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**DEVELOPMENT DOCUMENT FOR  
PROPOSED BEST TECHNOLOGY AVAILABLE  
FOR  
MINIMIZING ADVERSE ENVIRONMENTAL IMPACT OF  
  
COOLING WATER INTAKE STRUCTURES**



**UNITED STATES ENVIRONMENTAL PROTECTION AGENCY**

**DECEMBER 1973**

#### Publication Notice

This a development document for proposed effluent limitations guidelines and new source performance standards. As such, this report is subject to changes resulting from comments received during the period of public comments of the proposed regulations. This document in its final form will be published at the time the regulations for this industry are promulgated.

DEVELOPMENT DOCUMENT

for

PROPOSED  
BEST TECHNOLOGY AVAILABLE

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MINIMIZING ADVERSE ENVIRONMENTAL IMPACT  
OF COOLING WATER INTAKE STRUCTURES

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ENVIRONMENTAL PROTECTION AGENCY

## EXECUTIVE OVERVIEW

Development Document for Proposed Best Technology Available for Minimizing Adverse Environmental Impact of Cooling Water Intake Structures.

### Introduction

Water withdrawal for cooling by industrial point sources now amounts to approximately 70 trillion gallons per year. Steam electric powerplants withdraw approximately 80% of this, or 60 trillion gallons per year which is roughly 15% of the total flow of waters in U.S. rivers and streams. The intake of cooling water by broad categories of industry is given in Table A. The relative potential significance of average intake cooling water volumes for establishments within the broad categories is shown in the table. However, the maximum cooling water volumes for individual establishments will be dependent on factors such as products, processes employed, size of plant, degree of recirculation employed in the cooling water system, etc.

TABLE A  
Intake of Cooling Water by Broad  
Categories of Industry (Year 1967)

<u>Category</u>	<u>Intake Volume</u> <u>Billion gal/yr</u>	<u>No. of</u> <u>Estab</u>	<u>Avg. Intake</u> <u>Billion gal/yr/estab</u>
Steam Electric Powerplants	40,000	1,000	40
Petroleum Refineries	1,230	260	4.7
Primary Metals Mfg.	3,630	840	4.3
Chemical Plants	3,530	1,130	3.2
Pulp and Paper Mills	650	620	1.1
Rubber Mfg.	96	300	0.3
Wood Products Mfg.	52	190	0.3
Food Products Mfg.	430	2,350	0.2
Stone, Clay, & Glass Mfg.	140	590	0.2
Textile Mills	24	680	0.04
Leather Mfg.	1	90	0.01

Adverse environmental impacts that could occur from cooling water intakes relate to the net damage or destruction of benthos, plankton and nectonic organisms by external interaction with the industrial cooling system. Important aspects of the intake which relate to adverse environmental impact are the intake volume, the number and types of organisms which interact externally with the intake or which interact internally with the industrial cooling system, the configuration and operational characteristics of the intake and plant cooling system, the thermal characteristics of the cooling system, and the chemicals added to the cooling system for biological control.

The above impacts are highly site-specific. Therefore, adequate biological data would be needed in each case to determine the specific need and control strategy related to minimizing environmental impact of intake structures.

### Applicable Technology

The range of technologies corresponding to the control of the number and types of organisms which interact externally with the intake is comprised of two factors - the choice of the location of the intake relative to the location of the organisms; and the full array of process modifications including the use of recirculating cooling water systems employing offstream means to transfer process heat directly to the atmosphere, to minimize or in some cases eliminate the use of cooling water. The technology for controlling the number and types of organisms which interact internally with the cooling system is comprised of one factor in addition to location and flow volume controls as cited above for intake interactions, i.e., the degree to which the configuration and operation of the intake means prevents the entry of these organisms into the cooling system. The technology for preventing the entry of these organisms while minimizing damage due to external interactions with the organisms is diverse, including a multiplicity of physical and behavior barriers and including various fish bypass and removal systems.

Damage due to internal interactions with process cooling systems relate to the design and operation of these systems with respect to mechanical, thermal, and chemical characteristics. For example, the presence of a cooling tower in a nonrecirculating cooling system could affect the amount of organism damage due to the pumping, temperature changes, and possible chemical additives employed with the tower.

The extent of the known present application of these technologies to industrial cooling water intakes is extremely limited, and is largely confined to steam electric powerplants. However, some technologies applicable to industrial point sources have been applied to irrigation potentially and other flows.

### Costs

The choice of intake location, while a potentially available technology to some degree for all industrial sources for controlling the number and types of organisms interaction with the intake, could be more costly incrementally in the case of relocating an existing intake, than applying a recirculating cooling system to minimize or eliminate cooling water flow. In general, the incremental costs associated with choice of intake location or application of recirculating cooling systems to control the number and types of organisms interacting with the intake would be less for a new source than for a similar existing source. However, little is known concerning incremental costs since no

industrial point source, new or existing, is known to have added this technology (location).

