles or gas bladders, to explode and for dissolved gasses in blood or other body fluids to come out of solution, forming bubbles which can cause physical trauma (gas-bubble disease).

B.2.1.3 Velocity Shear Forces

Shear forces develop when spatial differences in velocity exist in a moving fluid. The greatest shear forces occur in close association with solid surfaces, such as pipe walls, pump impellers, traveling screens, and water boxes (Marcy et al. 1978). Shear stress has two major components, rotation and deformation.

The only known laboratory studies on the effects of shear stresses on early life stages of fish are those reported by Morgan (1974) and Morgan et al. (1973, 1976). Eggs and larvae of striped bass and white perch were exposed to velocity fields in a chamber formed by three concentric cylinders, the middle one of which was rotated to produce the experimental forces. According to Marcy et al. (1978), Morgan's data suggest that shear stress alone would be enough to cause up to 100 percent mortality of entrained eggs and larvae. Such conclusions are inconsistent with actual entrainment survival

data obtained at numerous power plants across the nation (Section B.3), and with the results of the condenser simulator studies (Section B.2.1.1). The results of a detailed analysis of Morgan's experiments by EA (1979a) indicate that the effect of velocity forces in these experiments cannot be related mathematically to average boundary shear, and that the experimental results cannot be extrapolated to other flow field situations such as those occurring in once-through cooling systems.

B.2.2 Thermal Stresses

Entrained organisms are subjected to a rapid rise in temperature as they pass through the condensers. The exposure duration to elevated temperatures is short, usually on the order of one to ten minutes, followed by a return to ambient temperature as the warmwater discharge is mixed with the waters of the receiving water body.

The thermal stresses experienced during cooling system passage, and subsequently in the discharge waters, depend upon the temperature rise above ambient (delta-T), the absolute value of the maximum temperature, and the duration of exposure. With brief exposures such as those typical of power plant passage, the maximum temperature and the maximum delta-T tolerated may be higher than those tolerated during extended exposures.

Specialized terminology used in the following sections is defined in this paragraph. A safe temperature is a temperature reported to cause no significant mortality upon exposure for a specified period of time. A TL50 is a temperature leading to mortality of 50 percent of the test organisms upon exposure for a specified period of time. A lethal temperature is a temperature reported to cause mortality of 100 percent of the test organisms upon exposure for a specified period of time. A threshold lethal temperature is a maximum safe temperature, above which significant mortality may be expected. Threshold lethal temperatures can be approximated by subtracting 2 C from TL50s (U.S. EPA 1976).

B.2.2.1 Fish Eggs

Investigations of short-term thermal tolerance have been made for the eggs of eight species of fish representing five families (Table B-1). All of these families are represented in San Francisco Bay or in the Sacramento and San Joaquin rivers.

TABLE B-1 SUMMARY OF SHORT-EXPOSURE THERMAL TOLERANCE DATA FOR FISH EGGS

Taxon: Common Name	Taxon: Family Species	Life Stage	Acclimation Temperature (C)	Exposure Duration (min)	Thermal Tolerance Limits: Safe	Thermal Tolerance Limits: TL50	Thermal Tolerance Limits: Lethal	Reference
	Clupeidae							
Alewife	*Alosa pseudoharengus*	Blastula	12-13	30		26-27		EA 1978b
		Tail-bud embryo	12-13	30		32-33		EA 1978b
		Tail-free embryo	12-13	30		32-34		EA 1978b
		4-8 cell	12	(a)	19[b]			Schubel 1974
		Early blastula	13	(a)	23[b]			Schubel 1974
		Late gastrula	13-14	(a)	23-24[b]			Schubel 1974
		Late embryo	15	(a)	25[b]			Schubel 1974
Blueback herring	*Alosa aestivalis*	Late blastula/ Early gastrula	18	(a)	28[b]			Schubel 1974
		Early embryo	15-18	(a)	28[b]			Schubel 1974
		Late embryo	18	(a)	28[b]			Schubel 1974
		Early to late embryo	18-21	(a)	28-31[c][d]			Schubel and Koo 1976
American Shad	*Alosa sapidissima*	Late cleavage	17	variable	27[b]			Schubel 1974
		Early embryo	17	variable	27[b]			Schubel 1974
		Mid to late embryo	17	variable	27[b]			Schubel 1974
		Early to mid embryo	20-21	variable	30-31[c][d]			Schubel and Koo 1976
	Engraulidae							
Northern Anchovy	*Engraulis mordax*	Blastodisc	16	5		33		Brewer 1976
		Blastopore closure	16	5		36		Brewer 1976
		Blastodisc	16	60		30		Brewer 1976
		Blastopore closure	16	60		31		Brewer 1976
	Percichthyidae							
Striped Bass	*Morone saxatilis*	Gastrula	16-18	30		32		EA 1978b
		Tail-bud embryo	16	30		34		EA 1978b
		Tail-free embryo	19	30		35		EA 1978b
		Late embryo	17	30		35		EA 1978b
		Early to late embryo	15-18	(a)	25-28[b]			Schubel 1974
		Early to mid embryo	17-20	(a)	32-35[b]			Schubel and Koo 1976
White perch	*Morone americana*	Early gastrula to early embryo	14-15	(a)	25-25[b]			Schubel 1974
	Cyprinidae							
Carp	*Cyprinus carpio*	Egg (various stages)	25	10			40	Frank 1974
		Egg (various stages)	25	10	~35			Frank 1974
	Gadidae							
Atlantic tomcod	*Microgadus tomcod*	Tail-bud embryo	2-3	10-60		20-27		EA 1978b
		Eyed-up embryo	2-3	10-60		24-31		EA 1978b

(a) 4- to 60-minute exposure followed by gradual cooling to within 1 C of acclimation temperature.
(b) Highest temperature tested resulted in mortality not significantly different from control mortality.
(c) Temperature 5 C higher significantly increased mortality.
(d) In one experiment, a brief (<5 min) exposure to 29 C (8 C delta-T) resulted in increased mortality.

Safe temperatures reported for short exposures (5-60 minutes) of fish eggs range from 19 to 35 C (Table B-1). Most of the reported safe temperatures less than 30 C were the highest temperatures tested in the experiments. Consequently, threshold lethal temperatures are probably higher than the safe temperatures reported in these cases. This assertion is supported by the observation that threshold lethal temperatures computed by subtracting 2 C from the TL50s reported in Table B-1 exceed 30 C in the majority of the cases. Notable exceptions were alewife blastulae acclimated to 12-13 C, whose 30-minute TL50 was 26-27 C; northern anchovy blastulae acclimated to 16 C, whose 60-minute TL50 was 30-31 C; and Atlantic tomcod embryos acclimated to 2-3 C, whose 10- to 60-minute TL50s ranged from 20 to 31 C. All three of these species spawn in relatively cold water, especially Atlantic tomcod, a cold-water fish of the north Atlantic coast of North America that spawns in midwinter at temperatures below 5 C.

The data presented in Table B-1 support the general assertion that short exposures to elevated temperatures remaining below 30 C will not harm the eggs of most species of fish. The eggs of some species will tolerate short exposures to temperatures of up to 30 C, but few if any species can be expected to tolerate exposure to temperatures over 35 C.

B.2.2.2 Fish Larvae and Juveniles

Investigations of short-term thermal tolerance have also been made for larvae and juveniles of 20 species of fish (Table B-2). These species represent 13 families, 12 of which are represented in San Francisco Bay or the Sacramento and San Joaquin rivers.

Fish larvae and juveniles are capable of tolerating short exposures (5-60 minutes) to temperatures 10-20 C above ambient during most seasons and 7-10 C above the mid-summer maximum ambient temperatures. All of the reported safe temperatures less than 25 C were obtained in experiments in which acclimation temperatures were very low (0-10 C); at higher acclimation temperatures, the safe temperatures would probably be higher. Lethal threshold temperatures, computed by subtracting 2 C from the TL50s reported in Table B-2 for 14 species, ranged from 28 to 38 C, with one exception: the lethal threshold for the cold-water Atlantic tomcod was less than 28 C. However, Atlantic tomcod larvae were capable of tolerating temperature increases (delta-T) of up to 21 C over acclimation temperatures of 3-8 C.

TABLE B-2 SUMMARY OF SHORT-EXPOSURE THERMAL TOLERANCE DATA FOR FISH LARVAE

Common Name	Family Species	Life stage (size in mm)	Temperature (C)	Duration (min)	Limits Safe	Limits TL50	Limits Lethal	Reference
	Clupeidae							
Alewife	Alosa pseudoharengus	Yolk-sac larva	14-24	10-60		32-37		EA 1978b
		Larva	22	30		31		EA 1978b
Blueback herring	Alosa aestivalis	Juvenile (34)	25	60		34		EA 1978b
		Yolk-sac larva	20-21	(a)			27-41(b)	Schubel et al. 1977
American shad	Alosa sapidissima	Juvenile (66)	24	60		33		EA 1978b
		Yolk-sac larva	21	(a)			28-41(b)	Schubel et al. 1977
Atlantic menhaden	Brevoortia tyrannus	Larva	10-15	0-40	22-25			Hoss et al. 1974
	Engraulidae							
Northern anchovy	Engraulis mordax	Yolk-sac larva	16	5		37		Brewer 1976
		Yolk-sac larva	16	60		32		Brewer 1976
Bay anchovy	Anchoa mitchilli	Juvenile (45)	24	60		33		EA 1978b
	Cyprinidae							
Goldfish	Carassius auratus	Yolk-sac larva	20	10-30		38-39		EA 1978b
		Larva	23	10-30		37-38		EA 1978b
Spottail shiner	Notropis hudsonius	Early juvenile (13-36)	23-26	5-30		36-38		EA 1978b
		Juvenile (20-65)	9-26	60		31-36		EA 1978b
	Ictaluridae							
White catfish	Ictalurus catus	Larva	25	10-30		36-37		EA 1978b
		Early juvenile	24-25	10-60		36-38		EA 1978b
		Juvenile (73-77)	8-17	60		31		EA 1978b
Brown bullhead	Ictalurus nebulosus	Larva	25	10-60		36-38		EA 1978b
		Early juvenile	26	10-30		36-38		EA 1978b
		Juvenile (44)	24	60		36		EA 1978b
	Gadidae							
Atlantic tomcod	Microgadus tomcod	Yolk-sac larva	2-5	10-60		25-27		EA 1978b
		Larva	3-8	10-60		23-28		EA 1978b
	Cyprinodontidae							
Striped killifish	Fundulus majalis	Juvenile	22	10		39-40		Hoss et al. 1971
	Atherinidae							
Atlantic silverside	Menidia menidia	Larva	17-20	13	31-34			Austin et al. 1975

(a) 4- to 60-minute exposure followed by gradual cooling to within 1 C of acclimation temperature.
(b) Results inconsistent; in some cases exposures to up to 36 C caused no significant increase in mortality.
(c) 0.1- to 6-minute exposure followed by gradual cooling to acclimation temperature.
(d) In one case, winter flounder larvae acclimated to 3 C and exposed to 17 C for 13 minutes incurred mortality significantly different from controls.

TABLE B-2 (CONT.)

Taxon: Common Name	Taxon: Family / Species	Life stage (size in mm)	Acclimation Temperature (C)	Exposure Duration (min)	Thermal Tolerance Limits: Safe	Thermal Tolerance Limits: TL50	Thermal Tolerance Limits: Lethal	Reference
	Percichthyidae							
Striped bass	*Morone saxatilis*	Yolk-sac larva	15-19	10-30		32-36		EA 1978b
		Larva	20-24	10-60		33-36		EA 1978b
		Early juvenile	18-24	10-60		32-37		EA 1978b
		Yolk-sac larva	19-21	(a)	29[b]			Schubel et al. 1977
		Larva (5-13)	17-21	(c)	~32			Kelly and Chadwick 1971
		Early juvenile (20-38)	16-22	(c)	~32			Kelly and Chadwick 1971
		Larva	22	30	29			Coutant and Kedl 1975
White Perch	*Morone americana*	Yolk-sac larva	15-22	10-60		31-38		EA 1978b
		Early juvenile	27	10-30		37		EA 1978b
	Percidae							
Yellow perch	*Perca flavescens*	Yolk-sac larva	15	10-30		30-32		EA 1978b
		Larva	15	10-30		32-35		EA 1978b
	Sparidae							
Pinfish	*Lagodon rhomboides*	Larva	15-20	0-40	27-32			Hoss et al. 1974
		Larva	5-10	0-40	20-25			Hoss et al. 1974
	Sciaenidae							
Spot	*Leiostomus xanthurus*	Larva	5-15	0-40	17-27			Hoss et al. 1974
	Pleuronectidae							
Winter flounder	*Pseudopleuronectes americanus*	Larva	0-12	13	14-28[d]			Valenti 1974 cited in Schubel et al. 1978
	Bothidae							
Gulf, Summer, Southern	*Paralichthys* spp.	Larva	5-10	0-40	23-28			Hoss et al. 1974
		Larva	15	0-40	30			Hoss et al. 1974

The data presented in Table B-2 support the assertion that, in general, larvae and juveniles of most fish species are not harmed by short exposures to elevated temperatures remaining below 30 C. Threshold lethal temperatures for larvae and juveniles acclimated to temperatures above 10 C exceed 30 C in most cases, although temperatures above 35 C are likely to be lethal to most species.

B.2.2.3 Macroinvertebrates

The short-term thermal tolerances of 13 species of macroinvertebrates have been investigated (Table B-3). Most of the species examined are similar to or closely related to species found in San Francisco Bay or the Sacramento and San Joaquin rivers. At least two of the species, *Neomysis mercedis* (= *N. awatschensis*) and *Rhithropanopeus harrisii*, are common in the San Francisco Bay system.

Safe temperatures reported for short exposures (5-60 minutes) of macroinvertebrates range from 10 to 39 C (Table B-3). Every safe temperature reported as less than 26 C was the highest temperature tested (at a given acclimation temperature). As noted for fish eggs (Section B.2.2.1), threshold lethal temperatures are probably higher than the reported safe temperatures in these cases. Again, this assertion is supported by the observation that threshold lethal temperatures, computed by subtracting 2 C from the TL50s reported in Table B-3, exceed 30 C in most cases.

The more thermally sensitive species tested include the mysid shrimps *Neomysis mercedis* and *N. americana* and the true shrimp *Crangon septemspinosa*. Lethal thresholds for these species range from approximately 28 to 32 C, depending on duration of exposure and acclimation temperature. *Neomysis mercedis* appears to be the most sensitive of the three species: when acclimated to 17-21 C it will not tolerate 10-minute exposures to temperatures in excess of 28-29 C (EA unpublished data).

The data presented in Table B-3 support the assertion that many macroinvertebrates can tolerate short exposure to elevated temperatures in excess of 30 C, while some, such as *N. mercedis*, cannot tolerate elevated temperatures in excess of approximately 28-29 C. In general, lethal threshold temperatures for macroinvertebrates are higher than those for fish eggs and larvae.

TABLE B-3 SUMMARY OF SHORT-EXPOSURE THERMAL TOLERANCE DATA FOR MACROINVERTEBRATES

Group/Species	Acclimation Temperature (C)	Exposure Duration (min)	Thermal Tolerance Limits			Reference
			Safe	TL50	Lethal	
Amphipoda (amphipods)						
Gammarus spp.	3	30		28		Lauer et al. 1974
	11	5-60		30-33		Lauer et al. 1974
	20	5-60		34-36		Lauer et al. 1974
	26	5-60		37-39		Lauer et al. 1974
Gammarus spp.	26	5-60	34			Ginn et al. 1976
	27	5	38			Ginn et al. 1976
Gammarus spp.	5-25	4[a]	10-30			Burton et al. 1976
Gammarus limnaeus	1-3	60	26			Krog 1954
	15-22	60	30-32			Krog 1954
Gammarus tigrinis	25	5-60	33-35			Krog 1954
Gammarus daiberi	25	5-60	33-35			Krog 1954
Gammarus spp.	25	10-60		35-39		EA 1978b
Monoculodes edwardsi	26	5-30		36-37		Lauer et al. 1974
Mysidacea (opossum shrimp)						
Neomysis americana	24-26	5-30		33-34		Lauer et al. 1974
Neomysis americana	24	10-30		31-34		EA 1978b

(a) Constant temperature exposure was followed by gradual cooling to acclimation temperature over 16 minutes.
(b) Reproduction (release of young) was inhibited at temperatures above 28 C.
(c) Some exposures to temperatures greater than the reported safe level were tolerated.
(d) Highest temperature tested resulted in no mortality.

TABLE B-3 (CONT.)

Group Species	Acclimation Temperature (C)	Exposure Duration (min)	Thermal Tolerance Limits			Reference
			Safe	TL50	Lethal	
Neomysis americana	5	4[a]	10[d]			Burton et al. 1976
Neomysis awatschensis	14-22	2-6[a]	30-31[b]			Hair 1971
Neomysis mercedis	17-21	10		30-31		EA (unpublished data)
Caridea (shrimps)						
Crangon septemspinosa	16-24	10-60		31-33		EA 1978b
Palaemonetes spp.	5-30	4[a]	10-35[d]			Burton et. al 1976
Brachyura (crabs)						
Callinectes sapidus	15-30	4[a]	20-35[d]			Burton et al. 1976
Rhithropanopeus harrisii	15-30	4[a]	20-35[d]			Burton et al. 1976
Insecta (insects)						
Hydropsyche sp. (caddisfly)	7-24	1-30	28[c]			Sherberger et al. 1977
Isonychia sp. (mayfly)	4-24	1-40	27[c]			Sherberger et al. 1977
Chaoborus sp. (midge)	25	30	39			NYU 1974b
Chaoborus sp. (midge)	19-26	10-60		39-43		EA 1978b

B.2.3 Chemical (Biocidal) Stresses

Entrained organisms may be exposed to chlorine when it is intermittently injected into the cooling water flow as a routine maintenance procedure to control fouling organisms. Average concentration at the condenser inlet is usually less than 0.5 mg/liter total residual chlorine. Organisms entrained during chlorination are exposed to chlorine for periods ranging from a few seconds to several minutes.

The effects on freshwater and marine organisms of short exposures to chlorine have been extensively reviewed (Brungs 1973; Mattice and Zittel 1976; Morgan and Carpenter 1978; Envirosphere Company 1978, 1979). Chlorine tolerance has been shown to vary widely among species of aquatic organisms. The extent of this variability has made it difficult to establish chlorine criteria to protect aquatic life.

Mattice and Zittel (1976) were the first to review the literature and organize the chlorine toxicity data to provide models for estimating exposure-dependent threshold lethal concentrations for the most sensitive marine and freshwater organisms.

Envirosphere Company (1978, 1979) subsequently refined and updated the Mattice and Zittel models. Using the Envirosphere Company models, the effects of specific power plant chlorine exposures can be predicted. For example, for an exposure of 5 minutes, the predicted threshold lethal concentration is 0.34 mg/liter total residual chlorine (TRC) for marine organisms and 0.99 mg/liter TRC for freshwater organisms. As exposure duration increases to 60 minutes, the predicted threshold lethal concentrations decrease to 0.14 mg/liter TRC for marine organisms and 0.25 mg/liter for freshwater organisms. If a specific chlorine exposure exceeds the lethal threshold, mortality of entrained organisms can be expected. The amount by which the exposure exceeds the lethal threshold will determine the extent of the resulting entrainment mortality.

B.3 REVIEW OF FIELD STUDIES PERTINENT TO ENTRAINMENT SURVIVAL

Discussed in this section are pertinent results of entrainment survival studies conducted at PGandE power plants and at plants outside of the PGandE system. These studies share a common experimental design. Cooling water samples are withdrawn from the discharge of a power plant and from a suitable control area, usually the

plant intake. The control samples account for sampling mortality and any other mortality unrelated to entrainment. Numbers of live and dead organisms in discharge and control samples are determined immediately. Live organisms may be held for up to 96 hours to allow detection of possible delayed entrainment effects. Entrainment mortality is estimated by comparing the proportions dead in the discharge and control samples, initially or at the end of the delayed-effects observation period.

Two methods of comparing the proportions dead in the discharge and control samples have evolved. By the first method, entrainment mortality is computed by subtracting the control proportion dead from the discharge proportion dead. This method results in the underestimation of entrainment mortality, especially when control mortality is high. By the second method, entrainment mortality is computed as follows:

$$\hat{p}_e = \frac{\hat{p}_D - \hat{p}_I}{1 - \hat{p}_I} \qquad \text{(B-1)}$$

where

$\hat{p}_e$ = proportion not surviving entrainment
$\hat{p}_D$ = proportion dead in discharge
$\hat{p}_I$ = proportion dead in intake.

The second method provides more accurate estimates of entrainment mortality (or survival) than the first, because entrainment mortality is not underestimated when control mortality is high.

Entrainment survival, the opposite of mortality, is computed as

$$\hat{p}_S = 1 - \hat{p}_e \qquad \text{(B-2)}$$

where

$\hat{p}_S$ = proportion surviving entrainment.

In the following review of entrainment survival studies involving ichthyoplankton and macroinvertebrates, any entrainment survival estimates originally computed using the

first method have been recomputed using the second method. This was done so that all survival estimates could be compared on a common basis.

To further facilitate comparison of studies, entrainment survival estimates presented are based on discharge temperatures less than 30 C whenever possible. Thermal stress was thereby excluded as a factor affecting the estimates, and the estimates largely represent survival of physical stresses alone.

B.3.1 Entrainment Survival Studies at PGandE Plants

Entrainment survival studies were conducted during 1978 and 1979 at the Potrero, Pittsburg, and Contra Costa power plants. The Potrero Power Plant study focused on Pacific herring larvae (PGandE 1980c). The Pittsburg and Contra Costa power plant studies focused on striped bass larvae, gammaridean amphipods, and *Neomysis mercedis* (PGandE 1980a, b).

All of the 1978-1979 PGandE studies shared the common experimental design discussed at the beginning of this section: control samples were collected from the plant intakes; both control and discharge samples were collected using high-capacity pumps; and live fish larvae were held for 96 hours to allow detection of any delayed effects of entrainment.

At the Potrero Power Plant, control sample mortality of Pacific herring larvae decreased with increasing body length. However, entrainment survival did not vary with body length, so a single estimate of the proportion surviving entrainment was computed. That estimate was 0.79 (i.e., 79 percent survival). Ninety-five percent confidence limits on the true proportion surviving were 0.63 and 0.95. No delayed effects of entrainment were detected. Survival of larvae collected from the intake and discharge did not differ significantly over the 96-hour observation period. Discharge temperatures during the study did not exceed 20 C.

Results of the 1978-1979 entrainment survival studies at the Pittsburg and Contra Costa power plants indicate that at discharge temperatures below 30 C, survival is high (Table B-4). Survival of striped bass larvae and juveniles at temperatures less than 30 C ranged from 60 to 81 percent at Pittsburg Power Plant Units 1-4 and 5-6 and at Contra Costa Power Plant Units 1-5 and 6-7. Survival of the opossum shrimp

TABLE B-4 ENTRAINMENT MORTALITY ESTIMATES FOR STRIPED BASS LARVAE, *NEOMYSIS MERCEDIS*, AND GAMMARIDEAN AMPHIPODS AT THE PITTSBURG AND CONTRA COSTA POWER PLANTS

Taxon	Discharge Temperature (C)	Mortality (%)			
		Pittsburg		Contra Costa	
		Units 1-4	Units 5-6	Units 1-5	Units 6-7
Striped bass	<30	38	40	19	21
	30-31.9	69	57	65	58
	32-33.9	100[a]	77	79	75
	≥34	100[a]	--	95	95
Neomysis mercedis	<30	--	10	--	28
	30-31.9	--	72	--	54
	32-33.9	--	100	--	100
	≥34	--	100	--	100
Gammaridean amphipods	<30	--	4	--	5
	30-31.9	--	0	--	12
	32-33.9	--	59	--	21
	≥34	--	79	--	84

(a) Low sample size--estimates imprecise.

Note: (--) indicates no data available.

Neomysis mercedis ranged from 72 to 90 percent, and that of gammaridean amphipods ranged from 95 to 96 percent (Table B-4). Survival of all taxa decreased at higher discharge temperatures. N. mercedis appeared to be the most sensitive of the three taxa to elevated temperatures.

Stevens and Finlayson (1978) studied entrainment survival of striped bass larvae at the Pittsburg and Contra Costa power plants in 1976, and estimated survival to be 86 percent when discharge temperatures remained at or below 31 C. The high survival observed by Stevens and Finlayson (1978) is consistent with that observed by Ecological Analysts.

The above studies indicate that at low discharge temperatures (< 30 C) entrainment survival at the PGandE power plants investigated is high (60-96 percent). Survival has been estimated to be high even for Pacific herring, a delicate clupeid species. Clupeids have been shown to be among the taxa most sensitive to entrainment stresses (see Section B.3.2.1). Consequently, the survival of the species not tested is likely to be as high as or higher than that of Pacific herring.

B.3.2 Entrainment Survival at Plants Outside the PGandE System

Entrainment survival studies have been conducted at a variety of freshwater, estuarine, and marine power plants across the United States. EA (1979a) critically reviewed and summarized survival studies dealing with ichthyoplankton. The results of that review are presented here along with a summary of survival studies dealing with macroinvertebrates.

B.3.2.1 Ichthyoplankton

Ichthyoplankton entrainment survival studies conducted with 21 taxa at 11 different power plants, six on freshwater systems, three on brackish-water systems, and two on marine (saltwater) systems are summarized in Table B-5. The entrainment survival estimates in Table B-5 represent, for the most part, survival of physical entrainment stresses. As indicated in the table, in some cases it was not possible to distinguish whether or not thermal stresses were present. The entrainment survival estimates in Table B-5 pertain to fish larvae and juveniles only; no survival data pertaining to fish eggs are available.

TABLE B-5 ICHTHYOPLANKTON ENTRAINMENT SURVIVAL ESTIMATES FOR POWER PLANTS OUTSIDE OF THE PGandE SYSTEM

Power Plant	Water Body	Salinity	Taxon: Common Name	Taxon: Family Species	Life Stage (Length [mm])	Survival (%)[a]	Reference
Connecticut Yankee	Connecticut River	Fresh	Herrings	Clupeidae	(<15) (>20)	29 13	Marcy 1976
Bowline Point	Hudson River	Brackish	Striped bass	*Morone saxatilis*	Larva Juvenile	88 90	EA 1978a
			White perch	*Morone americana*	Larva Juvenile	82 80	EA 1978a
			Herrings	Clupeidae	Larva	77	EA 1978a
			Atlantic tomcod	*Microgadus tomcod*	Yolk-sac larva Larva	92 54	EA 1978a
			Silversides	*Menidia* spp.	Larva	43[b]	EA 1978a
Roseton	Hudson River	Fresh	Striped bass	*Morone saxatilis*	Larva Juvenile	60 100	EA 1978g
			White perch	*Morone americana*	Larva	51	EA 1978g
			Herrings	Clupeidae	Larva	29	EA 1978g
			Atlantic tomcod	*Microgadus tomcod*	Yolk-sac larva	31[c]	EA 1978g
			Tessellated darter	*Etheostoma olmstedi*	Larva	98[b]	EA 1976b, 1978f
			Minnows	Cyprinidae	Larva	89	EA 1976b, 1978f
Lovett	Hudson River	Brackish	Striped bass	*Morone saxatilis*	Larva	75	EA 1978d
			White perch	*Morone americana*	Larva	74	EA 1977, 1978d
			Herrings	Clupeidae	Larva	57	EA 1978d

(a) Survival in absence of thermal effects. Values represent annual estimates, or means of annual estimates for those studies conducted for more than one year.
(b) Some thermal effects may be included.
(c) Represents weighted average of 22 percent for 2 circulating pumps operating and 77 percent for 3 circulating pumps operating.
(d) Survival recomputed using Equations B-1 and B-2 in text.

Source: EA 1979a.

TABLE B-5 (CONT.)

Power Plant	Water Body	Salinity	Taxon: Common Name	Taxon: Family Species	Life Stage (Length [mm])	Survival (%)[a]	Reference
Danskammer Point	Hudson River	Fresh	Striped bass	Morone saxatilis	Larva	95	EA 1976a
			White perch	Morone americana	Larva	100	EA 1976a
			Herring	Clupeidae	Larva	56	EA 1976a
			Minnows	Cyprinidae	Larva	52	EA 1976a
Indian Point	Hudson River	Brackish	Striped bass	Morone saxatilis	Yolk-sac larva Larva	63 85	EA 1978c
			White perch	Morone americana	Larva	77	EA 1978c
				Morone spp.	Larva	86[d]	Lauer et al. 1974
			Herrings	Clupeidae	Larva	40	EA 1978c
Port Jefferson	Long Island Sound	Salt	Winter flounder	Pseudopleuronectes americanus	Larva	100	EA 1978e
			Sand lances	Ammodytes spp.	Larva	27	EA 1978e
			American eel	Anguilla rostrata	Juvenile	100	EA 1978e
Brunswick	Cape Fear Estuary	Salt	Bay anchovy	Anchoa mitchilli	--	27[b][d]	Copeland et al. 1975
			Spot	Leiostomus xanthurus	--	75[b][d]	Copeland et al. 1975
			Atlantic croaker	Micropogon undulatus	--	64[b][d]	Copeland et al. 1975
			Gobies	Gobionellus spp.	--	60[b][d]	Copeland et al. 1975
			Gobies	Gobiosoma spp.	--	35[b][d]	Copeland et al. 1975
			Silversides	Atherinidae	--	27[b][d]	Copeland et al. 1975
Quad Cities	Mississippi River	Fresh	Freshwater drum	Aplodinotus grunniens	Yolk-sac larva to juvenile	62	Restaino et al. 1978
			Minnows	Cyprinidae	Yolk-sac larva to juvenile	51	Restaino et al. 1978
			Carp	Cyprinus carpio	Larva	79	Restaino et al. 1978
			Suckers	Catostomidae	Larva	60	Restaino et al. 1978
Monticello	Mississippi River	Fresh	Fathead minnow	Pimephales promelas	(36-60)	78	Knutson et al. 1976
Ginna	Lake Ontario	Fresh	Alewife	Alosa pseudoharengus	(<15)	23	EA 1979b

The entrainment survival estimates in Table B-5 range from a low value of 13 percent estimated for clupeids (>20 mm) entrained at the Connecticut Yankee Power Plant (Marcy 1976) to a high of 100 percent for striped bass juveniles at Roseton Power Plant (EA 1978g), white perch larvae at Danskammer Point Power Plant (EA 1976a), and winter flounder larvae and American eel juveniles at Port Jefferson Power Plant (EA 1978e). Nearly three-quarters of the survival estimates in Table B-5 exceed 50 percent.

