HEDL-TME 73-24
UC-12

A REVIEW OF THERMAL POWER PLANT INTAKE STRUCTURE DESIGNS AND RELATED ENVIRONMENTAL CONSIDERATIONS

HANFORD ENGINEERING DEVELOPMENT LABORATORY **P.O. Box 1970 Richland, WA 99352**
Operated by Westinghouse Hanford Company
A Subsidiary of Westinghouse Electric Corporation

Prepared for the U.S. Atomic Energy Commission
Division of Reactor Development and Technology
under Contract No. AT(45-1)-2170

PRELIMINARY REPORT

This report contains information of a preliminary nature prepared in the course of work under Atomic Energy Commission Contract AT(45-1)2170. This information is subject to correction or modification upon the collection and evaluation of additional data.

NOTICE

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy $5.45; Microfiche $0.95

HEDL-TME 73-24
UC-12

A REVIEW OF THERMAL POWER PLANT INTAKE STRUCTURE DESIGNS AND RELATED ENVIRONMENTAL CONSIDERATIONS

May 1973

John C. Sonnichsen, Jr.
Hanford Engineering Development Laboratory

Bruce W. Bentley
Hanford Engineering Development Laboratory

George F. Bailey
Hanford Engineering Development Laboratory

Roy E. Nakatani
Assistant Director
Fisheries Research Institute
University of Washington

HANFORD ENGINEERING DEVELOPMENT LABORATORY **P.O. Box 1970 Richland, WA 99352**
Operated by Westinghouse Hanford Company
A Subsidiary of Westinghouse Electric Corporation

Prepared for the U.S. Atomic Energy Commission
Division of Reactor Development and Technology
under Contract No. AT(45-1)-2170

ABSTRACT

The widespread national concern about the environmental impact of large steam-electric power plants is well known and has been the subject of considerable legislation and debate for several years. Although much of the publicized concern for the aquatic environment has focused on plant effluents and their thermal and chemical characteristics, the plant outfall represents only half of the interface with this environment. This report deals primarily with the other half of the interface--the intake structure where water is withdrawn from the water body for subsequent in-plant usage consisting largely of turbine condenser cooling. A review of present designs and the pertinent characteristics of various water bodies serving as coolant sources to the plants is followed by a discussion of biological considerations in intake design. An attempt is made to match biological and technological demands and some economic data are presented. A review of concepts presently under development is provided and conclusions and recommendations are offered. Finally, an appendix detailing eight representative designs is included.

ACKNOWLEDGMENTS

The authors take this opportunity to thank the following individuals and utilities who assisted in contributing material found in this report.

Special acknowledgment is made to the Corps of Engineers for providing a prepublication draft of the information being assembled by Prof. Milo Bell for the "Handbook and Design Criteria for Fish Facilities"; to Mr. Dan Bates, Mr. Earl Prentice, and Mr. Clifford Long for their assistance in describing the use of horizontal traveling screens and the fish collector basket; to Dr. Ed Raney for explaining the criteria used in the design of the Northeastern power plants; to Dr. John Alabaster for his assistance in explaining methods used in Great Britain; to Mr. John Skinner, Professors E. Salo, Q. Stober, and B. Marr of the University of Washington, and to Dr. Charles Coutant of the Oak Ridge National Laboratory for their general assistance.

Special thanks are given to Mr. Tom Merritt of Southern California Edison Company, Mr. Jim Adams of Pacific Gas and Electric Company, and Mr. Don Ward of the Baltimore Gas and Electric Company for their time in conducting tours. To representatives of both the Duke Power Company, Charlotte, North Carolina, and Houston Lighting and Power Company, Houston, Texas for supplying detailed information on the Marshall and P. H. Robinson Power Stations. To Professors John Geyer, Loren Jensen, and the participants of the Johns Hopkins Workshops held in January 1971 and February 1973. And finally, to Dr. G. L. Sherwood, Jr. of the USAEC for his guidance and assistance.

In addition, the following utilities responded to a letter survey conducted by the authors.

American Electric Power Service Corporation - New York, New York

Arkansas Power & Light Company - Pinebluff, Arkansas

Carolina Power & Light Company - Raleigh, North Carolina

Cincinnati Gas and Electric Company - Cincinnati, Ohio

Cleveland Electric Illuminating Company - Cleveland, Ohio

Connecticut Yankee Atomic Power Company - East Hampton, Connecticut

Consolidated Edison Company of New York, Inc. - New York, New York

Consumers Power Company - Jackson, Michigan

Dallas Power & Light Company - Dallas, Texas

Duke Power Company - Charlotte, North Carolina

Florida Power and Light Company - Miami, Florida

Gulf States Utilities Company - St. Gabriel, Louisiana

Houston Lighting & Power Company - Houston, Texas

Kansas Gas & Electric Company - Wichita, Kansas

Long Island Lighting Company - Hicksville, New York

Pennsylvania Electric Company - Johnstown, Pennsylvania

Pennsylvania Power & Light Company - Allentown, Pennsylvania

Philadelphia Electric Company - Philadelphia, Pennsylvania

Public Service Indiana - Plainfield, Indiana

Texas Power and Light Company - Dallas, Texas

Union Electric Company - St. Louis, Missouri

Wisconsin Electric Power Company - Milwaukee, Wisconsin

CONTENTS

CONTENTS (Cont'd)

APPENDIX

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

I. INTRODUCTION

Electrical power generation in the United States has doubled every ten years since 1945. At the present time, approximately 80% of the annual generation of electrical power, estimated at 1.5 trillion kilowatt hours, is produced by steam electric power stations which circulate vast quantities of cooling water through condensers to extract waste heat. The amount of water annually withdrawn for this purpose is estimated at approximately 40 trillion gallons/year, which equals roughly 10% of the total flow of water in the rivers and streams of the contiguous United States.

Much attention has been focused on the water quality effects resulting from discharge of this heated effluent and, in particular, on the subsequent effect of this discharge on the life forms inhabiting the water. However, it should be recognized that an intake structure also interfaces with the aquatic environment at the source (to the plant) of this cooling water. Although some attention has been directed towards the design and operation of water intake structures, they have received relatively little publicity, and normally have taken a back seat to the dissemination of other seemingly more important design information. As a result, the design engineer has been placed in a position where he may accept existing designs as precedent with little concern for review or for establishment of meaningful criteria to match specific plant designs to the local environmental conditions.

A properly designed intake structure is a marriage between the biological, hydrological and aesthetic demands of the particular site and the cooling needs and economic restrictions of power plant operation. The harmony of this marriage will depend on the development of standardized design criteria which are sufficiently flexible to accomodate the spectrum of site-related characteristics and to encourage the innovative designs required to minimize the environmental impact.

The Federal Water Pollution Control Act as amended in 1972 (Public Law 92-500) states under Thermal Discharges Section 316(b); . . . "shall require that the location, design, construction, and capacity of cooling water <u>intake structures</u>* reflect the best technology available for minimizing adverse

---

* Emphasis added by author.

environmental impact". . . The purpose of this report is to inform the industry, as well as to assist it in avoiding future design problems. Primary emphasis is placed on discussing ways the intake structure can be integrated into the source water environment so as to minimize the biological and ecological impact.

II. SUMMARY

Initial cooling water system concepts for a particular power plant must consider the quantity of water necessary for efficient plant operation. Next, the selection of cooling water system depends on the dominant physical and biological features of the water resource available. The results of a survey of power plants with a capacity greater than 500 MWe illustrate the current trend of intake structures used for particular combinations of cooling water systems and water source types. In general, present intake structures are engineered to economically fit water intake requirements to the particular site features.

The optimum economic solution for the cooling water intake structure design may not necessarily represent the optimum ecological solution. An assessment of the biological factors and characteristics which should be considered in the design stages is the first step in assuring an economic system which is also compatible with the aquatic environment. A biological survey to identify the abundance and temporal and spatial distribution of indigenous species will help point out critical species. Once these have been identified, parameters peculiar to their survival become important in the location and specification of the intake structure. For example, if the critical organism is a fish, then fish behavior and swimming performance in relationship to water temperature and fish size may be crucial. For smaller organisms, the intake structure may pose less of a problem than the stresses of being pumped through the condenser cooling system. Should these stresses be excessive, more stringent exclusion requirements are placed on the intake.

Once the environmental problems have been assessed, criteria must be developed to assure that intake structure design includes provisions to protect aquatic species. To properly protect these water-borne organisms, design features such as low approach velocities, proper screen mesh size, and

general layout of the intake structure should meet the criteria established by environmental considerations. Operational features such as water treatment, condenser cleaning, and structural protection should also be selected to minimize environmental impact.

Thus, the design process for an intake structure can be considered as having four parts:

1. Perform environmental surveys (hydrology, ecology) to determine the aquatic inhabitants and hydrologic characteristics of the proposed site.
2. Develop proper screening (or filtering) techniques according to the organisms considered.
3. Provide a means of excluding resident and migratory species from harmful areas (or of leading them past such areas) by consideration of their native avoidance and guidance characteristics.
4. Provide (for the case of screening) in the cooling system proper, a tolerant environment for those organisms which are pumped through the system.

These factors are each discussed in detail in the text of this report. The need for standardization of criteria (and of supporting data) is shown.

Final selection of a cooling water intake will depend on the economic as well as the environmental aspects. One section of the report addresses that topic specifically, including information on both shoreline and offshore installations.

Finally, sections on recommendations and on future design considerations have been provided to unify the presentation and to provide a logical and practical summary of the findings.

III. COOLING WATER AND PRESENT INTAKE STRUCTURE DESIGN: AN OVERVIEW

A. COOLING WATER SOURCES

The amount of cooling water required by a power plant strongly influences the intake structure design. A superficial examination of intake structures might suggest that a low water flow rate is desirable, as it minimizes the size of the structure. Several design goals satisfied by minimizing the amount of cooling water are: 1) a low approach velocity at the screens; 2) disturbance of only a small fraction of the total water resource and the associated biota; and 3) a compact design for reduced capital costs. Unfortunately, however, for once-through systems, the total cooling water system requires large water flow rates to reject the waste heat without violating discharge water temperature standards.

The important physical and biological features of the water source will affect the location and type of intake structure. An understanding of these characteristics is necessary to the subsequent discussions of intake structure location and economic considerations. Some aspects of this problem are discussed below.

1. Rivers

An attractive feature of rivers is that there naturally exists sufficient resistance due to gravity flow to permit the siting of a shoreline intake and possibly a shoreline discharge structure. The major drawback associated with using river flow for once-through cooling is the relatively small number of rivers possessing sufficient flow to permit utilization of this cooling method.

In a recent AEC-sponsored cooling capacity study[1], it was noted that only some 60 streams had a critical low flow greater than 1000 cfs, where the critical low flow was defined as the minimum mean monthly flow between the years 1950 and 1960. Using a criterion of 2000 cfs, the selection was limited to less than 40 rivers. In reality, other constraints exist which further restrict this selection. The first of these constraints is the cost of transporting power and the need to locate thermal stations near load centers.

The second is that usage of water for cooling is in constant competition with other domestic and industrial demands placed upon this resource. In a study made on the Missouri River,[2] it was noted that projected consumption from all uses reduces the 1970 mean annual discharge by approximately 50 per cent during the next fifty years. Finally, a third factor results from the presence of institutional constraints such as the Wild and Scenic Rivers Act, which effectively remove certain rivers (or reaches of rivers) from consideration as sources of cooling water.

The primary considerations in the design of an intake structure along a river are: 1) to properly allow for variation in the local hydrography; 2) to provide for handling debris and siltation; 3) to prevent recirculation (possible formation of an upstream thermal wedge should be examined); 4) to protect the local aquatic ecology; and 5) to maintain channels for navigation.

2. Estuaries

One normally thinks of estuaries as "drowned river basins" which are connected to a salt water inlet or the open sea. As a result, portions of the estuary are under the influence of tidal activity. Variations in these tidal forces, accompanied by the variable hydrology of inflowing rivers, create a constantly changing environment.

Estuaries are commonly cited as the most productive aquatic areas in the world. Estuaries and the coastal shoreline are the ultimate receiving waters for the discharges and environmental modifications caused by both natural and man-made activities inland. As a result, these areas are normally rich in nutrients. Marked changes in salinity brought about by changes in the balance of the hydrodynamic forces and variations in surface runoff contribute to the dynamic state of the estuary. Estuaries serve as nurseries for many aquatic organisms of importance to commercial and sports fisheries. Estuaries possess complex ecosystems and, as such, probably provide the biggest challenge to the design engineer. The range of design possibilities might extend from designing around a photosynthetic zone to designs accomodating the migratory or spawning behavior of anadromous fishes.

The design considerations for placing an intake structure on an estuary are a combination of the aspects discussed for rivers and the effects of stratification to be discussed with respect to lake sites. The presence of current reversals can bring about signficant recirculation problems. Large variations in the response of the local hydrography and similar variations in water chemistry should be considered. In addition, deposition from sediment transport is normally very significant.

3. Lakes

As opposed to rivers, lakes do not possess large gravity flow gradients and wind stresses provide the primary mechanism for convection, although in the larger water bodies, the effect of Coriolis forces might be significant. The combined effect of seasonal prevailing wind patterns, Coriolis forces and stratification produces the dominant circulation patterns.

Distinct zonation and stratification are characteristic features of lakes. In some large water bodies, marked stratification can exist in both the vertical and laterial or horizontal plane. This is evidenced by sampling results which show large differences in water quality and biological communities between inshore and offshore water. Horizontal and vertical stratification result from the presence of sufficient resistance to minimize interference between the mixing mechanisms in the various planes. In the Great Lakes, the horizontal stratification resulting from complex circulation patterns is called a thermal bar.

The ecosystem begins with what we shall call the photosynthetic zone, or the photic zone, in which the process of photosynthesis takes place. The productivity of this zone is determined by the degree of penetration of visible light needed for the process of photosynthesis, and the presence of necessary nutrients. Penetration of solar energy is a function of the water's clarity, a property usually referred to as transmissibility. It follows that shallow water should be the most productive, biologically speaking, since in this region, light is present and nutrients are continuously recycled from the bottom due to the vertical mixing process.

The design considerations for placing an intake structure on or in a lake are somewhat different than those discussed for river siting. As little as possible of the influent water should pass through the photosynthetic zone. In addition, it should be noted that a significant addition of waste heat to the epilimnion, or a significant withdrawal of cooler water from the hypolimnion, or a combination of both, could result in shifting of the thermocline. Care should be taken to guard against the possibility of recirculation. Depending upon the size of the water body, care should also be taken to protect the structure from adverse wave conditions. A minimum variation in the water surface elevation is normally anticipated. The movement of bottom sediments should be examined and the proximity of nearby inflow identified. Clearly, on navigable waters, the structure must not impede the flow of traffic and if there is a potential hazard, it must be properly marked.

4. Oceans

The section of the ocean floor adjacent to the continental land mass and having a water depth of about 200 meters is called the continental shelf. It is characterized by a gradual slope which can extend hundreds of miles offshore. Worldwide, the slope of the shelf averages about 0.2 per cent, or 2 fathoms per mile, although it is by no means constant or uniform. Along the California coastline, the slope is approximately five times as great. Large storm centers far offshore give rise to waves which are refracted to the point that they ultimately align themselves parallel to the shoreline. Under this same principle, wave energy is concentrated by the presence of headlands. Depending upon the relative size of the wave, slope of the shelf, and the depth of the water, the wave will ultimately break, resulting in a surf zone. It is within this zone of great turbulence and immense forces that perhaps the most difficult construction problem are encountered.

On the other hand, shoreline currents pose several different problems: the essentially undirectional, rather constant force of the current must be dealt with, deposition or removal of sediments can substantially affect performance, and the zone where the currents exist supports a rather dense population of aquatic organisms. Shoreline currents result from three conditions: 1) large scale circulation resulting from the overall balance of forces and imposed boundaries; 2) the return flow to sea of water transported by wave breaking; and 3) flushing and filling of nearby inlets due to tidal activity. Depending upon local conditions, the combination of these effects, often referred to as littoral or shoreline currents, can be significant.

The littoral zone is, biologically speaking, a highly productive region of the ocean, although it does not normally compare in productivity with estuaries. Beyond the surf zone, thermal stratification does exist, but not to the extent that it exists in lakes, primarily because of the higher level of vertical turbulence. Therefore, a photosynthetic zone in the ocean is not as sharply marked as in a lake. The photosynthetic or euphotic zone can range from 0 to 80 meters in depth.

In designing cooling systems to be placed in offshore open sea environments, primary consideration has centered on construction of the pipelines through the surf zone partly because the cost associated with this type of construction is high (see Section VI). The principal biological consideration has normally been merely the exclusion of large fish. The direction of the current or drift must be kept in mind when locating the intake and discharge structures to eliminate problems of recirculation. Once again, problems of sediment transport and the possibility of impeding navigation must be considered. The consideration of all of these factors ultimately governs the lengths of intake and discharge lines.

B. PRESENT DESIGNS

A brief discussion of present intake design techniques with special emphasis on the hardware, trash removal and flow control aspects is presented in this section. Further comments with greater emphasis on the biological aspects are found in Section V.

To gather up-to-date information, letters of inquiry were sent to power stations with capacities greater than 500 MWe listed in the Electrical World Directory of Electric Utilities (78th Ed.) Replies which were received from 26 utilities covered roughly 25% of these plants. Nearly all of the stations surveyed used traveling screens with 3/8-inch square mesh screen. Several plant designs did not consider screening to any great extent, since their cooling water sources are deep wells or private holding ponds.

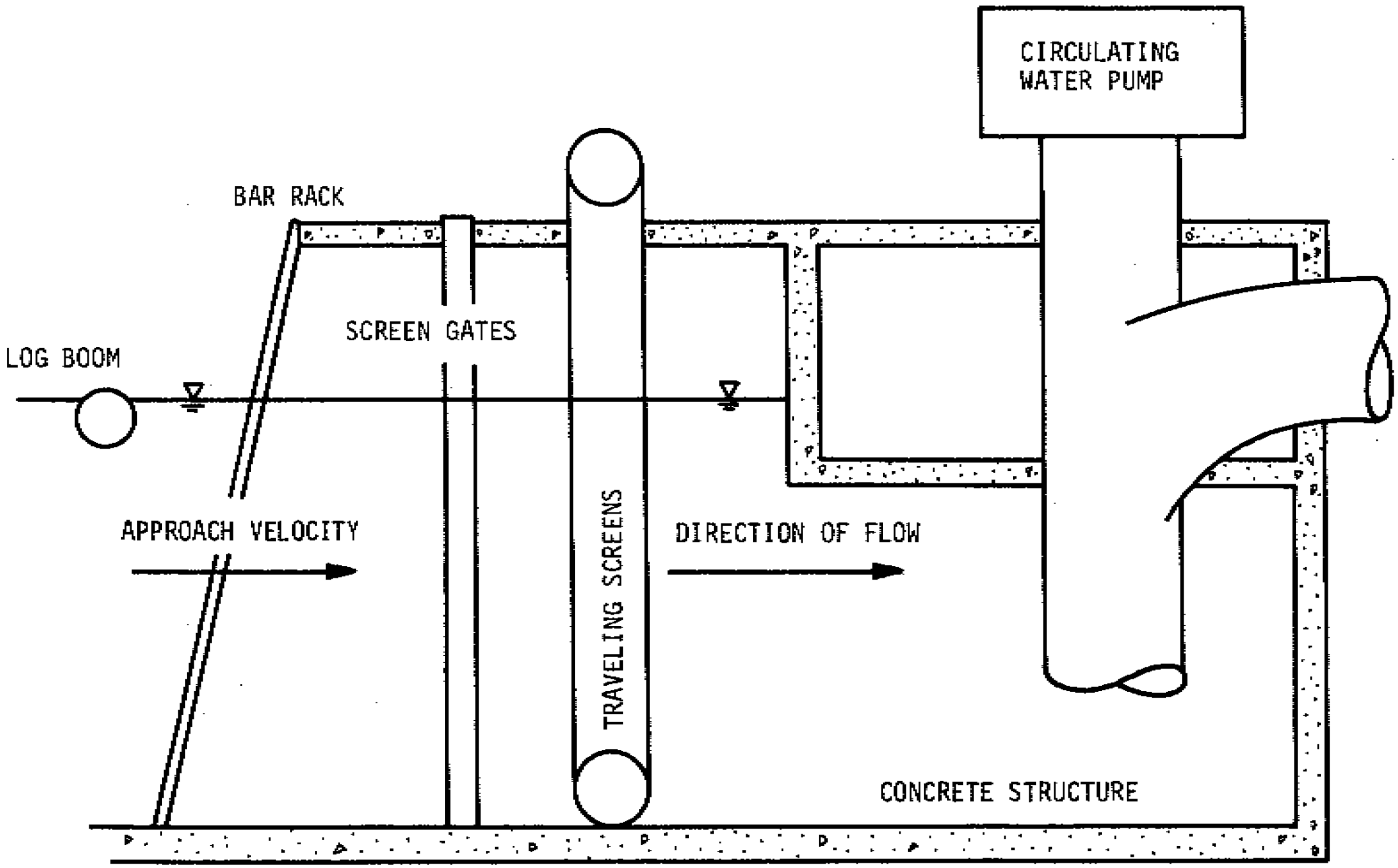
The simplest conceivable system is a once-through circulating water system with both intake and discharge structures on the shoreline. Conceptually, the overall system design requires sufficient resistance between the location of the intake and the outfall so that essentially no recirculation of coolant water between the two points can take place. In the natural state, few sites offer this condition without resort to structures, such as pipes or canals, to separate the two points. Optimally, the required pipe lengths can be minimized for sites located along a few of the larger flowing rivers, or at sites where cooling water can be received from one body of water and discharged into another.

In the following sections, a brief review of various intake designs is presented. The discussion begins with the more basic shoreline intakes, and progresses towards the more complex offshore intakes. A somewhat more detailed description of several structures is found in the Appendix.

1. Shoreline Intake Structures

There are two major engineering design requirements for an intake structure: 1) the structure must be of sufficient size to accommodate the design coolant flow rate; and 2) the structure must have provisions to remove, at this flow rate, debris that will not easily pass through the entire cooling system. The maximum debris size criterion is normally set at approximately 50% of the condenser tube diameter.

Based upon these two requirements, typical intake designs that have evolved contain the following features: a trash rack and sometimes a log boom, screen gates, and a set of screens. As shown in Figure 1, these features are arranged in order in front of the pump well. The coarse bar rack and log boom are necessary to exclude large debris and to protect the finer screens. The trash rack usually consists of 3-inch x 3/8-inch flat steel bars placed on approximately 4-inch centers oriented in a vertical plane. Gates or stoplogs follow the coarse rack and are used for unwatering and filling the screen well in the event of required maintenance. As mentioned, the screens are included to remove the finer debris. Normally, the screen is made of monel wire with a



HEDL 7303-36.1

FIGURE 1. Features of a Typical Shoreline Intake Structure.

mesh size of 3/8 or 1/2 inch, and is arranged as a belt which travels in the vertical direction. Movement of the screen is usually automated, and is governed by the pressure drop, measured by manometers, across the wire mesh. A high pressure water spray is used for cleaning the screen.

In many cases, the design of the intake structure must include provisions for changes in the surface elevation of the source water body. Along some rivers, the stage variation resulting from natural seasonal variation of the discharge hydrograph can be quite substantial. Design considerations, which include stage variations of 10 to 30 feet, are not uncommon along some of the major rivers. In consideration of this fact, a design which has been used on a number of occasions for plants located along the Mississippi River employs the use of a siphon. The siphon extends from the pump well located on shore to an intake well located in the river. Figure 2 presents the intake design with the sipon used at the Willow Glen Station near St. Gabriel, Louisiana.[3] In other designs, this variable stage factor is accounted for by simply sizing the intake structure based on the low flow design condition. It should be noted that the design of the water cooling system must be based upon the most adverse flow condition. The location of the pump house with respect to the location of the plant and the intake structure will, of course, depend on the particular aspects of a chosen site. On a few occasions, TVA has found it economical to place the circulating water pumps at the screenwell outside of the equipment area surrounding the power station.

In tidal waters, the ease with which recirculation can occur normally requires that either the intake or discharge structures be connected to a canal or pipe. This problem can, of course, be circumvented if it is possible to take cooling water from one body of water and discharge it into another, thus separating the source and sink reservoirs. Examples of how this technique can be used effectively are shown in the design of a number of stations owned and

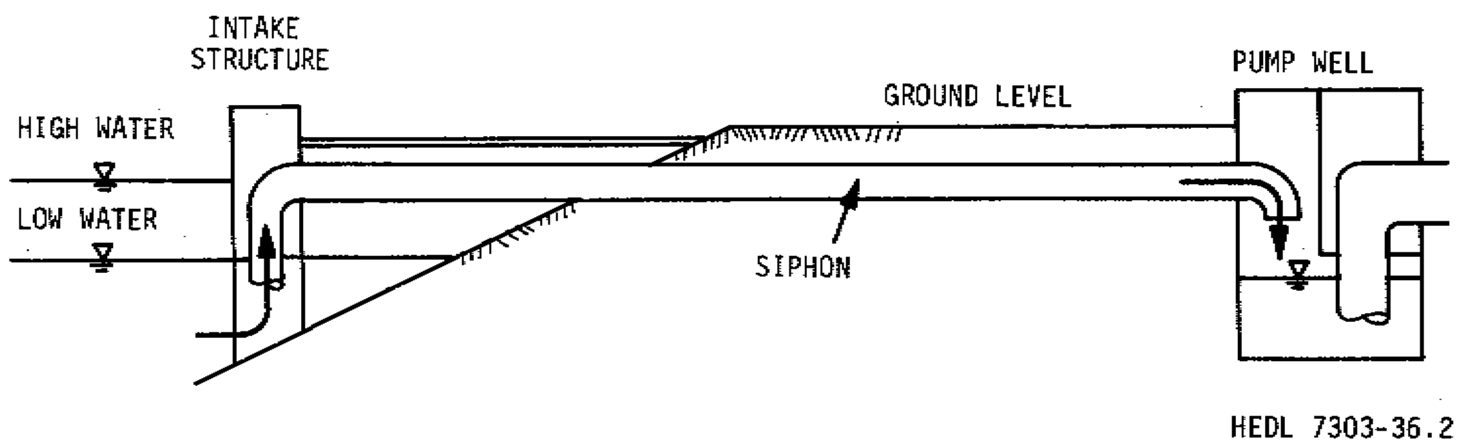


FIGURE 2. Schematic Representation of Siphon Used at Willow Glen Station, St. Gabriel, LA.

operated by Pacific Gas and Electric in Central and Northern California, e.g., the Moss Landing and Morro Bay power stations.