Some information is available concerning the performance and costs of various intake devices in specific applications both at steam electric powerplants and elsewhere. However, the reliability of predictions of performance at one site based on performance at another site is low in many cases.

No modification of a process cooling system is known to have been made by any industrial point source to minimize damage due to internal interactions. However, modifications, such as the incorporation of helper cooling towers to meet environmentally imposed temperature limits on discharges from nonrecirculating cooling water systems, have been made to steam electric powerplants which could have possibly increased damage to organisms interacting internally with the cooling water system.

#### Nonwater Quality Impacts

Energy requirements of available control technologies would be significant in individual cases, only in relation to the extent that certain types of recirculating cooling water systems would be employed to minimize or eliminate the use of cooling water.

Energy requirements and nonwater quality environmental impact of all other available technologies are not known to be significant.

#### Best Technology Available

Owing to the highly site specific cost versus benefits characteristics of available technology for minimizing environmental impact of cooling water intake structures no technology can be presently generally identified as the best technology available, even within broad categories of possible application. Within this context, a prerequisite to the identification of best technology available for any specific site could be, in some cases, a biological study and associated report to characterize the type, extent, distribution, and significant overall environmental relation of all aquatic organisms in the sphere of influence of the intake, and an evaluation of corresponding available technologies, in accordance with generalized guidelines to identify the site specific best technology available for minimizing adverse environmental impact of cooling water intake structure. Studies of the type outlined above could have a severe economic impact on certain relatively small establishments with relatively high cooling water intake volumes. From a nationwide perspective the costs versus benefits of full studies corresponding to all establishments with cooling water intake has not been shown to substantiate the requirements that all such establishments be required to submit reports of such studies. Further, in the case that incrementally costly intake structure technology would

be shown to be required, expenditures beyond the cost of recirculating cooling water systems would generally not be prudent since that option would remain to significantly reduce the intake volume of cooling water.

Requirements regarding the application of best technology available for intake structures could be very costly in the case of small establishments, point sources facing a later requirement under section 304(b) effluent guidelines to meet thermal limitations reflecting a recirculating cooling water system, or where the best technology available for intakes would require relocation of the intake.

Certain general guidelines have been developed for site characterization and the description of location, design, construction, capacity, operation and maintenance features of cooling water intake structures to reflect the best technology available for minimizing environmental impact. These guidelines and supporting data are presented in the body of the report.



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## SECTION I

### BACKGROUND

#### Scope

The Federal Water Pollution Control Act Amendments of 1972 state under "Thermal Discharges," Section 316(b): Any standard established pursuant to section 301 or section 306 of this Act and applicable to a point source shall require that the location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact.

This statement allows considerable latitude in its interpretation. Rather than calling for an explicit control and treatment technology to be broadly applied as in Section 301, Section 316(b) requires that intakes shall incorporate "best technology available" in terms of location, design, construction and capacity. The Act also does not indicate whether new intakes are to be treated any differently than existing intakes.

In addition, performance and maintenance are important factors which should be considered in addition to those itemized in the Act. The term "capacity" relates to the physical size of an intake, and has been considered as an integral part of design considerations. Consequently, this report has been divided into the following sections for location, design, construction and operation and maintenance.

Since the Act specifies cooling water intake structures, this document is addressed specifically to these types of intakes. It is evident, however, that the discussion could apply to many other types of water intakes; for example, non-cooling water intakes for industrial, irrigation or domestic water supply. A major feature of a powerplant intake, as distinguished from many others, is the necessity for continuous operation. Such a requirement imposes many design criteria that may not be necessary for other types of intakes. Powerplant intakes cannot normally be shut down to bypass temporary fish runs, to clean out silt or to lessen some other seasonal environmental impact. However, shutdowns may be feasible in some instances as with a nuclear powerplant scheduling refueling for a predictable critical fish spawning period.

#### Intake Structure Definition

From an environmental standpoint, an intake consists of all elements of a water drawing facility from the point of water inlet to the water screens. The water screens are the last point in the circuit at which aquatic life can be recovered. Common usage also often includes the

circulating and service water pumps, where those pumps are located in the same structure as the screens. However, these are not strictly a functional part of the intake, from an environmental standpoint. Figure I-1 shows two typical intake structures designating those parts which define the intake for the purposes of this study.

Cooling water intakes for industrial point sources fall into three general categories according to the magnitude of the water flow and the physical size of the structures involved.

**Circulating Water Intakes** - These intakes are for once-through cooling systems, which are designed to continuously withdraw the entire circulating water flow. The water is passed through the condenser and returned to the water source. The typical water usage for which the intake for powerplants must be designed is from about 0.03 to 0.1 m<sup>3</sup>/s (500 to 1500 gpm) per MW.

**Makeup Water Intakes** - These intakes provide the water to replace that lost by evaporation, blowdown and drift from closed cooling systems. The quantity of water required is commonly 3 to 5% of the circulating water flow. These intakes are therefore considerably smaller than the cooling water intakes for once-through systems.