Table B-6 summarizes entrainment survival data by taxonomic category. Of the 13 families represented in this listing, Clupeidae*, Engraulidae, Atherinidae, and Ammodytidae appear relatively sensitive to entrainment (23-43 percent survival). Entrainment survival estimates for the Gadidae, Gobiidae, and Catostomidae were intermediate (35-60 percent), and those for Anguillidae, Cyprinidae, Percichthyidae, Percidae, Sciaenidae, and Pleuronectidae were high (62-100 percent).

The results of field studies of entrainment survival reported in Tables B-5 and B-6 demonstrate that entrainment survival under certain plant operating conditions for hardy species may be as high as 100 percent. Survival has been shown to vary widely among species.

B.3.2.2 Macroinvertebrates

Macroinvertebrate entrainment survival studies conducted with 10 taxa at six different power plants, three on freshwater systems and three on brackish water systems, are summarized in Table B-7. The entrainment survival estimates presented in Table B-7 represent, for the most part, survival of physical entrainment stresses, although, as noted in the table, in some cases thermal effects may have been included.

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* Clupeids entrained in a freshwater environment appear to be more vulnerable to entrainment damage than those in brackish water. The median clupeid survivals at fresh- and brackish-water sites were 26 and 52 percent, respectively. The range of survival values was 21-56 percent at freshwater sites and 40-77 percent at brackish-water sites.

TABLE B-6 TAXONOMIC SUMMARY OF ICHTHYOPLANKTON ENTRAINMENT SURVIVAL ESTIMATES FOR POWER PLANTS OUTSIDE OF THE PGandE SYSTEM

Taxon				Survival[b]	
Order	Common Name	Family Species	N[a]	Median	Range
Anguilliformes	Freshwater eels	Anguillidae	1	100	---
	American eel	*Anguilla rostrata*	1	100	---
Clupeiformes	Herrings	Clupeidae	7	40	21-77
	Alewife	*Alosa pseudoharengus*	1	23	---
	Anchovies	Engraulidae	1	27	---
	Bay anchovy	*Anchoa mitchilli*	1	27	---
Cyprinidontiformes	Silversides	Atherinidae	2	35	27-43
		Menidia spp.	1	43	---
Cypriniformes	Minnows	Cyprinidae	4	78	51-89
	Fathead minnow	*Pimephales promelas*	1	78	---
	Carp	*Cyprinus carpio*	1	78	---
	Suckers	Catostomidae	1	60	---
Gadiformes	Codfishes	Gadidae	2	52	31-73
	Atlantic tomcod	*Microgadus tomcod*	2	52	31-73

(a) Number of power plants for which estimates have been made.
(b) Average of all life stages.

Source: EA 1979a.

TABLE B-6 (CONT.)

Taxon				Survival[b]	
Order	Common Name	Family Species	N[a]	Median	Range
Perciformes	Sand lances	Ammodytidae	1	27	---
		Ammodytes spp.	1	27	---
	Gobies	Gobiidae	1	48	35-60
		Gobionellus spp.	1	60	---
		Gobiosoma spp.	1	35	---
	Temperate basses	Percichthyidae	5	82	51-100
	White perch	*Morone americana*	5	77	51-100
	Striped bass	*Morone saxatilis*	5	80	74-95
		Morone spp.	1	86	---
Perciformes	Perches	Percidae	1	98	---
	Tessellated darter	*Etheostoma olmstedi*	1	98	---
	Drums	Sciaenidae	2	64	62-75
	Freshwater drum	*Aplodinotus grunniens*	1	62	---
	Spot	*Leiostomus xanthurus*	1	75	---
	Atlantic croaker	*Micropogon undulatus*	1	64	---
Pleuronectiformes	Flounders	Pleuronectidae	1	100	---
	Winter flounder	*Pseudopleuronectes americanus*	1	100	---

TABLE B-7 MACROINVERTEBRATE ENTRAINMENT SURVIVAL ESTIMATES FOR POWER PLANTS OUTSIDE OF THE PGandE SYSTEM

Power Plant	Water Body	Salinity	Taxon	Survival[a] (%)	Reference
Fort Calhoun	Missouri River	Fresh	Total drifting macroinvertebrates	88[b][c]	Carter 1978
			Ephemeroptera	92[b][c]	Carter 1978
			Hydropsychidae	92[b][c]	Carter 1978
			Other Trichoptera	92[b][c]	Carter 1978
			Chironomidae	84[b][c]	Carter 1978
			Other Diptera	87[b][c]	Carter 1978
			Other organisms	88[b][c]	Carter 1978
Roseton	Hudson River	Fresh	*Gammarus daiberi*	96	Cannon et al. 1978
			Chaoborus punctipennis	96	Cannon et al. 1978
Bowline Point	Hudson River	Brackish	*Gammarus daiberi*	100	Cannon et al. 1978
			Monoculodes edwardsi	92	Cannon et al. 1978
			Chaoborus punctipennis	98[c]	Cannon et al. 1978
			Neomysis americana	94	Cannon et al. 1978
Danskammer Point	Hudson River	Fresh	*Gammarus daiberi*	88	Cannon et al. 1978
			Chaoborus punctipennis	100	Cannon et al. 1978
Lovett	Hudson River	Brackish	*Gammarus daiberi*	96	Cannon et al. 1978
			Monoculodes edwardsi	73	Cannon et al. 1978
			Chaoborus punctipennis	99	Cannon et al. 1978
			Neomysis americana	100	Cannon et al. 1978
Indian Point	Hudson River	Brackish	*Gammarus* spp.	99[b]	Lauer et al. 1974
			Monoculodes edwardsi	98[b]	Lauer et al. 1974
			Neomysis americana	92[b]	Lauer et al. 1974

(a) Survival in absence of thermal effects. Values represent annual estimates, or means of annual estimates for those studies conducted for more than one year.
(b) Entrainment survival recomputed using Equations B-1 and B-2 in text.
(c) Some thermal effects may be included.

Entrainment survival estimates presented in Table B-7 range from 73 percent for Monoculodes edwardsi entrained at Lovett Power Plant to 100 percent for Gammarus daiberi entrained at Bowline Point, Neomysis americana entrained at Lovett, and Chaoborus punctipennis entrained at Danskammer Point, three plants located on the Hudson River. Almost three-quarters of the survival estimates reported exceed 90 percent. These data indicate that entrainment survival is high for a variety of macroinvertebrates, and is generally higher than that of larval fish (Section B.3.3.1).

B.4 SUMMARY AND CONCLUSIONS

Entrainment survival is influenced by physical, thermal, and chemical (biocidal) stresses potentially incurred by entrained organisms during cooling water system passage. The effects of some of these different stresses have been isolated in laboratory studies.

Entrained organisms appear to be tolerant of the physical stresses associated with condenser passage. Pressure increases at the circulating water pumps are not expected to cause significant entrainment mortality, but large pressure decreases (greater than about one atmosphere) across the condensers may damage entrained organisms.

Discharge temperatures greater than 30 C generally reduce entrainment survival, although thermal tolerance varies widely among species, and among life stages within species. Some species acclimated to temperatures of 26 C or less are capable of tolerating short exposures (5-60 minutes) to elevated temperatures as high as 40 C.

Entrainment survival may be reduced during condenser chlorination. Studies have shown that the maximum chlorine concentration tolerated by a given species or life stage is a function of the exposure duration. The maximum concentrations tolerated by the most sensitive marine and freshwater species are 0.34 and 0.99 mg/liter total residual chlorine (TRC) respectively, when exposure duration is five minutes. But as exposure duration increases to 60 minutes, the maximum concentrations tolerated by the most sensitive marine and freshwater organisms decrease to 0.14 and 0.25 mg/liter TRC, respectively. Chlorine tolerance varies widely among species, and therefore the concentrations tolerated by many species exceed the levels reported for the most sensitive species.

Field studies of entrainment survival demonstrate that entrainment survival of hardy species under certain plant operating conditions may be as high as 100 percent. Survival has been shown to vary widely among species. The families of fish whose larvae are most sensitive include Clupeidae, Engraulidae, Atherinidae, and Ammodytidae. Survival of entrained macroinvertebrates is as high as or higher than that of fish larvae. No data are available on survival of entrained fish eggs.

Entrainment survival of fish larvae and macroinvertebrates at PGandE power plants has been shown to be high when discharge temperatures remain below 30 C. Survival of striped bass larvae at the Pittsburg and Contra Costa power plants ranged from 60 to 81 percent. Survival of the opossum shrimp Neomysis mercedis ranged from 72 to 90 percent and that of gammaridean amphipods from 95 to 96 percent. Survival of Pacific herring, a sensitive clupeid species, averaged 79 percent at the Potrero Power Plant, considerably higher than values observed for clupeids at plants outside the PGandE system.

B.5 REFERENCES

Austin, H. M., A. D. Sosnow, and C. R. Hickey, Jr. 1975. The effects of temperature on the development and survival of the eggs and larvae of the Atlantic silverside, Menidia menidia. Trans. Am. Fish. Soc. 104(4):762-765.

Brewer, G. D. 1976. Thermal tolerance and resistance of the northern anchovy, Engraulis mordax. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 74(2):433-445.

Brungs, W. A. 1973. Effects of residual chlorine on aquatic life. J. Water Pollut. Control Fed. 45(10):2180-2193.

Burton, D. T., L. B. Richardson, S. L. Margrey, and P. R. Abell. 1976. Effects of low delta-T power plant temperatures on estuarine invertebrates. J. Water Pollut. Control Fed. 48(10):2259-2272.

Cannon, T. C., S. M. Jinks, L. R. King, and G. J. Lauer. 1978. Survival of entrained ichthyoplankton and macroinvertebrates at Hudson River power plants, in Fourth National Workshop on Entrainment and Impingement (L. D. Jensen, ed.), pp. 71-89. Ecological Analysts, Melville, N.Y.

Carpenter, E. J., S. J. Anderson, and B. B. Peck. 1974. Copepod and chlorophyll a concentrations in receiving waters of a nuclear power station and problems associated with their measurement. Estuarine Coastal Mar. Sci. 2(1):83-88.

Carter, S. R. 1978. Macroinvertebrate entrainment study at Fort Calhoun Station, in Fourth National Workshop on Entrainment and Impingement (L. D. Jensen, ed.), pp. 155-169. Ecological Analysts, Melville, N.Y.

Copeland, B. J., R. G. Hodson, and W. S. Birkhead. 1975. Entrainment and entrainment mortality at the Brunswick Nuclear Power Plant, in Report on Entrainment and Entrainment Mortality of Zooplankton and Larvae, and Impingement and Movement of Fish, Part I, pp. 1-31. Prepared for Carolina Power and Light Company.

Coutant, C. C. and R. J. Kedl. 1975. Survival of larval striped bass exposed to fluid-induced and thermal stresses in a simulated condenser tube. Oak Ridge Natl. Lab., Environ. Sci. Div. Publ. 637. ORNL-TM-4695. Oak Ridge, Tenn. 34 pp.

Ecological Analysts, Inc. (EA). 1976a. Danskammer Point Generating Station impingement and entrainment survival studies. 1975 Annual report. Prepared for Central Hudson Gas & Electric Corporation. EA, Middletown, N.Y.

Ecological Analysts, Inc. (EA). 1976b. Roseton Generating Station impingement and entrainment survival studies. 1975 Annual report. Prepared for Central Hudson Gas & Electric Corporation. EA, Middletown, N.Y.

Ecological Analysts, Inc. (EA). 1977. Lovett Generating Station entrainment and impingement studies. 1976 Annual report. Prepared for Orange and Rockland Utilities, Inc. EA, Middletown, N.Y.

Ecological Analysts, Inc. (EA). 1978a. Bowline Point Generating Station entrainment survival studies. 1977 Annual interpretive report. Prepared for Orange and Rockland Utilities, Inc. EA, Middletown, N.Y.

Ecological Analysts, Inc. (EA). 1978b. Hudson River thermal effects studies for representative species. Final report. Prepared for Central Hudson Gas & Electric Corporation, Consolidated Edison Company of New York, Inc., and Orange and Rockland Utilities, Inc. EA, Middletown, N.Y.

Ecological Analysts, Inc. (EA). 1978c. Indian Point Generating Station entrainment survival and related studies. 1977 Annual report. Prepared for Consolidated Edison Company of New York, Inc. EA, Middletown, N.Y.

Ecological Analysts, Inc. (EA). 1978d. Lovett Generating Station entrainment survival studies. 1977 Annual report. Prepared for Orange and Rockland Utilities, Inc. EA, Middletown, N.Y.

Ecological Analysts, Inc. (EA). 1978e. Port Jefferson Generating Station entrainment survival study. Prepared for Long Island Lighting Company. EA, Melville, N.Y.

Ecological Analysts, Inc. (EA). 1978f. Roseton Generating Station entrainment survival studies. 1976 Annual report. Prepared for Central Hudson Gas & Electric Corporation. EA, Middletown, N.Y.

Ecological Analysts, Inc. (EA). 1978g. Roseton Generating Station entrainment survival studies. 1977 annual report. Prepared for Central Hudson Gas & Electric Corporation. EA, Middletown, N.Y.

Ecological Analysts, Inc. (EA). 1979a. An assessment of the potential for ichthyoplankton entrainment survival at the Muskingum River Plant. Prepared for American Electric Power Service Corp. EA, Middletown, N.Y.

Ecological Analysts, Inc. (EA). 1979b. Ichthyoplankton entrainment survival and abundance sampling study. Research and development of gear and methods. Prepared for Empire State Electric Energy Research Corporation. EA, Middletown, N.Y.

Envirosphere Company (EC). 1978. Chlorine toxicity in marine ecosystems: an evaluation of the Mattice and Zittel model for deriving toxicity thresholds and a proposed alternative. Prepared for Edison Electric Institute. EC, New York, N.Y.

Envirosphere Company (EC). 1979. Chlorine toxicity in freshwater ecosystems: an evaluation of the Mattice and Zittel model for deriving toxicity thresholds and a proposed alternative. Prepared for Edison Electric Institute. EC, New York, N.Y.

Frank, M. L. 1974. Relative sensitivity of different development stages of carp eggs to thermal shock, in Thermal ecology. Proceedings of a symposium held at Augusta, Georgia, May 3-5, 1973 (J. W. Gibbons and R. R. Sharitz, eds.), pp. 171-176. U.S. AEC Symp. Ser. CONF-730505. U.S. AEC, Tech. Inf. Center, Oak Ridge, Tenn.

Ginn, T. C., W. T. Waller, and G. J. Lauer. 1976. Survival and reproduction of Gammarus spp. (Amphipoda) following short-term exposure to elevated temperatures. Chesapeake Sci. 17(1):8-14.

Hair, J. R. 1971. Upper lethal temperature and thermal shock tolerances of the opossum shrimp, Neomysis awatschensis, from the Sacramento-San Joaquin Estuary, California. Calif. Fish Game 57(1):17-27.

Hoss, D. E., L. C. Coston, and W. F. Hettler, Jr. 1971. Effects of increased temperature on postlarval and juvenile estuarine fish. Proc. Annu. Conf. Southeast Assoc. Game Fish Comm. 25:635-642.

Hoss, D. E., W. F. Hettler, Jr., and L. C. Coston. 1974. Effects of thermal shock on larval estuarine fish - ecological implications with respect to entrainment in power plant cooling systems, in The early life history of fish (J. H. S. Blaxter, ed.), pp. 357-371. Springer-Verlag, New York, N.Y.

Kelly, R. and H. K. Chadwick. 1971. Some observations on striped bass temperature tolerance. Calif. Dep. Fish Game, Anad. Fish. Branch Admin. Rep. 71-9. 11 pp.

Kerr, J. E. 1953. Studies on fish preservation at the Contra Costa Steam Plant of the Pacific Gas and Electric Company. Calif. Dep. Fish Game, Fish Bull. 92. 66 pp.

Knutson, K. M., S. R. Berguson, D. L. Rastetter, M. W. Mischuk, F. B. May, and G. M. Kuhl. 1976. Seasonal pumped entrainment of fish at the Monticello, Mn. nuclear power installation. St. Cloud State Univ., Dep. Biol. Sci., St. Cloud, Minn. 38 pp.

Krog, J. 1954. The influence of seasonal environmental changes upon the metabolism, lethal temperature and rate of heart beat of Gammarus limnaeus (Smith) taken from an Alaskan lake. Biol. Bull. 107(3):397-410.

Lauer, G. J., W. T. Waller, D. W. Bath, W. Meeks, R. Heffner, T. Ginn, L. Zubarik, P. Bibko, and P. C. Storm. 1974. Entrainment studies on Hudson River organisms, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 37-82. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Marcy, B. C., Jr. 1971. Survival of young fish in the discharge canal of a nuclear power plant. J. Fish. Res. Board Can. 28(7):1057-1060.

Marcy, B. C., Jr. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. J. Fish. Res. Board Can. 30(8):1195-1203.

Marcy, B. C., Jr. 1976. Planktonic fish eggs and larvae of the lower Connecticut River and the effects of the Connecticut Yankee Plant including entrainment, in The Connecticut River ecological study: the impact of a nuclear power plant (D. Merriman and L. M. Thorpe, eds.), pp. 115-139. Am. Fish. Soc. Monogr. 1.

Marcy, B. C., Jr., A. D. Beck, and R. E. Ulanowicz. 1978. Effects and impacts of physical stress on entrained organisms, in Power plant entrainment: a biological assessment (J. R. Schubel and B. C. Marcy, Jr., eds.), pp. 135-188. Academic Press, New York, N.Y.

Mattice, J. S. and H. E. Zittel. 1976. Site-specific evaluation of power plant chlorination. J. Water Pollut. Control Fed. 48(10):2284-2308.

Morgan, R. P. 1974. Testimony before Federal Power Commission, October 1974, Project No. 2338 (Cornwall), pp. 4735-4816.

Morgan, R. P., II and E. J. Carpenter. 1978. Biocides, in Power plant entrainment: a biological assessment (J. R. Schubel and B. C. Marcy, Jr., eds.), pp. 95-134. Academic Press, New York, N.Y.

Morgan, R. P., II, R. E. Ulanowicz, V. J. Rasin, Jr., L. A. Noe, and G. B. Gray. 1973. Effects of water movement on eggs and larvae of striped bass and white perch. Appendix 12 of Hydrographic and ecological effects of enlargement of the Chesapeake and Delaware Canal. NRI 73-111. 28 pp.

Morgan, R. P., II, R. E. Ulanowicz, V. J. Rasin, Jr., L. A. Noe, and G. B. Gray. 1976. Effects of shear on eggs and larvae of striped bass, Morone saxatilis, and white perch, M. americana. Trans. Am. Fish. Soc. 105(1):149-154.

New York University Medical Center (NYU). 1974a. The effects of changes in hydrostatic pressure on some Hudson River biota. Progress report for 1974. Prepared for Consolidated Edison Company of New York, Inc. NYU, New York, N.Y.

New York University Medical Center (NYU). 1974b. Hudson River ecosystem studies. Effects of entrainment by the Indian Point Power Plant on biota in the Hudson River Estuary. Progress report for 1973. Prepared for Consolidated Edison Company of New York, Inc. NYU, New York, N.Y.

New York University Medical Center (NYU). 1975. The effects of changes in hydrostatic pressure on some Hudson River biota. Progress report for 1975. Prepared for Consolidated Edison Company of New York, Inc. NYU, New York, N.Y.

New York University Medical Center (NYU). 1979. Power plant entrainment simulation utilizing a condenser tube simulator; results of experimental exposure of striped bass early life history stages, Gammarus spp. and Neomysis americana to variations in temperature, flow rate and biocide concentrations. Prepared for N.Y.S. Energy Research and Development Authority. NYU, New York, N.Y.

Pacific Gas and Electric Company (PGandE). 1980a. Contra Costa Power Plant cooling water intake structures 316(b) demonstration. Prepared by Ecological Analysts, Inc. PGandE, San Francisco. (in press)

Pacific Gas and Electric Company (PGandE). 1980b. Pittsburg Power Plant cooling water intake structures 316(b) demonstration. Prepared by Ecological Analysts, Inc. PGandE, San Francisco. (in press)

Pacific Gas and Electric Company (PGandE). 1980c. Portrero Power Plant cooling water intake structures 316(b) demonstration. Prepared by Ecological Analysts, Inc. PGandE, San Francisco.

Restaino, A. L., P. S. Bartholomew, and M. J. McGrath. 1978. The survival of entrained ichthyoplankton at Quad-Cities Station, 1978. Prepared for Commonwealth Edison Company. Hazleton Environmental Sciences Corporation, Northbrook, Ill.

Schubel, J. R. 1974. Effects of exposure to time-excess temperature histories typically experienced at power plants on the hatching success of fish eggs. Estuarine Coastal Mar. Sci. 2(2):105-116.

Schubel, J. R. and T. S. Y. Koo. 1976. Effects of various time-excess temperature histories on hatching success of blueback herring, American shad, and striped bass eggs, in Thermal ecology II. Proceedings of a symposium held at Augusta, Georgia, April 2-5, 1975 (G. W. Esch and R. W. McFarlane, eds.), pp. 165-170. CONF-750425. U.S. Energy Research and Development Administration, Oak Ridge, Tenn.

Schubel, J. R., C. F. Smith, and T. S. Y. Koo. 1977. Thermal effects of power plant entrainment on survival of larval fishes: a laboratory assessment. Chesapeake Sci. 18(3):290-298.

Schubel, J. R., C. C. Coutant, and P. M. J. Woodhead. 1978. Thermal effects of entrainment, in Power plant entrainment: a biological assessment (J. R. Schubel and B. C. Marcy, Jr., eds.), pp. 19-93. Academic Press, New York, N.Y.

Sherberger, F. F., E. F. Benfield, K. L. Dickson, and J. Cairns, Jr. 1977. Effects of thermal shocks on drifting insects: a laboratory simulation. J. Fish. Res. Board Can. 34(4):529-536.

Stevens, D. E. and B. J. Finlayson. 1978. Mortality of young striped bass entrained at two power plants in the Sacramento-San Joaquin Delta, California, in Fourth National Workshop on Entrainment and Impingement (L. D. Jensen, ed.), pp. 57-69. Ecological Analysts, Melville, N.Y.

U.S. Environmental Protection Agency (U.S. EPA). 1976. Quality criteria for water. Washington, D.C. 256 pp.

Valenti, R. J. 1974. The effects of temperature and thermal shocks on the development of embryos and larvae of the winter flounder, Pseudopleuronectes americanus. Final report (Contr. No. SR 73-44) to Long Island Lighting Company. 41 p. (mimeo) (As cited in Schubel and Marcy 1978).

Appendix C

Equivalent Adult Estimates Related to Operation of the Hunters Point Power Plant Cooling Systems

C.1 Estimate of Adult Equivalents of Larvae

C.2 Estimate of Total Equivalent Adults

C.3 References

APPENDIX C: EQUIVALENT ADULT ESTIMATES RELATED TO OPERATION OF THE HUNTERS POINT POWER PLANT COOLING SYSTEMS

The objective of the equivalent adult approach to power plant impact assessment is to translate the number of young fish cropped by a plant into an equivalent number of adult fish, using the appropriate survival values. The estimate of equivalent adults represented by fish that do not survive entrainment and impingement has two useful applications:

1. the estimated equivalent adults can be used to put the cropping of the power plant into perspective with estimates of adult standing stock, if these are available; and
2. for populations subject to a fishery, the estimated adult equivalents can be compared to cropping associated with the fishery.

The equivalent adult method has been applied to Pacific herring and northern anchovy because data are sufficient to do so; there is a fishery for each of these species in the San Francisco Bay region; and cropping estimates are high enough to warrant further examination of impact.

This Appendix presents the methodology employed to compute equivalent adult losses for Pacific herring and northern anchovy. Section C.1 presents discussions of a model developed by Goodyear (1978) for computing equivalent adult loss associated with larval entrainment, and of an earlier, simpler model (Horst 1975) from which the former model was derived. The derivation of each term needed for making the calculations is explained using information obtained during the monitoring study or from the literature for both Pacific herring and northern anchovy. In Section C.2, techniques are presented for computing equivalent adults associated with entrainment of eggs and impingement of juveniles.

C.1 ESTIMATE OF ADULT EQUIVALENTS OF LARVAE

In the model of Horst (1975), the number of equivalent adults lost, (N_a), is given by

$$N_a = SN \tag{C-1}$$

where

S = survival from larval stage to adulthood

N = number of larvae that do not survive.

By treating all larvae as a single class, Horst gives each entrained organism equal weight in computing equivalent adults. This can impart considerable bias into the predictions if survival rates vary among members of the entrained age groups. In fact, young larvae, with low natural survival rates, contribute fewer equivalent adults than an equal number of entrained older larvae, which have higher survival rates. To avoid this bias, Goodyear (1978) divides larvae into separate length classes, computes equivalent adults for each length class, and sums to get a more accurate estimate of equivalent adult loss associated with larval entrainment:

$$N_a = \sum_{k=1}^{n} F_k N_k S_k \tag{C-2}$$

where

k = an ordinal number assigned to each length class

n = number of length classes considered

F_k = entrainment mortality for length class k

N_k = number of organisms entrained of length class k

S_k = survival from length class k to adulthood.

The Goodyear model was applied to Pacific herring and northern anchovy length classes at 1-mm increments beginning with the length at hatch for each species. The application of these figures is presented in Tables C-1 and C-2. The entrainment mortality

TABLE C-1 EQUIVALENT ADULT LOSSES OF PACIFIC HERRING AT HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979

Length Class (k)	Number Entrained (N_k)	Survival From Egg to Length Class L ($S_{e,k}$)	Survival From Length Class L to Adulthood (S_k)	Equivalent Adults[a] ($N_k F_k S_k$)
6	14,709,217	0.1000000	0.0003275	3,950
7	9,376,423	0.0325256	0.0010069	7,742
8	2,462,809	0.0122941	0.0026638	5,380
9	929,115	0.0052119	0.0062835	4,787
10	326,177	0.0024189	0.0135392	3,621
11	210,942	0.0012079	0.0271131	4,690
12	75,240	0.0006408	0.0511101	3,153
13	191,078	0.0003576	0.0915764	14,349
15	176,540	0.0001261	0.2597724	37,605
16	189,510	0.0000845	0.3875153	60,219
17	76,532	0.0000845	0.3875153	24,319
18	84,272	0.0000845	0.3875153	26,779
19	32,545	0.0000845	0.3875153	10,342
20	186,027	0.0000845	0.3875153	59,113
21	250,964	0.0000845	0.3875153	79,747
22	254,963	0.0000845	0.3875153	81,018
23	197,959	0.0000845	0.3875153	62,904
24	111,825	0.0000845	0.3875153	35,534
25	167,228	0.0000845	0.3875153	53,139
47	25,272	0.0000845	0.3875153	8,031
48	28,949	0.0000845	0.3875153	9,199
Total:	30,063,589			595,619

(a) F_k, entrainment mortality, was set at 0.82 for all length classes.

TABLE C-2 EQUIVALENT ADULT LOSSES OF NORTHERN ANCHOVY AT HUNTERS POINT POWER PLANT, APRIL 1978 - APRIL 1979

Length Class (k)	Number Entrained (N_k)	Survival From Egg to Length Class L ($S_{e,k}$)	Survival From Length Class L to Adulthood (S_k)	Equivalent Adults[a] ($N_k F_k S_k$)
6	1,499,476	0.2483793	0.0007906	972
7	62,115	0.2152407	0.0009123	46
9	34,720	0.1616377	0.0012149	35
10	96,776	0.1400721	0.0014019	111
11	46,941	0.1213838	0.0016177	62
12	23,339	0.1051888	0.0018668	36
13	21,935	0.0911546	0.0021542	39
14	42,292	0.0789928	0.0024859	86
15	23,381	0.0684537	0.0028686	55
17	57,268	0.0514061	0.0038199	179
19	28,998	0.0386040	0.0050867	121
20	79,255	0.0334535	0.0058699	381
21	58,492	0.0289902	0.0067736	325
23	25,582	0.0217705	0.0090199	189
26	49,416	0.0141676	0.0138603	562
28	33,099	0.0106393	0.0184567	501
29	34,244	0.0092198	0.0212983	598
30	93,941	0.0079897	0.0245774	1,893
31	110,657	0.0069237	0.0283614	2,573
32	32,967	0.0060000	0.0327279	885
38	32,050	0.0025410	0.0772795	2,031
57	28,998	0.0005840	0.3362165	7,995
62	35,742	0.0005840	0.3362165	9,854
64	34,635	0.0005840	0.3362165	9,549
65	45,648	0.0005840	0.3362165	12,585
66	27,549	0.0005840	0.3362165	7,595
67	30,911	0.0005840	0.3362165	8,522
70	35,742	0.0005840	0.3362165	9,854
75	25,843	0.0005840	0.3362165	7,125
81	33,878	0.0005840	0.3362165	9,340
82	25,907	0.0005840	0.3362165	7,142
Total:	2,811,795			101,242

(a) F_k, entrainment mortality, was set at 0.82 for all length classes.

estimate, F_k, was set at 0.82 for all calculations. The other major terms of the equation, N_k and S_k, are derived in Sections C.1.1 and C.1.2.

C.1.1 Estimation of the Number of Organisms Entrained of Length Class k (N_k)

The number of larvae of length class k entrained at the Hunters Point Power Plant from April 1978 to April 1979 was computed as

$$N_k = \sum_{i=1}^{26} \sum_{j=1}^{3} \hat{E}_{ij} P_{ijk} \qquad \text{(C-3)}$$

where

j = life stage code: 1 = yolk-sac larva; 2 = larva; 3 = juvenile

$\hat{E}_{ij}$ = estimated number of life stage j fish entrained in the ith 2-week period

P_{ijk} = fraction of life stage j fish that are of length class k in stratum i.