Figure 3 shows a schematic of the once-through circulating cooling system used at the Moss Landing Station placed in service in 1950 at Monterey Bay. The intake structure is located on Moss Landing Harbor, with a 350-foot intake conduit located between the intake and the screen well. Flow at the intake is restricted to the lower 11 feet of the intake structure to take advantage of cooler water. The effluent is discharged into Elkhorn Slough. Similarly, at Morro Bay, the coolant is removed from Morro Bay, and discharged into the Pacific Ocean next to Morro Bay.

2. Offshore Intake Structures

The engineering problems associated with constructing an intake line extending thousands of feet through difficult terrain such as a surf zone can be immense, possibly even economically insurmountable. This aspect, along with the problems associated with designing structures to be comaptible with resident biological communities, is providing a major challenge to the designer.

As in the design of shoreline intakes, care must be taken to properly locate the intake and discharge structures to provide sufficient resistance to eliminate any interaction or circulation of flow. In addition to the horizontal resistance factor, sufficient vertical resistance sometimes exists in the larger water bodies such as lakes and bays. Under these conditions, it is possible to locate the intake structure offshore and the discharge structure on the shoreline. The buoyant behavior of the effluent, coupled with the low level of vertical turbulence, allows the water body to stratify. Proper location and design of the intake structure thus allows for the selective removal of the cooler subsurface water. As a general rule, for lakes, approximately 20 feet is suggested to assure the proper vertical resistance. However, the required depth may be as great as 60 feet, as recently suggested in the design of the proposed Bell Station on Lake Cayuga.[5] Thus, each site must be examined on an individual basis.

An example of placing the intake structure offshore and the discharge structure on the shoreline is found in the Blount Street Power Station on Lake

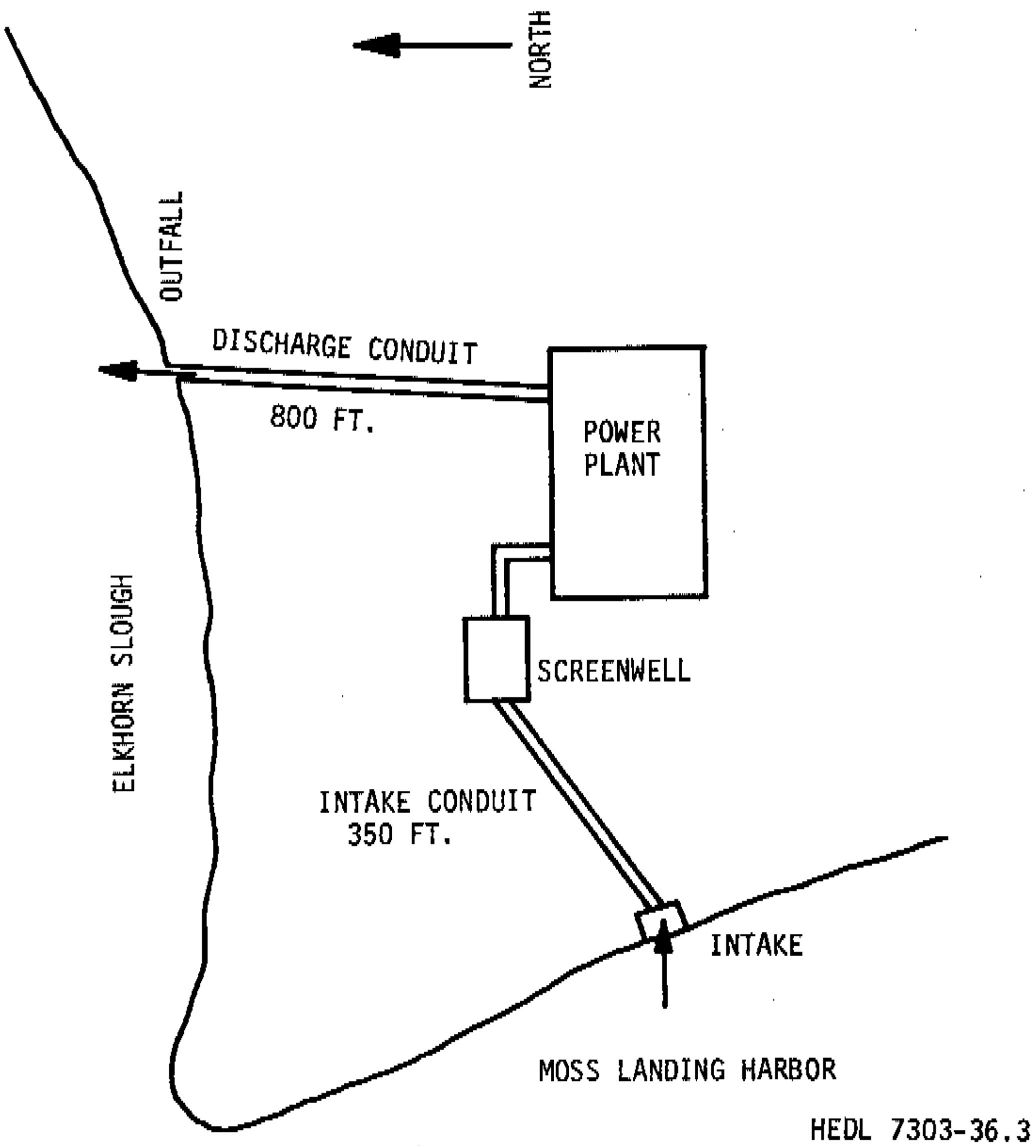
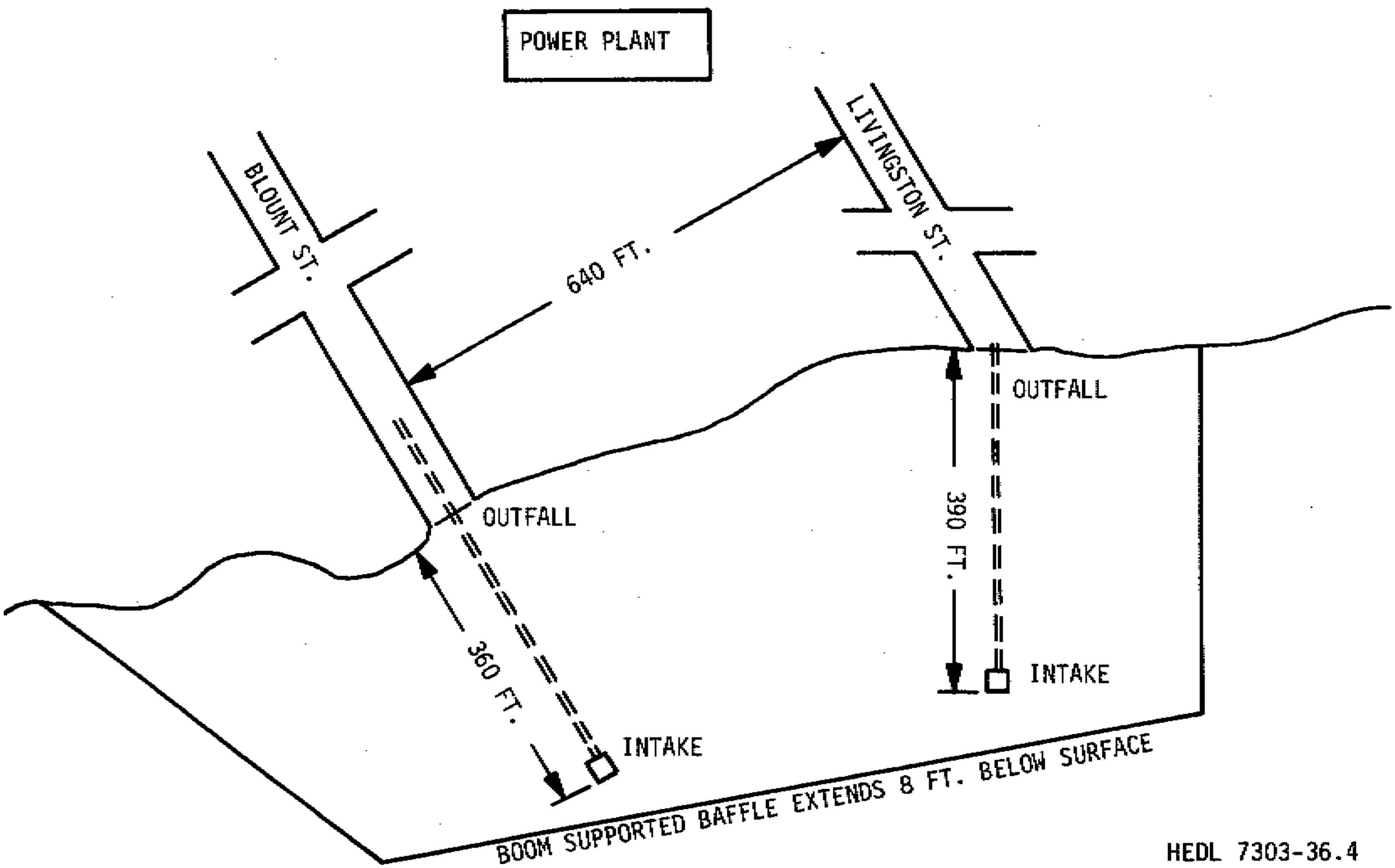


FIGURE 3. Moss Landing Electric Cooling Water System.

Monona (operated by Madison Gas and Electric Company). Figure 4 schematically shows the relative location of the two structures. The station is small, with a peak power production of approximately 120 MWe and a maximum coolant flow of 140 cfs. The intake structure is located 390 feet offshore in line with the outfall structure, at a normal depth of approximately 17 feet.[6,7] The operating experience indicates that there are few problems associated with recirculation.

When an offshore intake is employed, the pump station and screenwell are normally located onshore. In addition to the subject of recirculation, other engineering features included in the design of intake structure are: 1) the shoreline screenwell is placed at a grade which will permit gravity flow from the intake; 2) the actual intake structure is turned upright and is located above the bottom topography to minimize the problems of siltation and deposition; and 3) the intake structure is set at a grade which will not impede navigation.

The need to protect aquatic life adds another complication to the design. Requirements to minimize interference with aquatic biota as well as recreational activities, have on a number of occasions forced both the intake and discharge structures to be located offshore. Under this situation, the requirement to minimize recirculation still applies. This has normally been accomplished by separating the two structures by some distance from each other and from the shoreline, and by placing the intake structure in deeper water than the outfall structure. However, on occasion, the relative location of these two structures has been reversed.



HEDL 7303-36.4

FIGURE 4. General Layout of Cooling Water System and Ponded Outfall Blount Street Power Station, Lake Monona, Wisc.

IV. BIOLOGICAL CONSIDERATIONS

To develop intake designs that are responsive to biological considerations requires an understanding of the more important characteristics of the overall ecosystem and, more specifically, the important characteristics of the various species within the biological community. The aquatic organisms can be defined by mode of living as follows:

1) Benthos - bottom dwellers; can be either sessile or motile.
2) Plankton - microscopic or small organisms characterized by no motility.
3) Nekton - free swimming pelagic organisms (fish).

An analysis of the relationships and interactions between intake structures and biota requires careful identification of the local resident organisms. Complete elimination of interaction between the biota and the intake structure is unlikely. Motile organisms such as fish can be screend, but provisions should also be made to avoid trapping them in the structure. Fish guidance and avoidance characteristics should be considered when planning screenwell mechanisms and layouts. Fish swimming performance becomes a significant characteristic during selection of structural features which determine the approach velocity of the water at the screen face. Organisms with limited or no motility, and which are too small to screen from the cooling water, will be pumped through the system. The stresses imposed on the pumped organisms as they pass through the cooling water system should be identified so that the effects can be considered in the planning stages.

A. ABUNDANCE AND DISTRIBUTION OF INDIGENOUS SPECIES

Before a proper assessment of the potential effects of power plant siting on the aquatic environment can be made, it is necessary to have an accurate survey of the occurrences and abundance of resident and transient species at, or in the vicinity of, the proposed site. To achieve this goal, it becomes necessary to answer the specific questions of what, when, where, and how many aquatic species occupy the region.

What species are present is the first question that must be answered. This question commonly centers on the presence of a target species possessing some sport or commercial value. However, it should be pointed out that important differences do exist among biologists over what needs to be protected and the particular level of protection desired. It is not the intent of this study to examine this question to any extent. Rather, a general discussion is presented to assist in establishing guidelines to match specific environmental protection needs.

The range of target or desired species is considerable, extending from the more resident benthic shellfish such as oysters, clams, shrimp, lobster, etc., at one end of the spectrum, to the anadromous fish such as shad, salmon, etc., at the other end of the spectrum. In a complex ecosystem, such as an estuary, the list of important target species usually includes numerous organisms.

As part of this primary classification, the species should be sized, and a population estimate should be made. Care should be taken to include such aspects as proximity to spawning grounds and the spawning characteristics of the particular species. For example, when considering the spawning behavior of fish, it is important to note that, while some species deposit their eggs in a suspended fashion, others place their eggs in the bottom sediments and vegetation. Suspended eggs are planktonic, as defined previously. When considering the presence of benthic organisms, it is important to note that, during the larval stages, the organisms are usually suspended in the water column and, consequently, are also planktonic.

In addition to identifying major target species and their protection, consideration should be directed towards maintaining the integrity of the entire existing ecostructure. It must be noted that the flow of energy through an ecosystem can be limited by both water quality parameters (such as temperature and dissolved oxygen, etc.) and/or the direct interaction of one organism with another organism. Whenever it is possible to identify existing weak links or points of stress in the ecosystem, steps should be taken to design around these critical areas.

The question of when particular species occupy a specific locale is important as it relates to the ambient water quality parameters. At various stages of development, organisms require different optimal environments. It follows that the temporal and spatial variations of the important water quality parameters should be established. Design and operation of the cooling system must be referenced to these parameters.

The third question which must be answered as a part of the biological inventory concerns the location of the species. One aspect of this subject was touched upon in discussions concerning the identification of spawning grounds. In considering the plankton forms, care should be taken to identify any biological stratification that might exist. In addition to vertical stratification, it is conceivable that, in some water bodies, horizontal stratification of organisms may also be present. Furthermore, the location of these productive areas might vary spatially with time.

Resident species include both fish and bottom-dwelling invertebrates (crabs, clams, etc.) Studies should be conducted to identify the distribution in space of these resident populations during the various seasons

Anadromous fish may enter the area to spawn or they may simply migrate through. Local spawning grounds should be identified. The migratory pathways of fish passing the site must also be identified. The spatial and temporal distribution of these anadromous species must be charted for both adults and juveniles. In performing such a task, it is advisable to identify major physical factors such as rivers, inlets, etc., and relate their presence to the creatures' observed behavior.

B. GUIDANCE AND AVOIDANCE OF FISH

The incidents of fish becoming trapped in power plant facilities are numerous. On occasion, the impingement of fish on the intake screen has forced plants to lower load and even to shut down. Therefore, it is important to study guidance and avoidance in order to deal with fish that become trapped, as well as to develop methods to preclude fish entrapment. A number of studies have been conducted in hopes of better understanding fish behavior. In the laboratory, fish have been exposed to various stimuli and their responses measured.

Techniques used for guiding and controlling the behavior of fish have centered on the use of stimuli such as light, velocity and acceleration, pressure, electrical shock, chemicals, and temperature. The Corps of Engineers has sponsored intensive research programs related to effective passage of salmon around hydroelectric dams on the Columbia River. During 1960-1965, the cost of the program exceeded $4,000,000[8]. While the program has focused on safe passage around dams, the basic problem is to guide fish. The practical results of this program are reflected in more efficient fish facilities and in substantial savings in fishway costs. Of special interest to intake structure problems are the different stimuli that were studied to determine efficiency in guiding salmon. It is recognized that variations due to species of fish, age, physiological state, etc., do not permit simple extrapolation of response and behavior of salmon to all fish. Nevertheless, because of the extensive work, especially on juvenile salmon, it seems pertinent to briefly review the guidance of young salmon with various stimuli.

1. Light

Much work has been done by Fields[9] on the use of artificial light to guide young salmon to safe areas. Some of the early work indicated an apparent contradictory result because, under certain conditions, young salmon were attracted to light, but in other conditions they were repelled by light. Fields summarizes the two light-guiding principles as follows:

a) "Under some conditions, artificial light can repel migrants and divert them from certain areas. In such situations, the problem is one of balancing various environmental stimuli so that light intensity overrides velocity, turbidity, depth and temperature."

b) "Under other conditions, artificial light can attract migrants and concentrate them in particular areas. Some degree of light adaptation is necessary before attraction will occur."

Dark-adapted young salmon can be guided by light repulsion when they are in relatively clear water flowing at more than 1 ft/sec. Any light perceptibly brighter than the adaptation light will elicit the avoidance response under controlled conditions. In an area with a velocity of 4 ft/sec or more, unshaded lights, for example, placed along the stream banks will move the downstream migrants away from the bank. A constant light for young salmon is more effective than an interrupted or flashing light, because the fish float into or through the light barrier during the dark phase of the cycle.

Fields[9] found guidance by light attraction inevitably involved a certain degree of light adaptation. For example, a light barrier thrown across a stream at a 90-deg angle may block all migrants for a short time, but if the water current is swift, the fish will eventually be carried into areas of higher illumination. They will then swim toward a downstream light if the other lights are turned off. The brighter the initial adapting light and the longer the adaptation period, the better the movements of young migrants can be controlled. Overall light is not an effective guiding stimulus until it is combined with other stimuli, particularly with velocity.

2. Velocity

Cruising and lower sustained swimming speeds are generally attractive (see Section B for definition of terms). Fish are very sensitive to velocity changes. Consequently, all accelerations and decelerations should be gradual. Guidance by light is not effective in still water, but velocity combined with lights provides some effective guidance through alternate channels. Further comments on the use of velocity are to be found under Visual Stimuli.

3. Pressure

Pressure, in combination with light, showed an encouraging potential as a guiding stimulus. Smolts of three species of salmon and young steelhead trout uniformly respond by swimming toward a faint light source if they are quickly subjected to increased pressure. The increase in pressure encountered by fish at a dam site as they descend from the upper 20 feet of water to 65 to 70 feet was sufficient to evoke a response of swimming toward a light source of a 100 W, 200 W and 500 W surface lamp.

4. Electrical Shock

Electrical fields have been investigated as fish barriers and guiding devices for fish passage research. The results have been of very limited success in field applications[10]. Although electro-fishing devices using d.c. current in fresh water are effective in attracting and stunning fish for capture, there are a number of problems in using an array of electrodes with direct current or interrupted direct current to guide fish. One of the major problems is the phenomenon of "fatigue" in fish. When fish are guided down an electrode array, they are subjected to alternately strong and weak electric fields. This variable field induces a muscular fatigue reaction, but at a much faster rate than if the fish were expending muscular energy voluntarily. This phenomenon of fatigue is an important factor that may cause electro-guiding to fail, especially if the lateral distance over which the fish must be moved is large. On the other hand, such an electro-array may be effective in a screenwell to lead trapped fish into a fish bypass.

It is well known that alternating currents cause no electrotaxis in fish, but will bring about tetany, loss of equilibrium and death under extended exposure. Hence, alternating currents are effective as barriers for fish swimming against the current because if the fish becomes "stunned," it will be carried out of the electrical field by the water current. If there is a need to keep fish out of the discharge canal, a barrier at the mouth of the canal may be very effective. Finally, electric fields may be useful in fresh water systems, but sea water poses unique problems because of the high salt content.

5. Chemicals

Fish react differently to the presence of various chemicals. If possible, they apparently avoid sublethal levels of copper and zinc. Although they may avoid slugs of chlorine, they can become locked into an environment where the chlorine concentration level is lethal. Fish do not avoid all pesticides or herbicides, although salmon and trout have refused to enter areas where 2-4-D is present in extremely low concentrations.

6. Temperature

Fish are very sensitive to temperature gradients and they may avoid high temperatures, since they are capable of sensing low temperature differentials. However, it has been observed that fish will remain at temperatures near their upper tolerance for long periods before moving into cooler waters. Fish have been attracted to heated effluents, particularly in cold weather.

7. Sound

Sound has been used as a device to repel fish. A study performed by Van Der Walker[11] indicates that fish respond to selected frequencies. The fish tested did not become less sensitive after repeated exposure. However, use of sound to repel fish at the Indian Point Power Plant proved unsuccessful.

8. Visual

The other behavioral characteristic that should be discussed at this time deals with fish response to geometrical barriers. Two popular concepts which have been explored extensively during recent years in hopes of guiding fish involve the use of louvers and screens. Air curtains are another form of visual stimuli.

Screens are the most effective means of preventing fish from entering an area. Vertical traveling screens have become a standard feature in the design of thermal power stations. Depending on the mesh size and the size of the species present, fish can be totally screened. (This subject will be discussed in detail in Chapter V of this report.) When arranged properly, screens can also provide an effective means of guiding fish. It has been observed that as fish approach physical barriers, they will orient themselves perpendicular to, and with head away from, the physical barrier. A vectorial representation of this phenomenon is shown in Figure 5. Therefore, by placing screens or barriers at an angle to the direction of flow, fish can be guided in specific directions. In a study conducted in California, a coarse bar rack aligned at an angle of 20 to 30 degrees to the incoming flow proved effective in deflecting fish[12].

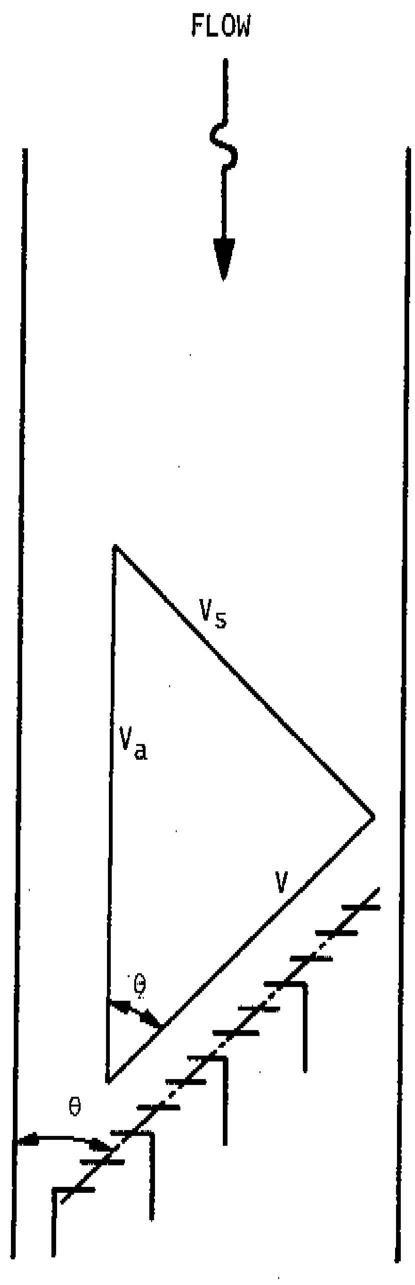
Louver screens which employ both visual and velocity stimuli have been used successfully as a means of guiding fish. Louvers take advantage of most

V_a = APPROACH VELOCITY OF FLOW IN FEET PER SECOND

V_s = SWIMMING SPEED OF FISH IN FEET PER SECOND

V = RESULTANT MOVEMENT OF FISH IN FEET PER SECOND

θ = ANGLE OF THE LINE OF LOUVERS



$\theta = 11.5°\text{-}45°$

HEDL 7303-36.5

FIGURE 5. Diagrams Showing Range of Angles in Lines of Louvers Tested and Vectors of Force in Flow and Fish Movement.

fishs' natural tendency to avoid entering a zone of high velocity when they can remain in a zone of lower velocity. This behavior, combined with the natural orientation which fish assume when confronted with a physical barrier, adds to the potential success of the design. Although, to date, most of their success has been confined to small-scale and laboratory studies, large-scale facilities using louvers are currently being designed into the California diversion projects[12]. Large-scale floating debris, which has defeated field efforts in the past[13], is restrained through the use of floating booms and trashracks located upstream. The California Delta Fish Protective Facility is shown in Figure 6.

Generally, the use of air screens or curtains have proved ineffective in restraining fish passage. This is particularly true at night when they cannot see the barrier. Air curtains combined with screens, temperature and other stimuli, show signs of usefulness; however, to date the results are rather inconclusive. Air can be used to minimize the formation of surface or fragile ice[12].

C. SWIMMING PERFORMANCE OF FISH

In addition to the size of the fish, environmental factors, such as water quality, play a significant role in determining the motility of fish. The two major factors, which normally define the desirability of an environment to a particular species, are water temperature and the level of dissolved oxygen. Therefore, parametrically, fish performance should be referenced from these two water quality characteristics. This entails considerable work and, consequently, not all studies have produced comparable results, although it can normally be assumed that the dissolved oxygen level was near saturation.