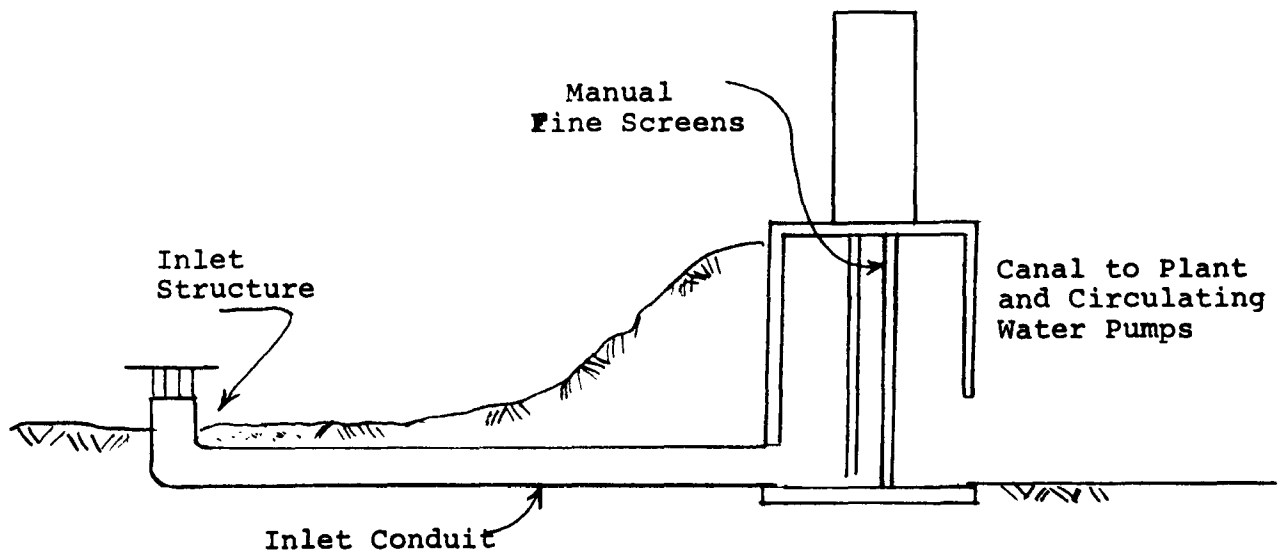
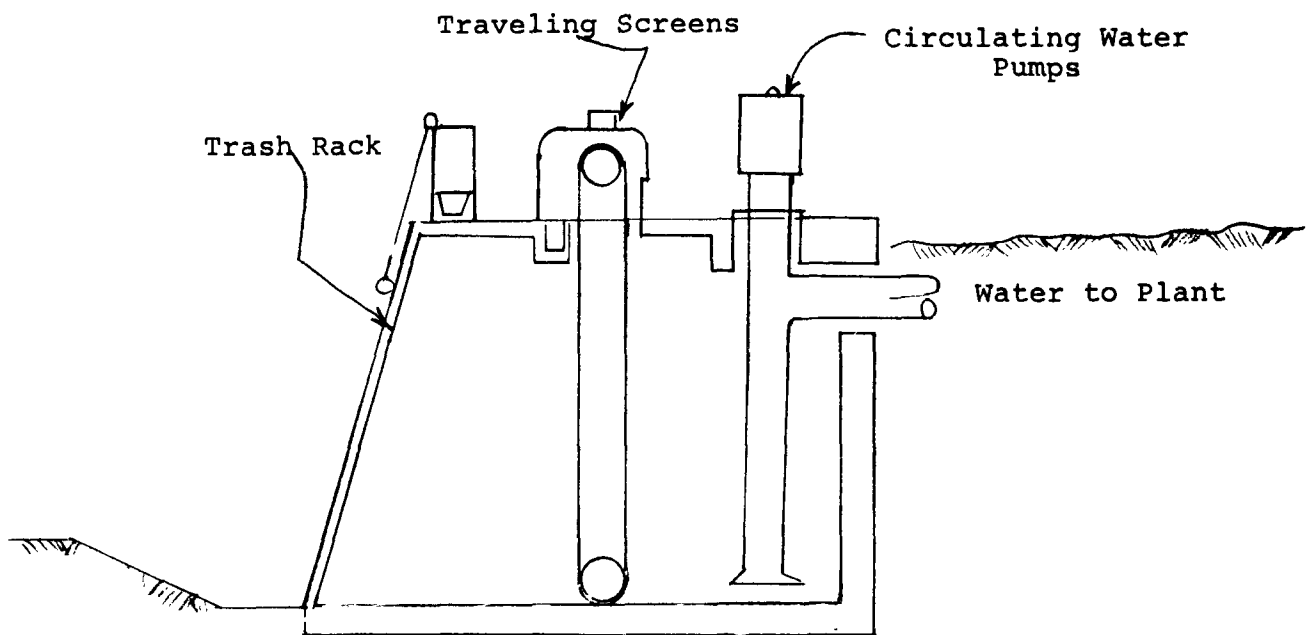
**Service Intakes** - These intakes provide the water required for essential cooling systems as in the case of a nuclear powerplant. Here, the water quantity is small when compared to the circulating water flow, averaging about 0.002 m<sup>3</sup>/s (30 gpm) per MW of capacity. The structure will be quite massive due to the requirements for redundancy of pumping and screening equipment and the need for both missile and earthquake protection. From an environmental standpoint, visual impact may be substantial.