Pacific herring were assigned to life stages in the following way: those with the adult number of anal fin rays were classified as juveniles; those lacking adult fin rays, and either having food in their gut or lacking a yolk sac, were classified as larvae; and those having a yolk sac and no food in their gut were classified as yolk-sac larvae. Individuals that could not be classified by these criteria were classified as yolk-sac larvae if less than 6.5 mm in length and as larvae if 6.5 mm or more.

Sometimes, when samples were especially large, mutilated fish were categorized as under 6 mm, over 7 mm, or in-between. Those over 7 mm were called larvae and those under 6 mm were called yolk-sac larvae. Those in between were apportioned into the yolk-sac larval and larval classifications according to the relative abundance of each life stage in the sample. This is shown in the second term of the following equation:

$$\hat{E}_{ij} = \hat{E}'_{ij} + \hat{E}_{ix} \frac{E'_{ij}}{\sum_{j=1}^{2} E'_{ij}} \qquad \text{(C-4)}$$

where

$\hat{E}'_{ij}$ = the estimated number of fish clearly classified as yolk-sac larvae or larvae entrained in stratum i

$\hat{E}_{ix}$ = the estimated number of in-between fish entrained in stratum i.

The same method of apportionment was used for northern anchovy that could not be measured because of physical damage, and also for any that measured less than the estimated length at hatching, L_O. This resulted in the assignment of such fish to longer length classes, on the average, which would tend to overestimate losses.

P_{ijk}, the other term in Equation C-3, was calculated from length frequency distributions: all, or a subsample of 25, of the yolk-sac larvae and all, or a subsample of 25, of the larvae in each sample were measured and the distribution calculated for each life stage. In general, fewer than 25 juveniles were found per sample.

These estimates were used in Equation C-3 to compute N_k. The estimated numbers of entrained larvae in each length class, N_k, are listed in Table C-1 for Pacific herring and Table C-2 for northern anchovy.

C.1.2 Estimation of Survival from Length Class k to Adulthood (S_k)

Since in most cases the data needed to compute S_k directly are unavailable, it must be estimated indirectly:

$$S_k = \frac{S_T}{S_{e,k}} \qquad \text{(C-5)}$$

where

S_T = survival from egg to adulthood

$S_{e,k}$ = survival from egg to length class k.

The estimation of S_T used stems directly from the population theory for determining replacement level reproductive success (Leslie 1945; Vaughan and Saila 1976). For a population to remain at equilibrium with a sex ratio of 1:1, each female must produce enough eggs through her lifetime that two individuals will survive to maturity to replace her and one adult male. The survival from egg to adulthood needed to achieve this equilibrium is twice the reciprocal of average lifetime fecundity,

$$S_T = \frac{2}{F_a} \tag{C-6}$$

where

F_a = average lifetime fecundity of an adult female.

Substituting Equation C-6 into Equation C-5 yields

$$S_k = \frac{2}{S_{e,k} F_a} \tag{C-7}$$

C.1.2.1 Estimation of Lifetime Fecundity (F_a)

Average lifetime fecundity is a function of age of recruitment, frequency of spawning, fecundity of age class, and survival within each age class. Defining the beginning of the adult stage as the initial age of spawning, average lifetime fecundity was computed as

$$F_a = \sum_{j=r}^{m} P_j E_j S_j \tag{C-8}$$

where

r = age of recruitment into the adult population
m = number of age classes in the population
P_j = fraction of females that are mature in age class j
E_j = average fecundity of mature females in age class j
S_j = survival from recruitment to age class j.

Pacific Herring

The estimate of F_a for Pacific herring, 61,070, is listed in Table C-3 along with values for the terms of Equation C-8. The age of recruitment into the adult population, r, and the number of age classes, m, were set at two and eight, respectively (Spratt 1976). Since all females of age class two and greater were considered to be mature (Rabin 1976), the value of P_j was set at 1.00 for all age classes.

The average fecundity of females in each age class, E_j, was computed from the linear relationship between standard length and fecundity taken from Rabin and Barnhart (1977):

$$E_j = -63,920.9 + 496.6(SL_j) \qquad \text{(C-9)}$$

where

SL_j = average standard length of age class j in millimeters.

Values for average standard lengths were taken from Spratt (1976).

Survival from recruitment to age class j, S_j, was computed from the equation

$$S_j = \text{EXP}\ [-Z(j - r)] \qquad \text{(C-10)}$$

where

r = age of recruitment into the adult population
Z = yearly instantaneous mortality rate.

Z was calculated from the age composition of fish in the commercial catch, following MacCall (1974):

$$Z = -\ln \frac{T}{n + T - 1} - \frac{(n - 1)(n - 2)}{n(T + 1)(n + T - 1)} \qquad \text{(C-11)}$$

TABLE C-3 FACTORS USED TO ESTIMATE AVERAGE LIFETIME FECUNDITY OF PACIFIC HERRING

Age Class j	Standard Length SL_j (mm)	Eggs per Female E_j	Proportion of Females Mature P_j	Survival from Age 2 to j S_j	Relative Contribution $E_jP_jS_j$
2	159	15,040	1.00	1.0000	15,040
3	176	23,480	1.00	0.6225	14,616
4	186	28,450	1.00	0.3875	11,024
5	197	33,910	1.00	0.2412	8,180
6	204	37,380	1.00	0.1502	5,615
7	214	42,350	1.00	0.0935	3,960
8	220	45,330	1.00	0.0582	2,635
				F_a, Average Lifetime Fecundity	61,070

where

$$n = \sum_{k=0}^{m-r} N_k$$

$$T = \sum_{k=0}^{m-r} kN_k$$

and

k = coded age: $k = 0$ for the youngest age group fully vulnerable to the sampling, $k = 1, 2 \ldots m - r$ for successively older age groups (assuming all older ages are completely vulnerable)

N_k = number of fish of coded age k present in the catch.

The age composition data used were those from the 1976-1977 San Francisco Bay round haul catch, considered by Spratt (Calif. Dep. Fish Game, 1979, personal commmunication) to be the only data set representative of an entire spawning season. Data from other years were rejected because either sampling occurred late in the spawning season or the fishery was closed after only one or two spawning runs during these years. The round haul catch was selected over the only other form of catch, gillnetting, because the latter technique tends to be selective for larger fish (Spratt 1976), which would inject a negative bias into the estimate of Z. Instantaneous annual adult mortality, Z, for Pacific herring was computed to be 0.474; the resulting values of S_j found in Table C-3.

Northern Anchovy

The estimate of average lifetime fecundity, F_a, for northern anchovy is listed in Table C-4, along with values for each of the parameters contained in Equation C-8. The age of recruitment into the adult population, r, was set at one because females have been shown to reach sexual maturity at that age (Brewer 1978; Clark and Phillips 1952). The number of age classes, m, was set at six (Baxter 1967). Values for P_j, the fraction of females that are mature for each class, were taken from Clark and Phillips (1952).

Northern anchovy are capable of spawning more than once a year (Baxter 1967), but the number of spawning attempts is not known. The number is here taken to be two,

TABLE C-4 FACTORS USED TO ESTIMATE AVERAGE LIFETIME FECUNDITY OF NORTHERN ANCHOVY

Age Class j	Standard Length SL_j (mm)	Weight W_j (g)	Eggs per Female E_j	Proportion of Females Mature P_j	Survival from Age 1 to j S_j	Relative Contribution $E_jP_jS_j$
1	121	18.5	21,225	0.167	1.0000	3,545
2	133	24.0	27,510	0.292	0.3362	2,701
3	140	27.6	31,665	0.567	0.1130	2,030
4	146	31.0	35,530	0.918	0.0380	1,240
5	152	34.6	39,680	0.975	0.0128	494
6	154	35.8	41,125	0.990	0.0043	175
					F_a, Average Lifetime Fecundity	10,185

based on Frey (1971) and on evidence from seasonal abundances of entrained eggs collected during the monitoring study. This estimate was used in computing E_j, the average fecundity of northern anchovy in age class j, in the following manner:

$$E_j = 2W_jF \tag{C-12}$$

where

2 = number of spawns per female per year
W_j = weight (g) per female in age class j
F = a constant, 574 (eggs/g) taken from MacGregor (1968).

Weight per female was computed from the following power function taken from Collins (1969):

$$W_j = 0.00003582(SL_j)^{2.74285}, \tag{C-13}$$

with values for SL_j taken from Collins (1969).

Values for S_j were computed from Equation C-10, with the yearly instantaneous mortality, Z, set at 1.09 (MacCall 1974). F_a, average lifetime fecundity for northern anchovy, was computed to be 10,185 (Table C-4).

C.1.2.2 Estimation of Survival from Egg to Larval Length Class k ($S_{e,k}$)

Survival from egg to larval length class k, $S_{e,k}$, was estimated with the general formula

$$S_{e,k} = H\frac{N_k}{N_0} \tag{C-14}$$

where

H = the fraction of eggs that hatch
N_k = the number of larvae of length class k
N_0 = the number of larvae that have hatched.

Pacific Herring

Egg viability, H, is highly variable in Pacific herring. Under certain laboratory situations, hatching success reaches nearly 100 percent (Alderdice and Velsen 1971; Taylor 1971), but Taylor has found that fewer than 20 percent of all eggs that are in masses more than ten layers thick will hatch. Predation by birds, fish, and shellfish can cause over 90 percent loss of herring eggs (Cleaver and Franett 1946; Outram 1958), and Spratt (1976) made spawning biomass estimates in San Francisco Bay that assumed 95 percent predation in one week. When spawning is heavy, predation is relatively moderate (Spratt 1976), but hatching success is low (Taylor 1971). Pacific herring spawning was heavy in San Francisco Bay during the winter of 1978-1979 (D. H. Thomas, Calif. Dep. Fish Game, 1979, personal communication). Consequently, the fraction of eggs that hatched, H, was set at 0.1.

A model devised by Hackney and Webb (1978) for computing the number of hatchlings that survive to length k has been used to compute the ratio N_k/N_0:

$$\frac{N_k}{N_0} = L_0{}^b L_k{}^{-b} \qquad \text{(C-15)}$$

where

L_k = total length in millimeters
L_0 = total length of hatchling, set at 6.0 mm
b = a rate coefficient describing a decrease in numbers through length classes.

This equation may be manipulated and log-transformed to yield

$$\ln N_k = \ln N_0 + b(\ln L_0) - b(\ln L_k). \qquad \text{(C-16)}$$

Combining constants produces

$$\ln N_k = a - b(\ln L_k) \qquad \text{(C-17)}$$

where

$$a = \ln N_0 + b(\ln L_0).$$

The rate coefficient, b, then becomes the negative slope of a straight line relationship between natural log abundance and natural log length. Figure C-1 depicts this relationship for Pacific herring, based on entrainment length frequency data collected during the winter of 1978-1979 at the Potrero Power Plant (PGandE 1980). The length frequency data collected at the Potrero Power Plant were used to estimate natural mortality rates for Pacific herring larvae of these lengths. A least-squares curve-fitting technique applied to these data (omitting the five longest length classes) yielded estimates of a = 31.638 and b = 7.246 ($r^2 = 0.959$, $p < 0.0001$).

If Equation C-15 is substituted in Equation C-14, it yields

$$S_{e,k} = HL_0{}^bL_k{}^{-b} \qquad \text{(C-18)}$$

From Equation C-18, estimates of $S_{e,k}$ were computed for each length class from 6 to 15 mm. These values were then applied to Equation C-7, along with F_a, equal to 61,071 (Table C-3), to produce an estimate of S_k for each length class in the range 6-15 mm.

Using the same equations, estimates of S_k for the 16- to 48-mm length classes proved to be unrealistically high, reaching values greater than 1.00 for the larger length classes. Unrealistically high survival estimates were determined to be those values which were greater than 0.3875, two-year adult survival. An upper limit of two-year adult survival was used because survival in early life stages is generally lower than adult survival for an equivalent period, and the time between the stage of larval entrainment and adulthood is approximately two years.

The unrealistically high estimates may have resulted from a number of causes. Some of the more likely are the following:

1. b may not be constant for all length classes;
2. F_a may have been underestimated;
3. H may have been underestimated;
4. L_0 may have been underestimated;

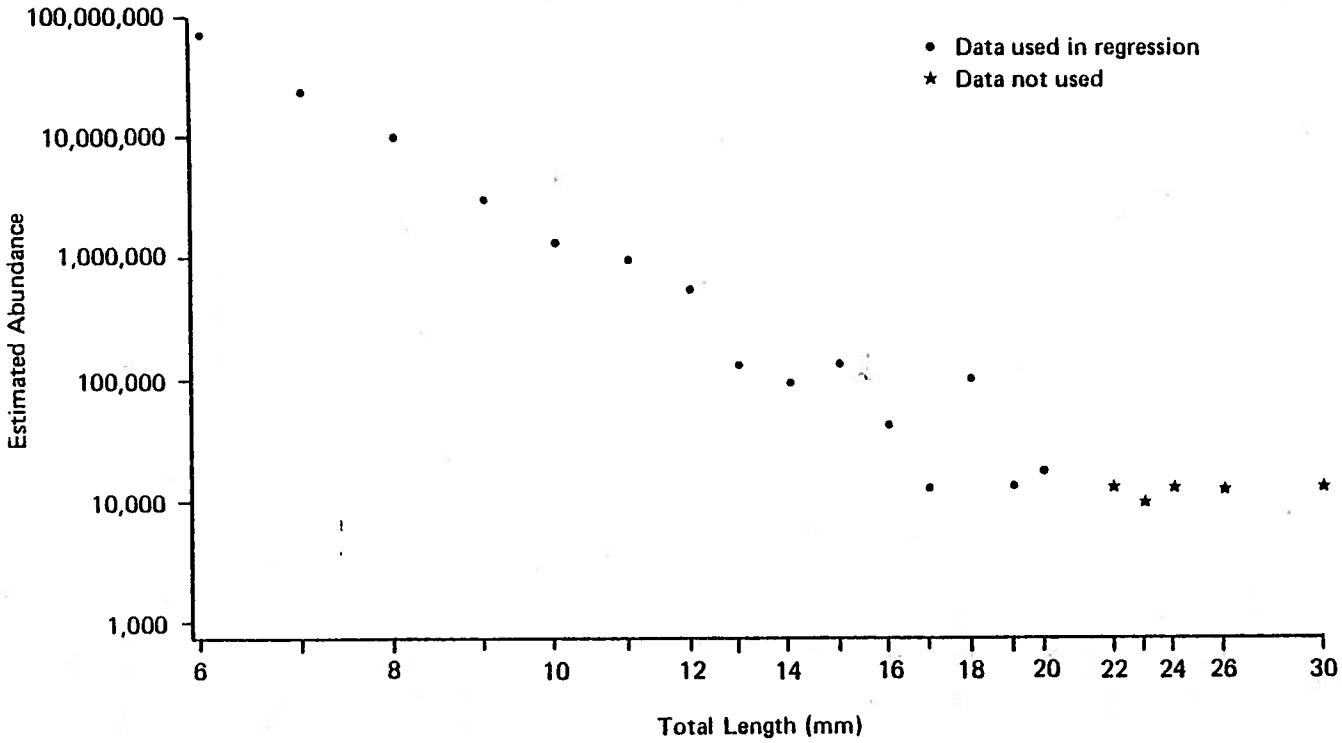

Figure C-1. Length frequency of Pacific herring entrained at the Potrero Power Plant from October 1978 to March 1979 used to compute larval mortality rate.

5. the Pacific herring population is not in equilibrium;
6. gear avoidance may occur for longer length classes.

All survival values computed from Equation C-7 to be greater than 0.3875 were set at 0.3875. These adjustments are considered to be conservative, in that the true survival values are likely to be less than 0.3875 and would result in fewer equivalent adults stemming from loss of larvae in the 16- to 48-mm length classes.

Northern Anchovy

As with Pacific herring, northern anchovy entrainment length frequency data collected from March 1978 to March 1979 at the Potrero Power Plant were used to compute values for N_k/N_0 for use in Equation C-14.

The model used, from Goodyear (1978), was:

$$\frac{N_k}{N_0} = \text{EXP}\ [-d(L_k - L_0)] \qquad \text{(C-19)}$$

where

d = mortality rate coefficient
L_k = total length in millimeters
L_0 = total length at hatching, set at 2.5 millimeters (Baxter 1967).

No single cohort could be distinguished from the data because of the continual spawning exhibited by northern anchovy (Baxter 1967). All length classes were used in computing d, the mortality rate coefficient, except for those less than 10 mm and greater than 50 mm, which were excluded because too few fish of these sizes were found in the samples.

This model, which assumes mortality to be a constant function of length, gave the best least-squares fit to the data, indicated by a linear relationship between length and natural log of abundance (Figure C-2). Values for the number of larvae that hatch, N_0, and the mortality rate coefficient, d, were computed as 0.1432 ($r^2 = 0.831$, $p < 0.0001$).

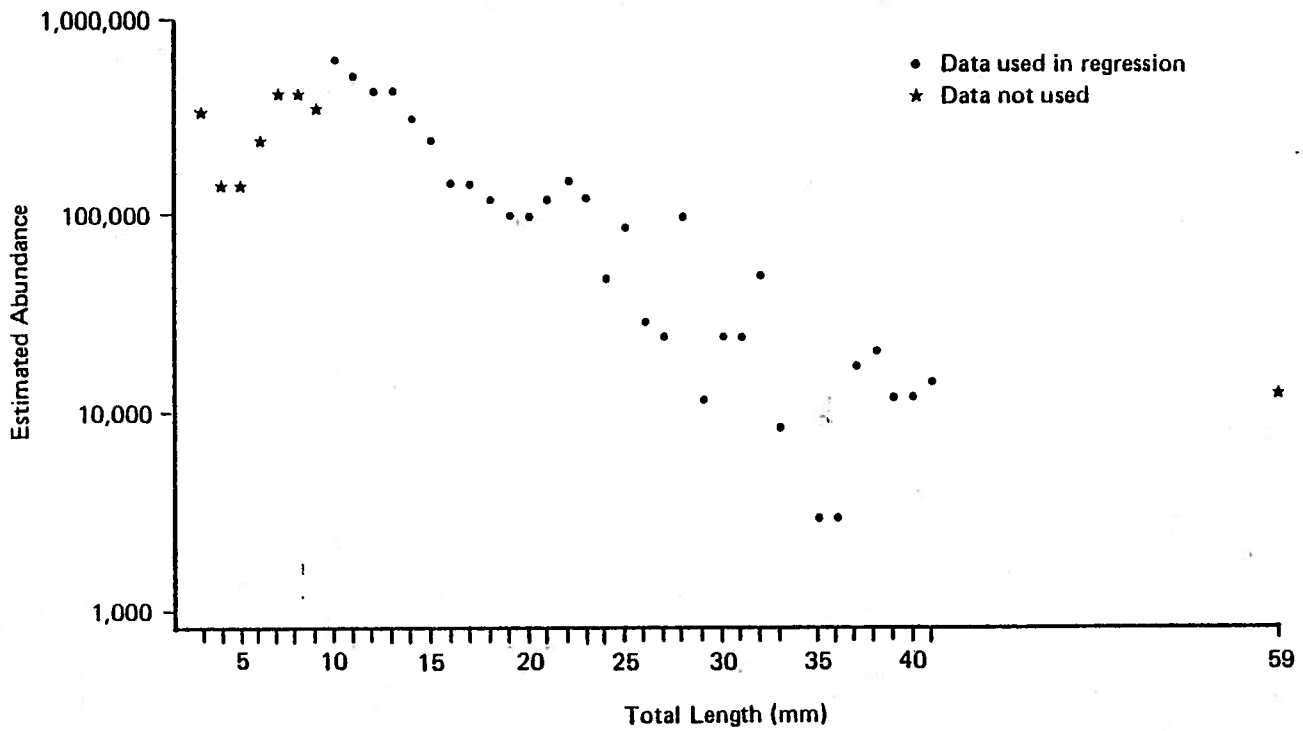

Figure C-2. Length frequency of northern anchovy entrained at the Potrero Power Plant from March 1978 to March 1979 used to compute larval mortality rate.

Although data from the 3- to 10-mm length classes were not used to estimate the larval mortality rate coefficient, the value of d was applied to these length classes in Equation C-19. This decision is supported by data presented in Smith (1972), which indicate that the relationship between length and mortality rate for larvae less than 10 mm long is similar to that for larvae of 10-16 mm.

Substituting Equation C-19 into Equation C-14 yields:

$$S_{e,k} = H \, EXP(-d[L_k - L_0]). \qquad \text{(C-20)}$$

The fraction of eggs that hatch was computed from data provided by Lasker and Smith (1977) as the mean number of 2.5-mm larvae divided by the mean number of eggs captured in California Cooperative Oceanic Fisheries Investigations surveys from 1955 through 1960. In this manner H was computed to be 0.41.

With H set to 0.41 and d equal to 0.1432, survival between egg and the length class k, $S_{e,k}$, was found.

The values of $S_{e,k}$ were used in Equation C-7 with F_a equal to 10,185 (see Table C-4) to produce an estimate of S_k for each length class. Equation C-7 yielded unrealistically high estimates of S_k for length classes between 57 and 82 mm. Applying the same logic used in the case of Pacific herring, S_k for these length classes was adjusted to 0.3362, the one-year survival for an adult northern anchovy. These values, and the corresponding equivalent adult loss estimates, are presented in Table C-2.

C.2 ESTIMATE OF TOTAL EQUIVALENT ADULTS

The equivalent adult methodology discussed so far has focused on the cropping of larvae of Pacific herring (24,650,000) and northern anchovy (2,300,000). In addition to these, an estimated 38,470,000 anchovy eggs were lost to entrainment and 74,934 juveniles to impingement; no Pacific herring eggs were entrained, but 12,058 juveniles were impinged.

An estimate of total equivalent adults must include those associated with this cropping of eggs and juveniles. Total equivalent adults, N_T, was computed according to the following formula:

$$N_T = N_a + \frac{2N_e}{F_a} + N_I S_{j,a} \qquad \text{(C-21)}$$

where

N_a = equivalent adults associated with larval (yolk-sac larvae and larvae) entrainment

N_e = total number of entrained eggs

F_a = average lifetime fecundity

N_I = total number of impinged juveniles

$S_{j,a}$ = survival from juvenile to adult stage.

F_a for anchovy was estimated at 10,185 eggs (Section C.1.2.1, Table C-4), and the equivalent adults for cropped eggs at 7,554. To facilitate computations, all impinged juveniles were treated as one-year-old fish. This caused each impinged northern anchovy juvenile to translate as an adult, since individuals of this species enter the adult population at age one. Since juvenile mortality rates for Pacific herring are not available, it was assumed that survival in the juvenile stage was equal to that of the adult stage, 0.6225, so survival from the juvenile to adult stage, $S_{j,a}$, was set at this figure. Both of these decisions are conservative. The effect of treating impinged juveniles as one-year-old fish and imposing adult survival rates on them is to overestimate the equivalent adult loss associated with impinged juveniles.

For Pacific herring, the total for the annual (April 1978 - April 1979) estimate of equivalent adults was 603,125. This total is the sum of the estimates for entrainment cropping of larvae (595,619) and impingement of juveniles (7,506).

For northern anchovy, the total annual estimate of equivalent adults was 183,730. This total is the sum of estimates from entrainment of eggs (7,554) and larvae (101,242), and from impingement of adults (74,934).

C.3 REFERENCES

Alderdice, D. F. and F. P. J. Velsen. 1971. Some effects of salinity and temperature on early development of Pacific herring (Clupea pallasi). J. Fish. Res. Board Can. 28(10):1545-1562.

Baxter, J. L. 1967. Summary of biological information on the northern anchovy Engraulis mordax Girard. Calif. Coop. Oceanic Fish. Invest. Rep. 11:110-116.

Brewer, G. D. 1978. Reproduction and spawning of the northern anchovy, Engraulis mordax, in San Pedro Bay, California. Calif. Fish Game 64(3):175-184.

Clark, F. N. and J. B. Phillips. 1952. The northern anchovy (Engraulis mordax mordax) in the California fishery. Calif. Fish Game 38(2):189-207.

Cleaver, F. C. and D. M. Franett. 1946. The predation by sea birds upon the eggs of the Pacific herring (Clupea pallasi) at Holmes Harbor during 1945. State Wash., Dep. Fish., Div. Sci. Res., Biol. Rep. 46B. 18 pp.

Collins, R. A. 1969. Size and age composition of northern anchovies (Engraulis mordax) in the California anchovy reduction fishery for the 1965-66, 1966-67, and 1967-68 seasons, in The northern anchovy (Engraulis mordax) and its fishery 1965-1968 (J. D. Messersmith), pp. 56-74. Calif. Dep. Fish Game, Fish. Bull. 147.

Frey, H. W., ed. 1971. California's living marine resources and their utilization. California Department of Fish and Game. 148 pp.

Goodyear, C. P. 1978. Entrainment impact estimates using the equivalent adult approach. FWS/OBS-78/65. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C. 14 pp.

Hackney, P. A. and J. C. Webb. 1978. A method for determining growth and mortality rates of ichthyoplankton, in Fourth National Workshop on Entrainment and Impingement (L. D. Jensen, ed.), pp. 115-124. Ecological Analysts, Melville, N.Y.

Horst, T. J. 1975. The assessment of impact due to entrainment of ichthyoplankton, in Fisheries and energy production: a symposium (S. B. Saila, ed.), pp. 107-118. Lexington Books, Lexington, Mass.

Lasker, R. and P. E. Smith. 1977. Estimation of the effects of environmental variations on the eggs and larvae of the northern anchovy. Calif. Coop. Oceanic Fish. Invest. Rep. 19:128-137.

Leslie, P. H. 1945. On the use of matrices in certain population mathematics. Biometrika 33(3):183-212.

MacCall, A. 1974. The mortality rate of Engraulis mordax in southern California. Calif. Coop. Oceanic Fish. Invest. Rep. 17:131-135.

MacGregor, J. S. 1968. Fecundity of the northern anchovy, Engraulis mordax Girard. Calif. Fish Game 54(4):281-288.

Outram, D. N. 1958. Seagulls biggest killers of herring spawn. West. Fish. 57(1): 38-42.

Pacific Gas and Electric Company (PGandE). 1980. Potrero Power Plant cooling water intake structures 316(b) demonstration. Prepared by Ecological Analysts, Inc. PGandE, San Francisco.

Rabin, D. J. 1976. Population characteristics of Pacific herring, Clupea harengus pallasi, in Humboldt Bay, California. M.S. thesis, Humboldt State University. 44 pp.

Rabin, D. J. and R. A. Barnhart. 1977. Fecundity of Pacific herring, Clupea harengus pallasi, in Humboldt Bay. Calif. Fish Game 63(3):193-196.

Smith, P. E. 1972. The increase in spawning biomass of northern anchovy, Engraulis mordax. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 70(3):849-874.

Spratt, J. D. 1976. The Pacific herring resource of Tomales and San Francisco Bays: its size and structure. Calif. Dep. Fish Game, Mar. Resour. Tech. Rep. 33. 44 pp.

Spratt, J. D. 1979. Personal communication. California Department of Fish and Game, Marine Resources Laboratory, Monterey.

Taylor, F. H. C. 1971. Variation in hatching success in Pacific herring (Clupea pallasi) eggs with water depth, temperature, salinity, and egg mass thickness. Rapp. P-V. Reun., Cons. Int. Explor. Mer 160:34-41.

Thomas, D. H. 1979. Personal communication. California Department of Fish and Game, Menlo Park.

Vaughan, D. S. and S. B. Saila. 1976. A method for determining mortality rates using the Leslie matrix. Trans. Am. Fish. Soc. 105(3):380-383.

Appendix D

Review of Technologies for Thermal Power Plant Cooling Water Systems

D.1 Summary

D.2 Cooling Water Systems

D.3 Intake Location in the Source Water Body

D.4 Intake Structure Design Parameters

D.5 Intake Guidance and Diversion Technologies

D.6 Intake Maintenance and Operation

D.7 References

APPENDIX D: REVIEW OF TECHNOLOGIES FOR THERMAL POWER PLANT COOLING WATER SYSTEMS

As a consequence of enactment of Section 316(b) of the Clean Water Act (PL 92-500 and 95-217), there are a number of cooling water system intake technologies that are either currently in use or have been proposed for use in power plant cooling water systems in an effort to minimize the loss of aquatic organisms. These technologies can be generally categorized as involving (1) cooling system alternatives, (2) intake location in the source water body, (3) intake structure design parameters, (4) intake guidance and diversion technologies, or (5) intake maintenance and operation.

The loss of aquatic organisms during the operation of a cooling water intake structure results from entrainment, entrapment, and impingement. Entrainment is the pumping of organisms into and through a condenser cooling water system. Entrapment results from the physical blocking of larger entrained organisms by a barrier, generally some type of screen located within the intake structure. Impingement occurs when aquatic organisms are caught, trapped, or held against the screening device of a cooling water intake as a result of cooling water withdrawal from the source water body through the screening system (Ohio EPA 1978). The loss of aquatic organisms can be minimized by reducing the probability of organisms encountering the intake and thereby reducing the number of organisms entrained or impinged. A second approach is to reduce the mortality rate among those organisms which are entrained or impinged. The biological and engineering considerations involved in selecting and implementing alternative technologies to achieve these goals are discussed in this review.

The objectives and scope of this review are to provide a comprehensive and systematic listing of technologies for thermal power plant cooling water systems, and to discuss the strengths and weaknesses of each alternative. An attempt has been made to identify intake designs that appear to be biologically effective in reducing organism losses while incorporating both demonstrated engineering feasibility and direct applicabilty to power plant intake systems. Intake designs that have not proven to be effective are also identified so that unsuccessful alternatives can be eliminated from the detailed site-specific intake evaluations. Information has been synthesized from published literature and reports and from discussions with plant operators, design engineers, utility and regulatory personnel, and equipment vendors.

D.1 SUMMARY

An overview of the recent information available on intake technologies and their effectiveness in minimizing the loss of aquatic organisms resulting from entrainment, entrapment, and impingement is presented. Factors contributing to the design of intake structures which reduce the number and mortality of impinged organisms are examined with emphasis on cooling water system designs, intake location in the source water body, and intake structure design parameters. Consideration is also given to the use of guidance, diversion, and fish return systems as well as operational strategies for reducing the biological impact of cooling water withdrawals.