The motility of fish can be discussed with respect to three ranges of swimming speed. These speeds, defined in order of endurance as suggested by Bell[6], are:

1) Cruising speed - that speed which may be maintained for long periods of time (hours). (V_c)
2) Sustained speed - that speed which can be maintained for minutes. (V_s)
3) Darting speed - that speed which can be obtained by a single effort. (V_d)

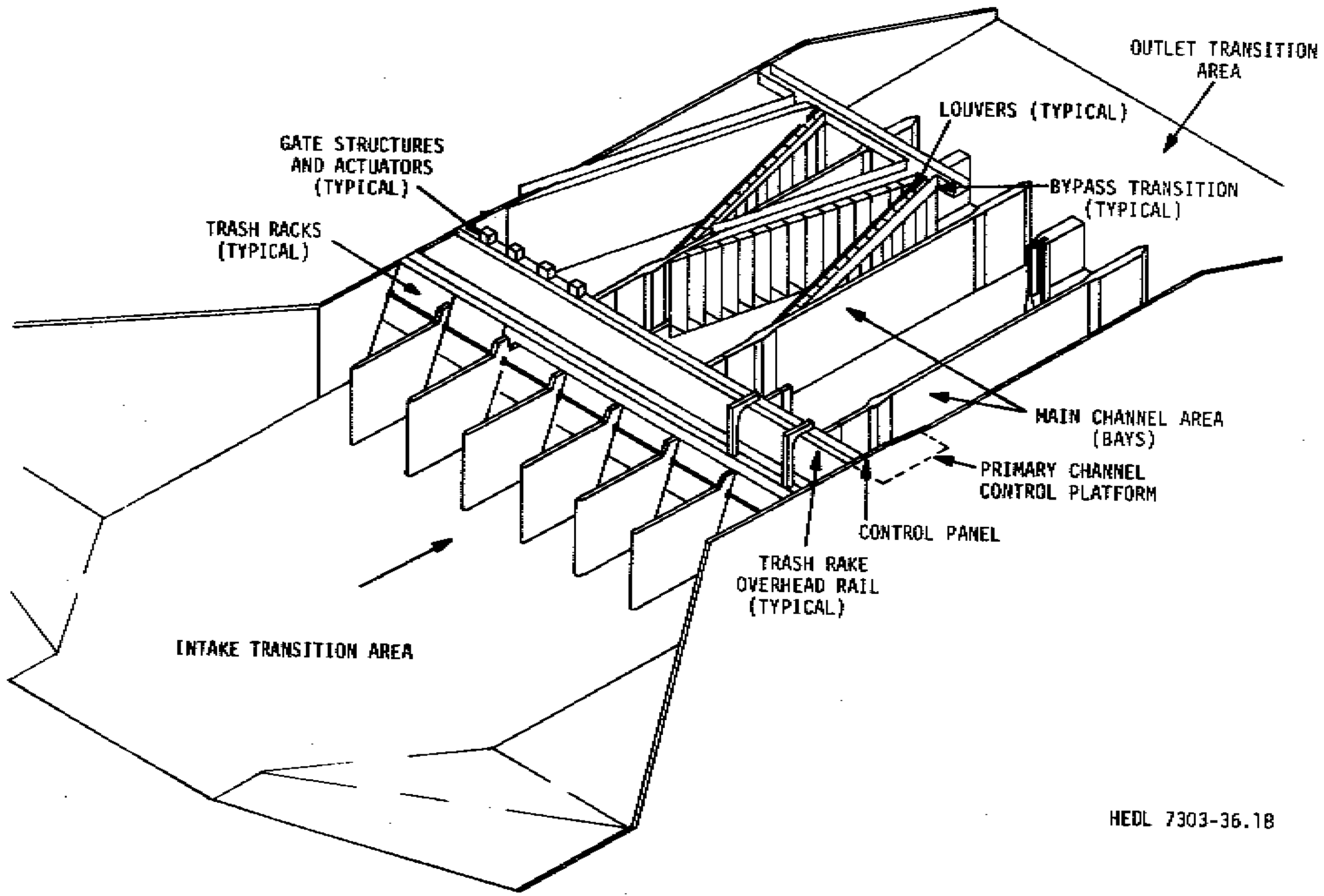


FIGURE 6. Delta Fish Facility Primary Channel System. (From California Dept. of Water Resources Manual OM-201.)

Fish employ a cruising speed for normal movement, such as migration. Sustained speeds are associated with avoiding minor perils. The darting speed is employed to avoid grave perils, or for purposes of predation. Each of these efforts requires a different amount of muscular energy.

A number of studies have been conducted to determine the relative range of these efforts for various species. As a general rule, a criterion that has been used to relate these various capabilities is that the sustained speed is greater than the cruising speed by a factor of 2 ($V_s = 2\ V_c$) and the darting speed is greater by a factor of 6 ($V_d = 6\ V_c$).[14]

Figure 7 graphically depicts the relative speeds for a number of fish using the above definitions. It should be noted that the variance associated with the use of the mean coefficients discussed above can be considerable.

The size of the fish directly affects its ultimate swimming speed. A number of empirical models have been presented that quantitatively summarize this aspect of performance. Theory developed by Lighthill[15] suggests that the swimming speed of a slender fish is directly proportional to the product of its length and the frequency of its tail motion. The theory was developed by assuming that fish propel themselves by passing a wave down their body. To the investigator in the laboratory, this motion becomes observable in terms of the frequency or beats of the tail. In a study performed by Bainbridge[16] using a trout, a dace, and a goldfish, the empirical model developed was:

$$V = 1/4\ L(3f-4)$$

where:

V = velocity in cm/sec,

f = frequency of tail motion in terms of beats/sec,

L = body length in cm.

The generality of the model is unknown. However, it should be noted that the empirical findings are consistent with the theory.

As mentioned previously, other factors directly affecting fish motility are the temperature and dissolved oxygen concentration of the ambient water. The absolute water temperature, as well as the thermal history of the organism, has a significant effect upon the performance of the fish as measured by its

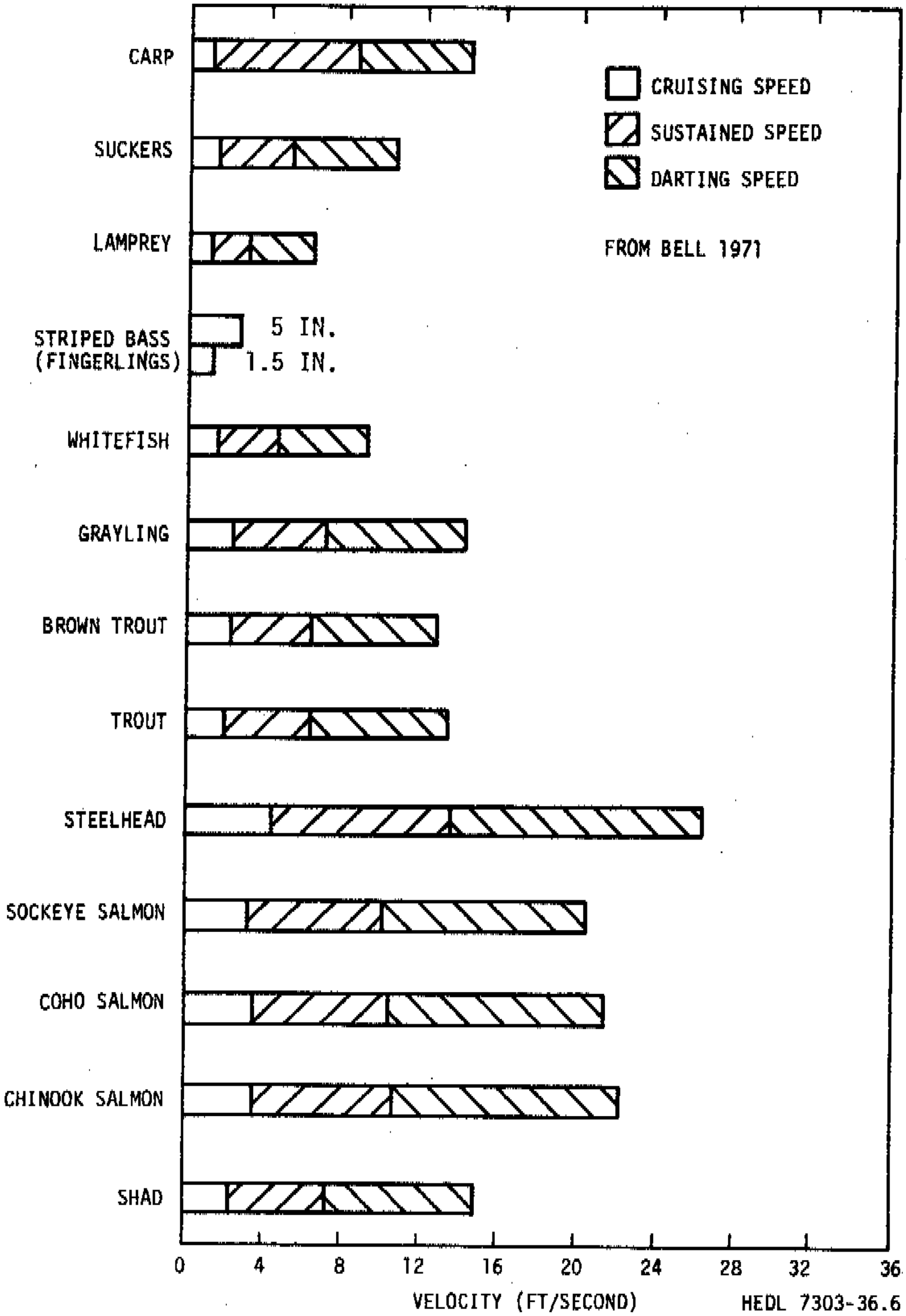


FIGURE 7. Relative Swimming Speeds of Averaged Size Adult Fish.

swimming speed. This statement has been confirmed in a number of studies. Temperature on either side of an optimal environment will affect the swimming performance. A graphical representation of this phenomenon is shown in Figure 8 from Brett[17]. This illustration indicates a 50 percent reduction of swimming effort over the entire tolerant temperature range shown.

The swimming performance is also affected by the available oxygen. Dissolved oxygen should be maintained near the saturation level. Studies have indicated that, as the oxygen content becomes reduced, the swimming performance falls off drastically. Reducing the oxygen level to one-third saturation reduces fish swimming performance by a factor of 2[14].

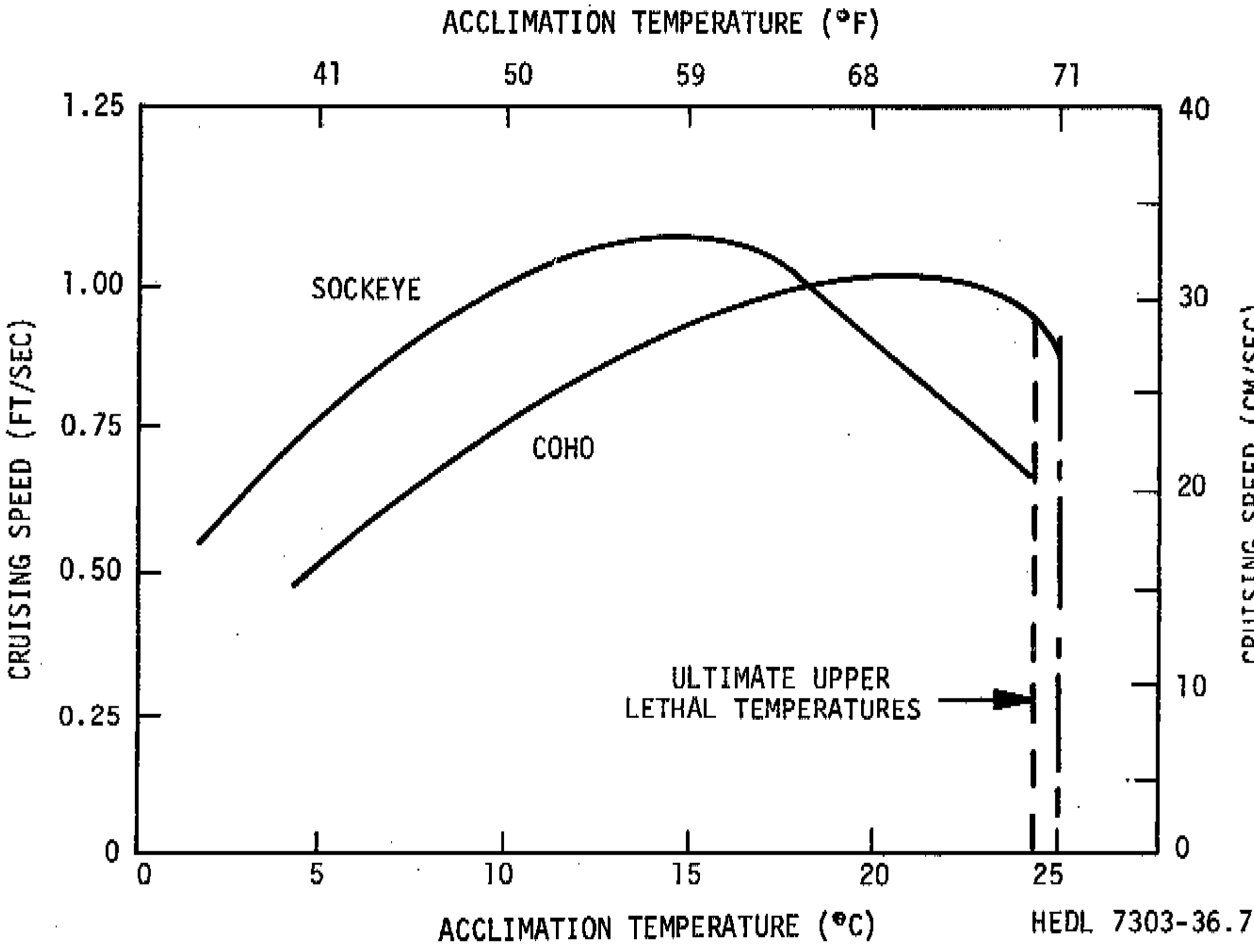


FIGURE 8. Maximum Sustained Cruising Speed of Sockeye and Coho Underyearlings in Relation to Temperature.

D. ENTRAINED OR PUMPED ORGANISMS

As discussed, using conventional designs, it is impossible to screen all organisms. Plankton and small fish are therefore ultimately sucked into the intake structure and subsequently pumped through the remainder of the cooling system. Plankton may include organisms from small microscopic zooplankton and phytoplankton to larger larval and juvenile fish. It is therefore important to examine the stresses imposed on these organisms in passing through the cooling water system if the potential biological damage is to be properly assessed.

1. Identification of Stresses

Organisms are exposed to various kinds of stresses as they pass through the cooling water system. These stresses result from the presence of mechanical devices, pressure changes, temperature changes, and chemical additions within the system.

Mechanical stress is defined as a stress brought about by the impingement of an organism on a rigid surface. This stress most notably would occur in passage through pumps, around bends in pipes, and through constricted areas. Two important variables in determining the measure of an organism's susceptibility to damage relate to the organism's size and density. A number of studies have been conducted by the Corps of Engineers in attempts to develop suitable models for predicting fish mortality resulting from their passage through turbines. The models developed indicate that the probability of contact is proportional to the rotational velocity of the impeller, length of the fish, overall cross sectional area of the passage, and the cosine of the inlet angle. To the authors' knowledge, relatively little effort has been expended on developing similar models describing the potential threat to plankton in secondary cooling systems.

Seemingly significant pressure changes and pressure gradients are experienced by organisms passing through cooling systems. Defining these potential stresses is difficult, since the pressure history that the organisms are exposed to varies from station to station, as well as from organism to organism passing through the same system. If it can be assumed that the organisms are hydrodynamically similar to water particles, we might consider the history of these organisms analogous to water particles.

As indicated in Figure 9, the first major pressure change in the cooling water system is developed in the cooling water pumps. The total pressure change at this point varies from station to station as dictated by the overall pressure losses throughout the system. Typical pressure changes range from 20 to 40 feet or 10 to 20 psi. In traveling from Point A to Point B, only a minor pressure gradient exists, the change in pressure resulting from losses experienced along the supply conduit. The system head loss and gradient across the condenser is larger than that of the supply conduit. In addition, it should be noted that for some designs, portions of the discharge side of the condenser can be above the system hydraulic gradeline, indicating the presence of a negative pressure. Finally, from the discharge side of the condenser, the cooling water is returned to a receiving body or sink.

In summary, it can be stated that, in addition to the presence of abrupt positive gradients, negative gradients are characteristic of the system.

The temperature change in the coolant water occurs across the condenser. This average temperature change has been included in Figure 9. The temperature change, of course, varies slightly from condenser tube to condenser tube and, once again, from power station to power station. The temperature gradient is dependent upon the time of travel through the condenser, normally a few seconds.

Chemicals are added for fouling and corrosion control. Chlorine is often added intermittently at the intake headworks just in front of the circulating water pumps. The chlorine residual on the exhaust side of the condenser is commonly 0.2 ppm or less. More complete discussion of this aspect can be found in Chapter V.

2. Studies on Induced Stresses

Although it is not the intent of this review to list in detail the studies performed to date dealing with biological damage to organisms passing through cooling systems, a few points should be mentioned.

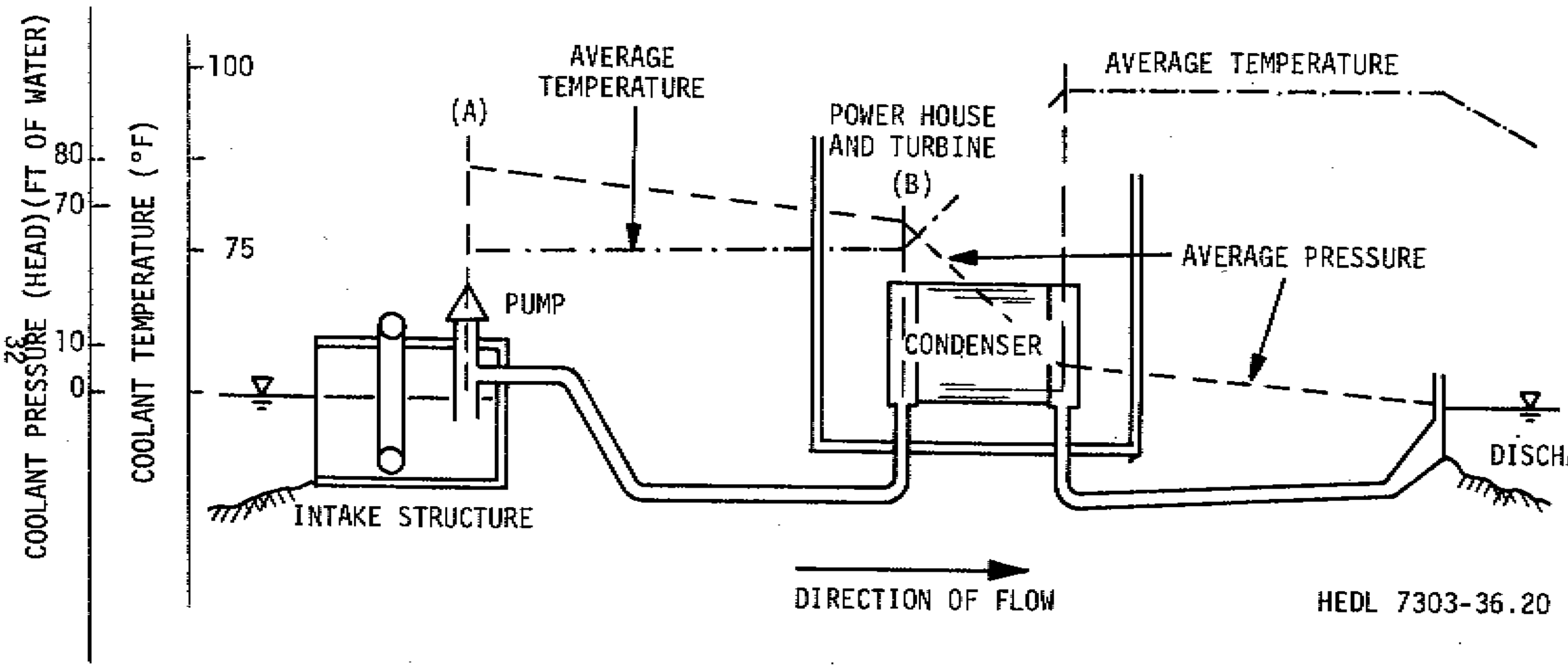


FIGURE 9. Hydraulic and Temperature Gradients Through a Secondary Cooling System.

Most of the effort that has been performed on the effect of induced stress to aquatic organisms has centered on the subject of thermal tolerance. Instantaneously changing an organism's environment can be thought of in terms of a dose. This dose is characterized by the acclimated temperature of the organism, the incremental rise of temperature, and the length of time or duration of exposure. In Figure 9, the thermal history of a water particle was shown. As indicated, the temperature increases as the water particle moves through the condenser. This increase, which usually occurs over a few seconds, might be termed a thermal shock. The organisms are then subsequently held at this temperature until the effluent is discharged into the receiving waters, where the temperature of the effluent is reduced primarily through dilution. The duration of time required to travel through the discharge conduit to the point of release is normally a few minutes. A number of field and laboratory studies have been conducted to measure the thermal tolerance of various species. The reader is referred to reviews presented by C. C. Coutant[18,19] and others.

One of the first studies conducted in the field to measure the effect of thermal shock was performed at the Contra Costa Power Station in 1952[20]. In this experiment, a condenser tube was isolated by extending it out on each end of the water box walls and connecting it to hoses. The hoses were in turn connected to dispersing and receiving tanks. Juvenile Chinook salmon and juvenile striped bass were then passed through the condenser tube. High survival was experienced by both species, indicating little, if any, effect.

A number of studies have recently been performed, and several are underway, to detect the effect on organisms passed through cooling systems under load by collecting measurements in both the intake and discharge structures. It is difficult to generalize the results of these studies unless sufficient care is taken to define the specific system stresses previously defined. The effect of gradients discussed previously, if not properly identified, could significantly reduce the usefulness of the study results. In addition, the interactive effects should be examined.

In support of this statement, let us consider the case discussed previously on passing fish through the Contra Costa cooling system. By connecting the condenser tubes to a separate dispersing and receiving tank, the system continuum was broken. Consequently, although the thermal history of the two systems is similar, the mechanical and pressure stresses may be different. Thus, the effect of pressure gradients and the mechanical stress factor were essentially removed from the experiment.

V. MATCHING BIOLOGICAL AND TECHNOLOGICAL DEMANDS

In Chapter IV, the various biological characteristics important to intake design were discussed. In this Chapter, an attempt is made to interface the requirements for the particular waterbody and its contained biological community with the requirements of the power plant to arrive at a best design. Meaningful guidelines or criteria should be established which relate the technological demands of the power plant to the level of protection thought desirable.

A. ESTABLISHING CRITERIA

As a point of discussion, consider the following criteria that were used in the design of the Calvert Cliffs Nuclear Power Plant cooling system. To quote from Reference 20:

1) Condensers should be designed so that the temperature rise in the cooling water which passes through them is as low as practicable. This will avoid subjecting pumped organisms to temperatures above their thermal damage threshold and will minimize thermal shock.

2) The cooling water intake to the plant should draw water from below the photosynthetic zone to minimize the entrainment of plankton and other microscopic organisms.

3) The intake velocity of the cooling water to the plant should be low enough to avoid disturbance of the schooling and swimming patterns of fish and to permit ease of egress for those fish that swim into the intake basin.

4) The cooling water system design should utilize mechanical equipment to clean condenser tubes to minimize the use of biocides for fouling control.

5) The point of discharge of the cooling water should be located far enough out from the shore so as not to disturb the current patterns and temperature regimes of the shallow water areas and should provide ample opportunity for mixing of the warmed cooling water with the receiving waters.

6) The cooling water discharge should be designed to create a high velocity jet to induce rapid mixing with the receiving waters to minimize changes in natural temperatures and oxygen content.

7) The cooling water discharge should be designed to minimize the time at which the maximum temperature elevation exists. Short exposure times as well as a minimum temperature rise are important in protecting the aquatic life."

Criteria 1 through 4 relate to intake design and the stresses found in the secondary cooling system. Criteria 5 through 7 relate to outfall design, and have been included to show added examples of environmental protection criteria.

As indicated in the previous chapter, the spectrum of aquatic life which might be considered in designing an intake structure extends in size from microscopic plankton to larger fish forms. It was suggested that screens provide a very effective means for both guiding and stopping fish. In concept, the sizing of the screen mesh is based on the size of locally important fish species. However, there are limitations to the minimum size of screen mesh that can be employed. Operationally, for a given flow rate, reducing the mesh size increases the head loss across the screened area, and increases the potential for fouling or clogging, since the open area of the barrier is reduced. The use of fine mesh also invites a potential frazil ice problem. In addition to the operational problem, reducing the screen mesh opening increases the probability for the smaller organisms to become impinged on the wire. Since these smaller organisms are extremely delicate, mechanical stresses of this type should be avoided. In practice, the normal mesh size ranged from 3/8 to 1/2 inch.

1. Plankton

Large water bodies can become both horizontally and vertically stratified. The governing factor, as indicated in Chapter III, depends on the relative resistance and scale. The location of the more highly productive areas of desired species that need protection should be identified by the biological survey discussed in Chapter IV. The existence of a clearly defined photosynthetic zone will vary from one water body to another, depending on a number of factors, including level of turbulence, convective motion in the vertical water column, and transmissibility of the water.

A study should be performed to relate cause and effect and to identify the reasons why some areas are more productive than others. Key factors to be identified include circulation, salinity, temperature, light, etc. Next, the operation of the power station should be superimposed upon this overall hydrologic/biologic structure. The effect of dispersing significant quantities of waste heat into the epilimnion, and removing large quantities of cooler water from the hypolimnion on the location of the thermocline should be examined. An example of such a study has been presented by Sundaram, et al.[5], in examining the effect of siting the Bell Power Station on Lake Cayuga.