Often service water systems and circulating water systems will be contained in separate bays at the same intake. Most new intakes will have this design. Older powerplants, built in a series of steps may have separate intakes for different functions and may use more than one water source.

#### Environmental Impact as Related to Intake Structures

The major impacts caused by cooling water intakes are those affecting the aquatic ecosystem. The aquatic organisms comprising this ecosystem may be defined in broad terms as follows:

**Benthos** - Bottom dwellers are generally small and sessile (non-swimming) but can include certain large motile species (able to swim). Location of major populations can be reasonably well defined and therefore avoided by adoption of appropriate locational guidelines. These species can be important food chain members.



SCHEMATIC DIAGRAMS TYPICAL INTAKE STRUCTURE  
(Point of Water Inlet to the Water Screening Facility)

FIGURE I-1



Plankton - Free floating microscopic plants and animals with limited ability to swim. The location of these species generally are apt to be rather diffuse throughout the water body and therefore the adoption of locational measures would not protect these species. However, vertical movement of some species is controllable leading to the aggregation of many plankters into layers. Locational measures, such as withdrawal of water from hypolimnetic waters, may serve to protect vulnerable plankton layers. Plankton are also important food chain organisms.

Nekton - Free swimming organisms (fish). Of major concern in many cases are egg and larval stages which are small and have limited mobility and therefore generally considered as plankton. Adult fish of most species will have the swimming ability to avoid the intake provided they are stimulated to do so. The location of spawning and nursery areas and migration paths are frequently definable and therefore should be reflected in locational measures.

One of the first steps that may be taken in the proper location and design of a cooling water intake structure from the environmental standpoint is the designation of the organism(s) to be protected. This approach has been outlined by the U.S. Atomic Energy Commission in reference 24. This approach requires the determination of the species present in the area of the intake. A determination of their spatial and temporal distribution is also required. A judgment may then be made as to which of the identified species are critical to the ecosystem and therefore would control the environmental design of the intake structure. It is sufficient to say at this point that the control strategy for minimizing environmental impact will be different for planktonic species than for nektonic species as discussed below.

#### Impacts on Aquatic Organisms

Impingement - The entrapment of nektonic species against a screen mesh by velocity forces across the screen. In general, impingement will be lethal for most species due to starvation and exhaustion in the screen well, descaling by screen wash sprays and by asphyxiation due to removal from water for prolonged periods of time.

Entrainment - The passage of relatively small benthic, planktonic and the smaller nektonic forms (egg and larval) through the condenser cooling system. Mortality of these organisms is quite variable and is a subject of considerable on-going research. Damage can occur from one or more of the following causes:

- physical impact in the pump and condenser tubing
- pressure changes across the condensers
- thermal shock in the condenser and discharge tunnel

- chemical toxemia induced by antifouling agents such as chlorine

Entrainment is not an impact of the intake structure but rather an effect caused by the subsequent condenser cooling water system.

#### Control Strategy for Limiting Impacts on Aquatic Organisms

As indicated above, the control strategy for minimizing environmental impacts at intake structures will vary with the type of organism considered. Impingement effects can be significantly influenced by both the location and design of intake structures. This is because the spacial and temporal distribution of nektonic species can be reasonably well defined by biologic examination, and sensitive areas avoided by proper location of the intake structure. In addition, the size of some adult nektonic species is sufficient to allow their impingement on fine mesh screens. Entrainment effects on the other hand are relatively less controllable by intake structures. This is because the size of the species are small and they generally lack significant mobility. The spacial and temporal distribution of these species is more difficult to define, which will limit the effectiveness of locational guidelines. Design strategies will also be generally ineffective for these species since their small size and lack of swimming ability will prevent them from being effectively screened on a fine mesh screen.

There are more effective ways to control entrainment effects where benthic and planktonic organisms are identified as critical design organisms. One approach would be to limit the volume of cooling water withdrawn from a source to a small percentage of the makeup water to that source. This would be a limitation placed on intake capacity rather than other an intake specification. For new plants this would mean that the large capacity intakes would be located further downstream and smaller intakes located upstream. Peterson <sup>16</sup> has made estimates of the thermal capacity of some of the Nation's larger waterways. This work could be expanded upon to establish relationships between intake volume and mean flow. Where existing stations exceeded the recommended volume, steps would be taken to reduce the intake volume. Implicit in this approach is that the impact of entrainment effects on a waterbody is related to the volume of intake flow, i.e., the lower the flow the lower will be the damage to planktonic and benthic species. The limiting intake volume is that at which the waterbody is able to compensate for the damage to entrained organisms.