D.1.1 Cooling Water Systems

Two alternative cooling systems are currently employed in thermal power plants—once-through and closed-cycle cooling. Closed-cycle cooling requires lower volumes of cooling water from the source water body and has therefore been suggested as a means of reducing impingement and entrainment rates. Use of closed-cycle cooling, however, results in 100 percent mortality of entrained organisms, in contrast to low mortality rates reported for many species entrained into once-through cooling systems. The effectiveness of closed-cycle cooling as an alternative to once-through cooling for reducing biological losses must be determined on a site-specific basis.

The operational efficiency of closed-cycle cooling towers is in part dependent on the water quality (e.g., sediment load and salinity) and may not be practical for use at many sites. Once-through cooling systems are limited to sites where a reliable water supply of sufficient volume is available.

D.1.2 Intake Location in the Source Water Body

Rivers, lakes, reservoirs, groundwater, estuaries, and oceans are used to supply cooling water to thermal power plants. The location of a cooling water intake structure within a water body may be along the shoreline, submerged offshore, or recessed from the shoreline. In order to minimize biological impact, the primary factor in siting an intake structure is to avoid areas of high fish and invertebrate population densities, such as spawning and nursery areas and feeding grounds.

D.1.3 Intake Structure Design Parameters

Principal intake design parameters which influence biological effectiveness are the intake velocity; intake screen design, mesh size, and screening material; intake configuration and location; and the design of a fish return system. Intake velocity design criteria include consideration of approach velocity and through-screen velocity. Swimming performance capabilities of fish provide a biological basis for establishing approach velocity criteria. Survival of impinged organisms is one factor to be considered in establishing through-screen velocity criteria. Engineering and biological considerations for the design of intake screens and selection of screen mesh sizes and materials are discussed. Specific criteria for intake screen design must be developed on a site-specific basis. The configuration of the intake structure should be designed to minimize the entrapment of organisms. Provisions for returning entrapped or impinged organisms to the source water body are required to reduce biological losses associated with the intake structure.

D.1.4 Intake Guidance and Diversion Technologies

The applicability and effectiveness of various behavioral and physical barrier systems for use in reducing entrainment and impingement at cooling water intakes are discussed. Behavioral barriers are intended to cause a guidance or avoidance response to divert organisms into bypass channels. To date, behavioral barriers have not proven to be an effective solution to the problem of minimizing the impingement of fish or macroinvertebrates. Sound, lights, and bubble curtains sometimes actually increase fish attraction to an intake structure. Electrical barriers cannot be considered for application in marine or estuarine sites. Velocity gradients and waterjet deflectors cause sediment deposition or erosion, and also may trap organisms within intake structures. Louvers and velocity caps rely on specific behavioral responses and swimming performance capability to be effective and hence are of little or no value in protecting planktonic fish eggs and larvae. As a result of variability in response patterns between species and age classes of fish, behavioral barriers are considered to be appropriate only in specific cases where a single species of fish of relatively uniform size and age is of concern.

Physical barriers are designed to block the passage of entrained or entrapped organisms. Some physical barriers rely on impinging organisms which are then mechanically

transferred to a bypass or return channel. Some physical barriers are designed to act as both a physical and behavioral barrier to exclude organisms from a cooling system. Recently, several physical barrier systems have been modified to include fine-mesh screen material in an attempt to minimize the number of eggs and larval fishes entrained into cooling water systems. The engineering reliability and operation as well as the biological effectiveness of various physical barrier systems are discussed. The application of alternative physical barriers for protecting larval as well as juvenile and adult fishes is considered. The demonstrated performance and operating experience with physical barrier systems used in association with once-through and closed-cycle cooling systems are considered.

The application and effectiveness of various fish conveyance and removal systems, including screenwash sluiceways, fish pump systems, fish basket collectors, and fish bypass-escape channels at intake structures are discussed. In specific applications, all of the fish conveyance and removal systems considered have proven to be effective. Factors such as the intake structure configuration and design, size and species of fish, and the behavioral response of the fish to various conditions encountered within an intake structure all affect the design and efficiency of a fish return system.

D.1.5 Intake Maintenance and Operation

Dredging to remove accumulated sediment from an intake is an effective means of ensuring that design velocities are maintained and uniformity of velocity gradients is maximized.

Reduction in cooling water volume by limiting the operation of circulating water pumps reduces the rates of entrainment and impingement. Reduced cooling system operation results in losses in generation capacity and thermal transfer efficiency of the cooling system, and increased temperature differential through the condenser system (delta-T). Although a reduction in cooling water volume reduces the number of organisms entrained, the increased delta-T may substantially reduce the survival of entrained organisms.

Cooling system curtailment is an effective approach for eliminating entrainment and impingement. Cooling system curtailment, however, also precludes electrical generation. Curtailment for short time periods on a seasonal basis may be effective in

reducing biological losses, although the costs of replacement power and reduced generation reliability throughout the service area must be considered.

Strategies for intermittent biofouling control using biocides such as chlorine are briefly discussed.

It was concluded, based on available data, that insufficient understanding of the role of shear forces, pressure regimes, and mechanical abrasion exists for entrained organisms to effectively recommend structural modifications to cooling system components (e.g., circulating water pumps) to reduce entrainment stresses.

Regulation of thermal elevations (delta-T) was examined. It was concluded that site- and species-specific information on the relative importance of thermal stress and mechanical stress in influencing survival of entrained organisms is needed to establish an effective management strategy. The process of determining the optimal cooling system operating strategy is briefly discussed.

D.2 COOLING WATER SYSTEMS

Two fundamental power plant cooling system designs exist—once-through (open-cycle) and closed-cycle cooling. In once-through systems, water is pumped directly from the source water body to the condenser and is then discharged into the receiving water body. In closed-cycle cooling systems, the cooling water is recirculated between the condenser and a cooling tower, or cooling pond. In an evaporative closed-cycle cooling system water is withdrawn from the source water body to provide makeup water during operation. The selection and design of a thermal power plant cooling system is dependent upon a number of factors, including water availability, engineering constraints, and regulatory limitions.

D.2.1 Open-Cycle or Once-Through Cooling

Once-through cooling may be considered to be feasible at power plant sites if a reliable water supply of sufficient volume is available. Variations in water quality and suspended sediments do not generally influence the acceptability of a power plant site for use with a once-through cooling system.

D.2.2 Closed Cycle Cooling

Closed-cycle cooling (cooling towers) decreases the volume of makeup water withdrawn from a source water body and thus reduces the number of phytoplankton, zooplankton, and ichthyoplankton entrained. However, for organisms that are entrained, 100 percent mortality results from exposure to increased temperatures, biocides, and mechanical abrasion. Therefore, the effectiveness of closed-cycle cooling in reducing entrainment and impingement losses as an alternative to once-through cooling must be determined on a site-specific basis.

Evaporative closed-cycle systems have had widespread freshwater application in the United States where water availability has been limited.

A survey of operating experience with saltwater closed-cycled cooling systems prepared for The Utility Water Act Group (Stone & Webster Engineering Corporation 1978) concluded that there are no known operating or proposed electric generating facilities in the United States which use seawater makeup in closed-cycle cooling systems. Seawater is characterized by salinities within the range of 26-36 ppt. The only power generating facility in the world which utilizes seawater in cooling towers is the Fleetwood Power Station in England, a small peaking plant (three 32-MWe units) with a low capacity factor (Stone & Webster Engineering Corporation 1978). The units are cooled by two natural draft cooling towers that have a circulating water flow rate of 67 cfs (1.9 m^3/sec) per unit. Salinity of the cooling water makeup at the Fleetwood Power Station typically ranges from 26 to 27 ppt. The circulating water is normally concentrated 1.2-1.5 times. Operational problems associated with corrosion and material deterioration have been reported.

There are approximately 25 power plants in the United States, ranging in capacity from 10 to 1,510 MWe and with circulating water rates of 4,900-540,000 gpm (11-1,200 cfs; 0.3-34 m^3/sec), that utilize brackish water makeup (0.5-26 ppt) in evaporative closed-cycle cooling systems. A survey of operating experience at these plants indicated several areas where operational difficulties occurred or could be attributed to the use of brackish water. These were (1) degradation of materials of the cooling tower, spray modules, or other plant structures, (2) switchyard and/or transmission line arcing, and (3) offsite property effects. The magnitude of these problems varied widely, from corrosion of handrails to forced outages of the units. Corrections

ranged from replacement of the complete cooling system to conversion to freshwater makeup. In addition, although the difficulty could not be attributed solely to the use of brackish water, nonattainment of design thermal performance was reported in a number of cases.

In addition, a number of other aspects must be considered in the early stages of power plant planning. These include air quality impacts from cooling tower drift, terrestrial effects of salt deposition, land use requirements, aesthetic considerations, and economic factors. Stone & Webster's review (1978) showed that no seawater closed-cycle unit has ever operated anywhere in the world for units of the size presently being constructed or planned by the utility industry (i.e., 700 MWe fossil or 1,150 MWe nuclear).

Dry closed-water-loop cooling systems have attraction as water-saving devices. They are technically feasible, but are costly and generally offer poorer plant performance than evaporative systems. The California Energy Commission reports that, "Effective heat transfer in dry cooling towers requires significantly more heat exchanger surface than in wet cooling systems (closed-cycle). Construction costs are therefore much higher. Although dry cooling systems use essentially no water, they work less effectively the higher the air temperature" (Stamets 1977).

A combination of wet and dry closed-cycle cooling is technologically feasible. Public Service Company of New Mexico faced a limited water allotment and has installed a wet/dry cooling tower of new design on its 500 MWe San Juan Unit 3. The plant is soon due to become operational. Cooling will be 70 percent dry (air) and 30 percent wet, resulting in roughly a 1,200 gpm (2.7 cfs; 0.075 m^3/sec) maximum makeup rate compared to a wet tower rate of 4,400 gpm (9.8 cfs; 0.28 m^3/sec) (Rittenhouse 1979). The value of the savings in water must be considered in relation to the relatively high capital costs of the wet/dry cooling tower as opposed to wet cooling towers.

D.2.3 Cooling System Retrofits

The feasibility of retrofitting a once-through cooling system with a closed-cycle system at an existing power plant would require extensive investigation. Since the cooling system is a major and integral part of the initial plant design, its proposed change

would require careful examination of overlapping operational, environmental, and economic considerations, and could be more complex than design of a new plant.

Operational considerations would include an evaluation of thermal performance, operating requirements, service life of system components, electrical conductor contamination by cooling tower deposition, and plant reliability.

Environmental considerations with closed-cycle cooling would center on air quality effects of cooling tower drift, terrestrial effects from salt deposition, land use requirements, and aesthetics.

Economic factors would include an evaluation of the capital costs for cooling system conversion, plant performance penalties, increased operation and maintenance costs, and higher site-related costs.

D.3 INTAKE LOCATION IN THE SOURCE WATER BODY

Rivers, lakes, reservoirs, groundwater, estuaries, and oceans are used to supply cooling water to thermal power plants in the United States. Each of these source water bodies has characteristics which affect the location, design, and operation of intake structures. Site selection involves consideration of the potential environmental impact and the location of suitable water bodies to provide cooling water. Biological information on potential impacts provides one input into a multidisciplinary site evaluation and choice of intake location.

Selecting the location of a cooling water intake structure to avoid areas of high fish and invertebrate population densities is desirable, and involves consideration of both the type of water body (i.e., lake, river, estuary, open ocean) and the location of the intake structure within the water body (e.g., onshore or offshore). The most favorable intake locations are those in areas considered to be of low biological value (U.S. EPA 1977). Few, if any intake locations are completely free of entrainable and impingeable organisms, but sites near migratory routes, spawning areas, nursery areas, or feeding grounds should be avoided whenever possible.

The location of a cooling water intake in a water body may assume one of three basic orientations with respect to the shoreline: (1) a shoreline intake structure where the

intake circulating pump well and screens are combined into a single structure, (2) an offshore intake where the inlet and screenwell-pump well are separated by some distance and connected through an enclosed conduit, and (3) an approach channel intake (recessed intake) where cooling water is diverted from the source water body to the intake screens by a conveyance channel. All three basic intake locations are currently used in the United States.

D.3.1 Shoreline Intake Structures

Shoreline intake structures similar to that shown in Figure D-1 are commonly used to supply cooling water to power plants located on lakes, rivers, estuaries, and bays. Locating a shoreline intake structure on a water body requires consideration of the vertical and horizontal distributions of aquatic organisms to avoid siting the intake in an area of high biological productivity. Consideration of the hydrology of the area is important to minimize recirculation and allow for variations in water level. Problems of sediment deposition and debris accumulation along shorelines also have to be considered.

General recommendations for the location of shoreline intake structures are summarized as follows:

1. avoid locating the intake in highly productive or high population density areas for fish and shellfish, or where there is susceptibility to debris or sediment accumulation; and
2. locate the intake in an area that will minimize the recirculation of cooling water, entrained organisms, and debris.

D.3.2 Offshore Intake Structures

Offshore intake structures similar to that shown in Figure D-2 are primarily used to supply cooling water to power plants located on large lakes and on beach zones along the coasts of oceans. Offshore intakes are used primarily to allow the selective removal of cooler subsurface water in water bodies which are vertically stratified, to isolate the cooling water intake and discharge to minimize thermal recirculation, to avoid disruption of lateral drift of beach sand, and to avoid shallow nearshore areas where the topography prohibits use of a shoreline intake structure. Offshore intake

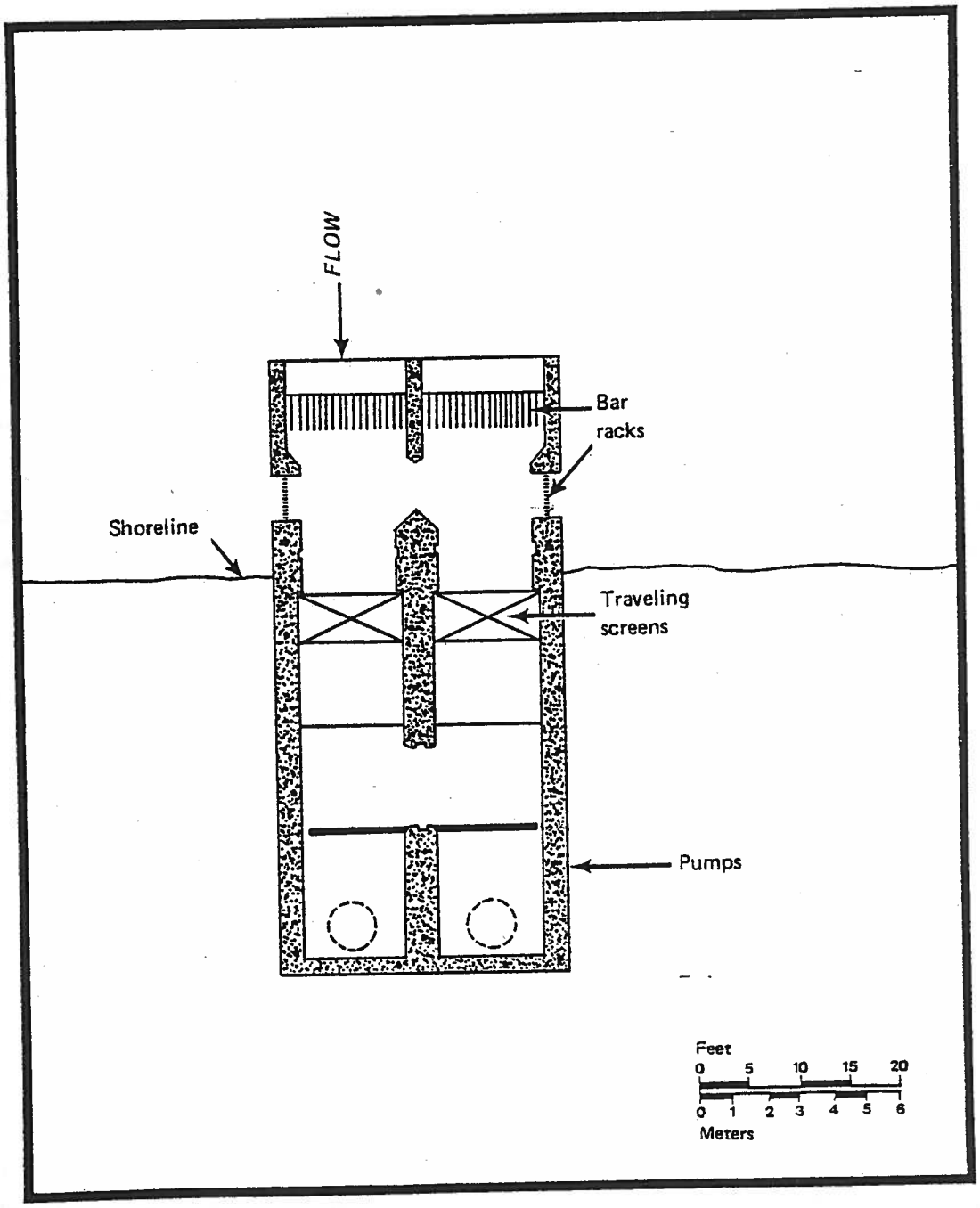

Figure D-1. Typical shoreline intake configuration.

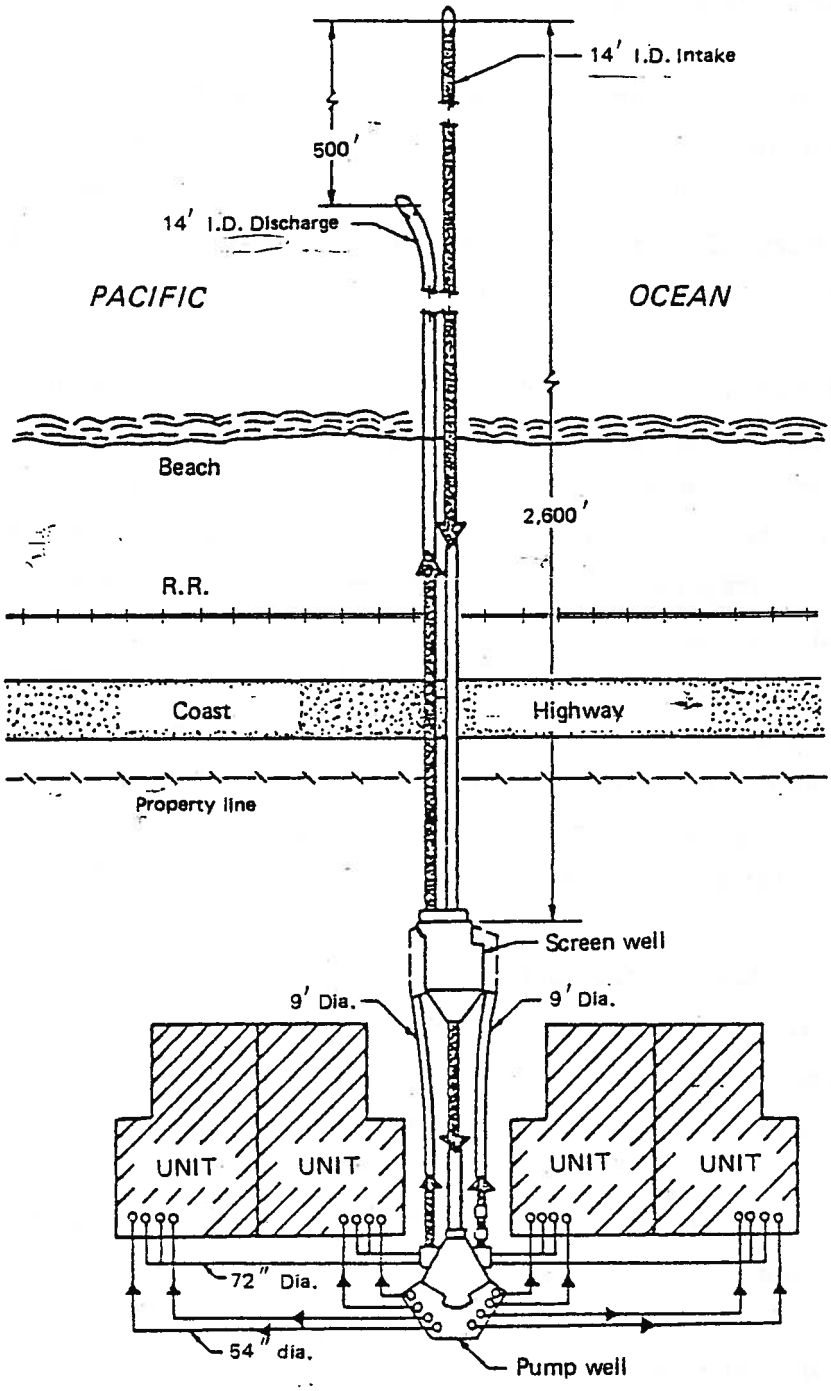

Figure D-2. Plan view of an offshore intake. (From Sonnichsen 1975.)

structures provide a greater degree of flexibility in selecting an intake location than is available for a shoreline intake, but the cost of installing an offshore intake is substantially higher than that for a comparable shoreline structure.

Locating an offshore intake structure within a water body requires consideration of the spatial distribution of aquatic organisms, vertical stratification of water temperature, and general hydrology of the area. Problems associated with sedimentation, biofouling control, fish removal and return, and obstruction of navigable waters must be addressed in the design and location of offshore intakes.

The arrangement of offshore intake structures includes an offshore point of water withdrawal, an enclosed conduit used to convey the cooling water to the power plant, and an onshore screenwell. This design results in a zone of fish entrapment between the offshore entrance to the intake structure and the intake screens. Attempts to alleviate the entrapment of fish within the intake have focused on preventing the entry of fish into the intake and on developing removal systems to return entrapped fish to the water body. Methods used to prevent fish entry into the intake include use of a velocity cap to reorient the flow pattern into the intake entrance from a vertical intake flow into a horizontal flow. Use of a velocity cap on the offshore intake structure of the El Segundo Power Station, located in the Pacific Ocean, reduced the tonnage of fish entering the intake by approximately 95 percent (Weight 1958).

Alternative methods of preventing fish entry into offshore intake structures include use of infiltration galleries, stationary fine-mesh screens, or traveling screens (caisson intake design) at the point of water withdrawal. These alternatives, and also fish removal and return systems, are discussed in later sections of this review.

General recommendations for the location of offshore intake structures are summarized as follows:

1. avoid locating the intake in areas which are highly productive or have high population densities of fish and shellfish;
2. locate the intake in an area which will minimize the recirculation of cooling water, entrained organisms, and debris;

3. base design intake velocities on the swimming performance capabilities and behavioral response of resident and migratory fishes as well as engineering constraints;
4. include provisions for the escape or removal of organisms from the intake structure; and
5. locate the intake where it will not impede navigation.

D.3.3 Approach Channel Intake Structures

Approach channel intake structures (recessed intakes) are used to provide a protected area for intake screens, to separate the intake and discharge locations to minimize thermal recirculation, or for other engineering reasons.

Such a system generally consists of an approach channel conveying water some distance from the shoreline to an intake structure, in either an enclosed conduit or an open canal. Fish can become trapped in the confined conduit or canal and may become stressed or fatigued, and eventually impinged.

Open approach channels generally have lower water velocities than do enclosed intake conduits. The open channel configuration also offers the possibility of greater behavioral avoidance and reduced entrapment of organisms. In general, the design of intake structures which utilize confined or enclosed conduits should be avoided in proposed installations whenever an alternative intake configuration can be used.

D.4 INTAKE STRUCTURE DESIGN PARAMETERS

The principal design parameters of an intake structure that influence organism losses are (1) intake velocities, (2) intake screen design, mesh size, and screen material, (3) intake configuration, and (4) fish return system. A brief discussion of intake velocity and intake screen design follows. A discussion of intake configuration is presented in Section D.3. Fish return systems are described in Section D.5.3.

D.4.1 Intake Velocities

Intake velocities at two locations have received the widest biological attention: the approach velocity of water entering the intake (generally in front of the bar rack

structure), and the through-screen velocity. To reduce impingement losses, the approach velocities should be based, in part, on the swimming performance of fish species present in the vicinity of the intake. Through-screen velocity should be based, in part, on the relationship between through-screen velocity and survival of impinged organisms.

D.4.1.1 Intake Approach Velocity

The development and evaluation of design criteria for intake structures based on swimming performance requires consideration of several factors. First, those species of fish to be protected are generally not the same from one geographical region to another. Second, certain species of fish are apparently more susceptible to entrainment and subsequent impingement than others. In addition, the susceptibility of a species to entrainment, entrapment, or impingement varies for each life stage. Third, key environmental variables such as water temperature, salinity, illumination, and dissolved oxygen concentration may alter the ability of a species to avoid entrapment and impingement. Fourth, the presence of a predator species may alter the behavioral pattern of individual fish or schools of fish and consequently increase their susceptibility to entrapment (Landry and Strawn 1974).

Extensive studies of fish swimming performance capabilities have been done on a variety of species by a number of researchers. It is difficult, however, to correlate their observations and establish a realistic approach velocity design criterion for swimming ability, because of variations, inconsistencies, or omissions in reporting data, pretest conditions, experimental design, physiological conditions, and environmental considerations.

Approach velocity design criteria typically range from 0.2 to 0.8 fps (6-24 cm/sec) for shoreline intake structures and 1.5 to 2.0 fps (46-61 cm/sec) for offshore velocity cap intake structures. An intake structure design should allow for an essentially uniform velocity profile across the entrance to the intake. In addition to biological considerations, the approach velocity for any intake structure is dependent on engineering constraints associated with the intake design and configuration, hydrology, and water quality of the source water body—all of which must be determined on a site-specific basis.

Dredging to remove sediment deposits from an existing intake structure will result in reduced approach velocities. Routine maintenance of the bar racks and intake entrance area to remove accumulated debris and obstructions is important to assure that intake operation is within the range of design parameters established for the specific intake structure.

D.4.1.2 Through-Screen Velocity

The probability of impingement mortality increases with increasing impingement duration and with higher water velocities, which hinder respiration by water pressure, a factor especially important for previously fatigued fish. Abrasion by the screen surface also results in higher impingement mortality associated with higher through-screen water velocities.

Biological studies on the survival of impinged fish have been conducted by Bibko et al. (1974), Prentice and Ossiander (1974), Landry and Strawn (1974), King et al. (1978), and many others (see Oak Ridge National Laboratory and Atomic Industrial Forum, Inc. 1979 for an extensive review). Findings of these studies indicate that, in addition to being affected by through-screen velocity, impingement survival is a function of the species, size, and life stage of impinged organisms; the season; spraywash pressure; and the duration of impingement. Hemorrhaging, descaling, and mechanical abrasion are important factors contributing to impingement mortality. As a result of the number of interacting factors which influence impingement mortality, it is difficult to isolate the contribution of through-screen velocity.

Through-screen velocities at intakes of U.S. utilities typically range from 0.5 to 1.5 fps (15-46 cm/sec) for conventional vertical traveling screen intake structures. As the available open area for water to pass through the intake screen mesh decreases, the through-screen velocity increases. Establishing appropriate through-screen velocity and impingement duration relationships is essential if a fine-mesh intake screen is being considered to remove fish eggs and larval fish from the cooling water (Tomljanovich et al. 1978). Data necessary to establish through-screen velocities based on impingement survival are presently not available for most species of fish. Data which are available on the relationship between impingement survival, duration of impingement, and through-screen velocity are, in many cases, inconclusive and do not provide

a reliable basis for establishing biological design criteria for through-screen velocity for a broad variety of fish species and life stages.

D.4.2 Intake Screen Design, Mesh Size, and Screen Material

A variety of intake screen designs are commercially available for use in power plant cooling water intake structures (see Section D.5.2 for a review of intake screening devices). The major engineering and biological design requirements for an intake screen include:

1. the intake screens must be of sufficient size to accommodate the coolant flow while maintaining through-screen velocities within the design parameter limits;
2. the intake screen must efficiently remove debris which would otherwise clog the condenser system;
3. the intake screen must provide sustained reliable operation to assure an adequate supply of cooling water; and
4. the intake screen should be designed to minimize mechanical effects resulting in injury or death of organisms from abrasion or suffocation during impingement on screen surfaces.

Design parameters for an intake screen to be utilized at a specific site require knowledge of the power plant cooling system design, characteristics of the source water body (including sediment and debris loads), and the species and sizes of organisms to be protected. As a result of the variety of conditions which influence intake screen design and the variety of intake structures available, no single intake screen design can be identified that would be the best available design for all sites.

Intake screen mesh sizing has historically been based on a design criterion which specifies that screen mesh openings should be approximately 50 percent of the condenser tube diameter. As a result of this criterion, the majority of power plant cooling systems, which are designed with 7/8-in. (22.2-mm) diameter condenser tubes, have 3/8-in. (9.5-mm) square woven-wire mesh intake screens. Recently, increased emphasis has been placed on determining screen mesh sizes based on the size of organisms to be eliminated from entrainment through the cooling water system. The primary criterion in selecting an intake screen mesh size for biological reasons is to

determine if the particular organism and life stage in question is better able to withstand impingement stresses than the stresses associated with entrainment through the cooling system.

A summary of the retention of various species of fish larvae by screen meshes of various sizes is presented in Figure D-3. Screen mesh with 0.02-in. (0.5-mm) openings is available commercially and will retain the majority of egg and larval fishes present in most source water bodies. However, before selecting a specific mesh size for excluding organisms from a cooling system, it is important to consider the relative survival of impinged versus entrained individuals. Tomljanovich et al. (1978) present a detailed discussion of experimental studies conducted under laboratory conditions to determine the feasibility of protecting larval fish at water intakes using fine-mesh screening. Additional considerations in selecting a screen mesh size include debris loading and screen clogging, available open area and through-screen velocity, and screen reliability under site-specific operating conditions.