Another approach to providing the proper level of protection suggests the relative volume of cooling water which can be withdrawn from the water source. Clearly, in rivers, the potential for damage is greater for a station where a substantial portion of the river flow is diverted or affected by the operation of a thermal power plant. In this context, it is worthwhile noting that, in the report of the Committee on Water Quality Criteria[22], a safe passageway (unaffected zone) was specified as consisting of 75 percent of the cross-sectional area and/or volume of flow in a river or estuary.

2. Fish

Once the species and size distribution of the resident population have been identified, the design criteria for the intake structure can be established. In establishing the design criteria for fish, such items as screen mesh sizing, the scaling of approach velocities, and the variation of fish endurance as it relates to the water quality parameters should be factored into the decision making process.

Depending on the species, size of species, and time of year, fish behavior and motility vary considerably. The speed at which fish can swim is related to their overall length. Their physical condition, measured by endurance, varies seasonally, depending upon the water quality. Both of these aspects should be considered for the species of interest. Specific questions that might be asked are:

1) At what velocities are fish safe against impingement?
2) What size screen mesh should be used to stop fish from penetrating the barrier?

Answers to these questions should account for the characteristics of local water quality; specifically, temperature and dissolved oxygen.

Typical endurance curves for salmon and striped bass are shown in Figures 10 and 11. The results were obtained in a study performed by the California Department of Fish and Game and the Bechtel Corporation for Pacific Gas and Electric Company[20] for the design of the Contra Costa Steam Plant. The experimental endurance curves were obtained by placing the test population of fish in a screened flume and subjecting them to the velocity shown in the abscissa for the duration of time indicated. At the conclusion of the test, the velocity was reduced to zero, and a typical head count was performed. Such experiments should be repeated for the range of environmental conditions that most probably will exist and for the various species of interest. A realistic approach velocity can be decided upon once this information is obtained.

The screen mesh sizing should be considered. The physical shape of fish varies with species and also varies individually within the species. Fish of the same age group may be long and slender or short and fat. If fish become exhausted, they normally become impinged broadside on the screens. Thus, it has been found that fish will be stopped by a screen, although they are physically small enough to pass through it. If, by chance, fish should align themselves perpendicularly to the mesh opening, the fish can be stopped physically by the bony part of their head, as indicated by Bell[14]. For this condition, Bell has proposed the following model for computing mesh size as a function of fish measurements.

$$M = 0.04\,(L - 1.35)F;\; 5 \le F \le 6.5 \qquad (5.1)$$

$$M = 0.03\,(L - 0.85)F;\; 6.5 \le F \le 8.0 \qquad (5.2)$$

where:

M = maximum screen mesh opening in inches

L = length of the fish in inches

D = body depth in inches

F = L/D = fineness ratio

However, as pointed out by Bell, the number of fish used to determine the model was small and, consequently, the formulation should be used primarily as a guide. The envelope or range of relationships using Equations 5.1 and 5.2 is shown in Figure 12. By way of comparison, the data presented by Kerr[20] are also shown in Figure 12.

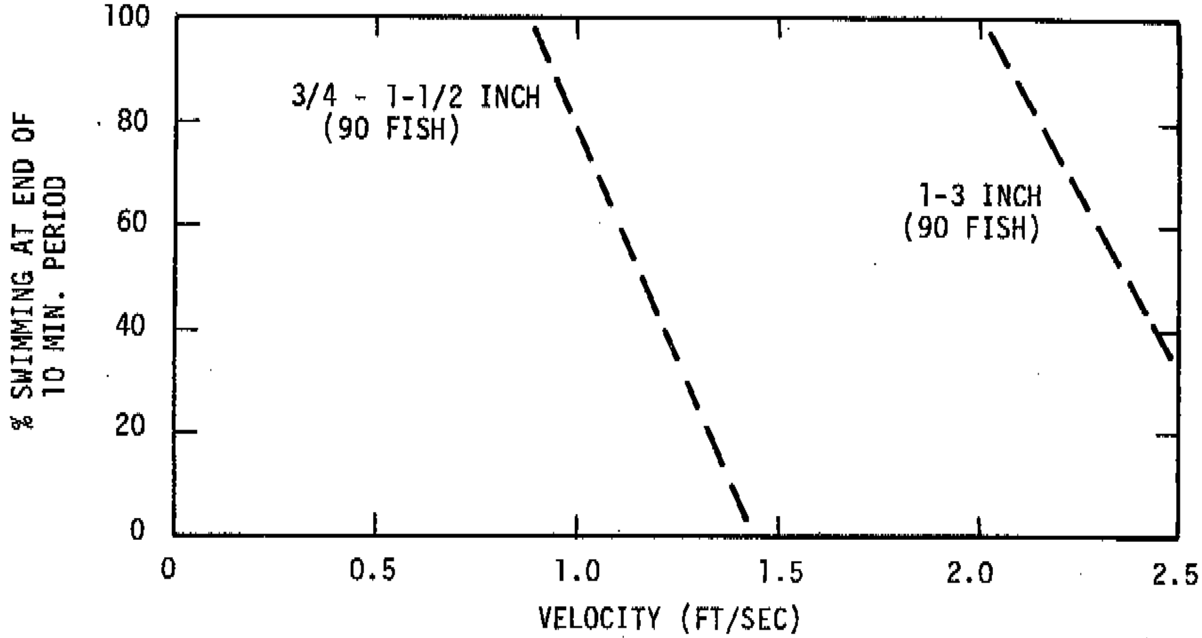


FIGURE 10. Ten-Minute Velocity Endurance Curve for Striped Bass.

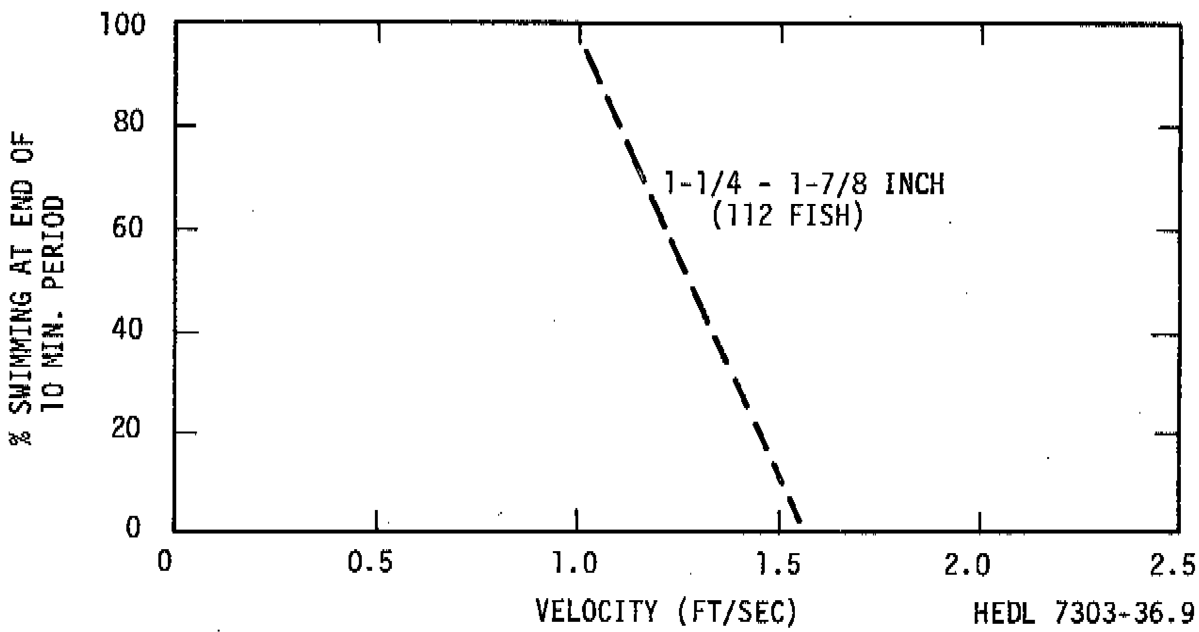


FIGURE 11. Ten-Minute Velocity Endurance Curve for Chinook Salmon.

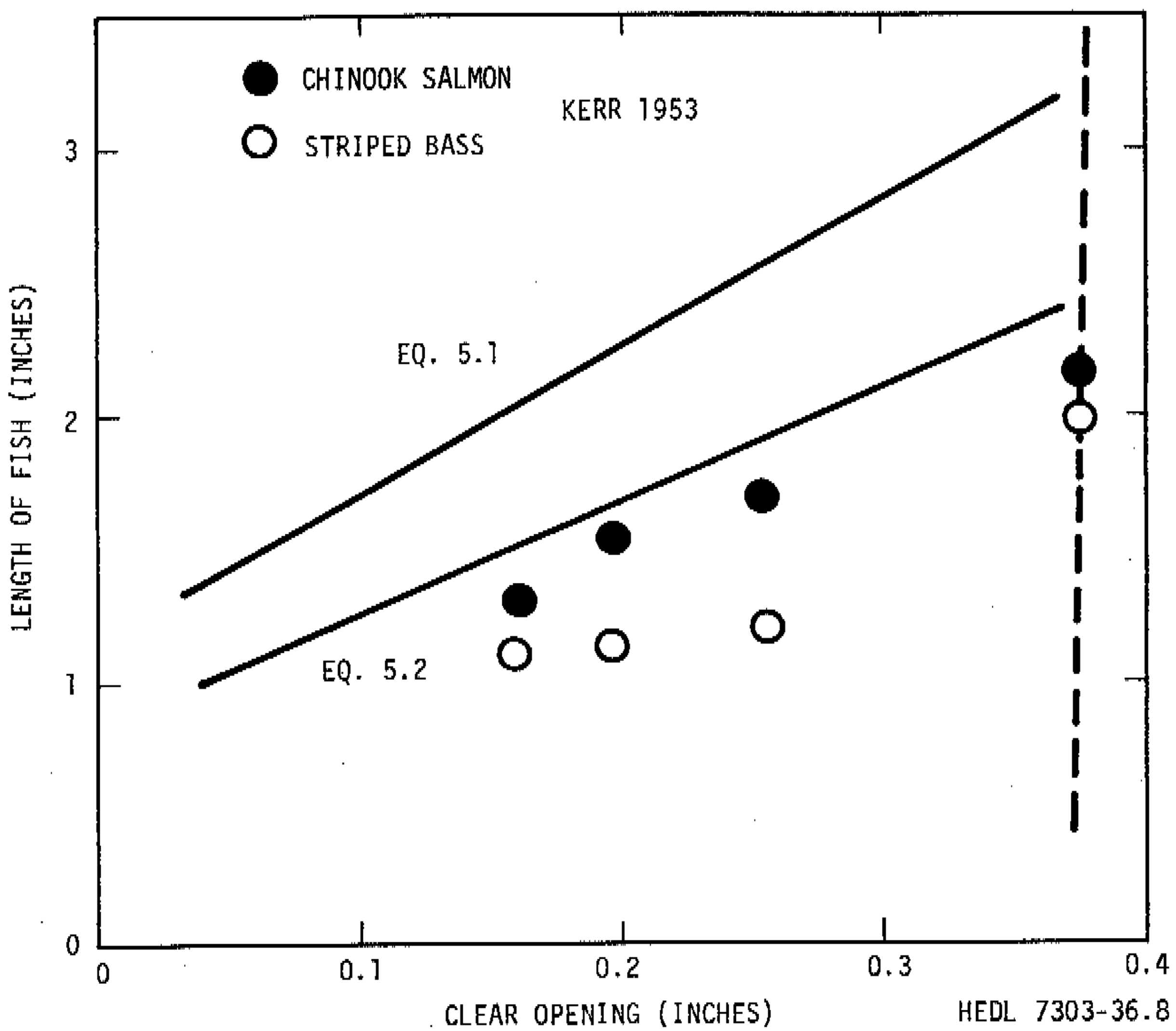


FIGURE 12. Effectiveness of Screening: Clear Opening vs Length of Fish.

The swimming ability of fish decreases as their size decreases. Thus, the designer must eventually reach a point where it is no longer feasible to design a structure based on approach velocities because reducing mesh size is no longer practicable. A value judgment must be made regarding the extent to which screen sizes can be reduced before significantly increasing the potential for impingement.

B. CANALS AND SKIMMER WALLS

On occasion, approach canals and skimmer walls have been used. If not designed properly, the use of these features can sometimes result in fish traps.

1. Canals

Intake canals have been built for purposes of: 1) providing a protected area for the intake structure; 2) a means of locating the intake structure and pump station near the power station, reducing pumping head losses, etc.; and 3) separating the location of the intake and outfall structure. The problem associated with the construction of an intake canal is that fish frequently swim into these recessed areas and become trapped. If an intake canal is used, some means of safely returning the fish must be included in the design.

Discharge canals are constructed for basically two reasons. First, they are a means of providing enough resistance between the intake and the discharge so that no recirculation occurs. Secondly, they provide a means whereby the temperature of the effluent can be reduced by dilution before it is discharged into the receiving water.

Warm water in discharge canals can either attract or repel fish, depending on the preferred temperature for the specific fish and on the time of year. Generally, during the cold season, fish congregate near the effluent discharge. This is particularly true of warm water species. However, during the warm summer months, the discharge canal may present a potential hazard. As indicated in

Figure 9, the temperature increase induced by the condensers remains until the cooling water temperature is reduced through dilution. If a discharge canal is included in the design, the reduction of this temperature is restricted and the thermal profile might instead look like the profile shown in Figure 13[19]. This situation should be avoided, as criterion 7 of the Calvert Cliffs plant indicates. The condition can, of course, be lessened by introducing auxiliary cooling units to temper the water. This particular concept is employed in the operation of the Fort Marlin station on the Monogahela River[23] and Oyster Creek station on Barnegat Bay[24]. Auxiliary pumps have been installed to reduce the effluent discharge temperature through dilution.

2. Skimmer Walls

Skimmer walls are used under conditions where vertical stratification exists and to collect floating debris. The walls, once again, are designed to provide the necessary resistance between the intake and discharge location. The presence of a skimmer wall can create problems similar to those encountered with the intake and discharge canal. Fish can find their way into the partitioned areas around intakes, and once there, remain. Skimmer walls used around discharge points to pond the heated effluent do not present as serious a problem as discharge canals, since fish can always sound in order to avoid the warm water, provided there is sufficient depth.

C. DESIGN

Comments on intake design based upon biological considerations are presented in this section.

1. Shoreline Intakes

The arrangement of the various features associated with conventional shoreline intake designs was shown in Figure 1 and a set of representative criteria suggested for their design (from Calvert Cliffs) was given at the beginning of this chapter. As suggested, the ecological survey should include the identification of biologically productive zones. In addition to vertical stratification (criterion 2) the presence of horizontal stratification should be examined. The intake velocity of the cooling water should be low enough

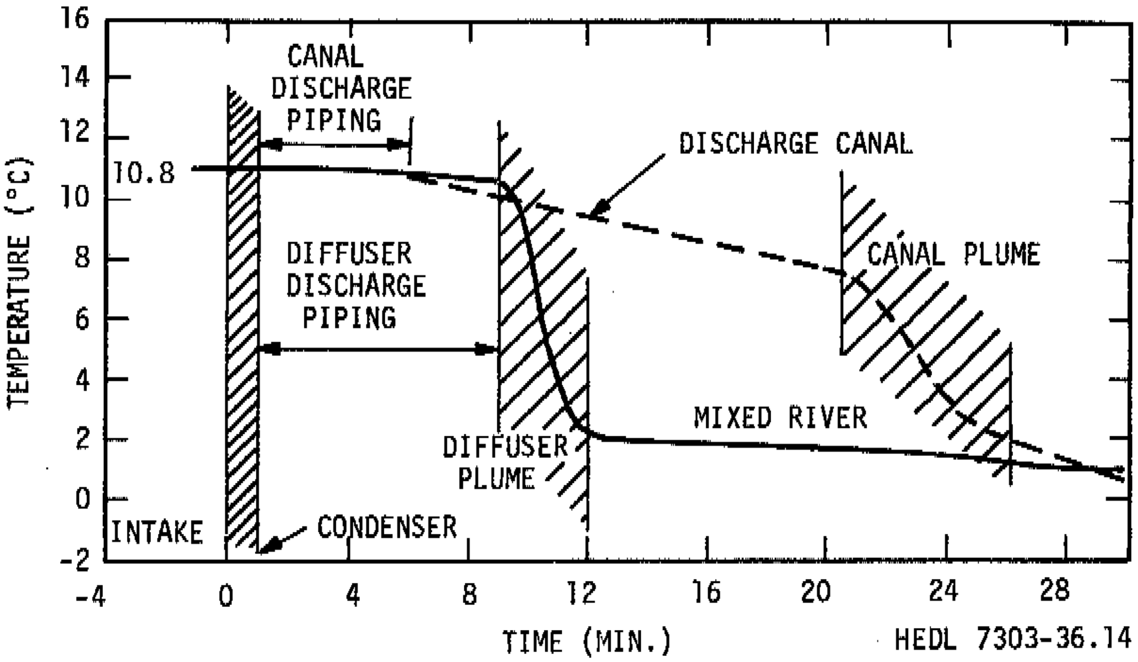


FIGURE 13. Comparison of Temperature Profiles in a Large River: Discharge Canal vs. Direct Discharge.

to avoid disturbing the fish's schooling and swimming patterns (criterion 3). In the case where anadromous species occupy the source water body, the location and operation of the intake structure should not impede their migration. The orientation of the structure is very important. The intake structure should be placed such that the integrity of the preconstruction shoreline is maintained. Extensive indentations such as canals should be avoided whenever possible.

The Pittsburg (California) power station employs the "Pacific Gas and Electric Intake Design." The design includes the basic features discussed previously. The intake and screenwell structure are placed together at the shoreline. The overall sizing of the structure has been considered in reducing the approach velocity to one that can be tolerated by the resident fish. The actual arrangement of the features of the PGE design is shown in Figure 14. The cooling water screens are placed flush with the face of the intake at the shoreline. The trash racks form a cage located out in the source water body, keeping debris from the screens, but allowing free passage of fish[25,26].

At the Pittsburg Station, the effluent is discharged upstream of the intake into Suisun Bay. Recirculation at the Pittsburg Station has been prevented by the construction of a retaining wall that extends from the shoreline approximately 800 feet outwards into the bay (Figure 14).

Based on the research performed using the resident anadromous species of the San Joaquin and Sacramento Rivers, striped bass and chinook salmon, the design approach velocities for the Contra Costa and Pittsburg steam plants were set at 1 ft/sec. The approach velocity is the velocity of flow through the exterior bar rack structure in front of the traveling screens. The fine mesh opening for both plants was set at 3/8 inch square.

The 3/8-inch mesh corresponds to stopping both 2 to 3 inch striped bass and 2 to 3 inch chinook salmon fingerling (see Figure 12). Both the 2-inch striped bass and the chinook salmon fingerling possess the capability of swimming at a sustained speed greater than 1 foot per second. Therefore, the fish intended to be excluded from being pumped through the system possess the swimming capability to tolerate the design approach velocities. It is presently believed that the design approach velocity should be as low as practical to minimize impingement.

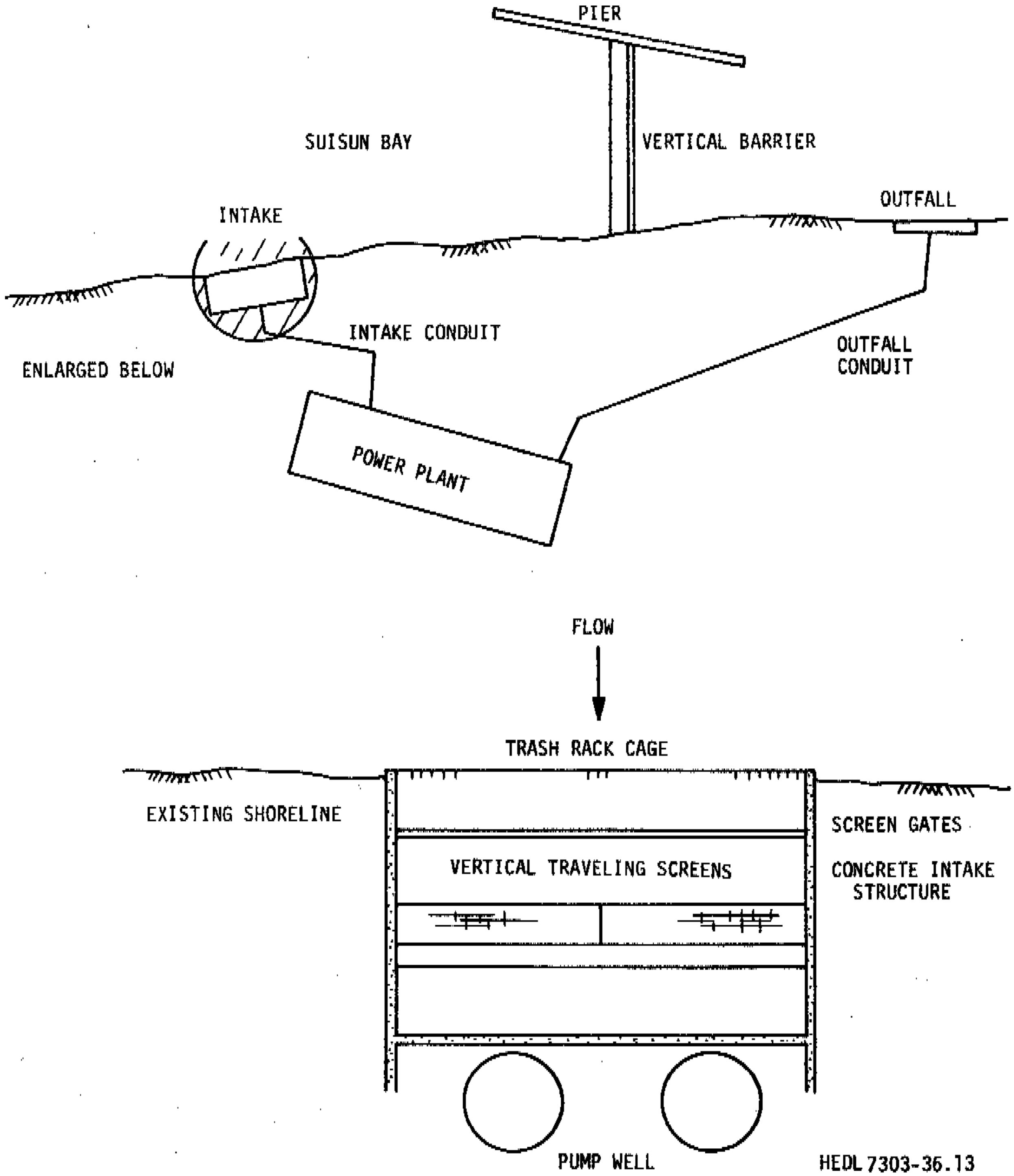


FIGURE 14. Secondary Circulating Cooling System used at Pacific Gas and Electric Pittsburg Steam Electric Plant.

In the design of the Peach Bottom Nuclear Station located on the Susquehanna River in Southeastern Pennsylvania, the recommended approach velocity was set at 3/4 foot per second[27]. This velocity was based on studies performed on the swimming speed of the native white crappie and channel catfish. At the Salem Nuclear Station to be located on the Delaware River Estuary[28], and the Millstone Station[29], a 1 foot per second approach velocity has been recommended.

2. Offshore Intakes

In the 1950's, the operation of the Redondo and El Segundo Power Stations by Southern California Edison resulted in occasional fish kills. Large schools of fish would enter the intake pipe and become concentrated in front of the fish screens[30]. Two basic approaches to alleviate the problem were considered. In the first approach, fish were prevented from entering the pipeline. In the second approach, fish were removed from the screenwell and returned to the open water.

A solution from the first approach of preventing fish from entering the intake pipe resulted from the observation that fish sense and subsequently react to vertical flow fields much more slowly than to horizontal flow fields. As a result, fish near a vertically oriented intake can be drawn into the structure quite easily. Steps were taken to reorient the flow pattern from the vertical plane into a horizontal flow field. This was accomplished by inserting a velocity cap on top of the previous design, as shown in Figure 15.

As mentioned in Reference 31, "...Test results were startling. Without a velocity cap, the small fish were swallowed up and rapidly disappeared into the pipe. However, it was almost impossible to draw any fish into the pipe when a velocity cap was being used..."