Another approach would be to design the cooling water system to minimize the effect on entrained organisms. This approach involves limiting the temperature, pressure, chemicals added, and time of exposure of the aquatic species to levels that will insure satisfactory survival of the design organisms. A considerable amount of research has been done on the subject of survival of entrained organisms after passage through condenser cooling water systems. The results of these studies are often

conflicting. A suggested guideline in this area has been offered by the National Academy of Engineering,<sup>34</sup> which recommended that the condenser system be designed according to the following formula:

$$t (T) \geq 2000$$

t = exposure time in seconds

T = temperature rise across the condenser (°C)

This formula implies that higher temperature rises could be tolerated by most species if the exposure time were kept to a minimum. It is believed that the experimental data upon which this formula is based was limited and therefore caution is suggested in the application of this formula.

It is noted that this approach is directed at the condenser cooling system and is not applicable for intake structures.

#### Other Environmental Impacts Related to the Intake Structure

**Aesthetic Impact** - Where the intake structure and balance of plant are separated by great distances the intake structure may have an imposing physical presence. This will be significant in wilderness areas and in natural and historical preserves. Where plant and intake are located close together architectural treatment can be applied to create an attractive appearance.

**Noise Impact** - The sound level of the large circulating pumps can be quite high. Current practice in milder climates is to construct these installations without enclosures. Enclosed intakes would not have significant sound levels.

#### Acquisition of Biological Data

Probably the most widely ignored aspect of data collection for intake structure design is the biological data on the aquatic species to be protected. Most of the data collected for intake structure design concerns the hydrological information relative to the water source. This information consists of data on water currents, sedimentation, water surface elevations and water quality. In general, relatively little data on the biological organisms is collected. The design of intakes should be based on protection of the critical aquatic organisms as well as the traditional design considerations of adequate flows, temperatures and debris removal. In addition, it has been noted that the design criteria for the protection of the aquatic environment will be significantly different for different species in the water source. It is therefore necessary that in each case sufficient data must be made available on the biological community to be protected. The data that

must be provided in some cases, depending on the severity of the problem and especially for new steam electric powerplants withdrawing water from sensitive water bodies, should consist of, as a minimum, the following:

- The identification of the major aquatic species in the water source. This should include estimates of population densities for each species identified, preferably over several generations to account for variations which may occur.
- The temporal and spacial distribution of the identified species with particular emphasis on the location of spawning grounds, migratory passageway, nursery area, shellfish beds, etc.
- Data on source water temperatures for the full year.
- Documentation of fish swimming capabilities for the species identified over the temperature ranges anticipated and under test conditions that simulate as closely as possible the conditions at the intake.
- Location of the intake with respect to the seasonal and diurnal spatial distribution of the identified aquatic species.

The criteria for the biological survey for the development of this data is not presented here. There are several excellent publications on the techniques to be used in the conducting of biological surveys. The EPA has published guidelines for the conduct of biological surveys. 9 The techniques will differ both with the type of organism and the source of water.

## SECTION II

### LOCATION

#### Introduction

Both the location and design of cooling water intakes can have an effect on the environment. This section is concerned primarily with intake location, although it will become evident that location and design are closely associated in many respects.

"Intake" as previously defined, means the entire intake facility which may consist of one or more elements including an inlet structure (the point of water entrance) closed conduits and open channels to a pump structure or a combined screen and pump structure. "Location" refers to both the horizontal and vertical placement of the intake with respect to the local above-water and under-water topography. This section attempts to answer such questions as: where is the intake to be located with respect to the shoreline, navigation channels, discharge structures, and fish spawning areas? Also, from what depths is the water to be drawn?

The discussion is concerned with three locational aspects of the intake's relation to the environment:

- . The operation of the intake insofar as its location affects operational characteristics. Operation will usually result in the major environmental influence to be expected from any intake facility.
- . Construction activities such as dredging, excavation and backfill for channels, inlet conduits, inlet structures, and pump and screen structures. The environmental influence may be considerable, but will normally be temporary if suitably controlled.
- . Aesthetics, the appearance of the intake facility and its relationship to the surroundings. Both the design and the location of one or more elements of the intake facility may be dictated in part by aesthetic considerations.

The most important locational factor influencing the intake design is the nature of the water source from which the supply is being taken.

Other locational factors which must be considered are the relative location of the intake structure with respect to the discharge structure, the vertical location of the intake, the location of the intake with respect to the balance of the plant and the avoidance of areas of important biological activity. In all water bodies, the intake

may be located off-shore, flush with the shoreline or inland with an approach channel as shown in Figure II-1. The reasons for selection of a particular orientation with respect to the shoreline are both to provide the required volume of the coldest available water and to avoid drafting from biologically sensitive areas.