The variety of screen mesh configurations currently available for use in cooling water intakes includes square mesh woven-wire, horizontal slot configurations using woven wire, and horizontal slot configurations using a welded wedge-wire design. Each of these mesh configurations is available in a variety of mesh sizes. Hydrodynamic and biological investigations are ongoing (e.g., Cook 1978; Heuer and Tomljanovich 1978; Walker and Kamata 1979) to determine the advantages and disadvantages of various intake mesh configurations. Insufficient data are currently available to conclude that one intake screen mesh configuration significantly reduces biological losses, debris loading, and hydraulic losses in comparison to other available configurations.

Intake screens are available in a variety of materials including polyester, nylon, Monel, and stainless steel. The selection of a screening material is dependent on the mesh size and configuration selected and on the desired durability of the screen. Polyester and nylon screen is used in applications where a fine-mesh screen (0.02-0.06 in.; 0.5-1.5-mm) is desired and when screen mesh is expected to be altered seasonally. Stainless steel is used in applications where durability over a long period of time in a corrosive environment such as salt water is needed. Monel is used extensively in both fresh- and saltwater environments, but requires greater maintenance and more frequent replacement than stainless steel. In addition to durability, capital cost and replacement cost are considered in the selection of screening material.

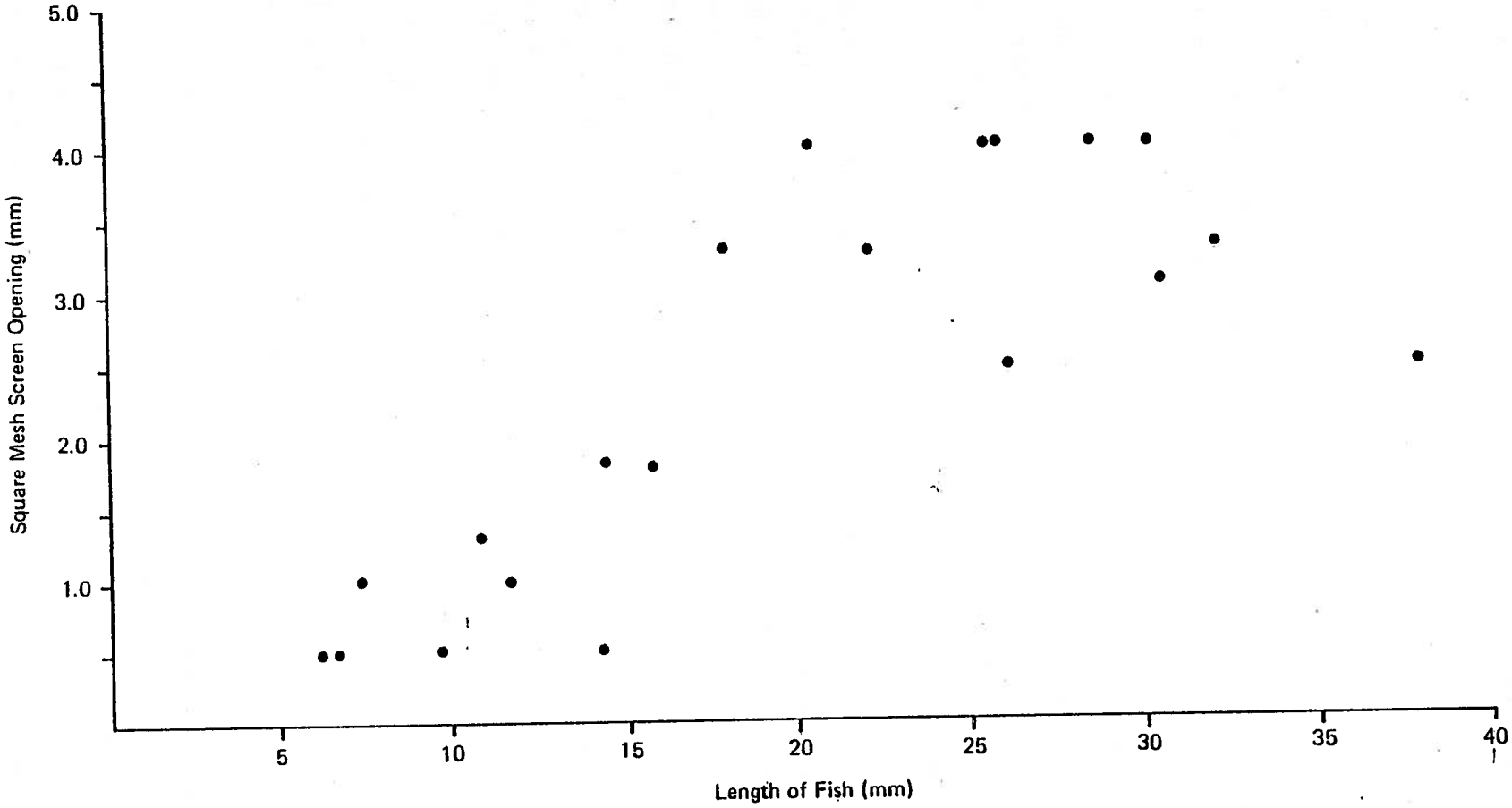

Figure D-3. Relationship between square mesh screen opening size required for 90 percent retention and length, for 12 species of fish. (Data from Erkkila et al. 1950; Kerr 1953; Clay 1961; Prentice and Ossiander 1974; Fisher 1978; Tomljanovich et al. 1978.)

No documentation exists that the type of screen material influences the survival of impinged organisms.

D.4.3 Other Intake Design Parameters

In the early 1950s PGandE and Bechtel Corporation undertook a study in cooperation with the California Department of Fish and Game to minimize intake entrapment and impingement losses (Kerr 1953). As a direct outgrowth of that study, PGandE established design criteria that have since been incorporated in all subsequent intake structures.

A typical shoreline intake configuration can be seen in Figure D-1. Basically, the structure meets a number of hydraulic and mechanical criteria in addition to reducing entrapment and impingement. Fish protection criteria identify preferences for location in the water body (previously discussed in Section D.3) and provide for lateral fish escapes between the bar racks and traveling screens. Low approach velocities, short cooling water system transit times, and minimization of turbulence are specified.

D.5 INTAKE GUIDANCE AND DIVERSION TECHNOLOGIES

D.5.1 Behavioral Barriers

Various types of stimuli, such as light, sound, velocity gradients, electric shock, and chemicals, have been tested in an attempt to frighten or deter fish from entering cooling water intakes. Louvers and velocity caps have been used to provide stimuli for guiding fish away from a water intake. Because these behavioral barriers rely on the ability of an organism to respond to a stimulus, they are of little or no value in protecting planktonic fish eggs and larvae. In addition, the behavioral response of fish to artificial stimuli varies among species of fish and also within a species because of differences in age or physiological state (Sonnichsen 1975). As a result of the variability in response to a stimulus, behavioral barriers are considered to be most appropriate in those cases where a single species of fish of relatively uniform size and age is of concern.

The primary application of most behavioral barriers has been in addition to, or in combination with, conventional intake systems (physical barriers) on either an intermittent

or continuous basis. Many behavioral barriers have not been subject to rigorous testing under field conditions, so conclusions as to their effectiveness have been drawn, where possible, from laboratory studies. Qualitative conclusions are presented in Table D-1.

D.5.1.1 Light

Intense illumination was characterized by Bibko et al. (1974) as a passive deterrent for striped bass, only temporarily deterring fish passage under experimental conditions. Fields (1966) reported that the avoidance response of salmonids to artificial light varied, depending on the light adaptation of the species, water clarity, and flow conditions. Constant light was reported by Fields to be more effective than interrupted or flashing light for guiding young salmon. Adaptation to light intensity substantially decreases the guidance efficiency of light barriers.

Available data on the effectiveness of light as a behavioral barrier are contradictory. In some tests, fish are attracted to light, while in other tests fish are repelled by it. In addition, light would not provide an effective barrier during the daytime or in highly turbid water. Thus, light barriers are not considered to be an effective method of reducing the numbers of organisms entrained or impinged at an intake stucture.

D.5.1.2 Sound

Sonic techniques for repelling fish from industrial water intake structures have been reported by Moore and Newman (1956), Burner and Moore (1962), VanDerwalker (1964), and Trefethen (1968). Moulton and Backus (1955) reviewed the literature regarding the guidance efficiency of sonic barriers.

In general, maximum avoidance response has been observed for low-frequency, high-intensity sound, but variation in hearing ability among species and high-level background noise leads to poor repeatability of the behavioral response of fish to sonic barriers. Burner and Moore (1962) reported that the behavioral response to sound frequency or intensity was insufficient to be effective in guiding young salmonids to safe passage around dams and diversions. The Virginia Electric and Power Company (Vepco) attempted to use relatively high-intensity, multifrequency sound to repel fish from power plant intakes (J. White, Vepco, 1976, personal communication). It was

TABLE D-1 SUMMARY OF EXPERIENCE WITH BEHAVIORAL BARRIERS FOR REDUCING ORGANISM LOSSES AT COOLING WATER INTAKES

Technology	Reduces Larval Entrainment	Reduces Impingement	Reduces Entrapment	Operationally Reliable	Comments
Light	○	?	○	●	Attracts some species
Sound	○	○	○	●	After initial avoidance, fish acclimate to sound
Velocity gradient	○	○	○	○	Requires relatively high velocities, stable water level
Bubble screen	○	?	○	●	Attracts some species at night
Electrical barrier	○	?	○	?	Applicable to fresh water only; can induce fish mortality
Chemicals	○	○	○	○	Discharge of chemicals into receiving waters; undemonstrated
Magnetic barrier	○	○	○	○	Undemonstrated
Cables and chains	○	○	○	○	Undemonstrated
Louvers	○	◒	○	◒	Lack automatic debris-cleaning capability
Velocity cap	○	●	●	●	Applicable to offshore intakes only

Legend

● Demonstrated effective

◒ Demonstrated somewhat effective

? Data inconclusive, conflicting or variable

○ Demonstrated ineffective or no data

concluded that although sound was partially effective, sound alone was inadequate for repelling fish from the cooling water intake, because of the diversity of species, the diversity of sizes of fish encountered, and the diversity of behavioral patterns.

An underwater pneumatic impact device (popper) was tested as a sonic barrier at a power plant intake structure by Schuler and Larson (1975). It was concluded that the effective range of sonic barriers is limited and that fish quickly become accustomed to a sound stimulus and no longer show an avoidance response.

Thus, although fish are initially frightened by sound barriers, tests conducted under laboratory conditions and at power plant intakes indicate that they rapidly become accustomed to sound stimuli, rendering the barrier ineffective. On the basis of negative results from field and laboratory studies, no further testing of sonic barriers at power plant intakes is warranted.

D.5.1.3 Velocity Gradients

Kerr (1953), Clay (1961), Bates (1964), Bates and VanDerwalker (1964), Niggol (1964), and Prentice (1966) discussed flow acceleration or deceleration barriers for guiding or deflecting fish. Flow acceleration barriers produce an increase in the approach velocity over a relatively short distance by use of wedges in approach channels. Bates and VanDerwalker (1964) reported a 70 percent diversion efficiency for an experimental waterjet deflector at an approach velocity of 2.5 fps (76 cm/sec). High diversion efficiencies (81 percent) have been reported by Prentice and Ossiander (1974) for vertical flow accelerators oriented at a 20° deflection angle for channel velocities ranging from 1.2 to 2.4 fps (37-73 cm/sec). Horizontal flow accelerators had an average deflection efficiency of 56 percent for channel velocities from 1.5 to 2.3 fps (46-70 cm/sec) (Prentice and Ossiander 1974). No difference in diversion efficiency was observed for tests conducted during the day and night. Blinded fish, tested by Gerold and Niggol (1964), were guided by flow acceleration barriers with diversion efficiencies comparable to those for normal fish.

No application of velocity gradients for diverting fish from power plant intake structures has been tested. The use of velocity gradients within an intake structure requires a confined approach channel to the intake structure and use of relatively high approach velocities. This combination is expected to result in a condition which would

entrain and entrap fish and would require effective guidance of diverted organisms into a bypass system. Further, this combination may also lead to the establishment of a resident predator population. Velocity gradients are not a reliable technique for reducing entrainment or impingement at power plant intakes.

D.5.1.4 Air-Bubble Screens

Air-bubble screens have generally been reported to be unsuccessful at consistently diverting fish (Brett and MacKinnon 1953; Fields 1966; Mayo 1974). However, several cases have been reported where partial success was observed. Bibko et al. (1974) reported that striped bass would not actively pass through an air-bubble screen at 40 or 52 F (4.5 or 11.1 C), but were found to drift passively through the screen when water temperature was 33 F (0.8 C). Striped bass were found to pass through an air-bubble screen at all test temperatures if openings 2 in. (5.2 cm) or greater were allowed in the screen. Gizzard shad would not pass through an air-bubble screen at water temperatures of 52 F (11.1 C), but were not deterred at 33 F (0.8 C) (Bibko et al. 1974). Bates and VanDerwalker (1964), studying juvenile migrant salmon, reported that air-bubble screens produced diversion efficiencies up to 95 percent during daylight, but declined to 28 percent at night and were not improved by artificial lighting. Alevras (1974) observed that an air-bubble screen at the Indian Point Power Station on the Hudson River did not appear to repel fish during the daytime, and his preliminary data indicated that the air-bubble screen may attract fish to the intake at night.

Because of the variability in response among species, poor effectiveness at night and in turbid water, and lack of success in field applications, air-bubble screens are not an effective method of reducing either entrainment or impingement.

D.5.1.5. Electric Barriers

Electric barriers have been used to divert fish from several small power plants, dams, irrigation canals, and municipal water supply systems with variable success. Holmes (1948) discussed the history, developmental problems, and practical applications of electrical techniques for fish diversion. Applegate et al. (1954) reviewed the literature related to the use of electric fish screens.

Pugh (1962), Pugh et al. (1964), and Elliott (1970) reported that pulsed current was most effective in terms of guidance, diversion, and power requirements. The behavioral reaction of fish to an electric field are: (1) avoidance, (2) electrotaxis, and (3) electronarcosis leading to paralysis and eventual death (Applegate et al. 1954; Elliott 1970; Maxwell 1973). In general, the required current density and resulting behavioral response varies among species and sizes of fish (Pugh 1962; Pugh et al. 1964).

Trefethen (1955) reported 68 percent guidance efficiency of electric barriers in large-scale laboratory experiments using fingerling salmon. Efficiency decreases as water velocity exceeds 0.5 fps (15 cm/sec) (Pugh 1962; Pugh et al. 1964). Maxwell (1973) reported variable success of electric barriers used at small freshwater intakes, usually with resident rather than migrating fish species. Because of low electrical resistance, no application of electric fish barriers has been made in salt or brackish waters.

Electric barriers are most effective at intake structures where the impingement of only a few species of relatively uniform size is of concern. At intakes where a variety of species and sizes of fish are encountered, or at intakes sited in marine or estuarine waters, electric barriers are not effective in minimizing impingement (U.S. EPA 1976).

D.5.1.6 Chemicals

A barrier consisting of a fish-repelling chemical, discharged near the entrance of an intake structure, may be used to discourage the entry of fish into the intake. Fish-repelling chemicals are available, but no large-scale testing has been conducted. Chemical barriers would be of little practical value because of the large volumes of cooling water involved and the adverse effect of the discharge of fish-repelling chemicals on nontarget organisms inhabiting the receiving water body.

D.5.1.7 Magnetic Barriers

Magnetic fields have been examined as a potential method of guiding juvenile salmonids past water diversions (Cannon et al. 1979). Salmonids did not respond to changes in magnetic fields under experimental conditions. No tests have been conducted to examine the effectiveness of magnetic barriers at power plant intake structures. In the absence of any information suggesting the applicability of magnetic fields for

reducing entrainment or impingement, further consideration of magnetic barriers is not warranted.

D.5.1.8 Chains and Cables

Chains and cables hung vertically at the entrance to a water intake structure or water diversion have been examined as a potential behavioral barrier. Results of experiments conducted with juvenile salmonids by Brett and Alderdice (1958) suggest that chain and cable barriers are not effective in consistently diverting fish. In the absence of demonstrated effectiveness, chain and cable barriers are not considered to be a reliable technique for reducing the entrainment or impingement of fish at water intakes.

D.5.1.9 Louvers

The application of fixed louvered deflectors for diverting juvenile migrant salmonids and striped bass has been discussed by Bates and Vinsonhaler (1957), Bates and Jewett (1961), and Skinner (1974). Diversion of downstream migrants of anadromous species with louver deflectors has had variable success. Diversion efficiency is influenced by the approach velocities and the species and size of fish. Louvers have proven to be a relatively well-developed engineering and biological design concept, requiring minimum handling of fish. They do not, however, divert fish eggs and larvae, are vulnerable to biofouling accumulations, and are not self-cleaning.

Skinner (1974) discussed the diversion efficiency of the Delta Fish Protective Facility near Byron, California, which diverts water from the Sacramento - San Joaquin river system primarily for agricultural usage. The facility is a fixed louver design oriented 15° to the flow, with primary and secondary bypass facilities. Present diversion capacity of the facility is approximately 6,000 cfs (170 m^3/sec). Louver efficiency for white catfish was found to be directly related to fish length. Primary diversion efficiency ranged from 4 percent for white catfish 0.4-0.5 in. to 68 percent for those 3.0-3.9 in. long (10-12.5 mm and 75-100 mm). Diversion efficiency for salmonids was related to fish length and water velocity. Velocity was found to influence diversion efficiency of smaller fish greatly, but as fish increased in size and swimming capabilities, velocity became less critical. Diversion efficiency for salmonids ranged from 65 to 84 percent in 1970 and from 84 to 90 percent in 1971 for salmon 2.0-5.9 in.

(50-150 mm) long. Differences in diversion efficiency between the two years was thought to be related to the operator's ability to attain and maintain test parameters. Based on observations of 1.3 million striped bass 0.2-4.9 in. (5-125 mm) in length, there appeared to be an inverse relationship between diversion efficiency and channel approach water velocity. Lower approach velocities were most favorable for striped bass less than 1.2 in. (30 mm) long. The diversion efficiency of the louver system for striped bass was 69 percent.

Schuler (1974), using an experimental approach, observed the behavioral reaction of marine fish to fixed louvers oriented at various angles to the flow, to various louver vane spacings, and to various approach velocities. For marine fish, highest guidance efficiency was observed for louvers oriented 20 : and 30° to the flow with vanes 1 in. (2.5 cm) apart. Maximum diversion efficiency occurred at a mean approach velocity of 2 fps (61 cm/sec). Schuler (1974) observed for marine species, that the guidance component extended 5.9-7.9 in. (15-20 cm) from the louver face and test species guided better along an array of louvers than along screens.

Louvers have been used effectively for diverting migrating anadromous fishes from several large agricultural water diversions; however, the application of louvers to power plant cooling water intakes has not been attempted. Louvers do not provide a positive barrier for eliminating either entrained organisms or debris from a cooling water flow, and entrainment could result in blockage of the condenser tube system and lead to reduced operating reliability and increased maintenance of the cooling water system.

One U.S. utility has recently begun construction of a combined louver - traveling screen intake for application at a power plant cooling system intake. The structure is designed to provide the guidance characteristics of louvers and the positive physical barrier of a screen. No conclusions can be drawn regarding the effectiveness of the louver - traveling screen system in diverting fish from a power plant intake until the intake structure is operational and field studies can be completed.

D.5.1.10 Velocity Cap

During the early 1950s, operation of offshore intakes would occasionally result in large schools of fish becoming entrapped within the intake conduit. The entrance of these

offshore intake conduits were unscreened and oriented vertically in the water column to minimize sediment deposition within the intake structure. The large numbers of fish entrapped within the intake would eventually become impinged on the intake screens and would, on occasion, force shutdown of the power plant cooling system. Based on results of experimental testing, it was determined that fish sense and react to vertical flow fields much more slowly than to horizontal flow fields. As a result of these observations, a velocity cap (Figure D-4) was placed over the entrance to the offshore intake to reorient the flow pattern from a vertical to a horizontal flow field. The quantity of fish removed from one intake structure decreased from 272 tons the year before installation of the velocity cap to 15 tons the year after installation, a reduction of nearly 95 percent (Weight 1958).

Velocity cap intake structures are presently in use in offshore intakes in the Pacific Ocean off southern California and in Lake Michigan. A velocity cap functions as a behavioral barrier and is used in combination with onshore intake screens, which function as a positive physical barrier for those fish that do enter the intake. A velocity cap does act as an effective behavioral barrier for reducing the numbers of impinged fish when used with an offshore intake structure. Velocity caps are not expected to reduce the numbers of planktonic organisms entrained.

D.5.2 Physical Barriers

Historically, intake screens and other physical barriers used in power plant intake structures have been designed to remove entrained debris from the cooling water supply prior to passage through the condenser cooling system. During recent years, extensive effort has been devoted to designing and modifying physical barriers to provide exclusion of entrained fish and invertebrates from the water supply while minimizing mortality due to impingement. In addition to excluding debris and organisms from a cooling water supply, an acceptable physical barrier must be mechanically dependable and operate as designed under a variety of conditions.

Physical barriers are designed to block the passage of entrained or entrapped organisms on the basis of the size of organisms encountered at specific intake systems. Some physical barriers rely on impinging organisms for brief periods, while they are mechanically transferred to a bypass channel. Recently, many physical barrier systems (e.g., vertical traveling screens and centerflow screens) have been modified on

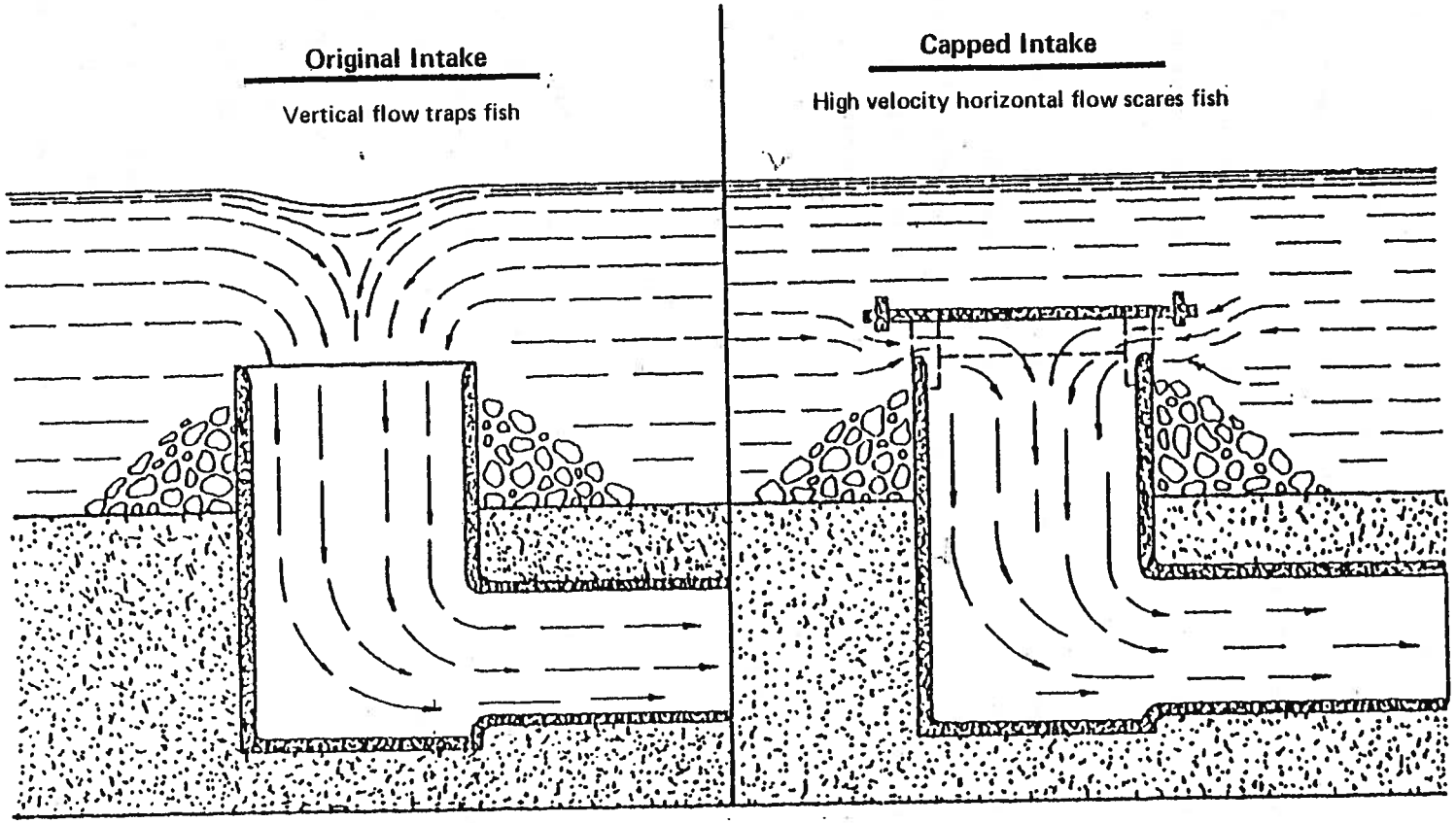

Figure D-4. Schematic representation of an offshore intake with velocity cap. (From Weight 1958.)

an experimental basis to include fine-mesh (0.02- to 0.1-in.; 0.5- to 2.5-mm) screen material, in an attempt to minimize the number of eggs and larval fish entrained into cooling water systems.

In the sections which follow, biological and engineering considerations associated with the use of various physical barriers at power plant intakes are reviewed. Discussions are based on a review of laboratory studies, prototype field studies, and actual operating experience at water intake and diversion structures. Alternative designs discussed include various media filters and infiltration systems, various fixed screen concepts, and various traveling screen designs. Qualitative conclusions are presented in Table D-2.

D.5.2.1 Rapid Sand Filters

The high-capacity rapid sand filter (infiltration gallery) has the potential to prevent entrainment, entrapment, and impingement of all species and life stages of fish in power plant cooling systems. Free flow across the filter surface and low approach velocity combine to eliminate potential fish kills and the need for handling and disposal of debris. These filter systems, however, are plagued by operational problems, primarily those associated with clogging of the filter media. As a result of these operational problems, filters have had limited use at power plant intake structures.

The Montour Steam Electric Generating Plant, located on the Susquehanna River, Pennsylvania, utilized a filter bed designed to provide makeup cooling water at a rate of approximately 33,000 gpm (73 cfs; 2 m^3/sec). Filter operation was considered to be unacceptable as a result of the clogging of the filter media by algae and fine sediments. Despite several modifications to the original design, the operational reliability of the filter was considered unacceptable, and its use was discontinued. The filter bed intake was replaced by a perforated pipe intake design.

The feasibility of using a filtration bed as a cooling water intake structure in the marine environment was examined by Stober et al. (1974) and Strandberg (1974). It was concluded that a filter intake system is an effective means of excluding pelagic eggs and larval fish from power plant cooling systems. However, the present technology is not considered to be sufficiently developed to allow reliable design and operation of filter intake systems.

TABLE D-2 SUMMARY OF EXPERIENCE WITH PHYSICAL BARRIERS FOR REDUCING ORGANISM LOSSES AT COOLING WATER INTAKES

Technology	Applicable to Once-Through	Applicable to Closed-Cycle	Reduces Entrainment	Reduces Impingement	Operationally Reliable	Comments
Rapid sand filter	○	●	●	●	○	Suitability limited to extremely low flow rates
Porous dike	Ex	Ex	Ex	Ex	Ex	Three-year field training program underway, 1979-1981
Radial well collector	○	●	●	●	○	Suitable for low flows; depends on geology, groundwater levels, and water quality
Stationary screen, perforated pipe, and plate	○	●	Ex	Ex	○	Possibly suitable where debris loading is light and biofouling minimal
Drum screen	○	○	○	?	●	Vertical type ineffective for subadult fish
Horizontal traveling screen	○	○	○	?	○	Mechanical performance under sediment load and varying water conditions unsatisfactory
Rotating disc screen	○	○	○	○	○	Limited non-power-plant application
Centerflow traveling screen	●	●	○	?	?	Requires increased screen-to-pump distance; irregular flow patterns
Vertical traveling screen	●	●	○	○	●	Impingement survival depends on design and operation parameters

Legend

● Demonstrated

? Inconclusive, conflicting or variable data

Ex Undergoing experimental studies, developmental stage

○ Demonstrated ineffective or no data

Low infiltration rates of media filters require large surface areas, approximately 10 acres (24.7 hectare) for every 1,000 gpm (2 cfs; 0.07 m^3/sec) of cooling water, which makes their application at many sites infeasible even when used to supply makeup water for closed-cycle cooling systems.

Operational problems and poor reliability of filter intake systems, as a result of clogging, siltation, and biofouling, make further consideration of this concept for use at power plant intakes unwarranted.

D.5.2.2 Porous Dike

A porous dike or leaky levee uses a filter medium of stone and gravel to exclude organisms from a cooling water system. Porous dikes are in the developmental stage and have not been used to date. The porous-dike concept is applicable for both shoreline and offshore intakes, may provide a behavioral and physical barrier for larval and juvenile-adult fishes, and eliminates the necessity of a fish return system. Operational reliability under actual field conditions and maintenance associated with biofouling, clogging, and sediment accumulation have not been determined.

Preliminary criteria for the design and use of a porous dike as an intake structure include the following:

1. the dike must be stable and resistant to erosion by water currents and wave action;
2. the size and composition of the medium must provide structural integrity, acceptable water flow rates, and exclusion of organisms;
3. the hydraulic efficiency must be high and biofouling and sediment accumulation low; and
4. the dike must not require excessive maintenance.

Hydraulic investigations of flow-through porous-dike structures have been conducted under laboratory conditions (Roberge 1978) and provide the basic foundation for the design of large-scale porous dikes. It was concluded from an engineering evaluation of porous-dike intake structures (Roberge 1978) that the concept is feasible, but long-term prototype testing under field conditions is required to develop a more complete understanding of the engineering feasibility and performance of a porous-dike intake.

The primary biological advantage of a porous dike is its effectiveness in excluding larval and juvenile fishes from the cooling water system. Schrader and Ketschke (1978) reviewed the biological aspects of porous-dike intake structures and concluded that a porous dike may act as both a behavioral and a physical barrier for larval and adult fish. Available information, however, is insufficient to determine its exclusion efficiency for various sizes and species of fish as a function of medium size and approach velocity; nor have the exclusion efficiency and survival of entrained fish eggs been determined for porous-dike intake structures.