The entrance velocity is controlled by the opening of flow gap, which is adjusted by setting the lid at the desired grade. The flow gap at the El Segundo intake is set at two feet, giving a maximum normal entrance velocity of approximately 3.5 feet per second. The flow gap at the Huntington Beach Station is set at 4.5 feet, resulting in an entrance velocity of approximately two feet per second. The design entrance velocity should, of course, depend upon the local species of fish and should be such that the fish are capable of tolerating the

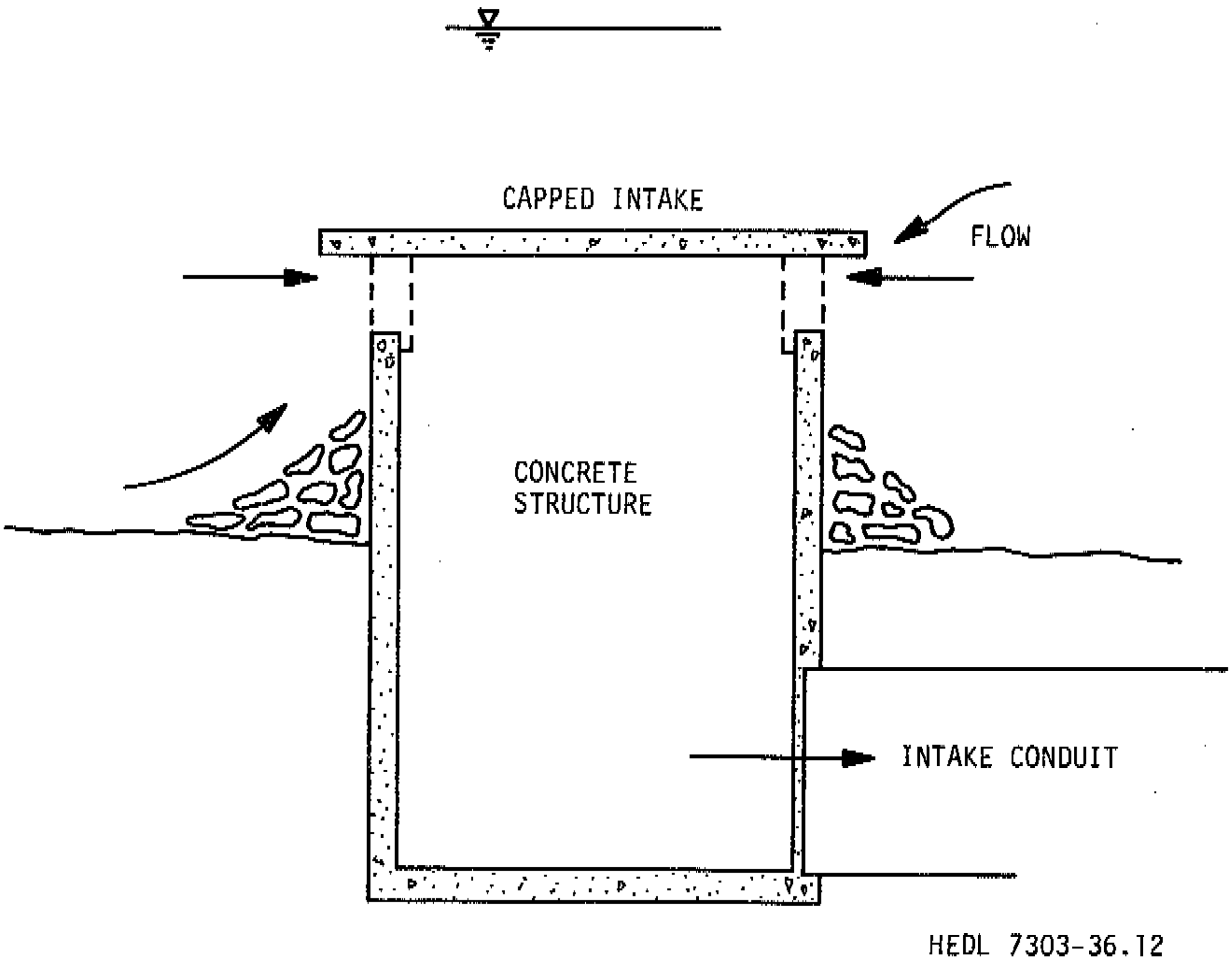


FIGURE 15. Velocity Capped Intake Structure.

field. Again, it would seem the design velocities should be set in the species' cruising speed range. A rule of thumb for approximating the cruising speed of salmon species can be obtained by multiplying the length of the fish by a factor (2/sec)[14].

The first prototype velocity cap was inserted on the El Segundo intake in June 1957. The velocity cap provided at El Segundo consists of a concrete slab 12 inches thick, 24 feet long, 23 feet wide, having four hairpin legs for seating upon the lip of the intake tower, and weighing 43 tons. The apparent effectiveness of the velocity cap, as shown in Reference 9, reduces the tonnage of fish entering the screenwell by approximately 95%[31]. Presently, there is some controversy over this assessment of the structure's effectiveness.

A design similar to the velocity cap concept has been proposed for the intake structure of the Zion plant along the shores of Lake Michigan[32]. Figure 16 shows the proposed structure. The major difference between the design of the proposed Zion structure and the design of the California structure is that the Zion structure includes provisions for melting ice.

The design of the intake structure for the Point Beach nuclear plant, also located along the shores of Lake Michigan, is shown in Figure 17[33]. The structure has been designed around what might be termed an inflow gallery concept. The plan calls for the gallery, to be constructed with steep piling and limestone blocks, to form a hollow cylinder which will extend from the lake bottom to a height 8 feet above the water surface. The cooling water enters the gallery by flowing through a number of 30-inch diameter pipes located in the wall of the cylinder with 1" x 1" x 13/16" bar grating over the faces of the portals.

Water enters the Zion intake at approximately 2.5 ft/sec and the Point Beach intake at two ft/sec. These velocities, which are higher than those typically recommended for shoreline intakes, have been considered suitable for offshore structures provided they were not located in "nursery grounds" containing large numbers of juvenile fish. Since the typical offshore location does not contain enough vegetation or other cover for protection of small fish from predation, the higher velocity seems generally appropriate on the basis of behavior of a single fish. It is possible that schooling characteristics could modify this approach, and where schooling is active, a lower velocity may be indicated.

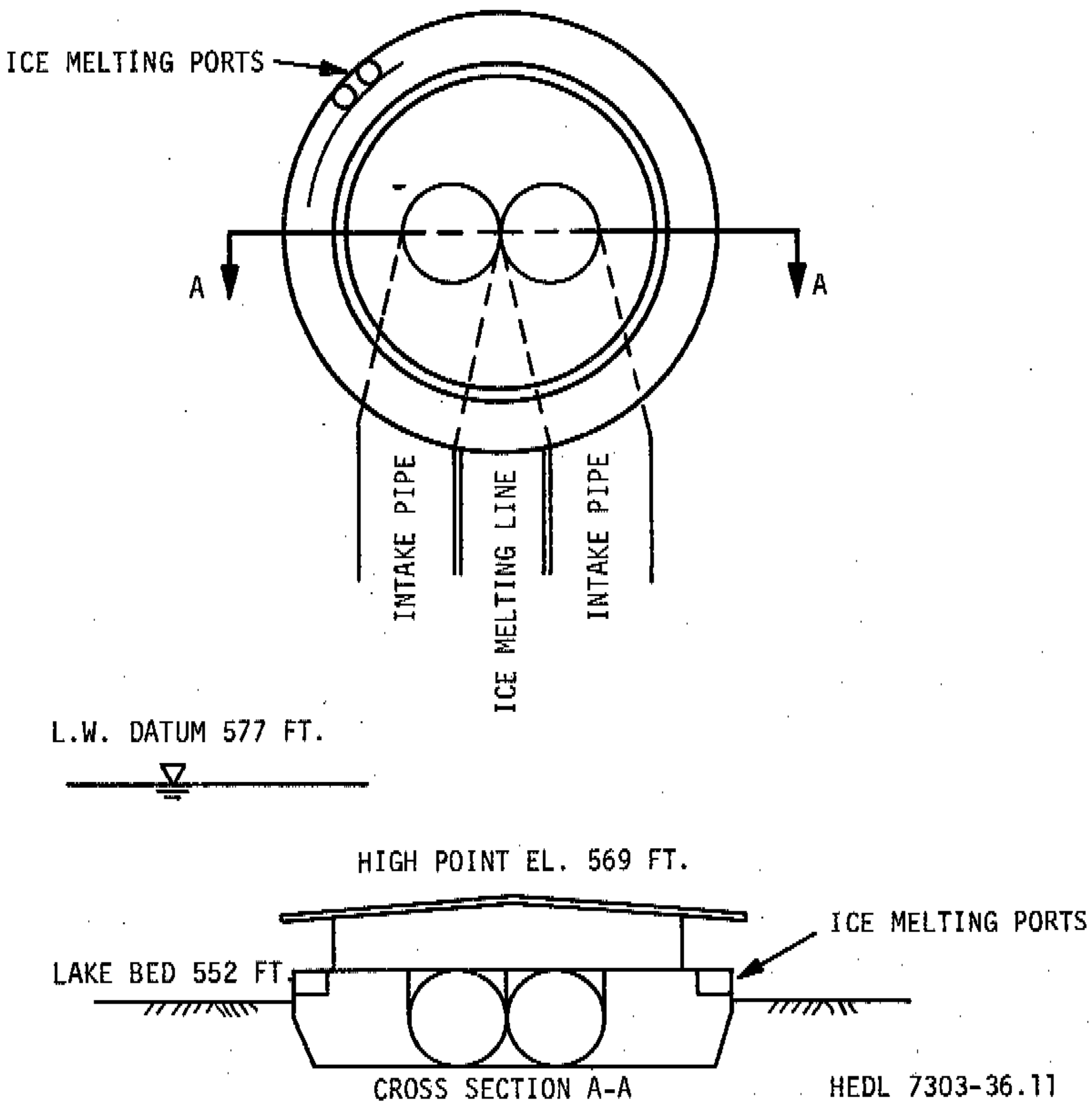


FIGURE 16. Proposed Intake Structure for the Zion Nuclear Plant on Lake Michigan.

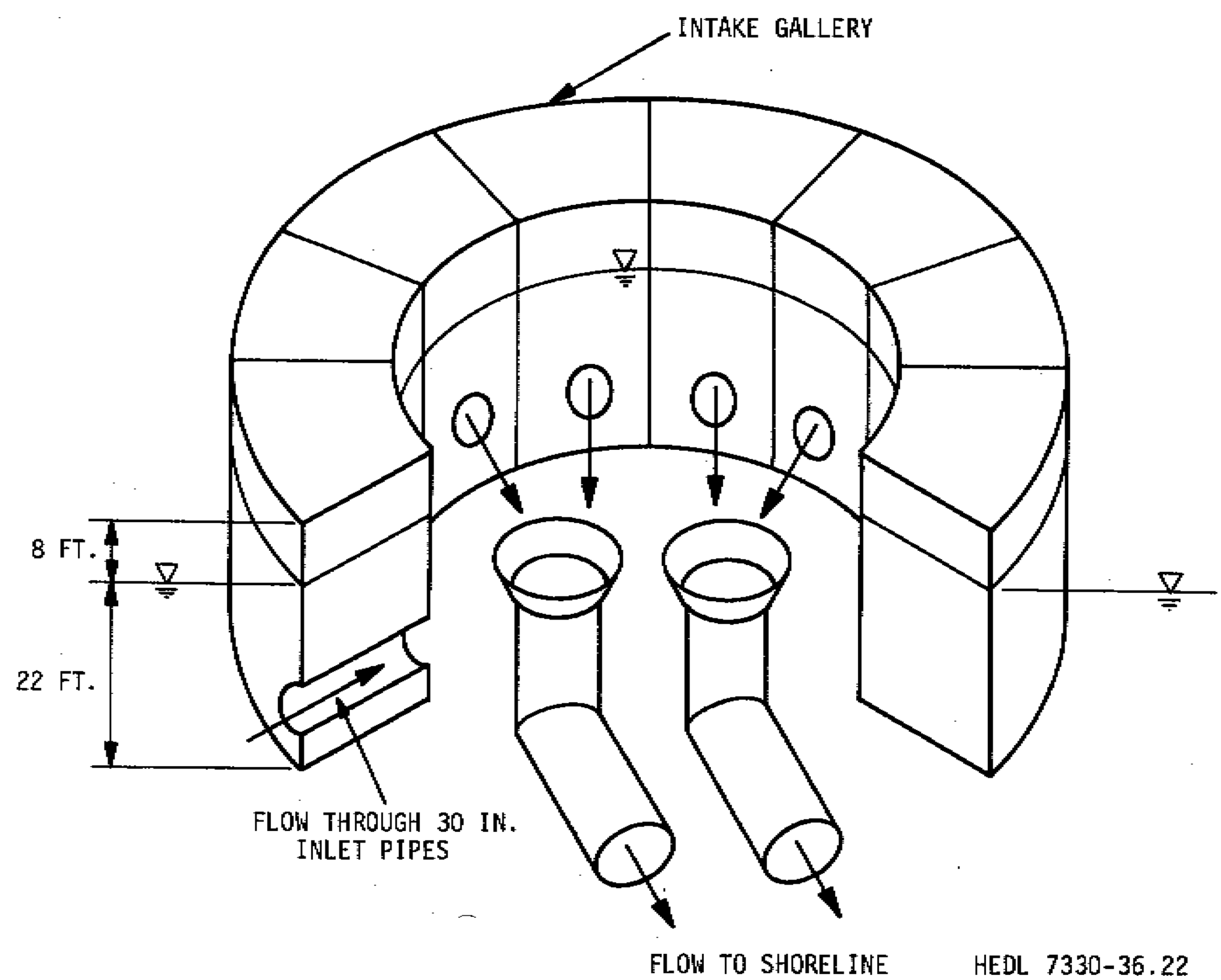


FIGURE 17. Intake Structure of Point Beach Nuclear Plant.

3. Screenwells

The screenwell is located between the intake and the pumpwell. Depending on the overall system design, the distance separating the location of the various features might be considerable. Fish that become sucked into the intake structure flow into the screenwell structure. Therefore, the design of the screenwell structure should include provisions for removing fish.

In the design of the Huntington Beach Power Station, extensive model studies were performed on the screenwell structure. The purpose of the studies was twofold: 1) to assure that the proper hydraulic conditions existed in the screenwell; and 2) to include proper provisions for the handling of fish.[31]

A review of the Huntington Beach screenwell design indicates that the water flows into the screenwell structure through a 14-foot diameter pipe with a design velocity of approximately 6 feet per second. Since this velocity was too high for proper screening, the cooling flow had to be decelerated. To spread the coolant flow uniformly over the four screens used in the design, a series of turning vanes was included. This feature is shown in Figure 18. As a solution to the possible fish problem, the decision was made to provide quiet areas within the screenwell where fish might congregate so that they could be collected and safely returned to sea. The location of these quiet rest areas is also shown in Figure 18. The degree of success has varied considerably, as recently reported by the utility. However, it should be noted that fish will congregate in the low velocity area only if they first become sufficiently fatigued from swimming against the currents in the screenwell so that they attempt to seek out these quieter zones and, secondly, if they can find these quieter zones once they do become fatigued.

A design concept that has recently been suggested by Bell[14] is shown in Figure 19. The design overcomes the problems mentioned above by providing directional guidance to a built-in fish bypass system. In addition, the system has no irregularly projecting surfaces that could pocket or inhibit fish movement. The concept could be used with both fixed or moving screen installations. Model studies performed on the concept will assure the proper hydraulic characteristics.

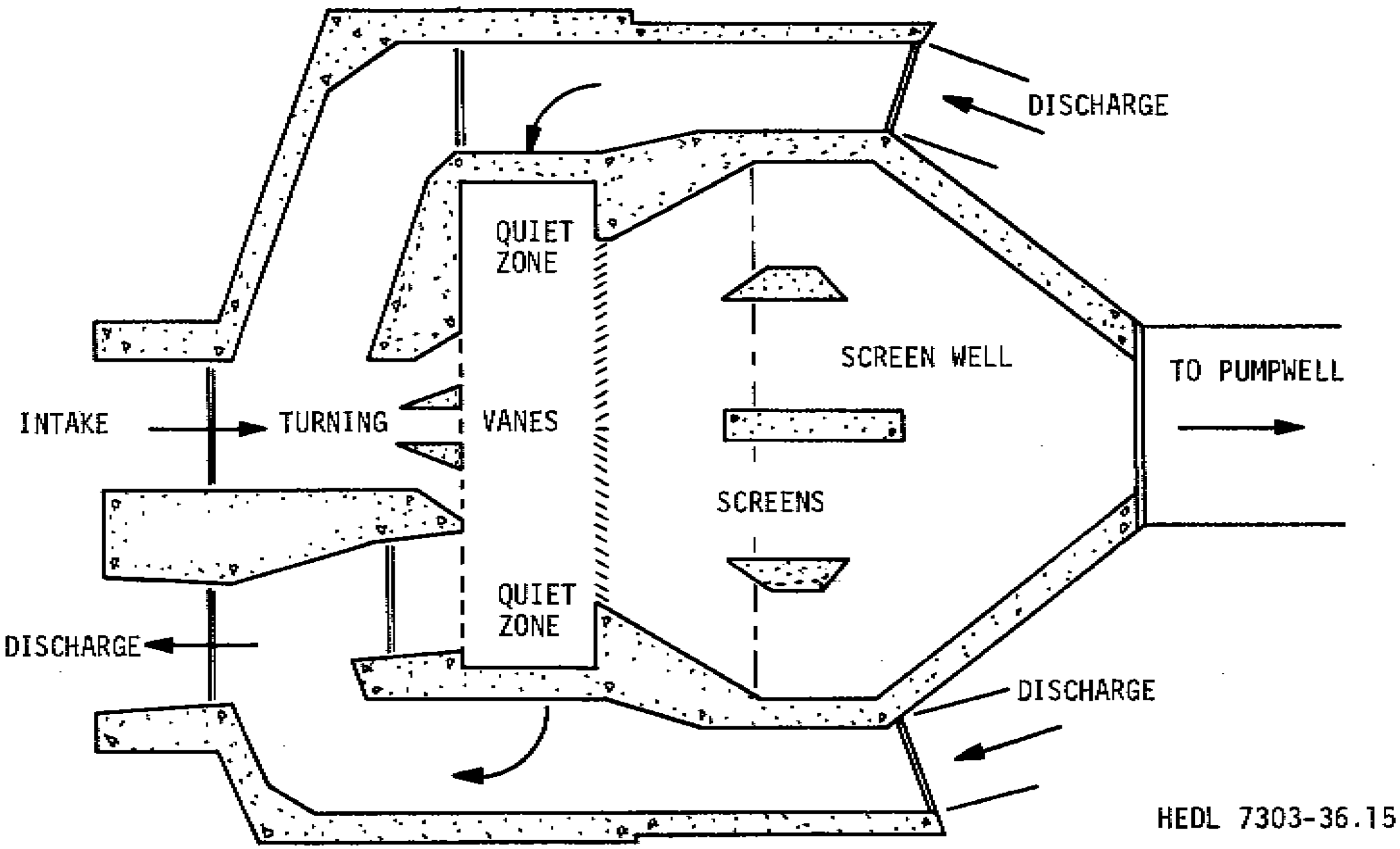


FIGURE 18. Plan View of Screenwell Used at Huntington Beach Steam Electric Plant.

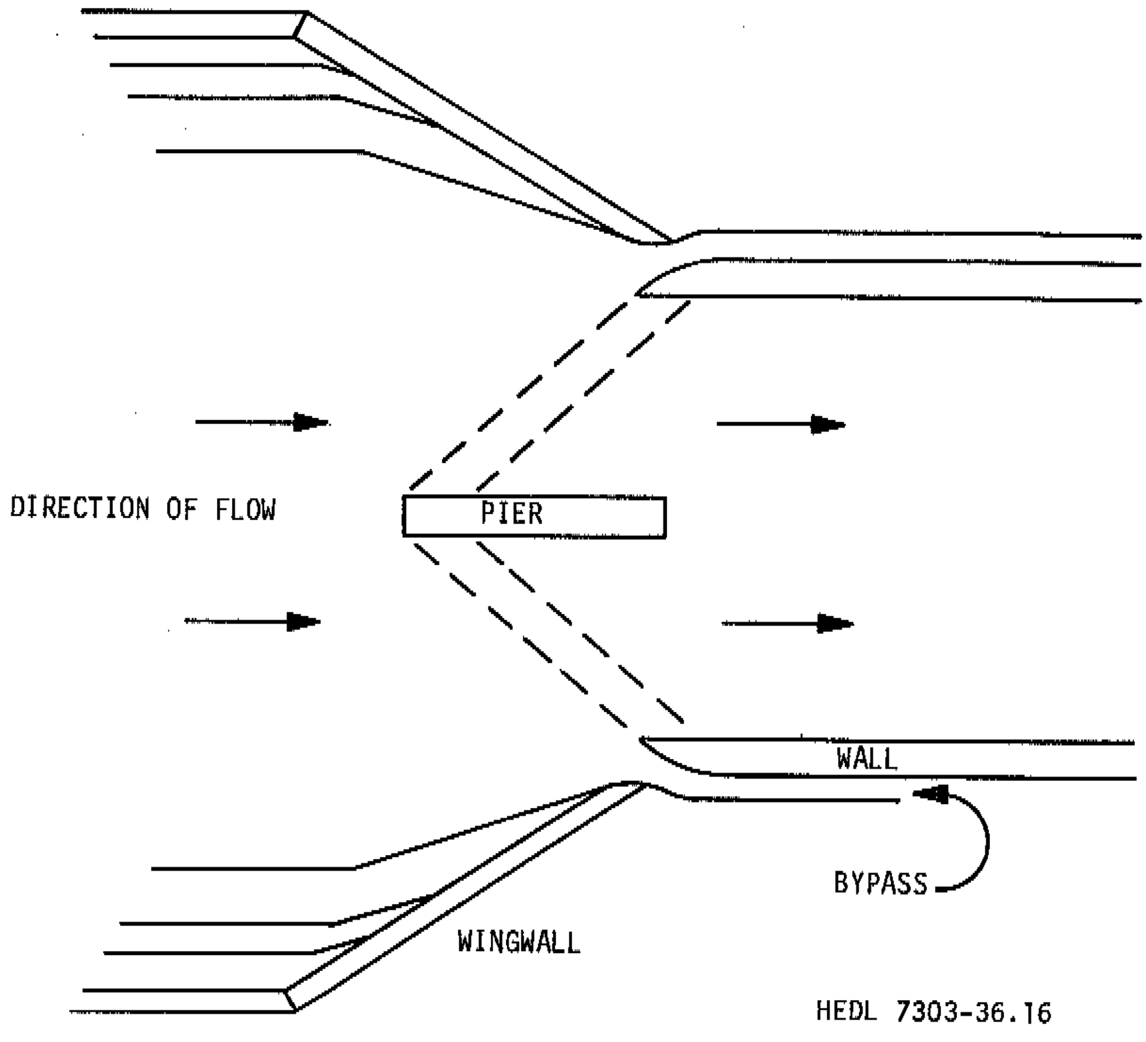


FIGURE 19. Proposed Concept to Provide Directional Assistance for Fish to Bypass Structures.

D. FISH REMOVAL TECHNIQUES

Fish must be removed from screenwells if significant numbers become trapped. However, in order for fish removal techniques to be efficient, the fish must first be concentrated into a relatively small area. Once the fish are concentrated, several techniques can be used for removing them. The more popular techniques include the use of fish pumps, locks and elevators, and nets.

1. Fish Pumps

Fish pumps have become a potential technique for handling fish. The pumps employed normally possess a special impeller and the casing has been contoured to remove sharp edges. On several occasions, centrifugal pumps designed to move produce have been used. Tests conducted in California fish hatcheries using produce pumps have been quite successful. Using a 5-inch pump, fish ranging in size from 2 to 12 inches were pumped without harm.[34] Optimum performance for fish of all sizes was achieved by operating a pump speed of 700 revolutions per minute.[14,34] During one test, a total of 2000 pounds of trout were pumped during a 6-minute interval.[35]

As mentioned in Chapter IV, a number of techniques have been used in attempts to guide fish. Velocity of flow in conjunction with an a-c electric field was used at the Wheeler Dam hydroelectric station (TVA) to concentrate and remove gizzard shad from the tail race.[35] It was observed that the shad would concentrate along one of the power house wing walls as the flow rate through certain generating units was increased. A string of electrodes was placed along the wing wall. As the shad drifted into the area, they were stunned by the electric field and, subsequently, carried by the water current into a funnel arrangement which was connected to a 6-inch fish pump. It has been reported that 1100 pounds of shad have been removed during a one-hour period by this method.

Lights have been used on several occasions to guide or attract fish. A light arrangement has been used in conjunction with a fish pump by Southern California Edison at the Huntington Beach Power Station. The light attracts the fish into an area where they are removed by the suction of a 6-inch fish pump.[36]

2. Fish Elevators

Fish elevators can also be used to remove fish. However, to be effective, the use of this device requires that the fish be concentrated to an even greater extent. The concept behind a fish elevator is to first concentrate the fish, next, close off their escape route, and then lift the fish into a discharge canal. The fish can be raised by placing a screened bottom on the chamber (lock) and moving it through the water column.

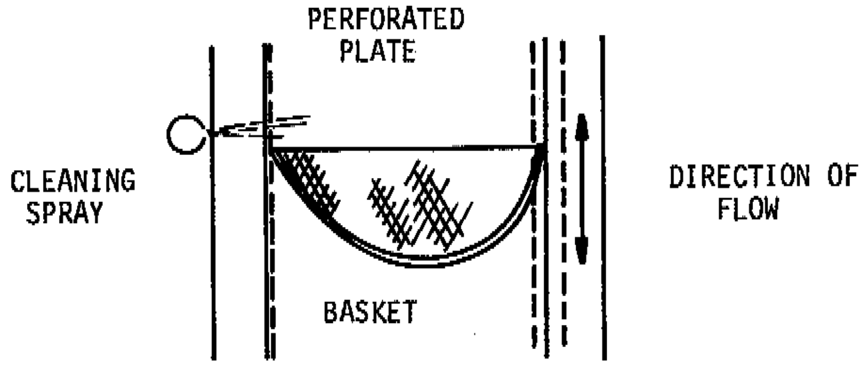
3. Nets

Recently, a concept which has received considerable support involves using a moving basket screen. The basket moves vertically along the face of the vertical traveling screen. The concept, called a "Fish Collector Basket" is shown in Figure 20.