## Water Sources

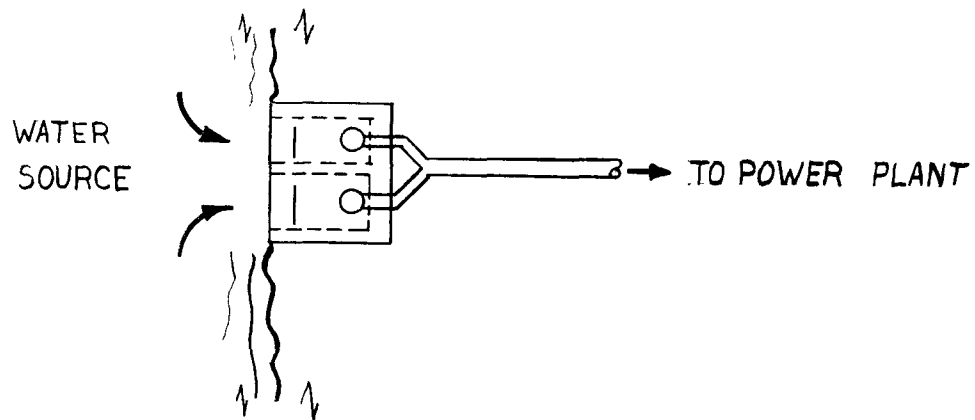
### Fresh Water Rivers

Rivers normally are characterized by unidirectional flow, which eases the intake design problem. Most large rivers will generally possess sufficient resistance to recirculation due to the velocity gradient to permit the siting of both intake and discharge at the shoreline. Recirculation might present a problem at extremely low flows. The base of the river intake is generally set at the lowest river bed elevation, however, it should be set above significant silt accumulations to prevent silt deposition in the intake. Different locations in streams have different susceptibilities to silting. The inner sides of river bends are more susceptible to silting than the outer sides. The top of the intake is usually set for high flow and flood conditions. The pump operating deck is usually placed several feet above the flood crest level. Frequently, large water levels and flow variations can make river intake structures correspondingly high.

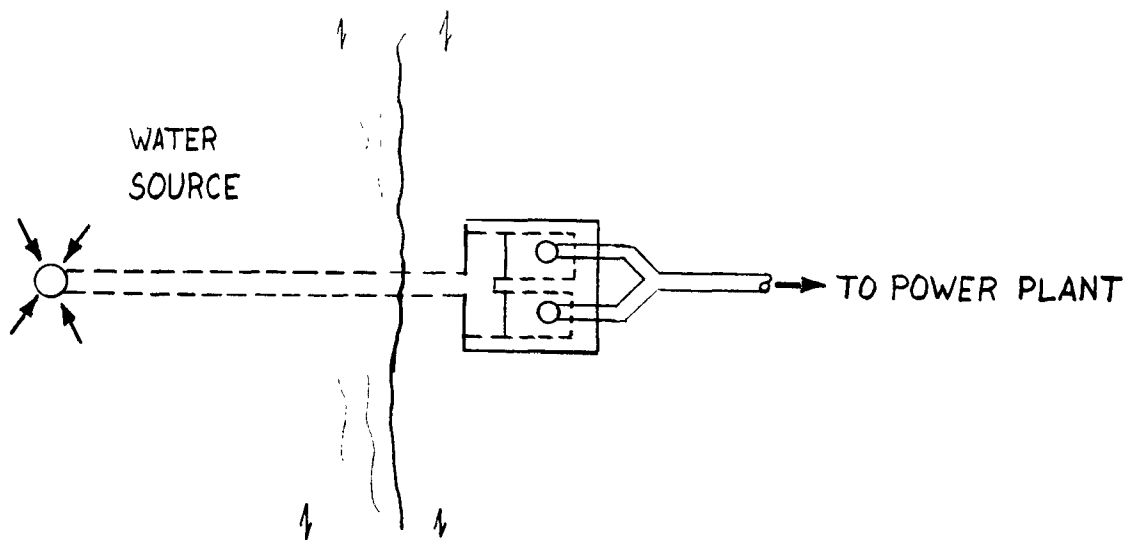
Ice flows and debris loading are also significant for many river locations as are the maintenance of navigation passages. Rivers will usually possess minimum temperature stratification when compared to lakes because of greater vertical and horizontal mixing. Finally, it is necessary to protect the aquatic life from entrapment in the intake. In doing this, it is best to locate the diversion structure at the shoreline and employ the sweeping currents of the river to carry fish downstream. However, such a structure could trap upstream migrants, leading them to the intake structure.