A 3-year field testing program to determine the operation and maintenance, engineering performance, and biological effectiveness of a large-scale prototype porous dike is currently being considered. Testing would be conducted at the Brayton Point Steam Electric Station located on an estuarine portion of Narragansett Bay, Massachusetts.

No conclusions regarding the engineering feasibility or biological effectiveness of porous-dike intake structures can be made until data from the field testing program become available.

D.5.2.3 Radial Well Collectors

The radial well is a subterranean intake system that withdraws water from an aquifer or from an overlying water source such as a river or lake. Radial wells have been used to supply water for domestic and industrial usage and are planned to be used to supply cooling tower makeup water at several steam electric power plants. The maximum capacity of a typical radial well collector is approximately 55,500 gpm (124 cfs; 3.5 m^3/sec), which is insufficient to meet the demands of a once-through cooling system. Limitations in aquifer size, sediment permeability, and groundwater hydrology make it technically and economically impractical to build radial wells big enough to provide adequate water volume for once-through cooling.

Radial well collectors rely on induced infiltration through unconsolidated alluvial deposits; they furnish water that is typically low in turbidity and concentrations of suspended solids. In addition, because of the extremely large surface area associated with radial well collectors, the water velocity at the water body/sediment interface is extremely low, less than 0.0003 fps (0.01 cm/sec) (Mikels and Bennett 1978). The low velocities and positive physical barrier created by the substrate result in complete

exclusion of egg and larval fish and microzooplankton from the water being withdrawn. Thus, the radial well functions as an effective intake device for minimizing or eliminating the biological impact associated with either entrainment or impingement.

Engineering and operational considerations include the suitability of geological structures and groundwater hydrology of a particular site, sediment deposition, presence of iron bacteria, biological fouling, and accumulation of debris. Before a radial well collector can be considered acceptable for a specific site, the potential for depleting groundwater storage reserves, particularly during periods of drought, and the operational reliability of the intake system through the life of the power plant must be evaluated.

The radial well collector provides a biologically effective intake structure which eliminates entrainment and impingement. The use of radial wells, however, is limited to specific sites, because of substrate permeability and aquifer characteristics, and is limited to meeting small water demands comparable to the makeup water requirements for closed-cycle cooling. The limited capacity and siting constraints significantly limit the applicability of radial well collectors at power plant intakes.

D.5.2.4 Stationary Mesh Screens, Perforated Plates, and Pipes

Stationary screens have long been used in irrigation canals and industrial water intake systems. Debris accumulations on screen surfaces reduce water flow volume and the efficiency of these screen installations. Blockage of a stationary intake screen by impinged debris results in unacceptable operational reliability of stationary screens for use in once-through cooling water intakes.

Perforated plates and pipes provide a positive barrier for adult and subadult fish and have the potential for the protection of eggs, larvae, and juvenile fish (Maxwell 1973; Richards 1978). Perforated intakes, however, are not self-cleaning, and thus require backwashing and mechanical removal of debris; and biofouling and debris accumulations reduce reliability. Perforated pipe intake structures are being used to supply makeup water at several power plants, but perforated pipe has not been used for once-through cooling systems.

Stationary cylindrical screens are presently being considered for use in power plant cooling water intakes. Currently, one power plant, Big Sandy Generating Station in Louisa, Kentucky, uses four cylindrical screens, each 2 ft (0.6 m) in diameter and 9.8 ft (3 m) long, to provide cooling tower makeup water at a rate of 22.2 cfs (0.63 m^3/sec). The application of stationary cylindrical screens for once-through cooling system intakes is being evaluated (Key and Miller 1978; Cannon et al. 1979). Wedge-wire cylindrical screens are presently in the developmental stage and are not considered to be available technologies for application to once-through cooling water systems (Cada et al. 1979).

The design of stationary, submerged, cylindrical screens typically includes the use of a wedge-wire material. Wedge-wire screen is manufactured by welding wire of triangular cross-sections to a support structure (Figure D-5). Wedge-wire screen is generally constructed with slot widths ranging from 0.01 to 0.1 in. (0.25-2.5 mm) and offers 20-35 percent open area for water passage. This design results in a smooth screen surface and screen openings that widen inwards, facilitating screen cleaning (backwashing) and increased hydraulic efficiency (Cook 1978). The cylindrical screen configuration, which promotes radial flow into the screen, and the use of wedge-wire screen material are expected to reduce screen clogging from impinged organisms and debris.

A typical intake system with stationary, completely submerged, cylindrical screens is shown in Figure D-6. The cylindrical screens can be used individually, in pairs, or in a manifold design to provide the necessary cooling water volume. The fish protection potential of a cylindrical wedge-wire screen depends on the location and orientation of the screen with respect to ambient water currents, on the size of the screen openings, and on the through-screen velocity. The absence of a confining screenwell which may entrap organisms and the design of screens with through-screen velocities less than 0.5 fps (15 cm/sec) serve to reduce the numbers of organisms entrained and impinged.

Biological data on the potential effectiveness of cylindrical screens using wedge-wire screening to minimize entrainment and impingement are limited to prototype flume experiments conducted by Hanson et al. (1978). The entrainment and impingement of fish of various sizes (eggs, larvae, and subadults) on screen cylinders 1 ft (0.3 m) in diameter and 2 ft (0.6 m) long, made up of wedge-wire screen with slot widths ranging from 0.01 to 0.04 in. (0.25-1.0 mm) was tested.

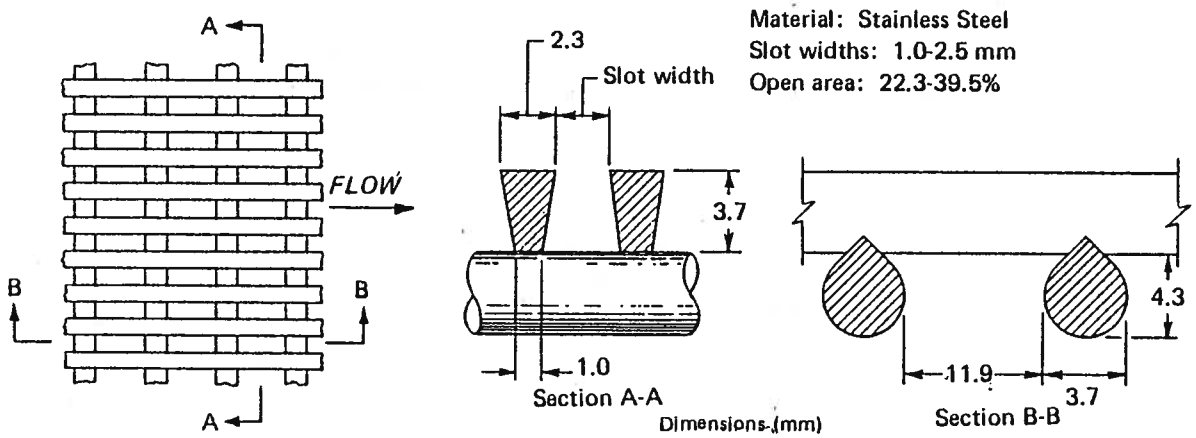

Figure D-5. Characteristics of flat wedge-wire screen panels used in the TVA hydraulic test. (From Cada et al. 1979.)

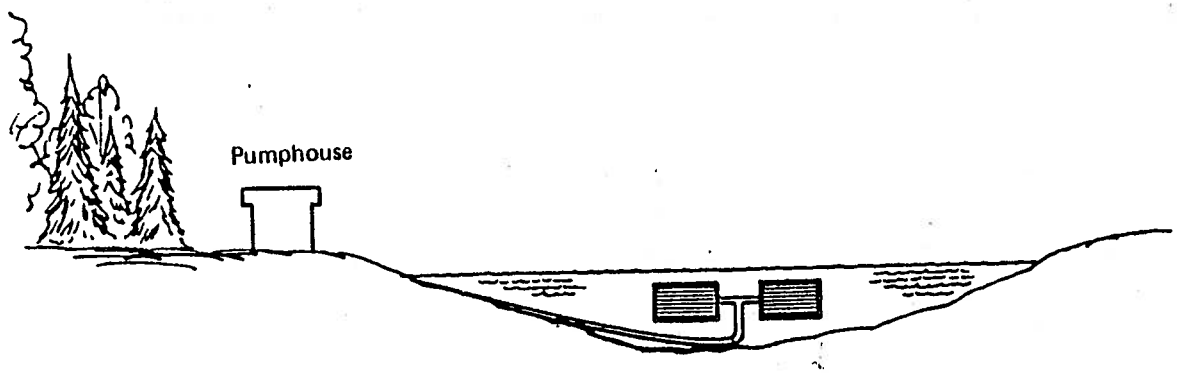

Figure D-6. A design concept for cylindrical wedge-wire screens at power plant cooling water intakes. (From Cada et al. 1979.)

Through-screen velocity was 0.5 fps (15 cm/sec) and channel velocity ranged from zero to 2.6 fps (79 cm/sec). Results of these experiments indicate that (1) impingement of fish larger than 0.6 in. (15 mm) in fork length was virtually eliminated on screens with 0.02-in. (0.5-mm) slot width; (2) fish 0.5-0.7 in. (12-17 mm) in fork length which were impinged on the screen showed excellent ability to escape impingement; (3) less than 0.1 percent of the striped bass eggs tested were entrained through screens with slot widths of 0.01-0.02 in. (0.25-0.5 mm); (4) mortality of striped bass eggs impinged on 0.02-in. (0.5-mm) wedge-wire screen for 0.5-2 minutes ranged from 0 to 11.9 percent and averaged 1.4 percent for all tests. These results suggest that cylindrical wedge-wire screens offer a potentially effective means of reducing impingement and entrainment losses at power plant cooling water intakes. A cylindrical wedge-wire screen 3.3 ft (1 m) in diameter and 9.8 ft (3 m) long with slot widths of 0.04 in. (1 mm) is currently being field tested (Ecological Analysts 1979) to evaluate the potential effectiveness of this screen concept for reducing fish entrainment under operating conditions.

Primary engineering concerns for stationary cylindrical wedge-wire screens focus on maintenance and operational reliability of the intake, which are influenced by the extent and frequency of debris clogging and biofouling accumulation on the screen surface. Each cylindrical screen must be equipped for either air-burst or hydraulic backwashing to remove accumulated debris. An ambient water velocity past the screen greater than the through-screen velocity promotes self-cleaning. The significance of a tangential velocity component across the screen to minimize clogging is discussed by Hanson et al. (1978); the problem of removing biofouling organisms from screens in brackish water or marine environments is described by Key and Miller (1978). The effects of clogging and biofouling on the operational reliability of stationary cylindrical screens must be extensively investigated, especially for intakes sited in the marine environment or in areas of heavy detrital loading, before they can be used in once-through power plant cooling water intakes.

The design and operation of stationary screening systems have been established in many small industrial applications. Stationary screening systems such as the wedge-wire cylindrical screen have only recently been applied to power plant intakes. Field and laboratory testing is underway to establish the biological effectiveness of stationary screens and to refine engineering design criteria for screen location, orientation,

through-screen velocity, and mesh opening size. Operational reliability, screen clogging and biofouling, and maintenance requirements for stationary screens sited in fresh and salt water need to be determined. The operational reliability of stationary screen intakes for once-through cooling systems has not been demonstrated.

D.5.2.5 Drum Screens

Vertical drum screens have been used for fish diversion in irrigation canals, and in British steam electric stations for the protection of salmonids, with variable success (Eicher 1974). Vertical drum screens having diameters of approximately 9.8 ft (3 m) are commonly aligned in rows leading to a bypass channel. Screen rotation carries impinged fish toward the bypass and provides self-cleaning of debris. Vertical drum screens provide a positive barrier for adult and subadult fish, but do not appear to be capable of protecting eggs and larval fish. Fluctuations in water depth do not affect the performance of vertical drum screens.

Horizontal drum screens have been used for fish diversion in irrigation facilities, power plants, and hydroelectric projects, as discussed by Maxwell (1973), Eicher (1974), and Mayo (1974). These well-developed and proven screens provide a positive barrier for adult and subadult fish, but do not protect fish eggs or larvae. The screen surface is cleaned through screen rotation, but screen rotation is detrimental to impinged fish if no bypass facility is provided. Diversion efficiency of horizontal drum screens is sensitive to fluctuating water levels.

Drum screens, although acceptable for use in intake structures of once-through power plant cooling systems, offer no biological or engineering advantages over conventional vertical traveling screens. Drum screens have not been utilized extensively in electric generating stations in the United States, partly because of problems associated with the carry-over of debris into the condensers, which reduces system reliability.

D.5.2.6 Horizontal Traveling Screens

The horizontal traveling screen (Figure D-7) developed by Bates (1969) has been proposed for fish diversion in canals, hydroelectric dams, irrigation intakes, and power plant intakes. Major attributes of the horizontal traveling screen concept include (1) formation of a complete physical barrier, (2) high diversion efficiency of juvenile

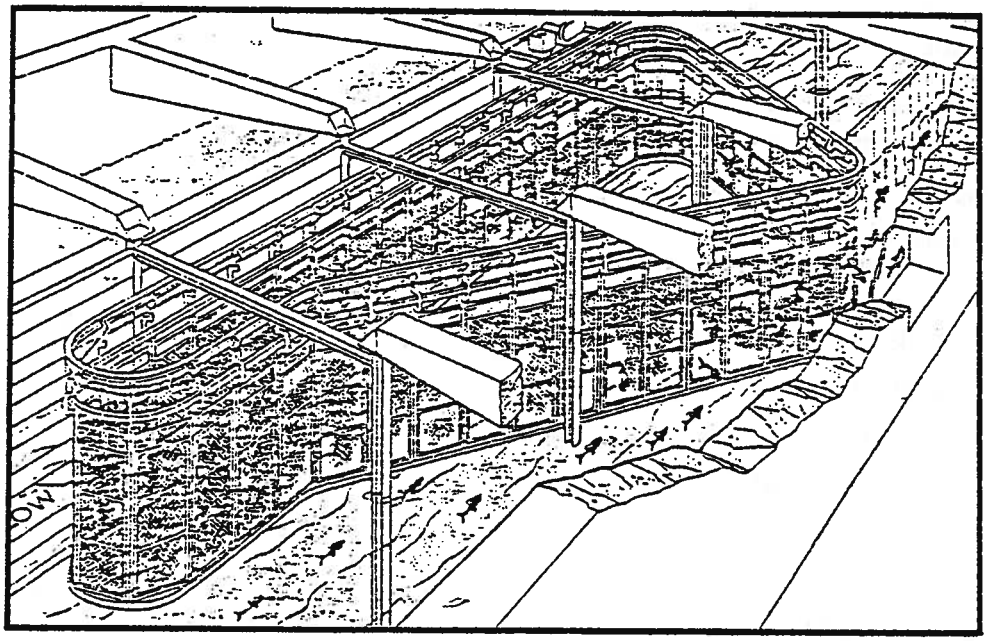

Figure D-7. Horizontal traveling screen. (Courtesy of Envirex.)

migrant fish, and (3) release of impinged fish into a bypass without passing the air-water interface. Operation of horizontal traveling screens is not greatly affected by fluctuations in water depth. The screen is self-cleaning, minimizing head loss, and is capable of operating under higher approach velocities than is normally possible with other types of screens. Research and development of the horizontal traveling screen has been reported by Bates (1969), Bates et al. (1970), Farr and Prentice (1974), and Prentice and Ossiander (1974).

Prentice and Ossiander (1974), studying 2.8-in. (70-mm) fingerling chinook salmon (Oncorhynchus tshawytscha), observed 98 percent diversion efficiency of a traveling screen aligned at an angle of 30° to a flow of 1.5 fps (46 cm/sec) under lighted conditions, and a 91 percent diversion efficiency under dark conditions. Diversion efficiency for 6.7-in. (170-mm) salmonids tested under similar conditions was 99.6 and 99.8 percent during day and night tests, respectively. No screen impingement was observed during these tests; 48-hour post-test survival exceeded 97 percent for all experiments.

Mechanical performance of horizontal traveling screens is not, at present, acceptable for continuous operation at a power plant intake. Prototype tests designed to examine mechanical operation and to assess performance limitations are discussed by Farr and Prentice (1974). Solutions to mechanical problems, resulting from suspended sediment and sediment bedload, have yet to be perfected.

Horizontal traveling screens appear to be effective in minimizing fish impingement but are not expected to reduce the number of organisms entrained into a cooling system. The lack of reliable operation of horizontal traveling screens, however, precludes any further consideration for their use in cooling water intake structures.

D.5.2.7 Rotating Disc Screens

Rotating disc screens have been used in both small irrigation diversions and municipal water supplies. No application of rotating disc screens in power plant intake structures has been reported. Rotating disc screens offer no biological or engineering advantage over conventional vertical traveling screens for use in cooling water intakes.

D.5.2.8 Centerflow Traveling Screens (Single-Entrance, Dual-Exit Traveling Screens)

The centerflow traveling screen represents a relatively new intake screening technology in the United States, although it has been utilized extensively in European industrial and electric generating facilities for almost three decades. Centerflow screens (Figure D-8) are oriented parallel to the approaching waterflow, and water enters through the center of the screen and exits through both vertical faces. Screen panels on centerflow screens are attached to a continuous drive chain and, unlike conventional vertical traveling screens, each screen panel forms a concave basket, increasing available screening surface area. Screen mesh sizes range from 0.02 to 0.4 in. (0.5-9.5 mm), with many units having 0.04- to 0.1-in. (1.0- to 2.5-mm) mesh. As a result of potentially rapid debris accumulation on the small mesh commonly used in centerflow screens, they are designed to operate with continuous screen rotation.

The hydraulic flow patterns associated with centerflow screens are more complex than those associated with vertical traveling screens. Water flows into the screen chamber through a keyhole-shaped opening in the front wall of the intake screen structure, turns 90° to flow through the screen mesh, and turns 90° to complete its transit to the circulating water pump. Effective screening occurs on both the ascending and descending sides of centerflow screens, thus increasing available screen surface area. As a result, average through-screen velocity of the centerflow screen is less than the approach velocity to the screen. However, through-screen velocities are highly variable across the screen face because of flow patterns and screen orientation; velocities tend to increase with distance downstream from the chamber entrance. The turbulent effect of the flow may negate potential benefits from reduced average through-screen velocities. The high velocities at the entrance to the screen may also serve as a behavioral barrier preventing the escape of fish entrapped within the screen structure.

Screenwash mechanisms are similar for both centerflow and vertical traveling screens. Spraywash pressures generally range from 50 to 100 psi. Debris and impinged organisms dislodged from the screens fall directly into a single sluiceway for return to the source water body. Fish-protection systems for centerflow screens, although not currently commercially available, may involve such modifications as installation of

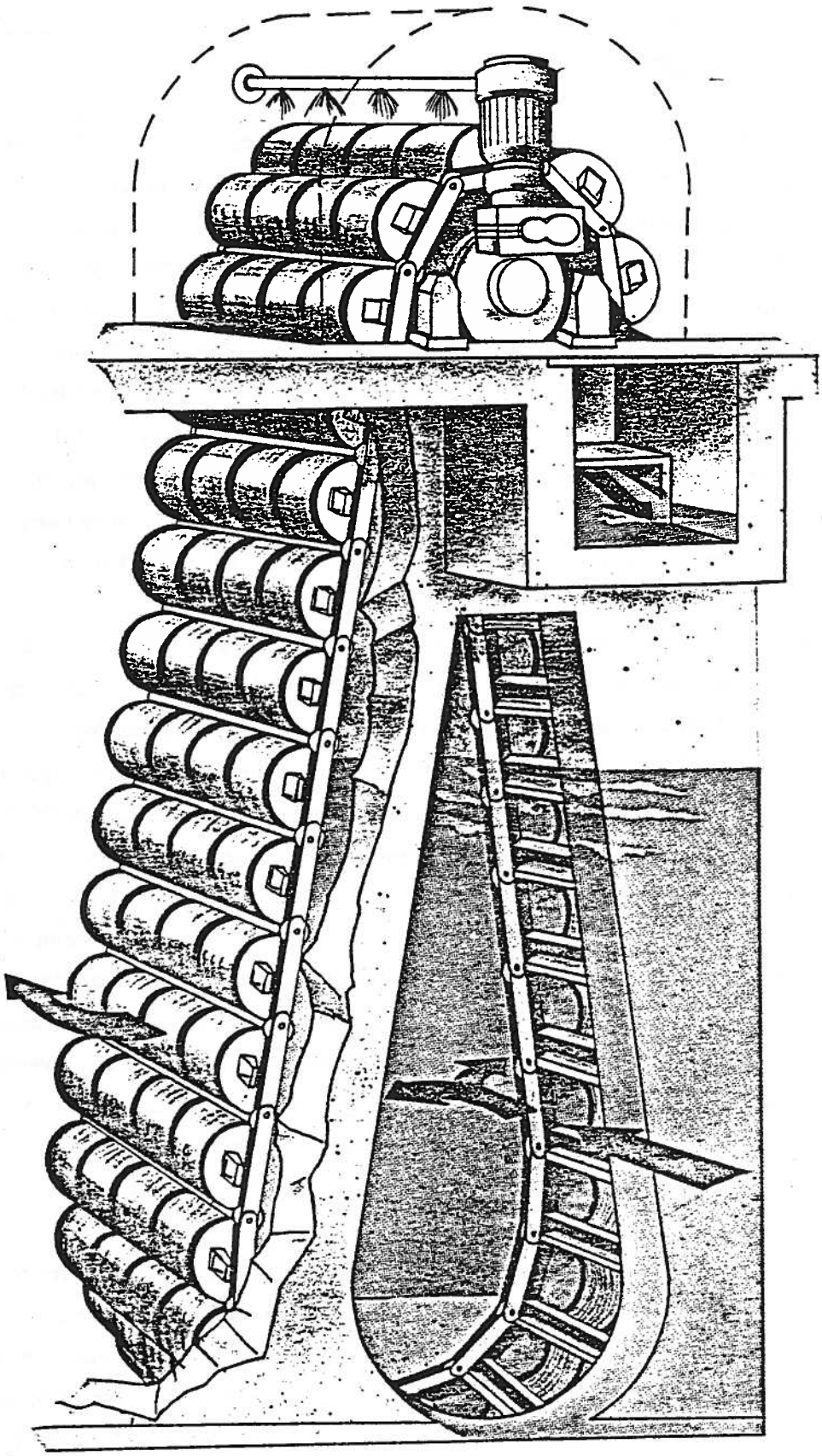

Figure D-8. Center-flow traveling screen. (Courtesy of the Passavant Corporation.)

watertight holding troughs at the base of each screen panel; installation of a low-pressure (10-20 psi) spraywash, and installation of an additional sluiceway to return impinged organisms to the source water body.

Murray and Jinnette (1978) examined the initial survival of organisms impinged on continuously rotating centerflow screens located at the Barney M. Davis Steam Power Plant, Corpus Christi, Texas. Initial impingement survival for 15 species of invertebrates and 37 species of fish was estimated to be 86 percent (10,406 individuals alive; 1,654 individuals dead) during the 12-month study. Impingement survival was found to vary among species and among months of the year. Lowest initial mortality for the dominant species by month occurred in February, when menhaden (mean standard length = 0.8 in. [21 mm]) experienced a 5 percent initial impingement mortality. Highest initial mortality for a dominant species by month occurred in June, when bay anchovy (mean standard length = 1.0 in. [25 mm]) experienced a 98 percent initial impingement mortality. No studies were performed to examine long-term survival of organisms impinged on centerflow screens.

Fine-mesh centerflow screens are being investigated in laboratory studies to determine their potential effectiveness for protecting larval fish at power plant intakes (Magliente et al. 1978). Field and laboratory studies are required to evaluate the initial and long-term survival of eggs and larval fish impinged on fine-mesh centerflow screens. Insufficient data preclude a detailed comparison of the potential survival of egg and larval fish impinged on modified vertical traveling screens (fine-mesh screen material, fish buckets, low-pressure spraywash, continuous rotation) and centerflow screens (fine-mesh screen material, continuous rotation).

Centerflow screens require increased screen-to-pump distance over that required for conventional vertical traveling screens. This may make a screen retrofit of an existing intake infeasible because of space limitations. Irregular velocity patterns, turbulence, and attendant head losses are inherent with the waterflow patterns for the centerflow screen. Highest water velocities occur in the entrance area of centerflow screens and could contribute to fish entrapment. Within the screen chamber, velocity varies irregularly as it changes direction, resulting in nonuniform flow through the screening surface. Use of average approach and through-screen velocities for centerflow screens is thus an inappropriate and misleading design parameter. The turbulence associated with centerflow screen systems was examined by Alden Research

Laboratory (1974), who found that circulating water pump performance was adversely affected by flow irregularities if screen-to-pump distances were too short or baffling was inadequate.

Operating and maintenance experience with centerflow screens in the United States is limited to one installation, the Barney M. Davis Steam Power Plant, where centerflow screens have been in use since 1974. Originally, a 0.02-in. (0.5-mm) polyester mesh screening material was used on these screens. However, the polyester screen material fatigued and subsequently failed during operation and was replaced with a nylon mesh material with 0.04-in. (1.0-mm) openings which is giving satisfactory performance. Other than operational problems encountered during start-up of the centerflow screens, routine maintenance has been described as nominal (P. Benes, Passavant Corp., 1978, personal communication). Details of operating and maintenance experience for centerflow screens outside the United States are unavailable.

Several alternative design configurations for the centerflow screen concept have been proposed in an attempt to minimize the probability of organisms becoming entrapped within the screen structure. In addition to the single-entrance/dual-exit design shown in Figure D-8, there is a double-entry/single-exit design in which water enters the screen from two sides and passes out through one end. This design can be located either within a screenwell or supported from a platform with no confining concrete housing (Figure D-9). A double-entry/double-exit screen design has also been proposed. To date, biological and engineering data are not available to compare the relative effectiveness of these alternative screen configurations.

It can be concluded from available information that centerflow screens represent an acceptable intake screening technology for proposed units based on a consideration of engineering performance, operational reliability, and maintenance. Retrofit installation of centerflow screens into an existing intake structure would require extensive modification of the intake, and may adversely affect the performance and reliability of circulating water pumps; centerflow screens do not offer any major biological advantages over conventional vertical traveling screens. Significantly increased impingement survival has not been satisfactorily demonstrated for these systems.

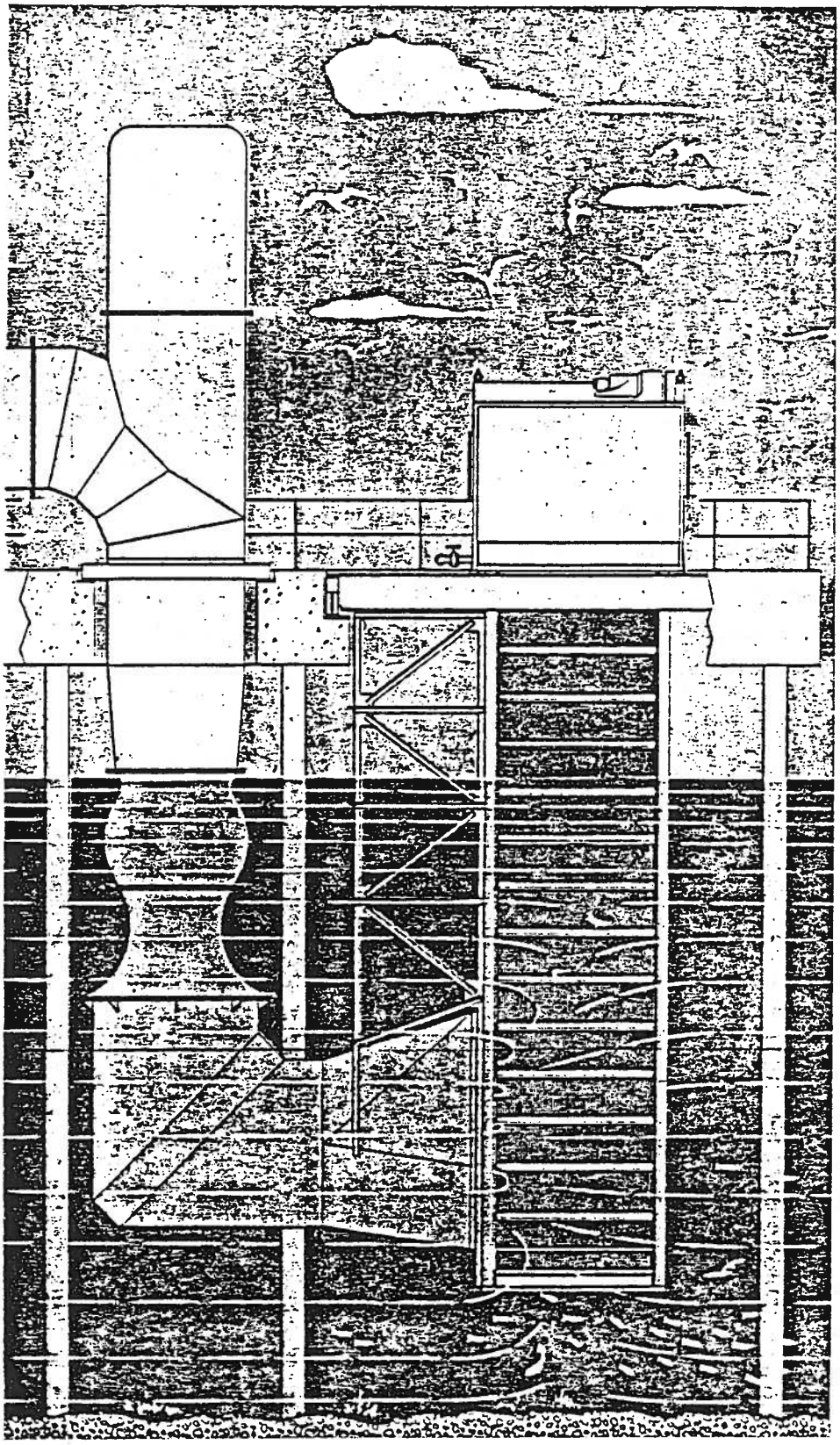

Figure D-9. Double-entry/single-exit screen. (Courtesy of FMC Corporation.)