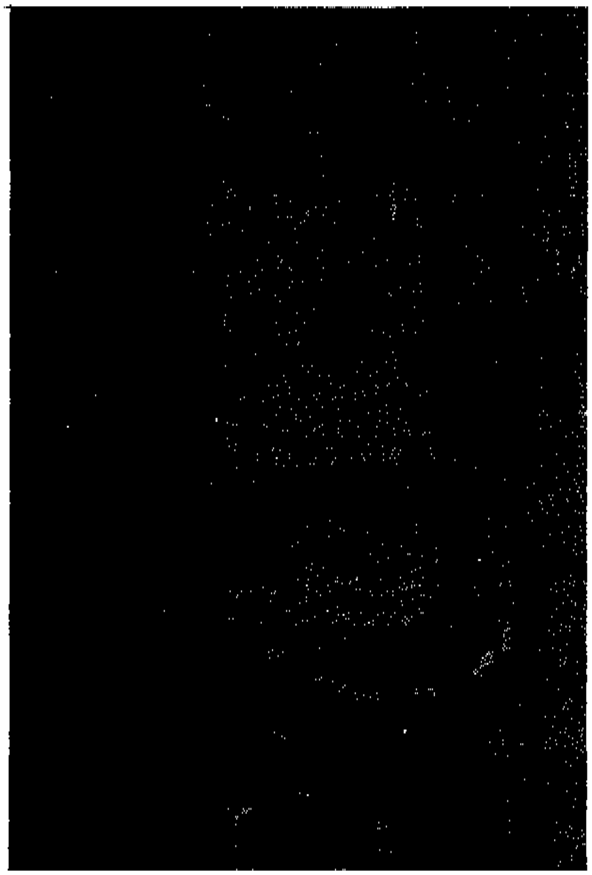
This concept has not been tested under prototypic conditions. However, the design has undergone considerable model testing. The concept tentatively includes replacing the vertical traveling screen with a perforated plate. The perforated plate can be mounted directly on the front of the support piers, thus eliminating irregular surfaces which can act as fish pockets. The basket collector moves along the front of this perforated plate as shown in Figure 20. Manual operation of fish nets simply involves dipping the fish from the screenwell and transporting them to a discharge point.

E. MATERIALS OF CONSTRUCTION AND OPERATIONAL CONSIDERATIONS

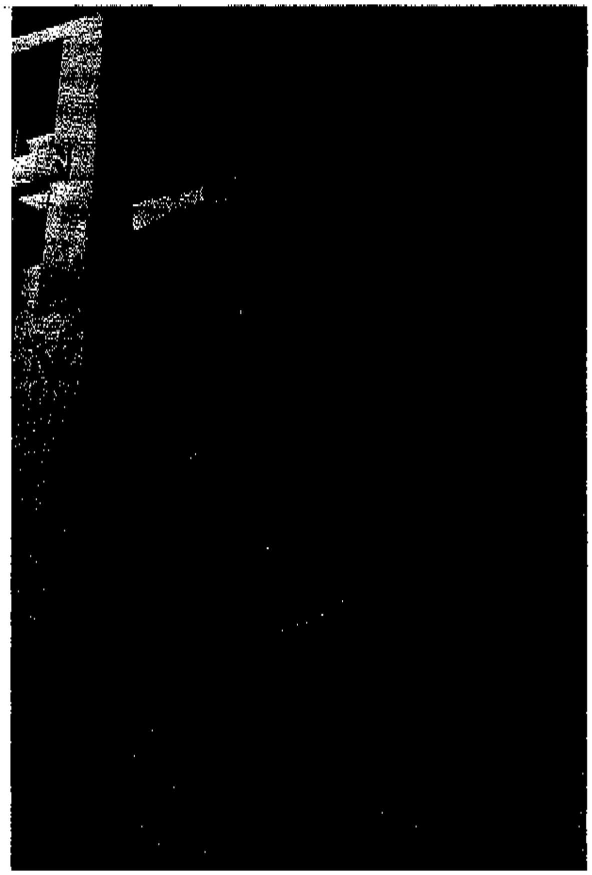
Fouling and corrosion in the power plant cooling system reduces efficiency and can ultimately cause plant shutdowns for cleaning or repairs. Prevention, or at least control, of a particular power plant's fouling and corrosion problems must be considered during the design stage as well as the operational stage. The techniques intended for ultimate use in the plant should be selected with consideration of their effects on the entrained plankton and the organisms associated with the intake structure. Protection of the ecosystem is an important standard to meet when considering antifouling methods, but it is certainly not the only consideration. Improper techniques for intake structure protection could result in detaching organisms from the structure and allowing



DEFINITION SKETCH



MOVING ALONG PLATE



AT TOP

HEDL 7303-36.21

FIGURE 20. Proposed Fish Collector Basket.

them to enter the cooling system. So it is important to characterize the organisms associated with a plant site and their response to fouling and corrosion control techniques.

Fouling, the growth of organisms on the surfaces of water system components, can range from scaling by biological slimes to system blocks by large organisms such as mussels. Slime-forming microorganisms include bacteria, algae, fungi and diatoms. Besides forming scale, some of these organisms release acids and gases along the surface they attach to, leading to anodic corrosion.[37] Common seawater fouling organisms listed by Anderson and Richards[38] are:

Plants	(Algae and Slimes)
Sea Mosses	(Hydroids)
Sea Anemones	(Metridium)
Barnacles	(Balanus)
Mussels	(Mytilus)

Methods of controlling fouling depend either on preventing the attachment of embryos on cooling system surfaces or by removing or killing the adult organisms. A number of techniques for the control of fouling have been proposed. They include:[38]

1) An increase in temperature
2) Removal of dissolved oxygen
3) High water velocities
4) Protective toxic coatings
5) Protective toxic materials
6) Filtering the water
7) Acid treatment
8) Poison treatment
9) Increase or decrease in salinity (seawater systems)
10) Mechanical removal

Common techniques used currently are heat treatment and chlorination. Adequate water velocities to prevent setting of organisms and toxic cooling system materials (90-10 copper-nickel) show promise for some applications. The other methods listed should be given consideration for specific problems, and all the techniques should be carefully analyzed to determine their disadvantages. For example, filtering water to remove microscopic organisms is not likely to be economical. Acid or poison treatment should be regulated to avoid cooling system corrosion or harmful effects to organisms.

The possibility of using several of the methods in combination might be advantageous. For example, the exposure time to kill mussels with chlorine is dramatically reduced by combination with heat treatment, as shown in Figure 21.

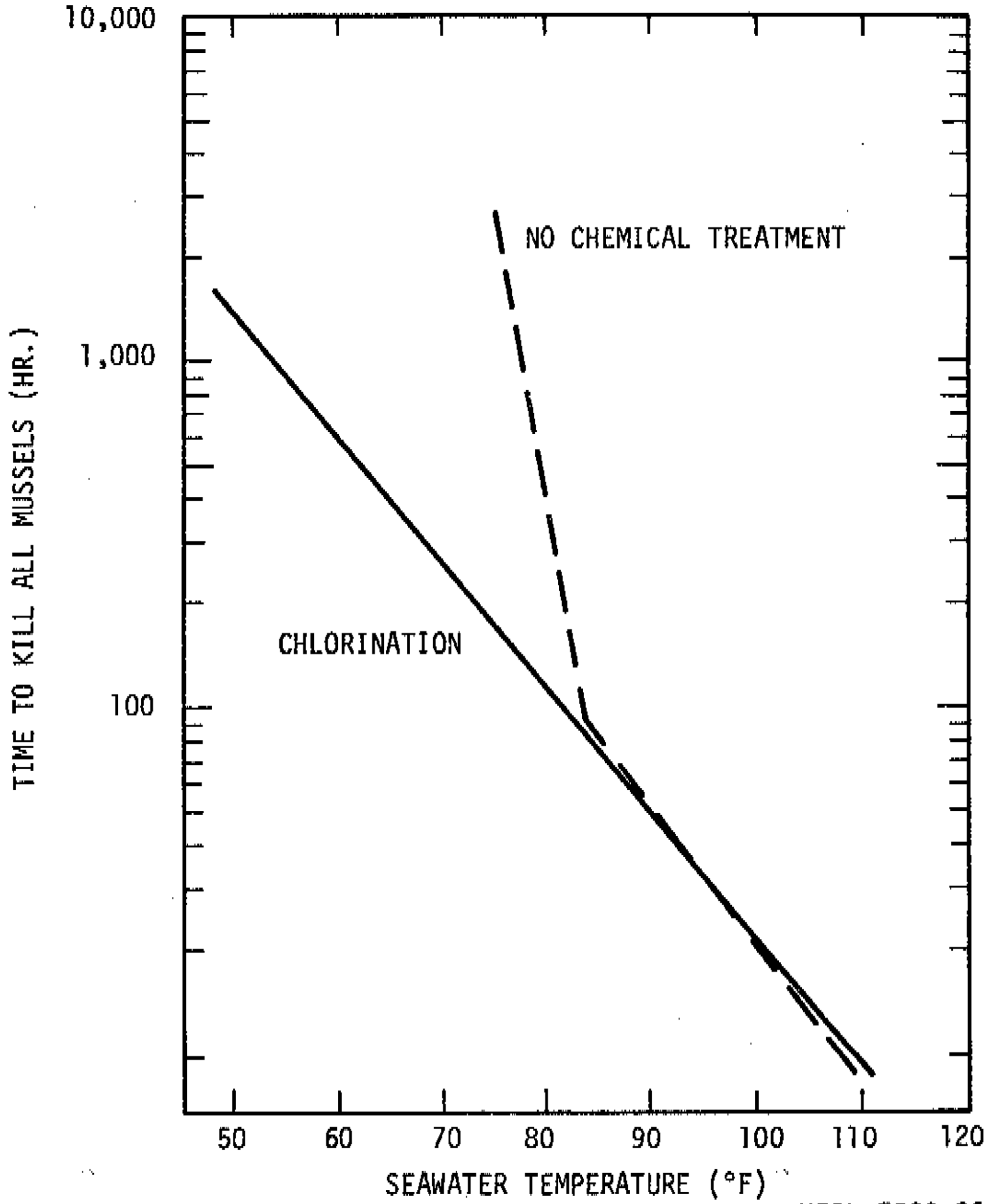
Details of various fouling control methods for seawater intake structures can be found in a recent Office of Saline Water Handbook.[38]

Corrosion in cooling water systems can be extremely expensive in terms of equipment repairs and revenue lost during shutdowns, so the economic incentive to prevent corrosion is high. The basic methods of controlling corrosion are:

1) Protective coatings
2) Sacrificial anode protection
3) Use of materials suited for conditions
4) Control of corrosive environment

Protective coatings, such as dips, paints and plastic or concrete sheaths have been used to protect structural members from corrosion in water environments. The recent application of PVC for traveling screens has dramatically reduced screen corrosion. Sacrificial anodes which have found application in marine equipment might have success in some instances. The methods discussed so far prevent corrosion in ways which are unlikely to be harmful to organisms associated with the intake structure. However, corrosion prevention by control of the water composition normally requires physical and/or chemical treatment which might be harmful to biota. The various methods used for water treatment in the power industry are listed in Table 1.[22]

The treatment used to adjust the water quality to standards necessary for use in the power plant are selected on the basis of available technology and economics. The chemical composition of effluent streams or intake streams which may affect the plant environment must meet certain standards. Some criteria for the protection of fresh and seawater organisms can be found in "Report of the Committee on Water Quality Criteria."[22]



HEDL 7303-36.10

FIGURE 21. Comparative Time for Killing Shelled Mussels Chlorination and Temperature.

Additional standards or regulations might apply to specific stations. The standards, of course, are not all-inclusive and special attention to limiting conditions for specific site environments must be considered. Analyses to determine the effects of fouling and corrosion controls on the organisms in the water source should include the possibility of changes in organism types and relative quantities due to site modifications. Physical and chemical alterations which might cause organism population changes include water temperature, disturbance of the water bottom, chemical composition of the water, and additional strata for attaching organisms, such as intake pipelines. Early treatment of structures such as pipelines and canals prior to plant start-up can prevent initial growth of foulants and ease the burden on control systems during operation.

Several special applications of fouling and corrosion control deserve mention. The use of backwashing to remove organisms from the intake structure has found moderate success. Increased water velocities detach some organisms and the flow reversal removes them from the structure vicinity. Backwashing in combination with heat treatment can be applied by stations with the ability to discharge heated effluents through a portion of their intake strucutres, or to introduce heat by some other means. Another physical means of control used in condensers is the Amertap system. This technique provides physical scrubbing of the condenser tubes by passing small sponge rubber balls through the condenser. Two types of balls are available--one plain, and one with a narrow band of abrasive material on its surface.

In summary, the sources and controls for fouling and corrosion are numerous and complex. Protection of the cooling system and the aquatic environment demands an analysis of the total interacting system during the station design stage. The selection and application of corrosion and fouling control techniques should be exercised with care to prevent damage to the ecosystem. Minimum standards are available from federal and state regulations, but detailed examination and thoughtful solution to specific site problems is the best assurance of cooling system protection without detrimental effects to the station environment.

TABLE 1

WATER CONTROL CRITERIA

	Cooling	
	Once-through	Recirculated
Suspended Solids and Colloids Removal:		
Straining	X	X
Sedimentation	X	X
Coagulation	-	X
Filtration	-	X
Aeration	-	X
Dissolved Solids Modification Softening:		
Cold lime	-	X
Hot lime soda	-	-
Hot lime zeolite	-	-
Cation exchange sodium	-	X
Alkalinity Reduction:		
Cation exchange hydrogen	-	X
Cation exchange hydrogen & sodium	-	X
Anion exchange	-	-
Dissolved Solids Removal:		
Evaporation	-	-
Demineralization	-	X
Dissolved Gases Removal:		
Degasification-mechanical	-	X
Degasification-vacuum	X	-
Degasification-heat	-	-
Internal Conditioning:		
pH adjustment	X	X
Hardness sequestering	X	X
Hardness precipitation	-	-
Corrosion inhibition general	-	X
Corrosion embrittlement	-	-
Corrosion oxygen reduction	-	-
Sludge dispersal	X	X
Biological control	X	X

Notes: "-" not used. "X" may be used.

VI. ECONOMICS

The cost associated with constructing a power plant intake structure is strongly site-dependent. Variation in capital costs result from differences in: construction rates; land acquisition costs; taxes; shipping charges; and of course the type of water body utilized. With due respect to this limitation, a discussion of costs associated with the construction of various intake structures is presented in this section. Since economy is generally considered inherent in design, the intent is to provide the reader with some insight as to the cost of protecting the environment by means of providing unit costs for various design features.

A. COSTS ASSOCIATED WITH OFFSHORE CONSTRUCTION

Offshore construction costs depend primarily upon the behavior of the water body and the condition and/or composition of the bottom material. Constructing a pipe line through a difficult environment such as a surf zone can be significantly more expensive than laying a pipe line on the bottom of a quiescent body of water such as a lake. The usual construction method calls for laying a line through a surf zone using a traveling crane. First, a trestle is built which extends through the zone on which the crane can travel. Excavating the trench and laying the line is then performed with the crane. Normally, after the pipe is installed and buried, the filled trench is protected with heavy rip rap.

The cost of construction through various surf zones can vary significantly from site to site. The overall cost of the El Segundo system, two 10-foot precast conduits extending 2600 and 2100 feet offshore, excluding the intake structures, was $2,6000,000*.[4] The cooling water system was installed during 1955 and 1956. Construction costs associated with the Redondo Beach Power Station cooling system were $4,400,000.[4] Water flows to this power station through 10-foot diameter concrete conduits located 1700 feet offshore. Construction took place during 1957. The cost associated with the 14-foot diameter intake and discharge conduits at Huntington Beach was $4,100,000[4] in 1958.

* Figures shown in the text are actual cash costs and do not reflect interest and/or inflation.

This converts to an overall unit cost ranging from 550 to 900 dollars per foot, or a present cost range of approximately 1300 to 2000 dollars per foot. However, as will be noted later, the unit costs can be much higher.

All of the structures mentioned above terminate in 30 to 40 feet of water just beyond the surf zone. Less costly construction methods can be used beyond this zone. Excavation and pipe handling might be performed from a barge or from a mobile floating tower and the costs should be comparable to placing large conduits in lakes or bays. Under these conditions, the cost of construction is primarily dependent on the depth at which the construction is taking place and the diameter of the pipe being placed. Cost estimates based upon a 1966 study[39] for an 8 to 10-foot diameter pipe are shown in Table 2.

TABLE 2

UNIT COSTS OF OFFSHORE CONSTRUCTION

Depth	Unit Costs ($/ft)
Up to 100 ft	380/ft
100 to 200 ft	480/ft
200 to 300 ft	950/ft

The estimates include trenching and backfilling with a rock cover.

B. SHORELINE INTAKES AND SCREENWELLS COSTS

In Sections 4 and 5, establishment of appropriate approach velocities was discussed. Knowing the system design flow rate and the approach velocity, the required cross-sectional area of the intake can be readily determined. It would be convenient to have a unit cost factor to evaluate this design feature. As in the case of defining the cost associated with offshore constructions, the cost of constructing screenwells varies significantly, depending upon the local conditions and the design employed. The figures presented herein should be used as a guide to relative costing, rather than the detailed costing of proposed construction. This caution will become evident as the discussion develops.

A series of reports has been published by the Tennessee Valley Authority[41,41,42,43,44] which itemize in detail the cost of constructing thermal power stations. Under Account 141, the cost of constructing the circulating water system is presented. Only the cost data presented for the Paradise and Bull Run steam plants will be used here.

The cost of excavating, backfilling, and constructing the screenwell for the Paradise Steam Plant (built in 1965) was given as approximately $400,000. Design flow rate for the first two units was approximately 1100 cfs. At design minimum water level, the velocity through the traveling screens is 2.1 feet per second. This suggests a unit cost of approximately $760 per square foot. Performing a similar analysis for the Bull Run Steam Plant results in a unit cost of approximately $660 per square foot.

The cost of installing the vertical traveling screens, backwashing facilities, sluiceway, etc. for the Paradise Steam Plant was approximately $130,000. This converts to a unit cost of $250 per square foot. The cost of installing similar equipment at the Bull Run steam plant was approximately $150,000, which converts to approximately $300 per square foot.

The total cost of these two items at both the Paradise and Bull Run steam plants was therefore approximately $1000 per square foot. It is interesting to note that, for the Calvert Cliffs Nuclear Station, a comparative cost figure can be established using the overall construction cost estimates. A total of $10,000,000[45] has been estimated for the construction of the cooling system, neglecting the cost of the condenser. The design flow rate is approximately 5000 cfs, with an approach velocity of approximately 0.5 foot per second. This converts to a unit cost of approximately $1000 per square foot. For the cases discussed, the cost of inflation has tended to offset the economy of scale.

All of the designs mentioned above use 3/8-inch mesh screens. It should be mentioned that, in reducing the mesh size, the proportion of open area decreases. For example, decreasing the mesh size from 3/8 to 1/4 inch decreases the open area of the screen by approximately 15%[46]. Unit cost figures should be modified to reflect this condition if smaller mesh sizing is desired.

VII. FUTURE DESIGN CONSIDERATIONS

In this section, a few designs which might be considered for future use are discussed.

Traveling Screens

The horizontal traveling screen has been under development by the National Marine Fisheries Service since 1965. The structure consists of an endless belt of wire cloth strung in a horizontal, rather than a vertical plane. In concept, the screen is placed across the flow field at an angle. The rotational motion of the screen is compatible with the direction of flow. The orientation and motion of the screen act to reduce the seriousness of impingement by the organisms on the screens. Figure 22 shows the use of the screen as proposed for the Leaburg Power Plant intake canal at Eugene, Ore.[47].

The use of the horizontal traveling screen could be included in the design of intake structures. The concept could be included in both the design of basic shoreline intake structures, or the design of screenwell structures. The horizontal screens could be included in the design proposed by Bell shown in Figure 19. Due to the manner in which the screens continually move, they are somewhat self-cleaning. The current feeling appears to be that its biological and hydraulic performance, its practical features, such as bottom and side seals, and inspection and maintenance methods for it requires systematic investigation before any major prototype can be considered.[14]

Revolving Drum Screen

The revolving drum screen is a large, perforated drum, usually installed with its axis of rotation horizontal and across the stream flow. The drum revolves slowly, with the exposed upper surface moving in a downstream direction, preventing passage of fish but lifting impinged debris clear of the water. The debris is washed off into the downstream side of the channel by the flow through the screen, unless a jetting system to wash debris into a collecting trough is incorporated. Drum screens could be used with various orientations. It is conceivable that the drums could even be mounted in a vertical plane replacing the vertical traveling screen, provided a uniform velocity across the face of the screen and provisions for escapement are included.

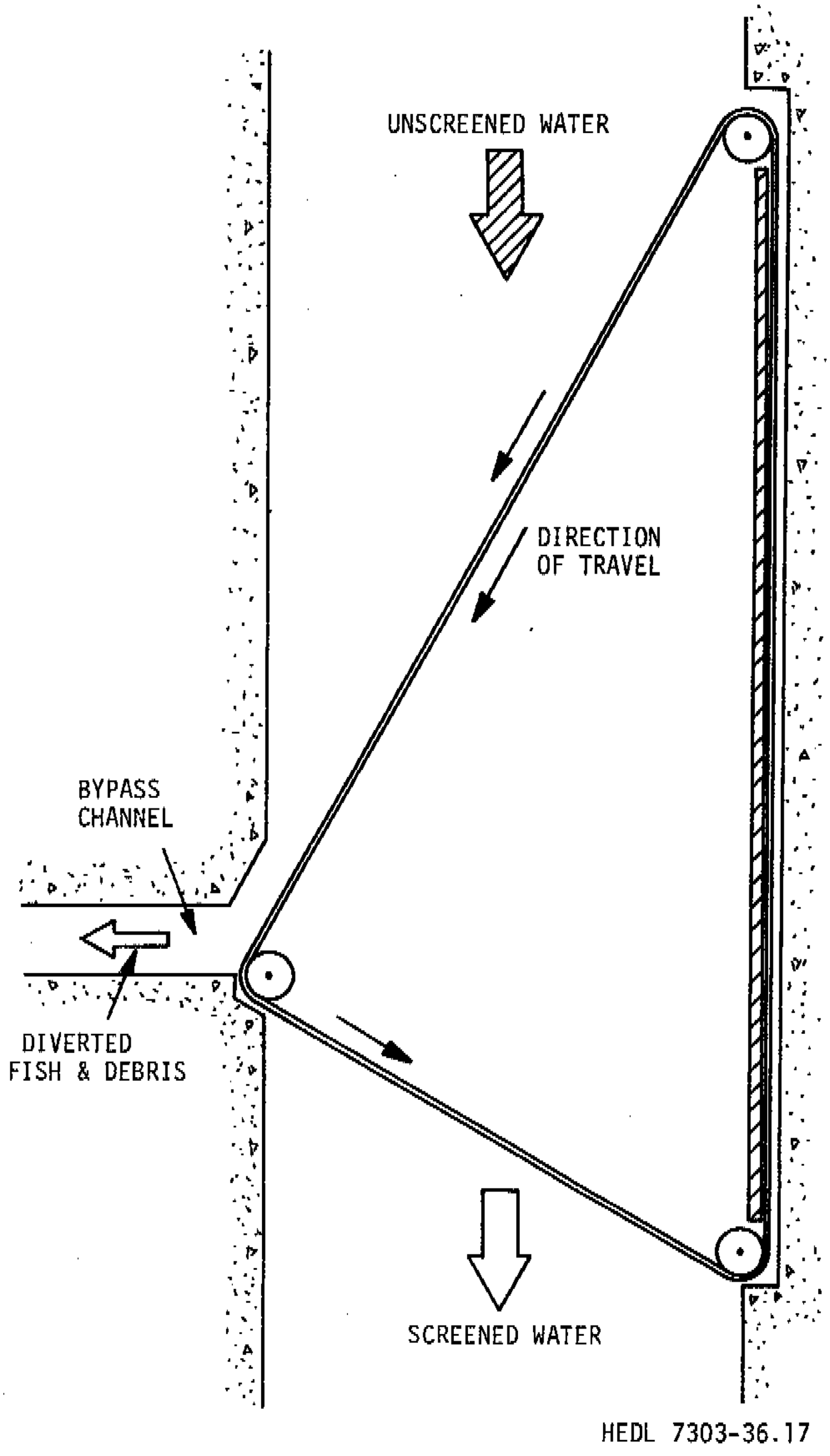
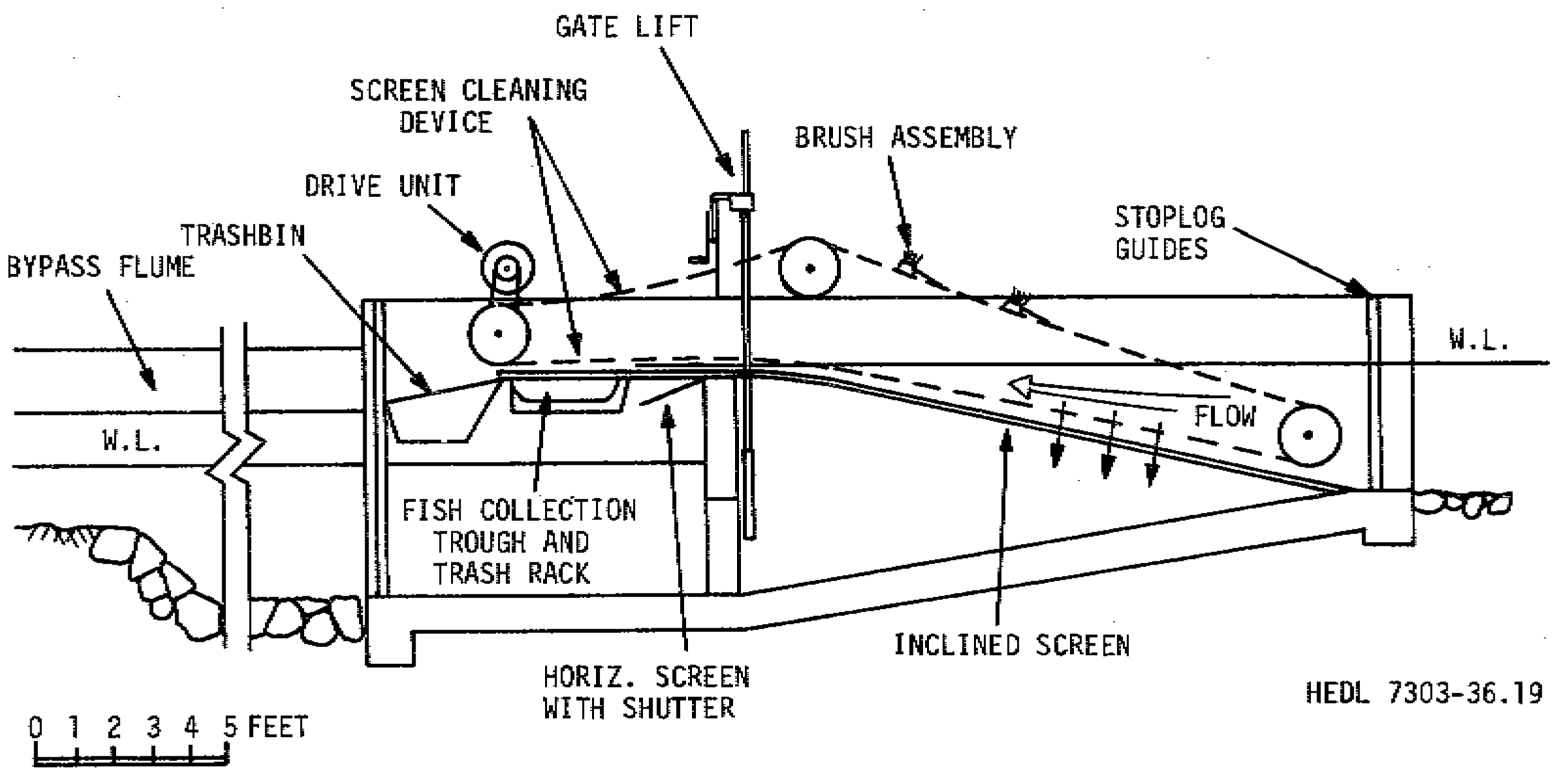


FIGURE 22. Horizontal Traveling Screen-Schematic Layout.