### Fresh Water Lakes and Reservoirs

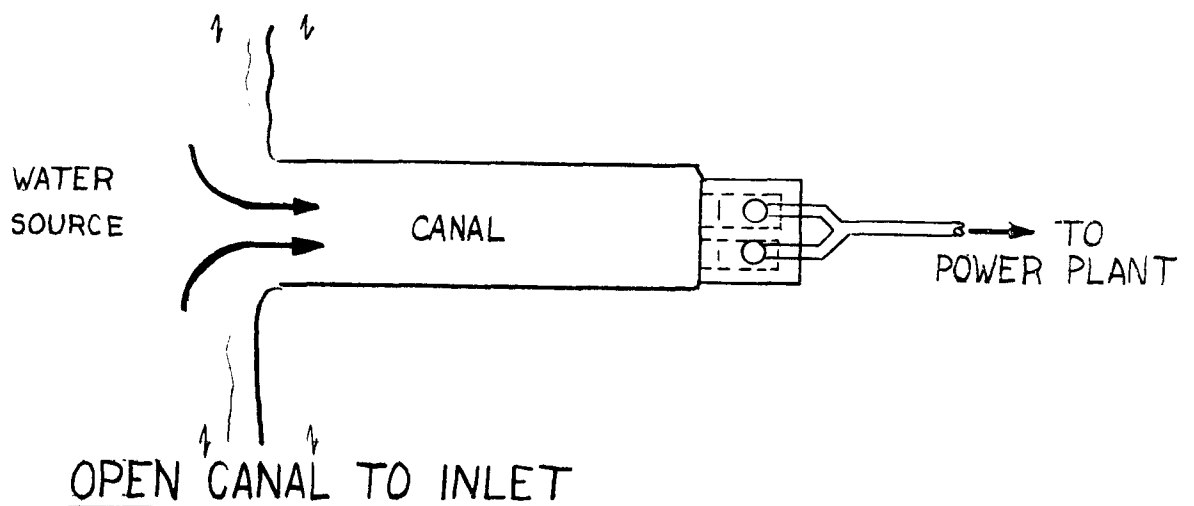
The most significant difference between lakes and rivers is the fact that the former are often stratified with respect to temperature. The thermal stratification of lakes is a rather complex phenomenon. The heat balance of a lake depends on ambient air temperature, wind speeds, the topography of the lake bottom and flows into and out of the lake. It is clear that a large withdrawal or discharge of cooling water can significantly affect thermal stratification. The zone of cold water at the bottom of the lake is called the hypolimnion. The water in the hypolimnion is relatively low in dissolved oxygen and often high in nutrients (nitrates, phosphates).



INLET FLUSH WITH SHORELINE



OFFSHORE INLET



OPEN CANAL TO INLET

INTAKE LOCATION WITH RESPECT TO SHORELINE

FIGURE II-1

Lying above the hypolimnion of a stratified lake is a zone of distinctly warmer water, the epilimnion. The significant features of this zone are that it is the area from which evaporation takes place; it is the region into and out of which the natural stream courses flow; it washes the shoreline or littoral zone which is a region of highly abundant life and it supports considerable populations of life throughout its extent. The water in this zone is usually high in dissolved oxygen. Artificial reservoirs may have poorly defined littoral zones because of drawdown procedures. While the littoral zone of a reservoir would be attractive because it does not support as much life, it is of little use to the intake designer who will find a shoreline intake too often high and dry.

Within the epilimnion is the uppermost zone which is called the photic zone. The productivity of this zone is a function of the degree of penetration of sunlight and the presence of necessary nutrients. As little water as possible should be taken from the epilimnion and the absolute minimum from the photic zone. Off-shore intakes with multiple entrance ports appear to have great application in stratified lakes.

Lakes generally do not have the pronounced flushing currents that many rivers have. Therefore, the possibility of recirculation becomes more significant. In addition, there is no assistance by current flushing to wash debris and fish past the intake.

Wind forces provide most of the water level variation, and wave protection is an important design consideration in intake structures for lakes. Commercial navigation is generally not as important a factor as in rivers, since shoreline and dams prevent access to most lakes. However, recreational use is more prevalent on lakes than in many rivers. The Great Lakes constitute an important exception to this generalization regarding navigation.

## Estuaries

A number of factors combine to make intake design and location selection for estuaries the most difficult of all water source types. Flow is two directional which complicates the design of many screening systems. Similar to lakes, most estuaries exhibit stratification, although stratification in estuaries is generally less stable than in lakes. Water density depends on both water temperature and salinity. Volumetric fluctuations are greater due to the periodic influx of sea water. The salt content varies with tidal cycles. Estuaries are often stratified with respect to salt content, with fresh water tending to ride above the salt. In areas where cooling water discharge effects are present, density stratification in potential intake areas is further complicated by the differing buoyancies of warm and cool water, and fresh and salt water.



Estuaries are frequently major spawning areas for both ocean fish and shellfish, with wide seasonal variations of biologic activity. The presence of current reversals can also create severe recirculation problems. Because of the high salt content and tidal variations which create periods of high and low water, corrosion becomes much more significant in intakes designed for estuaries.