D.5.2.9 Vertical Traveling Screens

The conventional vertical traveling screen (VTS), the most commonly used intake screening device at power plants in the United States, is commercially available from a number of manufacturers in a wide range of lengths, widths, and materials. It consists of a series of screen panels attached to a chain drive, mounted vertically in a concrete structure which normally functions as the screenwell and circulating pump well (Figure D-10). A design recently proposed by Western LNG Associates (California Public Utilities Commission 1978) would put the vertical traveling screens, but not the circulating water pumps, in an offshore intake structure in the form of a caisson. Although in recent years modifications have been made to enhance the fish protection capabilities of the screens, their primary function is to prevent clogging of the condenser tubes. The screens are designed to remove particles whose diameters are more than one-half that of a condenser tube. In most situations, 3/8-in. (9.5-mm) mesh is used. The screens rotate intermittently, either at regular intervals of several hours or when debris buildup causes a predetermined pressure differential across the screen; most screens are not equipped to rotate continuously for extended periods of time. During rotation, debris is removed by a high-pressure (50-100 psi) spraywash and either returned to the source water body or transferred to trash bins for disposal.

D.5.2.10 Other Physical Barriers

A wide variety of physical barriers, in addition to those previously discussed, either have been or are currently being examined for their application to power plant intakes. Many of these alternative designs originated as intake structures for industrial or municipal water supplies, at irrigation water diversions, or in association with hydroelectric dams. There is an expanding effort to identify, design, and test the potential effectiveness of intake design concepts under laboratory conditions.

The most promising alternative intake design concept is the use of vertical traveling screens oriented at an angle to the intake flow and leading to a bypass. This design concept has been tested under laboratory conditions (Taft and Mussalli 1978) and was 100 percent effective in diverting alewife into a bypass. The angled-screen intake design is currently being incorporated into the intake structure design of several proposed and existing power plants. Field verification of the diversion efficiency of an

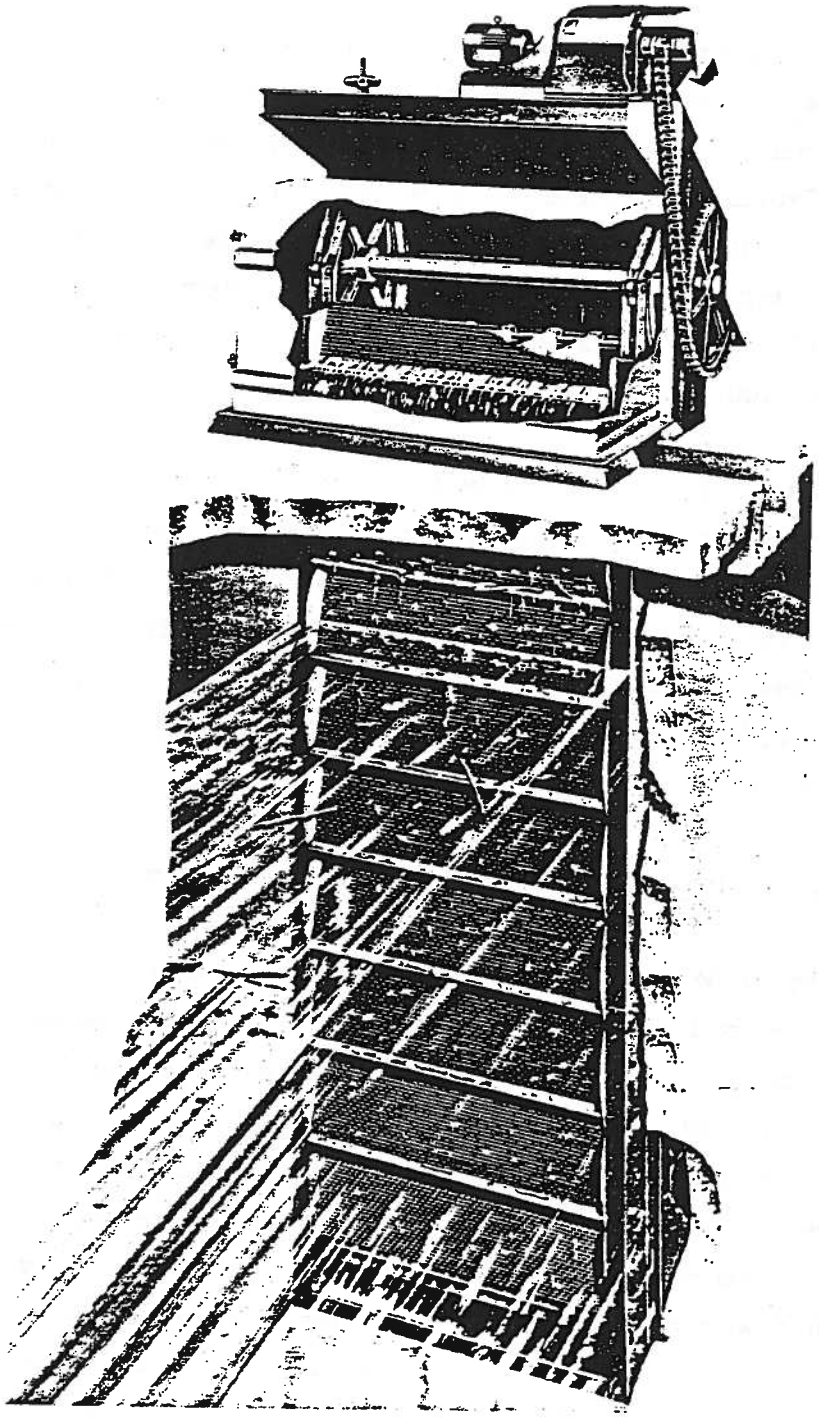

Figure D-10. Conventional vertical traveling screen. (Courtesy of Envirex.)

angled-screen intake under actual operating conditions is not yet available. Engineering performance and operational reliability under field conditions is unknown.

Attempts have been made to exclude fish from the area around an intake by encircling the intake area with netting. The netting is believed to form both a physical and behavioral barrier for fish. Results of field testing conducted to date have been inconclusive. Problems associated with debris accumulation on the net, the maintenance of the integrity of the net barrier especially in areas where bottom topography is irregular and following storms, and the hazard to navigation have not been adequately resolved. Net barriers are applicable only in lacustrine environments where currents are minimal.

Variations of intake designs previously discussed include the use of offshore louvers, a caisson offshore intake structure which is surrounded by vertical traveling screens, inclined traveling screens (conveyor screen), and "hump-back" screens. Sonnichsen (1975) discusses the development and use of many of these alternative designs. Few of these alternatives are generally applicable to power plant intake screening, but may have site-specific applicability depending on the biological characteristics and engineering requirements.

D.5.3 Fish Collection, Removal, and Conveyance Systems

Three basic approaches exist for designing fish return systems for use in association with a cooling water intake structure. The first approach relies on excluding organisms from the cooling system by use of an intake structure that minimizes or eliminates impingement and entrapment (e.g., radial wells, sand filters, porous dikes, submerged stationary cylindrical screens, perforated pipes), and therefore requires no fish return system. The second approach, use of fish return-conveyance systems, relies on impinging organisms for brief periods until they are mechanically transferred to a screenwash sluiceway for return to the receiving water body. The third approach, fish removal systems, relies on concentrating entrapped organisms within an intake structure and removing them by use of pumps, elevator baskets, or bypass channels.

The following sections review the design considerations, effectiveness, and application of fish return-conveyance systems and fish removal systems at power plant intakes. Intake structures which rely on exclusion of organisms rather than use of a return

system are discussed in Section D.5.2. Qualitative conclusions are presented in Table D-3.

D.5.3.1 Vertical Traveling Screen Fish Buckets and Accessories

Impingement survival of aquatic organisms depends upon a host of interrelated factors: the species, life-history stage, size, impingement time, stress, fatigue, hydraulic parameters, and debris loading. Impingement survival for some species has been improved by the incorporation of watertight collection buckets along the base of each screen panel to prevent repeated impingement of organisms and to provide a holding area for organisms during screen rotation (Figure D-11). In conjunction with this addition, a low-pressure wash system has been installed to remove impinged organisms from the screen and reduce the stress and abrasion from exposure to the high-pressure debris removal spraywash. A second sluiceway-fish return system was used to transport organisms back to the receiving water body. Continuous screen rotation has also been used to reduce stress on impinged organisms.

The modification of an existing vertical traveling screen to incorporate some of these features involves consideration of the specific intake structure and its performance. Potential problems include (1) alteration of the hydraulic characteristics of the intake structure which would influence the performance and reliability of circulating water pumps; (2) requirements for additional screen area to maintain acceptable approach velocities while providing adequate cooling water volumes; and (3) increased maintenance and reduced reliability resulting from screen clogging and continuous operation.

A dual spraywash system would require separate sluiceways for fish and debris, additional pumps, control mechanisms, piping, and an associated increase in maintenance costs. Installation of either watertight buckets on each screen panel or fine-mesh screen material would require reinforcement of structural supports to maintain structural integrity of the screen under increased static and dynamic loads. In the absence of extensive operating information for the modified screens, especially for those equipped with fine mesh, predictions of operation and maintenance problems that might influence reliability cannot be made with certainty.

King et al. (1978) compared the effects of different screen rotation frequencies and screenwash pressures on survival of fish impinged on conventional vertical traveling

TABLE D-3 SUMMARY OF EXPERIENCE WITH FISH COLLECTION, REMOVAL, AND CONVEYANCE SYSTEMS FOR REDUCING ORGANISM LOSSES AT COOLING WATER INTAKES

Technology	Enhances Impingement Survival	Reduces Impingement	Reduces Entrainment	Reduces Entrapment	Operationally Reliable	Comments
Vertical traveling screen, fish buckets, and accessories	●	○	○	○	●	Some larvae are subject to increased mortality through physical handling; debris-fish-larvae separation undeveloped
Fish pump	○	●	○	●	●	
Fish bypasses or escapes	○	●	○	●	●	Lateral fish escapes are an outgrowth of the Kerr (1953) studies
Fish basket collector	○	○	○	Ⓔx	Ⓔx	Possibly applicable when fish pumps are not
Sluiceway and pipeline return	?	○	○	○	?	Design parameters difficult to identify for biological effectiveness

Legend

●	Demonstrated
?	Inconclusive, conflicting, or variable data
Ⓔx	Undergoing experimental studies, developmental stage
○	Demonstrated ineffective or no data

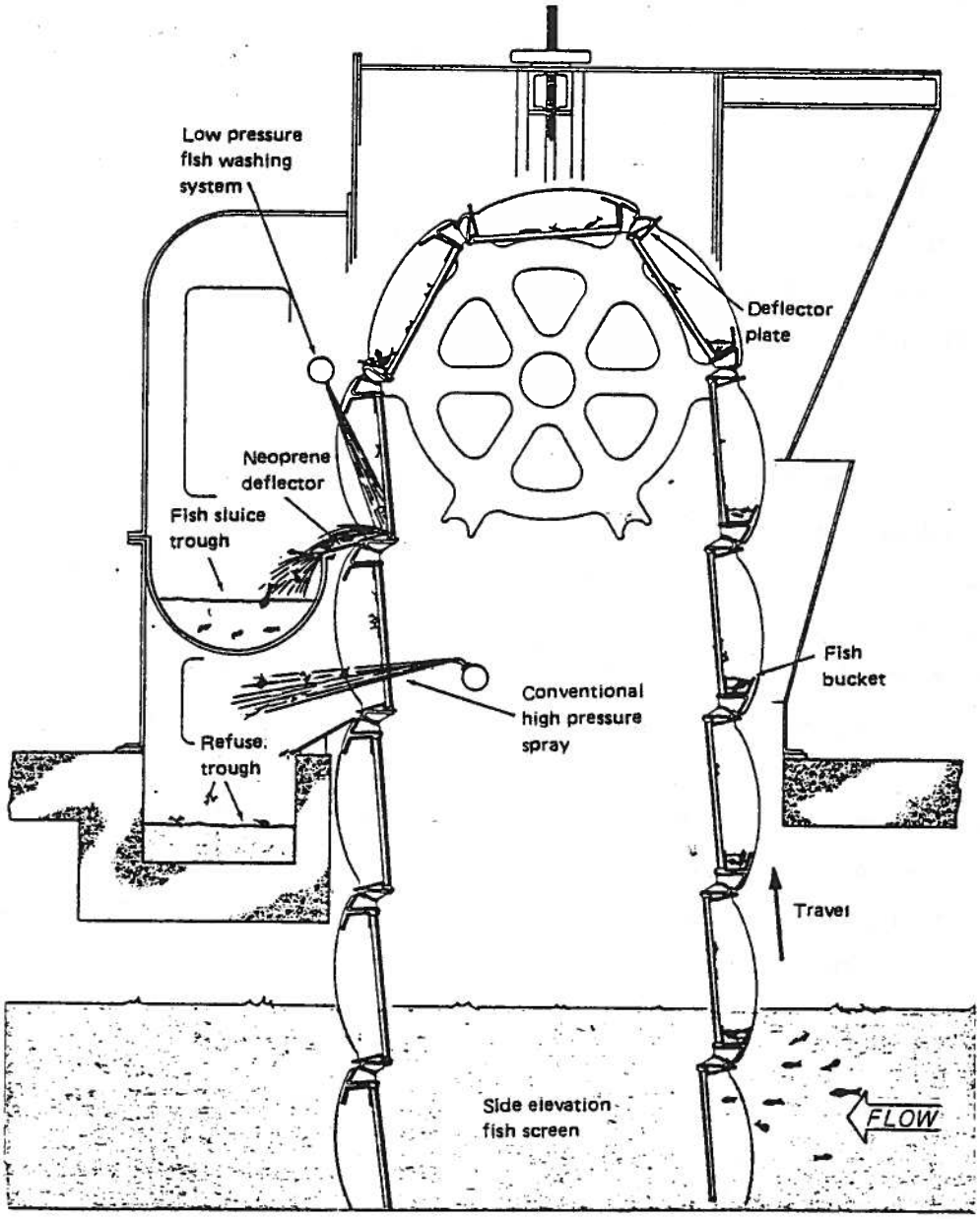

Figure D-11. Ristroph modified traveling screen with fish buckets, a modified spray water system, and a sluiceway for fish. (Courtesy of Envirex.)

screens at three power plants on the Hudson River (Table D-4). Continuous screen rotation resulted in better impingement survival for young-of-the-year white perch than screenwash at either 2- or 4-hour intervals (Figure D-12). Low-pressure screenwash sprays (50 psi) resulted in better initial and long-term (84-hour) survival of impinged white perch on several occasions, but the results of screenwash pressure studies were generally inconclusive.

White and Brehmer (1976) evaluated the initial survival of fish impinged on a modified vertical traveling screen, similar to that shown in Figure D-11, which has been in operation since 1974 at the Surry Power Station, James River, Virginia. Average initial survival for 58 species of impinged fish was 93.3 percent. Survival of impinged fish beyond the 15-minute holding and observation period was not determined.

The effectiveness of a low-pressure spraywash system in removing impinged fish from a modified vertical traveling screen was examined by Public Service Electric and Gas Company (1977, cited in Cannon et al. 1979) on modified screens installed at the Salem Nuclear Generating Station. The number of impinged fish washed into a fish return sluiceway by a low-pressure spraywash (15 psi) and those washed into a debris sluiceway by a high-pressure spraywash (100 psi) was determined. A total of 3,770 fish were collected, of which 23.3 percent were removed from modified traveling screens by the low-pressure spraywash. These results indicate that low-pressure spraywash systems may be ineffective in removing impinged fish from an intake screen. Additional development and evaluation of low-pressure spraywash systems is required, especially for intake screens subjected to high detrital loading or when large fish are expected to be impinged.

Impingement survival of juvenile chinook salmon on modified vertical traveling screens located on the Columbia River was reported by Page et al. (1976, 1978). Initial survival of impinged chinook salmon was 95.6 and 97.2 percent, respectively, in 1976 and 1977. Long-term (96-hour) survival of impinged chinook salmon in 1976 was 94.8 percent. Long-term survival was not reported for 1977. In addition, Page et al. (1978) estimated initial impingement survival of yellow perch fry to be approximately 92 percent. Additional information on the initial and long-term survival of a variety of fish species and sizes, impinged on modified vertical traveling screens under a variety of environmental conditions, is needed before the general effectiveness of intake screen modifications, designed to reduce impingement mortality, can be assessed.

TABLE D-4 IMPINGEMENT SURVIVAL OF JUVENILE WHITE PERCH UNDER VARIOUS CONVENTIONAL VERTICAL TRAVELING SCREEN OPERATIONAL MODES AND SCREENWASH PRESSURES AT THREE HUDSON RIVER POWER PLANTS DURING NOVEMBER AND DECEMBER 1976

Power Plant	Screen Operational Mode	Washwater Pressure (psi)	Survival (%)	
			Initial	Long-Term[a]
Roseton	Continuous	50	98	44
	Continuous	100	79	6
	2-hr intermittent	50	96	8
	2-hr intermittent	100	92	5
	4-hr intermittent	50	96	17
		100	71	0
Danskammer Point	Continuous	55-65	82	29
	2-hr intermittent	55-65	62	15
Bowline Point	Continuous	10-20	98	56
	Continuous	30-50	96	55
	2-hr intermittent	10-20	90	26
	2-hr intermittent	30-50	90	32
	4-hr intermittent	10-20	75	19
	4-hr intermittent	30-50	69	19

(a) Long-term survival at Roseton and Danskammer Point determined 84 hours after impingement; at Bowline Point, 96 hours after impingement.

Source: King et al. 1978.

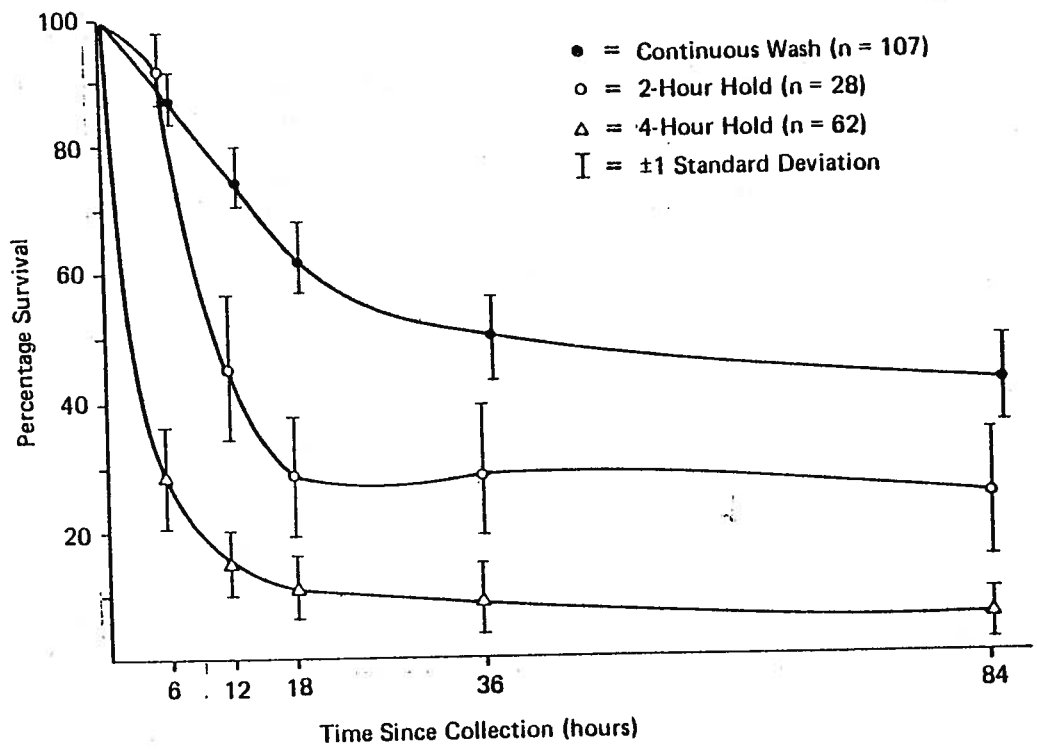

Figure D-12. Probability of surviving impingement for young-of-the-year white perch and adult Atlantic tomcod collected at the Danskammer Point Plant. (From King et al. 1978.)

Ecological Analysts (1979) has investigated the use of fine-mesh screen material (0.1-in. [2.5-mm] nylon mesh) in a vertical traveling screen tested under field conditions, in an effort to reduce the number of larval fish entrained into a power plant cooling system. It was concluded that early life stages of striped bass were not able to withstand the stresses imposed by impingement and collection. For larval striped bass (0.6 in. [15 mm] mean length) 96-hour survival was estimated to be 60 percent. For juvenile striped bass (0.8 in. [19 mm] or greater in length) survival is expected to exceed 75 percent.

The survival of entrained striped bass passing through the Indian Point Power Plant cooling system and survival of striped bass impinged on the 0.1-in. (2.5-mm) screen at the Indian Point cooling water intake were compared (Ecological Analysts 1979). It was concluded, based on the low retention and survival of eggs and smaller larvae impinged on the fine-mesh traveling screen, that fine-mesh screens would not be effective for reducing entrainment losses for these life stages. In addition, since the survival of larger larvae and juveniles following entrainment was comparable to that following impingement on the fine-mesh screens, selectively diverting these fish at the intake would not appreciably affect their survival.

Texas Instruments Inc. (1977) examined the survival of young-of-the-year and yearling fish impinged on a modified vertical traveling screen (low-pressure spraywash, dual-screenwash sluiceways, fish buckets) equipped with 0.1-in. (2.5-mm) nylon screen mesh. The vertical traveling screen was rotated continuously during the impingement survival studies. Of the 3,619 fish collected, bay anchovies, blueback herring, and white perch accounted for the majority. Mean initial survival of all species was 41 percent, and mean survival after 84 hours was 20 percent for all species. A summary of results for impingement survival of each species is presented in Table D-5. Species-specific survival patterns are apparent, with high long-term survival for species such as white catfish, white perch, and Atlantic tomcod and low survival for species such as bay anchovy and rainbow smelt.

Tomljanovich et al. (1978) have conducted a series of laboratory studies designed to examine factors influencing the retention and postimpingement survival of larval fish impinged on fine-mesh screen material. Four square-mesh screens ranging from 0.02 to 0.1 in. (0.5-2.5 mm) were tested; only the 0.02-in. (0.5-mm) screen provided 100 percent retention of larval fish tested. Postimpingement survival of larval fish was

TABLE D-5 INITIAL AND LONG-TERM IMPINGEMENT SURVIVAL OF YOUNG-OF-THE-YEAR AND YEARLING FISH IMPINGED ON A CONTINUOUSLY ROTATING FINE-MESH (2.5-mm) MODIFIED VERTICAL TRAVELING SCREEN (DATA FROM TEXAS INSTRUMENTS, INC. 1977)

Common Name	Scientific Name	Age Class[a]	Number Collected	Survival (%) Initial	Survival (%) 84-hour
Striped bass	*Morone saxatilis*	1	13	85	75
White perch	*Morone americana*	1	223	45	26
White perch	*Morone americana*	2	37	41	18
Atlantic tomcod	*Microgadus tomcod*	1	78	92	58
Atlantic tomcod	*Microgadus tomcod*	2	2	100	100
Blueback herring	*Alosa aestivalis*	1	509	93	19
Blueback herring	*Alosa aestivalis*	2	1	100	0
Bay anchovy	*Anchoa mitchilli*	1	2,415	25	1
Bay anchovy	*Anchoa mitchilli*	2	65	55	13
Alewife	*Alosa pseudoharengus*	1	107	69	6
American shad	*Alosa sapidissima*	1	4	100	0
Hogchoker	*Trinectes maculatus*	1	4	100	100
American eel	*Anguilla rostrata*	2	4	100	100
Banded killifish	*Fundulus diaphanus*	1	1	100	ND[b]
White catfish	*Ictalurus catus*	1	27	100	100
Spottail shiner	*Notropis hudsonius*	1	2	100	100
Sea lamprey	*Petromyzon marinus*	1	1	100	100
Largemouth bass	*Micropterus salmoides*	1	1	100	100
Yellow perch	*Perca flavescens*	1	1	100	100
Weakfish	*Cynoscion regalis*	1	3	67	67
Bluefish	*Pomatomus saltatrix*	1	4	100	0
Rainbow smelt	*Osmerus mordax*	1	20	10	0
Rainbow smlt	*Osmerus mordax*	2	4	25	0
Menhaden	*Brevoortia* spp.	1	1	100	ND
Gizzard shad	*Dorosma cepedianum*	2	5	100	0
Unid. clupeids	Clupeidae	1	80	51	ND
Centrarchids	Centrarchidae	1	5	100	100
Northern pipefish	*Syngnathus fuscus*	1	1	0	ND

(a) Age class: 1 = young-of-the-year; 2 = yearling or older.
(b) ND = no data.

Source: Texas Instruments, Inc. 1977.

shown to be inversely related to the duration of impingement, and dependent on species and size of fish tested and, to a lesser extent, on water velocity. The survival of larval fish at 48 hours, after impingement for 16 minutes, ranged from less than 1 percent for striped bass to 96 percent for bluegill and smallmouth bass.

Results of studies available to date suggest that the entrainment of larval fish through power plant cooling water systems can be virtually eliminated by use of 0.02-in. (0.5-mm) intake screen mesh. But survival of larval fish impinged on fine-mesh intake screens may be no higher than the survival of larval fish passing through a cooling water system (Cada et al. 1979), and survival on a fine-mesh screen that is operated in an intermittent screenwash mode or is subject to high detrital loads may be extremely low (Tomljanovich et al. 1977).

It can be concluded from available information that vertical traveling screens are an acceptable intake screening technology. The vertical traveling screen has demonstrated performance capability and an extensive and impressive history of operational reliability. Two major classes of modifications have been proposed for vertical traveling screens: (1) "fish buckets," a system of troughs and low-pressure sprays to minimize damage to impinged fish, and (2) fine-mesh screens, which impinge ichthyoplankton instead of entraining them. The merits of these modifications depend on the specific biological and engineering conditions at the particular plant where they are to be installed.

D.5.3.2 Fish Return Conveyance Systems

Fish return conveyance systems, which are generally used in association with vertical traveling intake screens, are simply an open or enclosed trough which returns organisms and debris removed from the intake screens to the receiving water body. The sluiceway troughs are typically made of concrete or steel and utilize either gravity-induced flow or a pumping system. The design of conveyance systems has not been standardized nor extensively studied, so they vary widely from one power plant intake to the next. The limited data available, on the relationship between conveyance system design and survival of organisms returned to the receiving water body, make it difficult to identify and quantify the effects of various design parameters on the biological effectiveness of conveyance systems. The difficulties in extrapolating generalization from one site to another at the present time are particularly important in

considering the design of a fish return conveyance system, which will be used with a fine-mesh intake screen for removing egg and larval fishes from the intake.

Cada et al. (1979) proposed a set of recommendations concerning fish return conveyance systems which can be expected to contribute to the survival of fish being returned to the water body:

1. maintain sufficient water levels and velocities to expedite return;
2. avoid hydraulic turbulence in the conveyance wherever possible;
3. prevent ice formation in the conveyance in cold weather;
4. maintain smooth surfaces in the conveyance;
5. enclose the conveyance to minimize avian predation;
6. consider multiple release locations to minimize predation at the outfall;
7. prevent re-entrapment and avoid thermal shock; and
8. separate debris sluiceways from fish sluiceways.

Because sluiceway and pipeline returns are usually part of a physical barrier technology and an intake design technology, their implementation must be considered on a site-specific basis.

D.5.3.3 Fish Pump Systems

Fish pump removal systems have been developed in response to entrapment problems in which fish are known to be concentrated in a confined area of the intake structure and are susceptible to removal using a pump system. The first application of a fish pump removal system at a power plant intake occurred at the Contra Costa Power Plant (Kerr 1953). Prior to installing the fish pump system, the behavioral response of fish to various pump collector (intake) designs was tested in various velocity gradients. Based on observations and tests, a zone of fish concentration between the vertical traveling intake screen and a curtain wall was located within the intake structure. The placement of a large intake collector (similar in design to the inlet of a vacuum cleaner) in a zone of fish concentration, in combination with low suction velocities, resulted in high diversion efficiency and survival of all species removed from the intake structure. Kerr (1953) estimated the survival of fish following passage through

the fish pump system to be greater than 98 percent. Recent studies of the Contra Costa fish pump system (Ecological Analysts, unpublished data) indicate that the number of fish impinged on the power plant intake screens is reduced by approximately 80-98 percent as a result of the fish pump removal system. Following passage through the fish pump, initial and latent (96-hour) survival of juvenile striped bass were approximately 100 percent and 85-95 percent, respectively (Ecological Analysts, unpublished data). Based on available data, it is apparent that the fish pump systems at the Contra Costa Power Plant effectively reduce the number of fish impinged while maintaining high survival of those fish returned to the receiving water body.

Other fish pump installations have had mixed success. Studies of the Monroe Nuclear Generating Station estimate removal efficiencies of 52-99 percent and gizzard shad survival of 10-99 percent (Cannon et al. 1979). Southern California Edison reports a lack of success at its Huntington Beach and El Segundo generating stations (Stipanov 1976).

Mussalli and Taft (1977, cited in Cannon et al. 1979) have investigated the use of jet pumps as an alternative to either single-port or dual-port centrifugal pumps for use in fish removal systems. Based on results of laboratory testing, a peripheral-type jet pump fish return system has been designed for inclusion into the intake structures of the Nine Mile Point Nuclear Station Unit 2 and Oswego Steam Station Unit 6, both located on Lake Ontario.

From the available data, it is apparent that fish pump return systems may substantially reduce the entrapment and impingement of fish at many cooling water intake structures. However, data are insufficient to evaluate the conflicting nature of many of the findings. Additional research is needed to identify the specific behavioral responses of fish, which can be used to concentrate organisms within a confined area of an intake structure, and the design parameters for a fish pump system which will minimize fish mortality during removal from an intake.

D.5.3.4 Fish Basket Collectors

Fish basket collectors were developed for use in intake structures where fish pump return systems had not been effective. Fish basket collectors are designed to allow

fish to congregate in an area directly over the collection basket, which can then be raised to capture and return the entrapped fish to the receiving water body.