From Canadian Fish Culturist, No. 37, Sept. 1966.

FIGURE 23. Inclined Plane Screen.

Inclined Plane Screen

The inclined plane screen consists of a simple fixed screen inclined downstream as shown in Figure 23. Cleaning is accomplished by bars or brushes which slide up the screen surface, scraping debris into a trough at the crest. Where the screen is being used to divert fish, a shallow incline is used. The bars can then be used to nudge fish through shallows over the crest into a bypass trough. Such an installation is used in Canada to direct downstream migrating fish.[48] For the screen to be used in conjunction with the other standard shoreline intake features would require additional space and careful consideration of stage variations. Intuitively, inclusion of an inclined screen into the design of a thermal power plant intake structure seems quite feasible.

Beloit - Passavant Screen

This screen is a variant of the common vertical traveling screen. Although it has been used in Europe for some time, its introduction into the United States is fairly recent. The unique feature of this screen concept, shown in Figure 24, is that the water enters the central part of the screen and flows outward through both faces. This can be particularly attractive because it permits low flow velocities to be attained more economically. As with other designs, provisions must be included to allow easy escape, such as keeping both ends of the assembly open. The design warrants further biological testing.

Filter Beds

Studies have been conducted to determine the feasibility of siting a nuclear power station on Kiket Island in Puget Sound, some fifty miles north of Seattle, Washington. The site is near the Skagit River, which is one of the most productive salmon spawning streams in the state. As a result of the relative abundance of juvenile salmon passing the proposed site, the Fisheries Research Institute at the University of Washington has just recently completed a series of studies to examine the impact of plant construction and operation on the local ecology.[49] During the field studies performed to inventory the aquatic species in the vicinity of the proposed site, pink salmon were found along the shores of Kiket Island with their yolk sac partially intact. Based upon this size and

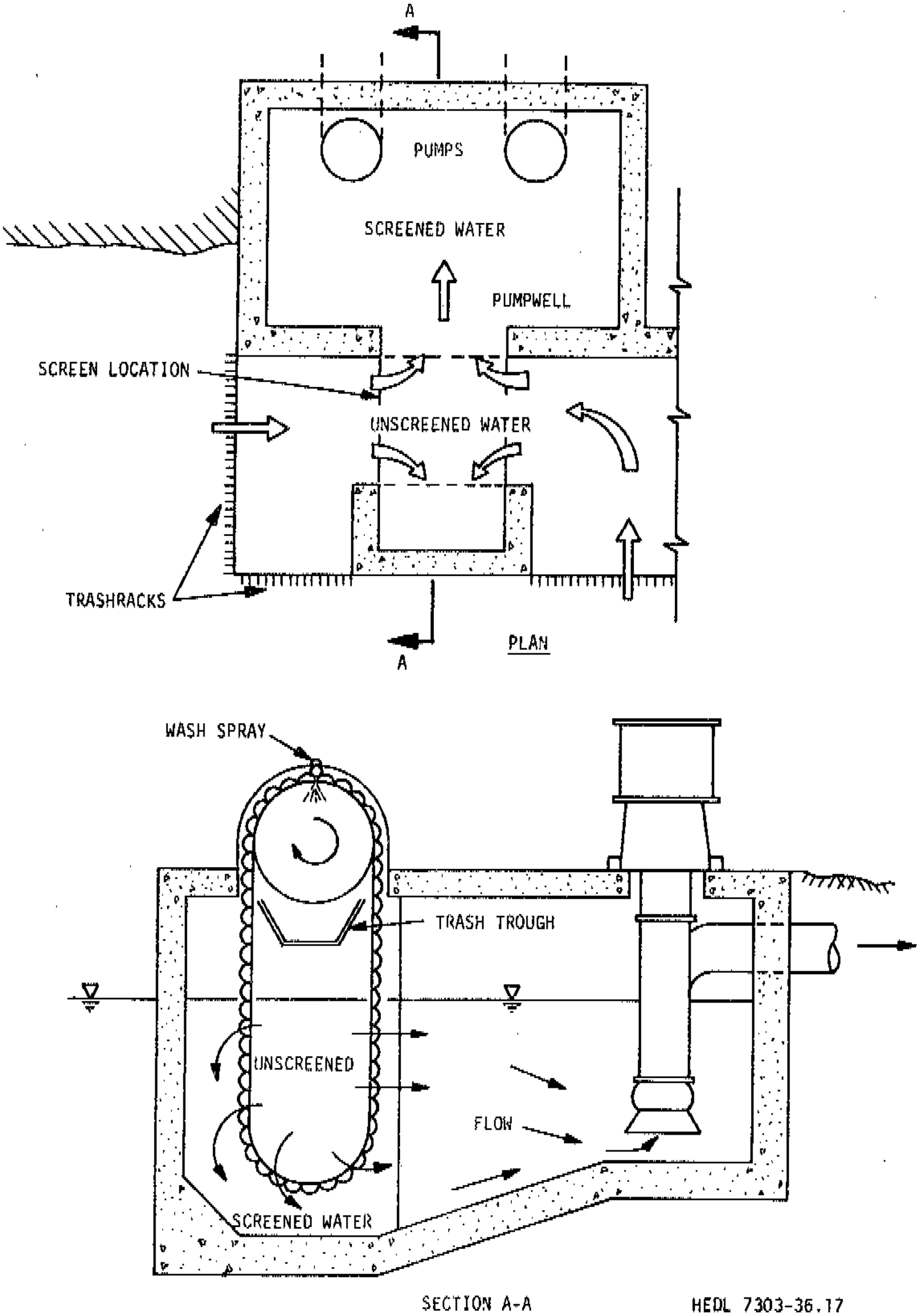


FIGURE 24. Beloit-Passavant Screen Installation.

stage of development, design approach velocities of 0.2 feet per second, and screen mesh sizing of 1/8 inch have been conjectured. As a result the use of a submarine filter system has been proposed as an alternative.

The overall size of a submarine filter suitable for providing the design coolant flow rate for a once-through 1000 MW thermal power plant is on the order of 2 to 4 acres. In addition to size, operational problems associated with flushing or unclogging the potential growth of marine organisms in the bed could reduce the feasibility. Capital cost estimates for a preliminary filter design, consisting of a graded gravel bed with an anthracite cover, and supporting structure, were approximately $8.5 million for a two acre bed. Operational expenses, which include daily backflushing and heat and chlorine treatment, were estimated at $800,000 annually[50].

Basket Collectors

A concept which has recently received considerable attention includes the use of "fish collector baskets". The concept, as shown in Figure 20, involves the use of a basket screen which moves in a vertical direction along the face of the fine filtering medium. In this design, the finer mesh screens have been replaced with perforated plates to eliminate projecting surfaces which could cause pockets creating fish traps.

Testing of the concept is planned for the near future. If the concept proves acceptable, it is a design which can easily be backfitted into existing screenwell designs to facilitate the removal of fish. The cost of backfitting the design to replace the present vertical traveling screens is estimated at less than $5,000 per panel[45].

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

I. The initial steps which should be undertaken when considering the design of a thermal power plant intake structure are as follows:

- Conduct both a hydrological and biological survey. The hydrologic survey should include a study of local currents, sedimentation, stage variation, and water quality. The biological survey should identify resident aquatic organisms. Size,abundance, temporal, and spatial distribution of the resident and migratory species should be identified.
- Assemble an interdisciplinary team of biologists, ecologists, hydrologists, and engineers to establish design criteria for the entire cooling system, including the outfall structure.

II. The design of an intake structure should be based upon meaningful criteria which will undoubtedly vary somewhat from site to site, reflecting specific demands. To date, intake design criteria have been based primarily upon the following considerations:

1. Select design approach velocity and an appropriate screen mesh size conducive to screening the design organism. In the case of fish, the technique should be based upon the cruising speed and body size. Care should be taken to provide a uniform velocity across the face of the screen.
2. Where possible, the intake structure should be located in an area of low productivity. The location should not coincide with heavy concentrations of fish or benthic shellfish. Structures such as wharfs, bulkheads, piling arrays, etc., should be avoided. The biological survey should delineate these more productive zones.
3. Recirculation of cooling water through the cooling system should be prevented for both engineering and biological reasons. Care should be taken to provide sufficient hydraulic resistance between the intake and outfall to eliminiate this possibility.

4. The selection and application of control techniques for fouling and corrosion should be exercised with care to prevent damage to the ecosystem. The effect of using various chemicals should be fully understood.
5. The use of attraction and avoidance stimuli might be warranted. Combinations of various stimuli can be used for guidance. Note that the use of warm water for purposes of deicing can attract fish.

III. Specifically, the following guidelines are presently being used in intake structure design.

SHORELINE INTAKES

Type of Water	Design Provision
Rivers Estuaries Bays Harbors	1. Establish a uniform velocity across the face of the screen. 2. Avoid the use of fixed skimmer walls and inverted weirs. 3. Place circulating water pumps behind screens. 4. Do not locate screenwell or intake in highly productive or high population density areas. 5. Prohibit recirculation of cooling water--suggest the use of physical model in design process. A. Screenwell flush with shoreline 6. Base total screen area requirements upon; design approach velocity, minimum stage, and maximum coolant flow rate. 7. Include provisions for the lateral escapement of fish. B. Screenwell located away from shoreline. 8. Include provisions within the screenwell for safely returning fish to the mainstream.

9. Avoid excessive negative pressures within the intake conduits.
10. Do not use intake canals.

OFFSHORE INTAKES

Types of Water	Design Provision
Ocean Shorelines Lakes	1. Do not locate in "nursery areas." 2. Provide for gravity flow from the intake to the screenwell. 3. Include provisions for safely removing fish from the screenwell. 4. Locate circulating water pumps behind screens. 5. Design approach velocities should be based upon resident and migratory fish. 6. The intake structure should not impede navigation. 7. Prohibit recirculation of cooling water--use a physical or analytical model. 8. Use velocity caps, or accept lower intake velocities.

IV. The backfitting of fish protection devices to existing intake structures has normally met with limited success. Although, occasionally avoidance and guidance of fish has been accomplished using a combination of stimuli, this approach is normally not sufficiently reliable to completely offset design inadequacies.

B. RECOMMENDATIONS

Within reasonable limitations, procedures for collecting and analyzing field data, both hydrological and biological, have been established. However, standardization of procedures which allows the extrapolation of field data into usable design information does not presently exist. Such standardization would include: 1) the development of a procedure to determine design approach velocities, and 2) the development of a methodology to assess the significance of loss through the modeling of population dynamics.

Apparently the results from numerous studies of fish swimming performance and behavior have not been published. For the cases where the results have been documented, there is seemingly little consistency in the reporting technique. The standardization of reporting techniques and the establishment of a repository and an information retrieval system for such information would be of great assistance. Such a facility could be used as a centralized means of collecting information on the operational experience from various power plants.

Due to the length of time required to construct large thermal power plants, the benefits of design changes will not be realized for some time. If present designs do not prove to be satisfactory, future improvements might include the following:

For Shoreline Intakes:

- Use of traveling screens, revolving drum screens, inclined screens, and the Beloit-Passovant screen to promote better screening. Each of these screens provides the designer with specific advantages. For example, the traveling and Beloit-Passovant screens appear to be better adapted to situations including substantial variations in stage. Whereas, under conditions of uniform channalized flow, revolving drum and inclined screens appear to be the better choice since they probably require less design and construction and hence may be less expensive.
- Use of louvers between the bar rack and screens (or perhaps even to replace the screens) to promote better fish guidance.
- Use of air rather than heat to inhibit the formation of ice.

For Offshore Intakes:

- Use of submarine filter beds.
- Modification of screenwell design to include better directional stimuli for bypassing fish.

IX. REFERENCES

1. D.E. Peterson, "Thermal Effects of Projected Power Growth: Summary", to be published HEDL.

2. Missouri Basin Inter. Agency Committee, "The Missouri River Basin Comprehensive Framework Study: Hydrologic Analyses and Projection" 1969.

3. Result of survey letter sent to Gulf States Utilities, Beaumont, Texas.

4. R.N. Spencer, J. Bruce, "Cooling Water Supplies for California Steam Electric Stations on Tidewaters," ASCE Power Division 1959.

5. T.R. Sundaram et.al. "An Investigation of the Physical Effects of Thermal Discharges into Cayuga Lake", CAL No. VT-2616-0-2 1969.

6. J.A. Hoopes et.al., "Heat Dissipation and Induced Circulations from Condenser Cooling Water Discharges into Lake Monona", University of Wisconsin Eng. Exp, Sta., Report No. 35, 1968.

7. J.A. Niemeyer, "Modeling of Power Plant Cooling Water Discharges into Lake Monona", M.A. Thesis U. of Wisconsin, 1969.

8. U.S. Army Corps of Engineers North Pacific Division, "Progress Report on Fisheries Engineering Research Program", 1965.

9. P.E. Fields, "Migrant Salmon Light-Guiding Studies at Columbia River Dams," Third Progress Report on Fisheries Engineering Research Program U.S. Army Corps of Engineers (1966).

10. J.R. Pugh, et. al., "Effect of Water Velocity on the Fish Guiding Effectiveness of an Electric Field" Fish Passage Research Program, U.S. Bureau of Commercial Fisheries, 1964.

11. J.G. Van Der Walker, "Response of Salmonoids to Low Frequency Sound", Marine Bio-Acoustics, Perganion Press, 1966.

12. H.S. Riesbol, P. Gear, "Application of Mechanical Systems to Alleviation of Intake Entrapment Problems", paper presented Atomics Industrial Forum, Wash., D.C., Oct. 2, 1972.

13. G.E. Monan, J.R. Pugh, "A Field Test of Electrical Guiding and Lower Deflection Combined into a Single Guiding System," U.S. Bureau of Commercial Fisheries (1964).

14. M. Bell, "Handbook of Design Criteria for Fish Facilities", prepublication draft provided by Corps of Engineers North Pacific Division.

15. M.J. Lighthill, "Note on the Swimming of Slender Fish," Journal of Fluid Mechanics, 1960,

16. R. Bainbridge, "The Speed of Swimming Fish as Related to Size and to the Frequency and Amplitude of the Tail Beat," Journal of Experimental Biology, 1958.

17. J.R. Brett, "The Relations of Size to the Rate of Oxygen Consumption and Sustained Swimming Speed of Sockeye Salmon," Fisheries Research Board of Canada, Journal 22, 1965.

18. C.C. Coutant, "Thermal Pollution-Biological Effects," Journal of Water Pollution Control Federation, 1967).

19. C.C Coutant, "Thermal Pollution-Biological Effects," Journal of Water Pollution Control Federation, 1969.

20. J.E. Kerr, "Studies on Fish Preservation at the Contra Costa Steam Plant of the Pacific Gas and Electric Company," State of California, Department of Fish and Game, Fish Bulletin No. 92, 1953.

21. F.J. Jeffers, "The Design of Power Plant Condenser Cooling Water Systems," presented at IES Second Thermal Pollution Seminar, Chicago, Illinois (1970).

22. Water Quality Criteria: Report of the National Technical Advisory Committee to the Secretary of the Interior (FWQA), April 1968, Washington, D.C.

23. Topic of Discussion; Entrainment Workshop, Johns Hopkins University, Jan 1971.

24. Oyster Creek Nuclear Power Plant, "Environmental Report", DOCKET 50219-171 June 1972.

25. J.R. Adams "Ecological Investigations Around Some Thermal Power Stations in California Tidal Waters", Chesapeake Science Vol. 10, No. 3&4, 1969.

26. Pittsburg Power Plant Cooling Water Studies, Pacific Gas and Electric Company, Dept. of Engineering Research, March 1970.

27. S. Moyer, E.C. Rancy, "Thermal Discharges from Large Nuclear Plants", ASCE Sanitary Engineering Div., 1969.

28. Salem Nuclear Power Plant," Draft Environmental Statement", DOCKET 50272-43, October 1972.

29. Millstone Nuclear Power Station, Unit 2, "Environmental Statement", DOCKET 50336-15, 1970.

30. R.W. Zeller, R.L. Rulifson, "A Survey of California Coastal Power Plants, " FWPCA Northwest Regional Office, Jan. 1970.

31. R.H. Weight, "Ocean Cooling Water System for 800 MW Power Station", ASCE Power Division, 1958.

32. Zion Station Units 1 and 2, "Environmental Report, DOCKET 50295-26, 1971.

33. Point Beach Nuclear Plant Units 1 and 2, Final Environmental Statement", DOCKET 50266-67, 1972.

34. G.W. Bedell, P.D. Flint, "Pumping Fish in California," The Progressive Fish Culturist, 1969.

35. B.G. Grinstead, "A Fish Pump as a Means of Harvesting Gizzard Shad from Tailwaters of TVA Reservoirs," The Progressive Fish Culturist, 1969.

36. T. Merritt, Engineer So. California Edison, private communication.

37. P.M. Sherwood, "Protect Your Power Plant from Bacterial Corrosion", Power Engineering, 1962.

38. "Engineering Aspects of Seawater Intake System for Desalination Plants", Dow Chemical for Office of Saline Water Contract 14-30-2579, 1971.

39. H.G. Arnold," Feasibility of Offshore Dual-Purpose Nuclear Power and Desalination Plants", ORNL-TM-1329, 1966.

40. The Johnsonville Steam Plant: Technical Report No. 31, United States Tennessee Valley Authority, 1958.

41. The Colbert Steam Plant: Technical Report No. 35, United States Tennessee Valley Authority, 1963.

42. The Paradise Steam Plant: Technical Report No. 37, United States Tennessee Valley Authority, 1964.

43. The Kingston Steam Plant: Technical Report No. 34, United States Tennessee Valley Authority, 1965.

44. The Bull Run Steam Plant: Technical Report No. 38, United States Tennessee Valley Authority, 1967.

45. D. Ward, Engineer, Baltimore Gas and Electric, Private Communications.

46. Wire Cloth: Bulletin No. WC-510, Newark Wire Cloth Company.

47. D.W. Bates "Diversion and Collection of Juvenile Fish with Traveling Screens", Fishery Leaflet 633, Washington, D.C., 1970.

48. K.H. Kupka, "A Downstream Migrant Diversion Screen", The Canadian Fish Culturist No. 37, 1966.

49. Q.J. Stober, "Sea Water Filtration and Fouling Control in a Model Rapid-Sand Filter for Exclusion of Fish from Power Plant Cooling System," Fisheries Research Institute, University of Washington, to be published.

50. Q.J. Stober, et al., "Model of a Rapid Sand Filter for Excluding Small Fishes from Thermal Power Plant Cooling Water," Fisheries Research Institute, University of Washington, December 1971.

APPENDIX

SELECTED INTAKE STRUCTURE DESIGNS

APPENDIX

SELECTED INTAKE STRUCTURE DESIGNS

Brief descriptions of intake structures at eight facilities are presented in this appendix. The principle intent is to illustrate the material presented in a general way in the text by presenting additional details of the concepts discussed. The facilities were selected to provide diversity in situation and in approach so that a few "typical" instances would give added insight. Four nuclear plants, two fossil plants, a proposed plant, and a water diversion facility are included. These facilities, taken from various geographic regions of the country encompass essentially all major types of water source. Concepts discussed include some of the newer ones proposed as well as some that are commonly used.

Some discussion of related environmental studies has also been included. The rather limited sampling presented here does not adequately reflect the substantial amount of research and monitoring presently underway, but does indicate the type of feedback information being developed.

DELTA FISH DIVERSION

The Delta fish diversion is located immediately downstream of the Old River diversion to the California Aqueduct east of San Francisco. The water diverted from the Old River flows into a 2300 acre forebay from which it then flows through a breach in the dike into the fish diversion facilities. The purpose of the facility, of course, is to remove the fish from the water before entering the aqueduct. The ultimate design capacity of the facility is 10,000 cfs.

The facility, consisting of three and one-half 40-foot bays, is shown in Figure A-1. Trash racks are located at the head end of each bay. Located behind each trash rack are louvers to divert fish into a bypass. The louvers are constructed outward from the walls of the bay at an angle of 15° to the direction of flow forming a vee pointing downstream. The fish are collected in a bypass located at the apex of the vee. From the primary facility, the bypass channel flows underground into a secondary facility containing another set of louvers to further concentrate the fish. In passing through the two sets of louvers the volumetric flow rate of the water containing the fish is reduced by more than 95%. The fish are ultimately discharged into a series of holding tanks.

The fish diversion facility has been designed to accommodate various kinds of fish. However, of primary interest have been the anadromous species consisting primarily of American shad, striped bass, chinook salmon and steelhead, trout. For purposes of design, a rather large range in fish size must be considered. For striped bass, for example, the size ranges from 1/2" to 5", for chinook salmon from 1-1/2" to 5", and for shad from 3" to 5". In studies conducted by the California Department of Fish and Game, it was concluded that for fish more than 1" long, screening efficiency is inversely proportional to flow velocity[A1]. The overall efficiency for removing fish 1/2" long or smaller was estimated at 40-60%. Present plans call for additional studies to be performed on diverting and screening small fish.

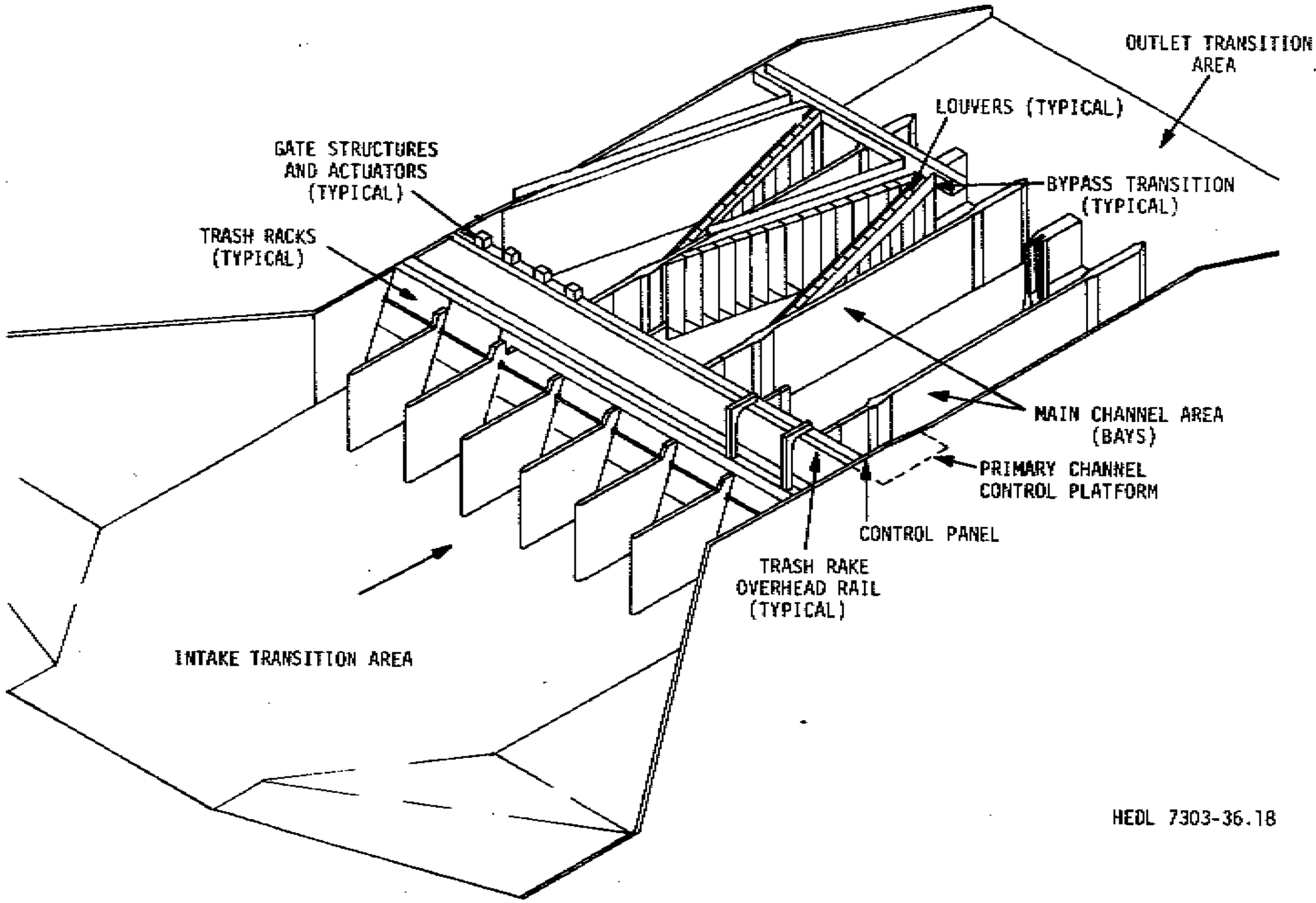


FIGURE A-1. Delta Fish Facility Primary Channel System. (From California Dept. of Water Resources Manual OM-201.)