Testing of fish basket collectors has been conducted at the Alden Laboratory (Stone & Webster Engineering Corporation 1975) and at the Redondo Beach test facility of the Southern California Electric Company (Schuler and Larson 1975). In both series of tests, a fish basket collector provided acceptable removal of fish. A full-scale fish basket collector has been developed for use at the San Onofre Nuclear Generating Station. To date, however, no operating experience is available on the effectiveness of fish basket collectors at power plant intakes.

Fish basket collectors are not expected to be effective for all species and sizes of fish. In addition, the hydraulic conditions within an intake structure, debris loading, and the configuration and design of an intake structure are expected to influence the effectiveness of fish basket collectors for removing entrapped fish. Fish basket collector systems are not generally applicable to shoreline intake structures.

D.5.3.5 Fish Bypasses and Escape Channels

Two intake structure configurations have been developed which provide bypasses or escape channels to minimize entrapment within the intake structure. A shoreline intake structure has been designed, and is currently in use at several power plants including the Pittsburg and Contra Costa power plants, in which the vertical traveling intake screens are located flush with the shoreline. In this shoreline intake configuration, concrete dividing walls between forebays have been eliminated and bar racks have been installed as a cage-type structure on both the front and lateral sides of the intake structure. The configuration allows a lateral flow of water across the face of the intake screens tending to guide entrapped fish away from the intake screens and out of the intake structure.

A second proposed intake structure configuration utilizes vertical traveling screens oriented at an angle to the inflow of water (Section D.5.2.10). The angled intake screens are intended to divert entrapped fish laterally across the face of the screen and into a bypass channel. This approach combines the advantages of intake screening with the diversion capability typical of louver intake structures.

Results of prototype testing (Taft and Mussalli 1978) indicate that high diversion efficiencies and survival rates for fish diverted by angled screens are possible. At present, however, no full-scale tests have been conducted to evaluate the efficiency of angle intake screens under field operating conditions.

One aspect of the use of angled screens to divert fish into a bypass which requires detailed consideration is the hydraulic flow pattern associated with the bypass. Concentration of fish in a bypass channel requires a nonturbulent flow in order to guide fish into the bypass. Backflows, eddies, and rapid changes in velocity of the water approaching a bypass will stimulate avoidance responses in fish, which interfere with their transit past the intake screens and into the bypass. A gradual acceleration of flow in the direction of the bypass provides the optimal hydraulic conditions for fish diversion (Taft et al. 1976).

The shoreline intake structure with fish escape channels has demonstrated performance at power plant intakes. The angled-screen diversion appears promising based on prototype evaluations; however, full-scale operation under field conditions is needed to confirm the effectiveness of diverting entrapped fish. The use of fine-mesh screen material on an angled-screen diversion may be effective in diverting larval fish, but no data are currently available. Angled-screen diversions are applicable for use in either offshore intake structures with a fish return system, or in shoreline intake structures.

D.6 INTAKE MAINTENANCE AND OPERATION

Operational modifications of power plant cooling systems to reduce entrainment and impingement losses focus on reducing the exposure of organisms to physical, chemical, and thermal stresses.

Physical stresses result when an organism is impinged on intake screens or when an entrained organism is exposed to shear and pressure forces or mechanical abrasion during cooling system transit. Physical stresses can be reduced by maintenance dredging in front of the intake to keep approach velocities low, or by reducing the volume of cooling water used. Cooling water volume reduction can generally be achieved by either limiting the operation of circulating water pumps or by complete curtailment of cooling system operation and thus, also, electrical generation. At the present time,

insufficient data are available to specify design parameters for cooling system components such as circulating water pumps which can assure minimization of the physical stress on entrained organisms.

Chemical stresses on entrained organisms result primarily from exposure to biocides used in cooling systems to control biological fouling. Operational modifications to reduce chemical stresses on entrained organisms focus primarily on minimizing the frequency, duration, and concentration of chemicals used for biofouling control.

Thermal stresses on entrained organisms result from exposure to elevated temperatures in the condensers and cooling water discharge. Operational modifications to minimize thermal stresses on entrained organisms focus on minimizing the temperature elevation (delta-T) and time of exposure during cooling system transit.

Qualitative conclusions are presented in Table D-6.

D.6.1 Dredging

Sediment transport, sediment deposition, and littoral drift are frequently encountered in the vicinity of an intake structure. Such deposition increases approach velocities. Dredging probably represents the simplest and most cost-effective means of minimizing physical stresses on aquatic organisms by ensuring that design velocities are maintained and uniformity of velocity gradients is maximized.

D.6.2 Reducing Circulating Water Flows

Reduction in the number of circulating water pumps in operation has been suggested as an operational strategy for reducing cooling water volume and intake approach velocities and hence reducing the rate of entrainment and impingement. A reduction in cooling water flow rate during full-load generation is expected to result in losses in both generation capacity and thermal transfer efficiency with more significant losses occurring at higher ambient inlet water temperatures. Changes in condenser backpressure resulting in reduced turbine cycle thermal efficiency, and increased temperature differentials through the condenser system (delta-T) are expected when cooling water flow rates are reduced during generation. Although a reduction in cooling water volume is expected to result in a decrease in the number of entrained organisms, the

TABLE D-6 SUMMARY OF EXPERIENCE WITH MAINTENANCE AND OPERATIONAL MEASURES FOR REDUCING ORGANISM LOSSES AT COOLING WATER INTAKES

Technology	Reduces Physical Stress	Reduces Chemical Stress	Reduces Thermal Stress	Operationally Reliable	Requires Outage Time to Implement	Comments
Dredging in front of intake	●	○	○	●	NO	
Reducing circulating water flows	●	○	⊗	○	YES	Increases delta-T
Curtailing plant operation	●	●	●	⊗	YES	Produces no electricity
Establishing biofouling procedures	○	●	○	●	NO	
Modifying circulating water system	●	○	○	○	YES	No mechanical data
Lowering the temperature differential	○	○	●	○	YES	Retrofit of major plant systems (Section C.2.3)

Legend

● Demonstrated or expected improvement

○ No change or unknown

⊗ Demonstrated or expected deterioration

associated increase in delta-T may substantially reduce the survival of those organisms which are entrained.

The biological effectiveness of reducing entrainment and impingement losses by reducing the volume of cooling water withdrawn has not been extensively examined. Quantitative information is needed on the relative contribution of physical stresses and thermal stresses for each species and life stage being considered before the benefits of reduced losses resulting from reduced cooling water volume can be determined. Insufficient data are available to optimize the balance between cooling water volume and delta-T for most power plants and fish species.

The regulation of cooling system volume and delta-T becomes increasingly complex when a diverse array of species and life stages, each with individual and unique tolerances to physical and thermal stresses, are present at an intake simultaneously. In addition, during those periods when the delta-T and absolute discharge water temperature exceed the upper lethal limit for thermal tolerance of a species, it may be desirable to increase the volume of cooling water and thus decrease the discharge water temperature below a lethal limit. The alternative approach of reducing cooling water volume to a minimum and increasing the delta-T above a species thermal tolerance may result in an absolute increase in the total number lost to the population.

The biological complexities of cooling system operational modifications are compounded by engineering constraints. Many circulating water pumps do not have the capability to be throttled or regulated. In addition, reducing the volume of cooling water reduces the thermal efficiency of the cooling system, resulting in a decreased generating capacity of the unit. Therefore, considerations of reduced generation in perspective with electrical demand are needed on a site-specific basis for a specific period of time.

Reducing the number of circulating water pumps in service when loads are low might reduce biological losses as well as operation costs. It would, however, reduce the ability of the unit to come up to full load, in proportion to the number of pumps turned off. Additional starts and stops would also increase the need for maintenance and the likelihood of motor failure in pumps not designed for intermittent use.

D.6.3 Curtailing Plant Operation

Entrainment and impingement losses of aquatic organisms at a power plant can be entirely eliminated by shutting down a particular unit or units. Cooling system curtailment, however, also results in curtailment of electrical generation, and hence involves cost implications, and a reduced system-wide capability for meeting electrical demand.

Cooling system curtailment may be feasible if the seasonal period of maximum abundance of a critical species is short and coincides with a period during the year when electrical generating capacity exceeds demands. The cost implications from loss of generation, electrical transmission from alternative sources, and availability of alternative sources of electricity (e.g., hydroelectric), must all be evaluated on a site-specific basis. Coordinating plant activities, such as scheduled outages for maintenance or refueling, with periods of high organism densities could also be considered.

Coordinating cooling system curtailment with periods of highest abundance of a critical species requires an ongoing biological monitoring program at each site to identify the period of maximum abundance. Coordinating scheduled outages with the temporal distribution of a particular species is also difficult in that outages require precise scheduling generally months in advance, while the temporal pattern of species abundance may not be as predictable as necessary.

The feasibility of utilizing cooling system curtailment to minimize biological losses must be examined on a site-specific and species-specific basis.

D.6.4 Biofouling Procedures

Schubel and Marcy (1978) have made the following biofouling recommendations for minimizing mortality associated with chemical stresses (most commonly from chlorine) during entrainment:

1. chlorinate intermittently;
2. reduce the concentration of free chlorine to the lowest possible level;
3. minimize transit time through the cooling system and thus exposure to the biocide; and
4. maximize the rate of dilution of the discharge water.

The use of alternative biocidal agents does not appear to be an effective method of minimizing mortality of nontarget entrained organisms. Mechanical fouling control techniques have not proven to be completely effective in controlling fouling accumulations in power plant cooling systems. An antifouling coating, Dupont's "no foul," is being tested for use in cooling water intakes by a number of utilities.

D.6.5 Modifying Cooling Water System Components

Structural modification of cooling system components in an attempt to reduce the mortality of entrained organisms is not effective at the present time. Insufficient quantitative data are available to isolate specific sources of mortality within a cooling water system. Design parameters for specifying pressure regimes, circulating water pump design and operation (e.g., rpm, impeller design), tolerable shear stresses, and cooling system designs for minimizing mechanical abrasion have not been developed.

Structural modifications have focused on the design and operation of intake structures, with particular emphasis on intake screening systems, which will reduce stresses imposed on impinged organisms (Section D.5.2). To date, greater effort has been devoted to developing methods for excluding fish eggs and larvae from cooling systems than on developing specific criteria for structural modifications which would reduce stresses imposed on entrained organisms.

D.6.6 Regulation of Thermal Elevations (delta-T)

To minimize mortality of entrained organisms resulting from thermal stress, Schubel and Marcy (1978) recommend that a once-through cooling system be operated in such a way that:

1. the minimum delta-T is used that is technologically practicable based on cooling system design and load;
2. transit time through the cooling system is minimized; and
3. the cooling water is discharged in a way that will promote rapid mixing and dilution.

Regulation of thermal elevations requires the integration of information on plant generating loads and delta-T, and species- and size-specific thermal tolerance data for

evaluating the effectiveness of various cooling system operating modes for reducing entrainment losses.

D.7 REFERENCES

Alden Research Laboratory (ARL). 1974. Hydraulic model study, Beloit-Passavant traveling screen, circulating water pump structure. Prepared for Long Island Lighting Company and Stone & Webster Engineering Corporation. Rep. 70-74/M10RF. ARL, Holden, Mass.

Alevras, R. A. 1974. Status of air bubble fish protection system at Indian Point Station on the Hudson River, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 289-291. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Applegate, V. C., P. T. Macy, and V. E. Harris. 1954. Selected bibliography on the applications of electricity in fishery science. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 127. 55 pp.

Bates, D. W. and R. Vinsonhaler. 1957. Use of louvers for guiding fish. Trans. Am. Fish. Soc. 86:38-57.

Bates, D. W. and S. G. Jewett, Jr. 1961. Louver efficiency in deflecting downstream migrant steelhead. Trans. Am. Fish. Soc. 90(3):336-337.

Bates, D. W. 1964. Exploratory research on guiding juvenile salmon, in U.S. Bur. Commer. Fish., Fish-Passage Research Program, Review of Progress 1964, vol. III. Seattle, Wash.

Bates, D. W. and J. G. VanDerwalker. 1964. Exploratory experiments on the deflection of juvenile salmon by means of water and air jets, in U.S. Bur. Commer. Fish., Fish-Passage Research Program, Review of Progress 1964, vol. III. Seattle, Wash.

Bates, D. W. 1969. The horizontal traveling screen, in Engineering aspects of thermal pollution. Proceedings of the National Symposium on Thermal Pollution, Nashville, Tennessee, August 14-16, 1968 (F. L. Parker and P. A. Krenkel, eds.), pp. 225-242. Vanderbilt University Press, Nashville, Tenn.

Bates, D. W., E. W. Murphey, and E. F. Prentice. 1970. Design and operation of a cantilevered traveling fish screen (model V), in Preliminary designs of traveling screens to collect juvenile fish, pp. 6-15. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 608.

Benes, P. 1978. Personal communication. Passavant Corporation, Birmingham, Ala.

Bibko, P. N., L. Wirtenan, and P. E. Kueser. 1974. Preliminary studies on the effects of air bubbles and intense illumination on the swimming behavior of the striped bass (Morone saxatilis) and the gizzard shad (Dorosoma cepedianum), in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 293-304. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Brett, J. R. and D. MacKinnon. 1953. Preliminary experiments using lights and bubbles to deflect migrating young spring salmon. J. Fish. Res. Board Can. 10(8): 548-559.

Brett, J. R. and D. F. Alderdice. 1958. Research on guiding young salmon at two British Columbia field stations. Bull. Fish. Res. Board Can. 117. 75 pp.

Burner, C. J. and H. L. Moore. 1962. Attempts to guide small fish with underwater sound. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 403. 30 pp.

Cada, G. F., J. B. Cannon, and D. W. Lee. 1979. Alternative screening devices at Indian Point Units 2 and 3, Bowline Point, and Roseton generating stations. Testimony prepared for Hudson River NPDES case before the U.S. Environmental Protection Agency, Region II. EPA Docket No. C/II-WP-77-01.

California Public Utilities Commission. 1978. Decision against Application 57626. Joint Western LNG Terminal Associates, Pacific Gas and Electric Company, and Pacific Lighting Service application to construct and operate a LNG terminal at Point Conception. Filed 14 October 1977. Interim Order No. 89177. Decision date 31 July 1978.

Cannon, J. B., G. F. Cada, K. K. Campbell, D. W. Lee, and A. T. Szluha. 1979. Fish protection at steam-electric power plants: alternative screening devices. Prepared for the U.S. Nuclear Regulatory Commission, Division of Site Safety & Environmental Analysis, and the U.S. Environmental Protection Agency, Region II. Contract No. W-7405-eng-26. Oak Ridge National Laboratory, Oak Ridge, Tenn. 138 pp.

Clay, C. H. 1961. Design of fishways and other fish facilities. Department of Fisheries of Canada, Ottawa. 301 pp.

Cook, L. E. 1978. The Johnson screen for cooling water intakes, in Larval exclusion systems for power plant cooling water intakes. Proceedings of the workshop held at Shelter Island Inn, San Diego, California, February 7-8, 1978 (R. K. Sharma and J. B. Palmer, eds.), pp. 149-157. NUREG/CP-002, ANL/ES-66. Argonne National Laboratory, Argonne, Ill.

Ecological Analysts, Inc. (EA). 1979. Evaluation of the effectiveness of a continuously operating fine mesh traveling screen for reducing ichthyoplankton entrainment at the Indian Point Generating Station. Prepared for Central Hudson Gas & Electric Corporation, Consolidated Edison Company of New York, Inc., Orange and Rockland Utilities, Inc., and Power Authority of the State of New York. EA, Middletown, N.Y.

Eicher, G. J. 1974. Adaptation of hydro fish facilities to steam-electric stations, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 273-276. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Elliott, F. E. 1970. On the status of electric fishing. Mar. Technol. Soc. J. 4(1): 58-60.

Erkkila, L. F., J. W. Moffett, O. B. Cope, B. R. Smith, and R. S. Nielson. 1950. Sacramento-San Joaquin Delta fishery resources: effects of Tracy Pumping Plant and Delta Cross Channel. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 56. 109 pp.

Farr, W. E. and E. F. Prentice. 1974. Mechanical operation of horizontal traveling screen model VII, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 215-222. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Fields, P. E. 1966. Final report on migrant salmon light guiding studies (Contract No. D.A.-45-108 CIVENG-63-29) at Columbia River dams. U.S. Army Corps of Engineers, North Pacific Division, Fisheries Engineering Research Program, Portland, Or. 267 pp.

Fisher, F. W. 1978. Retention of young king salmon, American shad, and striped bass by perforated plate and woven wire screens. Calif. Dep. Fish Game, Anad. Fish. Branch Admin. Rep. 78-18. 19 pp.

Gerold, M. and K. Niggol. 1964. Comparative response of blinded and non-blinded fingerling salmon to a louver barrier and to a sharp increase in water velocity, in U.S. Bur. Commer. Fish., Fish-Passage Research Program, Review of Progress 1964, vol. III. Seattle, Wash.

Hanson, B. N., W. H. Bason, B. E. Beitz, and K. E. Charles. 1978. A practical intake screen which substantially reduces the entrainment and impingement of early life stages of fish, in Fourth National Workshop on Entrainment and Impingement (L. D. Jensen, ed.), pp. 393-407. Ecological Analysts, Melville, N.Y.

Heuer, J. H. and D. A. Tomljanovich. 1978. A study on the protection of fish larvae at water intakes using wedge-wire screening. Tennessee Valley Authority, Div. For. Fish. Wildl. Dev., Tech. Note B26. 60 pp.

Holmes, H. B. 1948. History, development, and problems of electric fish screen. U.S. Fish Wildl. Serv., Spec. Sci. Rep. 53. 62 pp.

Kerr, J. E. 1953. Studies on fish preservation at the Contra Costa Steam Plant of the Pacific Gas and Electric Company. Calif. Dep. Fish Game, Fish Bull. 92. 66 pp.

Key, T. H. and J. C. Miller. 1978. Preliminary studies on the operating aspects of small slot width wedgewire screens with conceptual designs for power station use, in Fourth National Workshop on Entrainment and Impingement (L. D. Jensen, ed.), pp. 385-392. Ecological Analysts, Melville, N.Y.

King, L. R., J. B. Hutchison, Jr., and T. G. Huggins. 1978. Impingement survival studies on white perch, striped bass, and Atlantic tomcod at three Hudson River power plants, in Fourth National Workshop on Entrainment and Impingement (L. D. Jensen, ed.), pp. 217-233. Ecological Analysts, Melville, N.Y.

Landry, A. M., Jr. and K. Strawn. 1974. Number of individuals and injury rates of fishes caught on revolving screens at the P. H. Robinson Generating Station, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 263-271. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Magliente, S. H., D. A. Tomljanovich, J. H. Heuer, S. Vigander, and M. N. Smith. 1978. Investigations on the protection of fish larvae at water intakes using fine-mesh screening. Impingement-release concept: laboratory study of a single-entrance, double-exit, vertical traveling screen concept, in Larval exclusion systems for power plant cooling water intakes. Proceedings of the workshop held at Shelter Island Inn, San Diego, California, February 7-8, 1978 (R. K. Sharma and J..B. Palmer, eds.), pp. 69-77. NUREG/CP-002, ANL/ES-66. Argonne National Laboratory, Argonne, Ill.

Maxwell, W. A. 1973. Fish diversion for electrical generating station cooling systems: a state-of-the-art report. Prepared for Florida Power and Light Company. Southern Nuclear Engineering, Inc., SNE-123. NUS Corporation, Dunedin, Fla. 78 pp.

Mayo, R. D. 1974. Conventional fish screening systems and some promising alternatives, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 277-279. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Mikels, F. C. and T. W. Bennett. 1978. Cooling water intakes utilizing Ranney collectors or Ranney intakes, in Larval exclusion systems for power plant cooling water intakes. Proceedings of the workshop held at Shelter Island Inn, San Diego, California, February 7-8, 1978 (R. K. Sharma and J. B. Palmer, eds.), pp. 15-25. NUREG/CP-002, ANL/ES-66. Argonne National Laboratory, Argonne, Ill.

Moore, H. L. and H. W. Newman. 1956. Effects of sound waves on young salmon. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 172. 19 pp.

Moulton, J. M. and R. H. Backus. 1955. Annotated references concerning the effects of man-made sounds on the movements of fishes. Maine Dep. Sea Shore Fish., Fish. Circ. 17. 7 pp.

Murray, L. S. and T. S. Jinnette. 1978. Survival of dominant estuarine organisms impinged on fine-mesh traveling screens at the Barney M. Davis Power Station, in Larval exclusion systems for power plant cooling water intakes. Proceedings of the workshop held at Shelter Island Inn, San Diego, California, February 7-8, 1978 (R. K. Sharma and J. B. Palmer, eds.), pp. 79-87. NUREG/CP-002, ANL/ES-66. Argonne National Laboratory, Argonne, Ill.

Mussalli, Y. G. and E. P. Taft. 1977. Fish return systems. Presented at the 25th Annual Hydraulics Division Speciality Conference of the American Society of Civil Engineers, August 10-12, 1977, at Texas A&M University, College Station.

Niggol, K. 1964. Response of juvenile migrants to flow accelerations, in U.S. Bur. Commer. Fish., Fish-Passage Research Program, Review of Progress 1964, vol. III. Seattle, Wash.

Oak Ridge National Laboratory and Atomic Industrial Forum, Inc. 1979. Impingement: an annotated bibliography. Interim report. EPRI EA-1050, ORNL/EIS-135. Electric Power Research Institute, Palo Alto, Calif. 193 pp.

Ohio Environmental Protection Agency (Ohio EPA). 1978. Guidelines for the submittal of demonstrations pursuant to Sections 316(a) and 316(b) of the Clean Water Act and Chapter 3745-1 of the Ohio Administrative Code. Ohio EPA, Division of Industrial Wastewater, Columbus. 55 pp.

Page, T. L., R. H. Gray, and D. A. Neitzel. 1976. Fish impingement studies at the Hanford Generating Project (HGP), December 1975 through April 1976. Report to Washington Public Power Supply System. Battelle-Northwest, Richland, Wash. 22 pp.

Page, T. L., D. A. Neitzel, and R. H. Gray. 1978. Comparative fish impingement at two adjacent water intakes on the mid-Columbia River, in Fourth National Workshop on Entrainment and Impingement (L. D. Jensen, ed.), pp. 257-266. Ecological Analysts, Melville, N.Y.

Prentice, E. F. 1966. Response of juvenile salmonids to four flow accelerator wedge geometrics. U.S. Natl. Mar. Fish. Serv., Northwest Fish. Center, Seattle, Wash. Unpublished.

Prentice, E. F. and F. J. Ossiander. 1974. Fish diversion systems and biological investigation of horizontal traveling screen model VII, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 205-214. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Public Service Electric and Gas Company. 1977. Impingement monitoring program—Salem Nuclear Generating Station Unit No. 1. Report 2. Docket No. 50-272.

Pugh, J. R. 1962. Effect of certain electrical parameters and water resistivities on mortality of fingerling silver salmon. U.S. Fish Wildl. Serv., Fish. Bull. 62:223-234.

Pugh, J. R., G. E. Monan, and J. R. Smith. 1964. Effect of water velocity on the fish guiding effectiveness of an electric field, in U.S. Bur. Commer. Fish., Fish-Passage Research Program, Review of Progress 1964, vol. III. Seattle, Wash.

Richards, R. T. 1978. Engineering considerations in the use of artifical filter beds, in Larval exclusion systems for power plant cooling water intakes. Proceedings of the workshop held at Shelter Island Inn, San Diego, California, February 7-8, 1978 (R. K. Sharma and J. B. Palmer, eds.), pp. 5-12. NUREG/CP-002, ANL/ES-66. Argonne National Laboratory, Argonne, Ill.

Rittenhouse, R. C. 1979. Power plant cooling systems: trends and challenges. Power Eng. 83(8):42-47.

Roberge, J. C. 1978. An engineering evaluation of porous-dike intake screening systems, in Larval exclusion systems for power plant cooling water intakes. Proceedings of the workshop held at Shelter Island Inn, San Diego, California, February 7-8, 1978 (R. K. Sharma and J. B. Palmer, eds.), pp. 37-50. NUREG/CP-002, ANL/ES-66. Argonne National Laboratory, Argonne, Ill.

Schrader, B. P. and B. A. Ketschke. 1978. Biological aspects of porous-dike intake structures, in Larval exclusion systems for power plant cooling water intakes. Proceedings of the workshop held at Shelter Island Inn, San Diego, California, February 7-8, 1978 (R. K. Sharma and J. B. Palmer, eds.), pp. 51-63. NUREG/CP-002, ANL/ES-66. Argonne National Laboratory, Argonne, Ill.

Schubel, J. R. and B. C. Marcy, Jr., eds. 1978. Power plant entrainment: a biological assessment. Academic Press, New York. 271 pp.

Schuler, V. J. 1974. Experimental studies in guiding marine fishes of southern California with screens and louvers, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 305-315. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Schuler, V. J. and L. E. Larson. 1975. Improved fish protection at intake systems. Proc. Am. Soc. Civil Eng., J. Environ. Eng. Div. 101(EE6):897-910.

Skinner, J. E. 1974. A functional evaluation of a large louver screen installation and fish facilities research on California water diversion projects, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 225-249. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Sonnichsen, J. C. 1975. Fish protective devices: a compilation of recent designs, concepts, and operating experience of water intakes used in the United States. Prepared for U.S. Energy Research and Development Administration. Contract No. AT(45-1)-2170. HEDL-TME 75-38, UC-79. Hanford Engineering Development Laboratory, Richland, Wash. 82 pp.

Stamets, L. 1977. Power plant cooling options for California. AID-20A. California Energy Resources Conservation and Development Commission, Alternatives Implementation Division.

Stipanov, J. A. 1976. Investigations into minimizing fish loss at steam electric generating stations, in Report of a workshop on the impact of thermal power plant cooling systems on aquatic environments, vol. II, pp. 198-218. Spec. Rep. 38. Electric Power Research Institute, Palo Alto, Calif.

Stober, Q. J., C. H. Hanson, and P. B. Swierkowski. 1974. A high capacity sand filter for thermal power plant cooling water intakes. Part I: model studies and fouling control techniques, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 317-334. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Stone & Webster Engineering Corporation. 1975. First progress report—Indian Point plume study. Prepared for Consolidated Edison Company of New York, Inc.

Stone & Webster Engineering Corporation. 1978. Ocean-sited plants. Prepared for the Utility Water Act Group. 2 vols.

Strandberg, H. V. 1974. A high capacity sand filter for thermal power plant cooling water intakes. Part II: design concept, in Proceedings of the Second Workshop on Entrainment and Intake Screening (L. D. Jensen, ed.), pp. 335-343. EPRI Publ. No. 74-049-00-5. Electric Power Research Institute, Palo Alto, Calif.

Taft, E. P., P. Hofmann, P. J. Eisele, and T. Horst. 1976. An experimental approach to the design of systems for alleviating fish impingement at existing and proposed power plant intake structures, in Third National Workshop on Entrainment & Impingement (L. D. Jensen, ed.), pp. 343-365. Ecological Analysts, Melville, N.Y.

Taft, E. P. and Y. G. Mussalli. 1978. Angled screens and louvers for diverting fish at power plants. Proc. Am. Soc. Civil Eng., J. Hydraul. Div. 104(HY5):623-634.

Texas Instruments Incorporated (TI). 1977. Initial and extended survival of fish collected from a fine mesh continuously operating traveling screen at the Indian Point Generating Station for the period 15 June - 22 December 1977. Draft. Prepared for Consolidated Edison Company of New York, Inc. TI, Science Services Division, Dallas, Texas. 23 pp.

Tomljanovich, D. A., J. H. Heuer, and C. W. Voigtlander. 1977. Investigations on the protection of fish larvae at water intakes using fine-mesh screening. Tennessee Valley Authority, Div. For. Fish. Wildl. Dev., Tech. Note B22. 53 pp.

Tomljanovich, D. A., J. H. Heuer, and C. W. Voigtlander. 1978. Investigations on the protection of fish larvae at water intakes using fine-mesh screening, in Larval exclusion systems for power plant cooling water intakes. Proceedings of the workshop held at Shelter Island Inn, San Diego, California, February 7-8, 1978 (R. K. Sharma and J. B. Palmer, eds.), pp. 125-139. NUREG/CP-002, ANL/ES-66. Argonne National Laboratory, Argonne, Ill.

Trefethen, P. S. 1955. Exploratory experiments in guiding salmon fingerlings by a narrow D.C. electric field. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 158. 42 pp.

Trefethen, P. S. 1968. Fish-passage research: review of progress, 1961-66. U.S. Fish Wildl. Serv., Circ. 254. 24 pp.

U.S. Environmental Protection Agency (U.S. EPA). 1976. Development document for best technology available for the location, design, construction and capacity of cooling water intake structures for minimizing adverse environmental impact. EPA 440/1-76/015a. U.S. EPA, Washington, D.C. 263 pp.

U.S. Environmental Protection Agency (U.S. EPA). 1977. Guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment: section 316(b) P.L. 92-500. Draft. U.S. EPA, Office of Water Enforcement, Permits Division, Industrial Permits Branch, Washington, D.C. 59 pp.

VanDerwalker, J. 1964. Studies of the response of fish to low frequency vibrations. U.S. Bur. Commer. Fish., Fish-Passage Research Program, Review of Progress 1964, vol. III. Seattle, Wash.

Walker, W. F. and M. Kamata. 1979. Hydrodynamic evaluation of traveling water screens. Final report. Submitted to Royce Equipment Company. Rice Engineering Design and Development Institute. 186 pp.

Weight, R. H. 1958. Ocean cooling water system for 800 MW power station. Proc. Am. Soc. Civil Eng., J. Power Div. 84(PO6):1888-1 - 1888-22.

White, J. C., Jr. 1976. Personal communication. Virginia Electric and Power Company, Richmond, Va.

White, J. C., Jr. and M. L. Brehmer. 1976. Eighteen-month evaluation of the Ristroph traveling fish screens, in Third National Workshop on Entrainment & Impingement (L. D. Jensen, ed.), pp. 367-380. Ecological Analysts, Melville, N.Y.