SAN ONOFRE

The San Onofre nuclear power plant operated by Southern California Edison Company is located on the Pacific Coast near San Clemente, California. Unit 1 began operation in 1968. The intake system design is very similar to that of the Huntington Beach steam power station which utilizes the velocity capped intake structure shown in Figure A-2 and the screenwell shown in Figure A-3. San Onofre 2 and 3, scheduled to come on line in 1978-79, will also use a similar design[A2]. Each unit will be supplied by a separate intake structure located in 30 feet of water approximately 3500 feet off shore. The velocity capped structure will draw water from the bottom 10 feet of the water column at an inflow velocity of 2.5 feet/second. Water will flow into the screenwell through a conduit 18 feet in diameter buried in the ocean floor.

The annual number of fish entrapped in the San Onofre screenwell is less than has been experienced at the Huntington Beach facilities. The difference has been attributed primarily to the fact that fewer fish inhabit the vicinity of this intake structure. Although fish entrapment has not been of major concern at San Onofre Unit 1, provisions are being included in the design of the screenwells for Units 2 and 3 to safely remove entrained fish. Southern California Edison has recently completed a series of studies to determine the guidance/avoidance characteristics of indigenous species, principally anchovies, queenfish, and surf perch. Based upon studies conducted at the Redondo Beach Power Plant, it was concluded that louvers could be used in the design of the screenwell to guide fish into areas where they could be safety removed[A3]. Design details of the screenwell have not yet been disclosed by the utility.

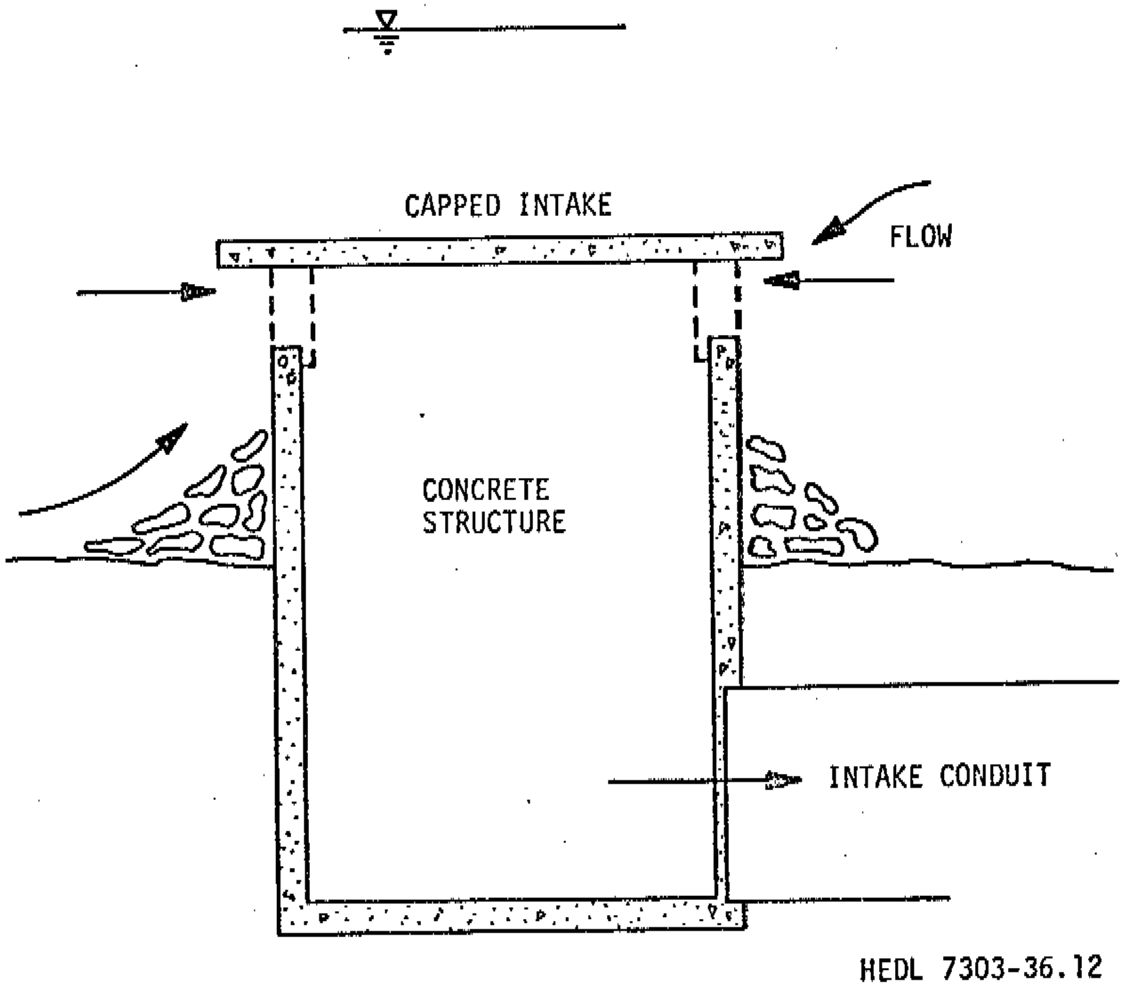


FIGURE A-2. Velocity Capped Intake Structure Typical of San Onofre Nuclear Plant.

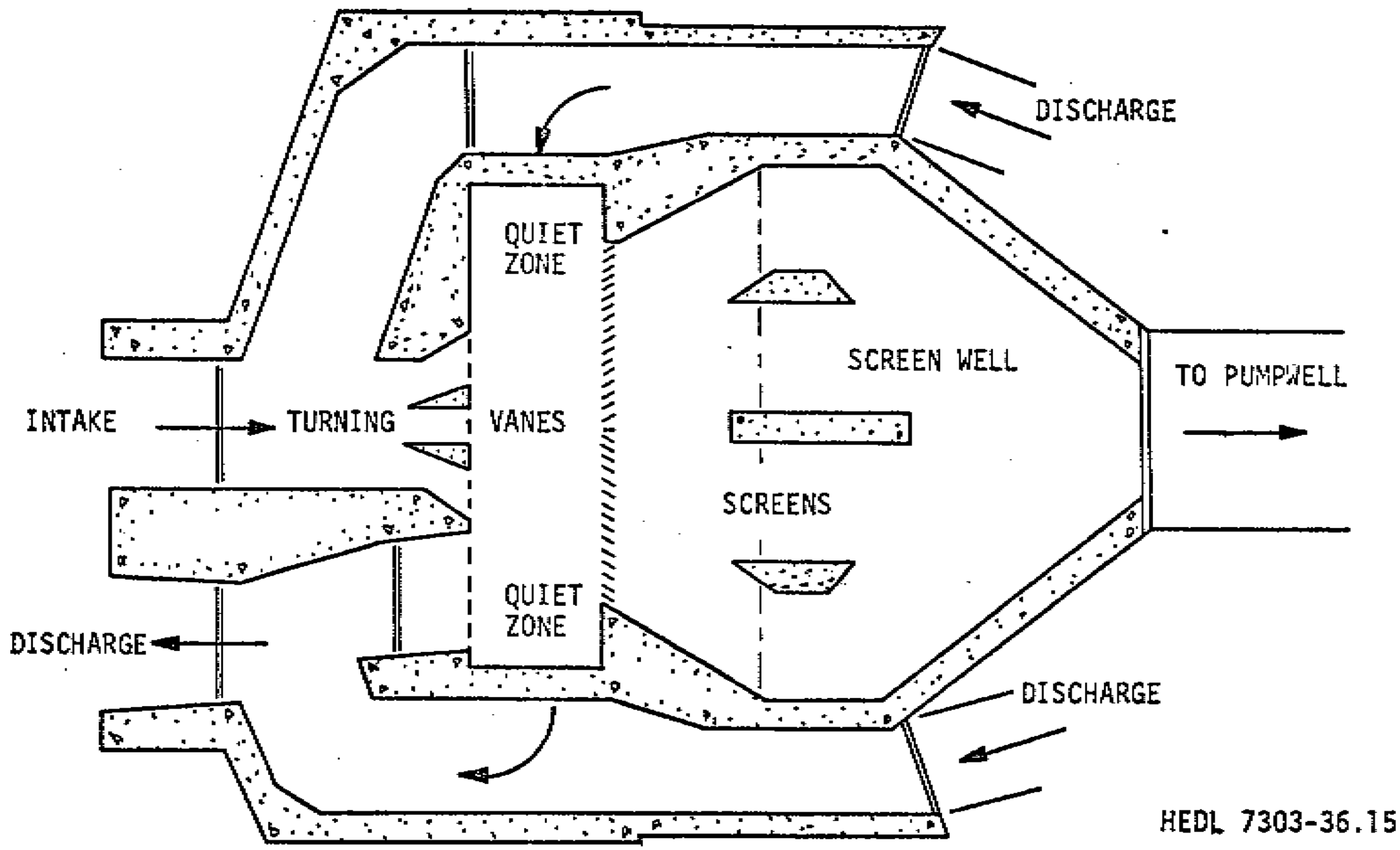


FIGURE A-3. Plan View of Screenwell Used at Huntington Beach Steam Electric Plant.

KIKET ISLAND

As mentioned, studies have been conducted on the feasibility of using rapid sand filters in connection with siting a nuclear power plant on Kiket Island in Puget Sound. The studies are being performed for Snohomish County P.U.D. and Seattle City Light.

A model rapid sand filter was mounted aboard a barge anchored off the shore of Kiket Island where the filter tests were conducted. Four different filter compositions involving various combinations of anthracite coal, sand, and gravel were tested[A4]. Water was drawn from the bay through the filter by a pump throttled to give three different filtering rates. The three flow rates investigated averaged 4.15, 6.49, and 9.54 gpm/ft^2 over the series of tests conducted. Head loss as a function of time was recorded for each of the three flow rates and four different filter compositions. When the head loss across the filter reached 70 inches the case was terminated and the filter backwashed at a rate of 15 gpm/ft^2.

The results from the tests can be summarized as follows[A5]: Filter flow velocities of 0.01 to 0.02 ft/sec were achieved. These velocities will not result in sink flow rates which affect the mobility of juvenile fish and larger invertebrates. The exclusion of plankton was not considered practical. Turbidity or silt loading seemed to have the greatest effect on reducing filter performance. The most effective technique for controlling fouling consisted of backwashing daily with heated chlorinated sea water, or inducing anoxia.

POINT BEACH

The Point Beach Nuclear Power Plant operated by the Wisconsin Michigan Power Company is located along the western shore of Lake Michigan approximately 30 miles southwest of Green Bay, Wisconsin. The first of the two 500 MWe units presently planned for the site began operation in December 1970. Cooling water for the plant is withdrawn from Lake Michigan using the intake structure shown in Figure A-4. Briefly, the intake structure consists of an array of steel piling filled with limestone blocks forming an upright hollow cylinder standing on the bottom.

Water enters the central chamber of the cylinder through void spaces around the limestone blocks and through several 30-inch diameter pipes which penetrate the cylinder wall at an elevation 5 feet above the lake bottom. The portals for these pipes are covered by 1-3/16" x 2 inch bar grating to prevent large fish and debris from entering the intake. The structure, located 1750 feet offshore in approximately 20 feet of water, is sufficiently large to provide cooling water for both units. To prevent icing during the winter months, heated water can be recycled through one of the intake conduits. The screenwell, located at the shoreline, contains a bar rack and vertical traveling screens. Although provisions for removing fish trapped in the screenwell are included in the design, the fish and debris are not returned to the lake[A6].

To establish baseline indicators benthic surveys were started during 1964-65. Since that time, a number of investigations have been undertaken. During the first year of operation entrainment studies were performed on Unit 1. The studies concluded that no significant mortality was incurred by phytoplankton in passing through the cooling system. For zooplankton, the physical damage caused by impingement was more significant than damage resulting from thermal exposure. Entrainment losses were estimated at less than 20%[A6]. Few eggs or larval fish forms were found in the intake water supporting the theory that the intake was not situated in a "nursery area". During 1971, a few fish were trapped in the screenwell when a portion of the intake structure failed. The opening was repaired promptly.

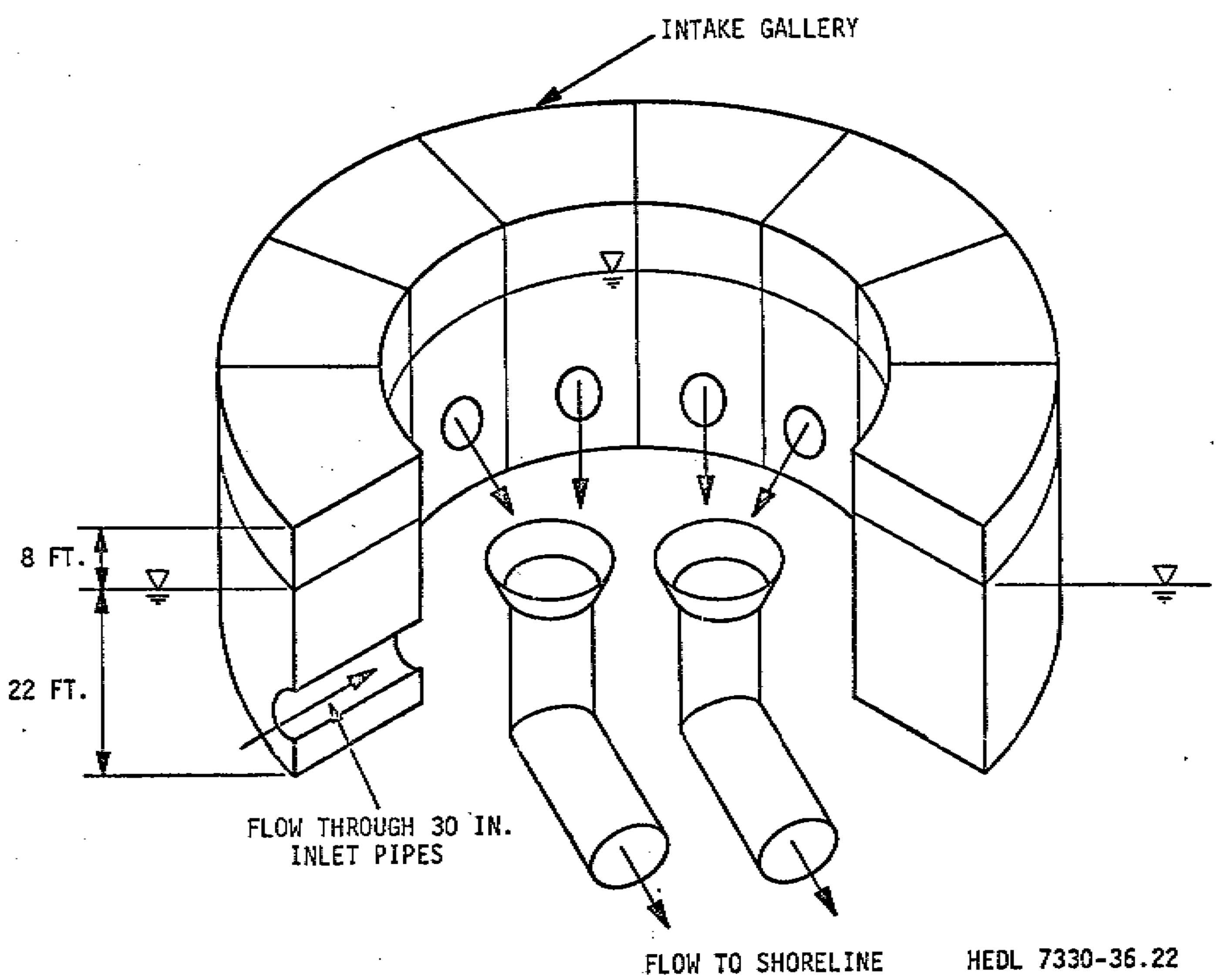


FIGURE A-4. Intake Structure of Point Beach Nuclear Plant.

MARSHAL

The Marshal Power Station, operated by Duke Power, is located in North Carolina on Lake Norman--a 33,000 acre lake formed in 1963 by the construction of Cowan's Ford Dam on the Catawba River[A7]. The 1971 generating capacity of the Marshal Steam Station was 2136 MW. It operates with an overall efficiency of 40%, discharging approximately 2500 MW of heat into the lake.

Cooling water is withdrawn from Lake Norman into an intake cave under a skimmer wall designed to restrain the upper 60 feet of water and withdraw coolant only from the hypolimnion. The intake structure, which is located at the end of the mile long intake cave, consists of six bays each of which contains a bar rack, a fixed galvanized wire screen (3/8" x 3/8"), and the circulating water pump. The overall width of the intake structure is approximately 100 feet.

Since 1965, a continuous program of data collection has been underway. Initially, the program consisted of collecting hydrological and meteorological data. In 1968, the program was expanded to include the collection of biological data pertaining to the effects of thermal discharges from the plant. Presently, studies include primary production, zooplankton entrainment, and population characteristics of plankton, benthic invertebrates, and fish[A8].

OYSTER CREEK

The Oyster Creek Nuclear Power Plant, rated at 640 MWe and operated by Jersey Central Power and Light, is located on Barnegat Bay along the New Jersey coast line. Cooling water is taken from the Bay and the South Branch of the Forked River through a dredged intake canal on the north side of the power plant. The heated effluent is discharged to a canal dredged into Oyster Creek and then flows into Barnegat Bay.

The intake structure contains the features typically employed. In addition to the trash rack, traveling screens, stop logs, and recirculating water pumps, provisions for deicing by circulation of heated water have been included in the design. Trash and fish collected on the intake screens are diverted to the discharge canal. The temperature of the effluent in the discharge canal is reduced through dilution, using three dilution pumps, each with a capacity of 260,000 gal/min, which together have the potential to reduce the temperature of the effluent by more than 50%.

To establish pre-operational baseline conditions, field surveys and studies were commenced in the spring of 1966. A number of monitoring stations have been established in the Bay and the canals. Since the inception, studies on fish, benthos, and plankton have been conducted by various agencies and consulting firms on a continuous basis. At the present time, the effect of operating the power plant on the aquatic inhabitants of Barnegat Bay is inconclusive although there have been fish kills, notably a winter, 1972, kill of Atlantic Menhaden in the discharge canal subsequent to a reactor shutdown[A9].

INDIAN POINT

The Indian Point Power Station, operated by Consolidated Edison, is located on the Hudson River several miles north of New York. Since the startup of Unit 1 in late 1962, there has been a history of intermittent fish kills. Although there has been controversy over the magnitude, the problem is generally recognized, and estimates place the loss at over one million fish (mostly white perch and some small striped bass) in some years[A10]. As a result, a number of modifications to the intake structure have been made in an attempt to alleviate the situation.

The intake structure, as originally designed, consisted of four eleven-foot wide open intakes located at the shoreline under a loading wharf. Water, normally 26 feet deep at this location, was drawn into a forebay under a 13-foot deep skimmer wall. Traveling screens were located in the forebay, roughly 30 feet from the shoreline.

Observations in 1963, and on many occasions since then, showed that fish were being attracted to the screenwells of the condenser circulating water system, indicating an inadequacy in the design of the intake structure. Air bubble screens were installed in front of the openings to the screenwells in the first attempt to repel the fish. Results proved that technique to be ineffective. Investigations using electrical fish screens proved ineffective due to the changing salinity level of the ambient waters[A11]. In the summer of 1963, an attempt was made to fence off the wharf area; however, the need for constant maintenance limited the usefulness of this approach. In February of 1964, Alden Laboratory constructed a physical model of the Indian Point Site. The results of the Alden Laboratory study coupled with the recommendation of a local consultant led to the removal of the hanging section of sheet piling at the North and South ends of the wharf. To reduce the possibility of recirculating,the discharge channel was extended 200 feet downstream. The openings in the concrete wall at the river's edge of the screenwell were enlarged to reduce the approach velocity to less than 1 ft/sec. Stainless steel screens with 3/8" mesh openings were installed in front of the screenwell openings and were situated so that there were no recesses where fish could become trapped. The modification proved effective in reducing fish kills by a factor of 10.

Since installation of the screens, two major problems have arisen: (1) during the winter, frazil ice forms on the fine screens blocking flow through the screens, and (2) during the other seasons there is excessive fouling of the screens with debris. In 1969 a special task force was organized to examine the problem. The task force recommended construction of a new intake structure.

Present plans call for a new structure to be built upstream from the present installation. The structure, containing bar racks and traveling screens, will be placed 75-100 feet out from the shoreline into the main channel. The design approach velocity will be less than 0.5/sec. Sheet piling will extend from the intake to the location of the outfall thereby blocking off the old intakes. The cost of this installation is estimated at $12,000,000 with a scheduled completion data during the summer of 1973.

P. H. ROBINSON

The P. H. Robinson plant, operated by Houston Lighting and Power Company, is located on the west side of Galveston Bay near Houston, Texas. The present capacity of the plant is 1550 MW, but a fourth unit of 750 MW is under construction and scheduled for start-up during 1974[A12]. The power plant is cooled by water from the Dickinson Bay section of Galveston Bay. Cooling water from the bay flows approximately two miles northeast through an intake canal to the plant. Heated effluent is returned through a canal to Galveston Bay. The intake structure is equipped with typical log stops, vertical traveling screens, and circulating water pumps. As an extra precaution, a fixed screen panel has been inserted between the traveling screens and the pumps. Fish and trash collected on the traveling screens are sluiced through a tunnel into the discharge canal.

A number of studies have been conducted to assess the effect of power plant operation on the local aquatic organisms. Since Dickinson Bay provides a "nursery grounds" for a large number of fish, they are continuously being drawn into the intake canal. The greatest number of fish pass through the cooling system during the spring[A12]. During the warm period of the year, the impact on the fish recruited into the discharge canal is lessened by diluting the effluent with water diverted from the intake canal through a bypass to the discharge canal. The effectiveness of reducing the temperature of the discharge canal is presently being assessed.

Rotation of the traveling screens is based upon the pressure drop across the face of the screen, as is common practice. Tests on operating the vertical traveling screens on a continuous basis indicate that loss through impingement could be reduced by 50%[A13]. Sampling of fish impinged at the screens of Units 1 and 2 as presently operated, indicate a total loss of fish in excess of 50 tons annually. Although this seems impressively large, it is alleged to be less than the impact of shrimping operations in the bay from a single boat[A13].

REFERENCES

A1) Discussion with John E. Skinner, California Department of Fish and Game.

A2) San Onofre Nuclear Generating Station, Units 2 and 3, "Draft Environmental Statement," DOCKET 50361-34, November 1972.

A3) V.J. Schuler, "Experimental Studies in Guiding Marine Fishes of Southern California with Screens and Louvers", Ichthyological Assoc. Bulletin, Feb. 8, 1973.

A4) Q. J. Stober, et al., "Model of a Rapid Sand Filter for Excluding Small Fishes from Thermal Power Plant Cooling Water," Fisheries Research Institute, University of Washington, December 1971.

A5) Q. J. Stober, "Sea Water Filtration and Fouling Control in a Model Rapid-Sand Filter for Exclusion of Fish from Power Plant Cooling System," Fisheries Research Institute, University of Washington, to be published.

A6) Point Beach Nuclear Plant, Units 1 and 2, "Final Environmental Statement," DOCKET 50266-67, May 1972.

A7) Discussion with Ira Pearce, Duke Power Company.

A8) Cooling Water Studies for Edison Electric Institute, Research Project RP-49, "An Interim Report on...Marshal Steam Station," Johns Hopkins University, Department of Geography and Environmental Engineering, August 1971.

A9) Oyster Creek Nuclear Power Plant Unit 1, "Environmental Report," DOCKET 50219-171, May 1972.

A10) Division of Compliance and Regulation, U.S. Atomic Energy Commission Report of Inquiry into Allegations Concerning Operation of Indian Point No. 1 Plant of Consolidated Edison Company, Vol. II, Report Details, October 1971.

A11) Fish Protection at Indian Point Unit No. 1, Consolidated Edison Company of New York, November 1970.

A12) M. M. McCullough, "A Study of the Juvenile Fish Fauna Associated with the Cooling Water of a Steam Electric Generating Station," Master's Thesis, Texas A&M University, College Station, Texas, 1971.

A13) A. M. Landry, Jr., "Final Report on the Number of Individuals and Injury Rates of Economically Important Fish Passing Through the P. H. Robinson Generating Station," Master's Thesis, Texas A&M University, College Station, Texas, 1971.

DISTRIBUTION

External

No. of Copies

UC-12 Basic List

Internal

No. of Copies

2 AEC, Richland Operations Office

T.A. Nemzek
R.M. Poteat

1 RDT Site Office

F.R. Standerfer

78 Westinghouse Hanford Company

15	G.F. Bailey
1	R.A. Bennett
10	B.W. Bentley
1	W.L. Bunch
1	W.L. Dotson
1	S.L. Engstrom
1	S.R. Fields
1	J.F. Fletcher
1	P.L. Hofmann
1	H.T. Knight
1	D.C. Kolesar
1	F.J. Leitz
1	W.W. Little
1	J.N. Grace
1	D.E. Peterson
1	D.P. Shiveley
1	P.M. Schrotke
20	J.C. Sonnichsen
1	A.E. Waltar
5	Document Control
2	Technical Communications
10	R.E. Nakatani Fisheries Research Institute University of Washington