## Oceans

The most important consideration in the design of ocean intakes is the storm wave protection system. Wave damping upstream of the screens is required. There may also be heavy sediment load in the surf area. Other factors to be considered are littoral drift and shoreline instability. The littoral zone is highly productive biologically, although generally not as productive as are estuaries.

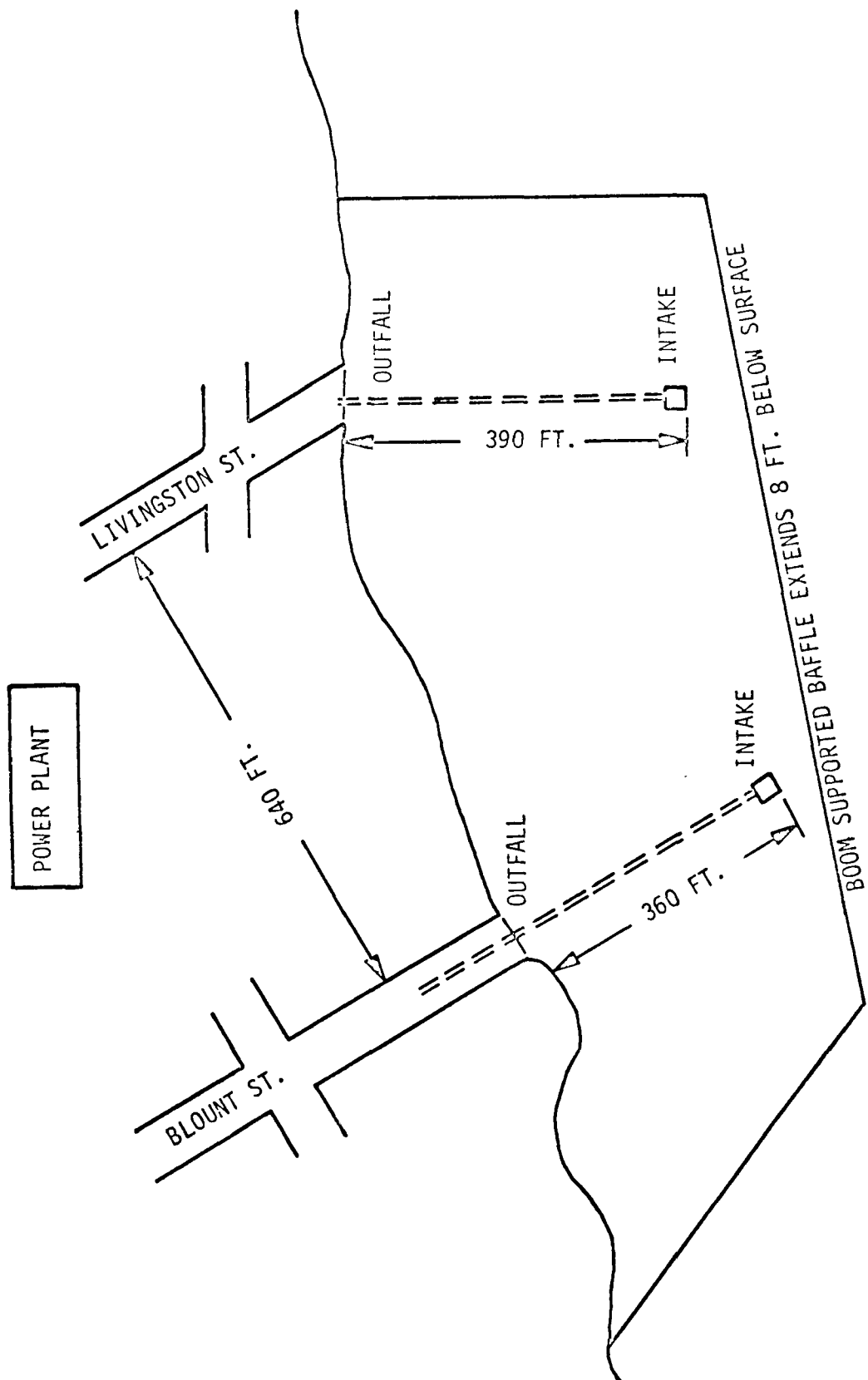
Thermal stratification exists but is not as stable as that in lakes because of the higher degree vertical turbulence in oceans. Navigation passageways must also be considered.

### Intake Location with Respect to Plant Discharge

From the point of view of plant cooling water requirements the use of coolest available water is desirable. Accordingly, considerable attention has normally been given to avoiding the inadvertent recirculation of warm water discharge back into the intake. From a fish attraction standpoint, the avoidance of recirculation is also advantageous. Long experience has shown that many species of fish tend to congregate in warm water areas, especially in the cooler seasons of the year. In at least one major nuclear plant, a small amount of recirculation attracted fish to the intake area in winter. The fish thus attracted were also lethargic due to the low winter temperatures of the water and they tended to be carried into the screens.

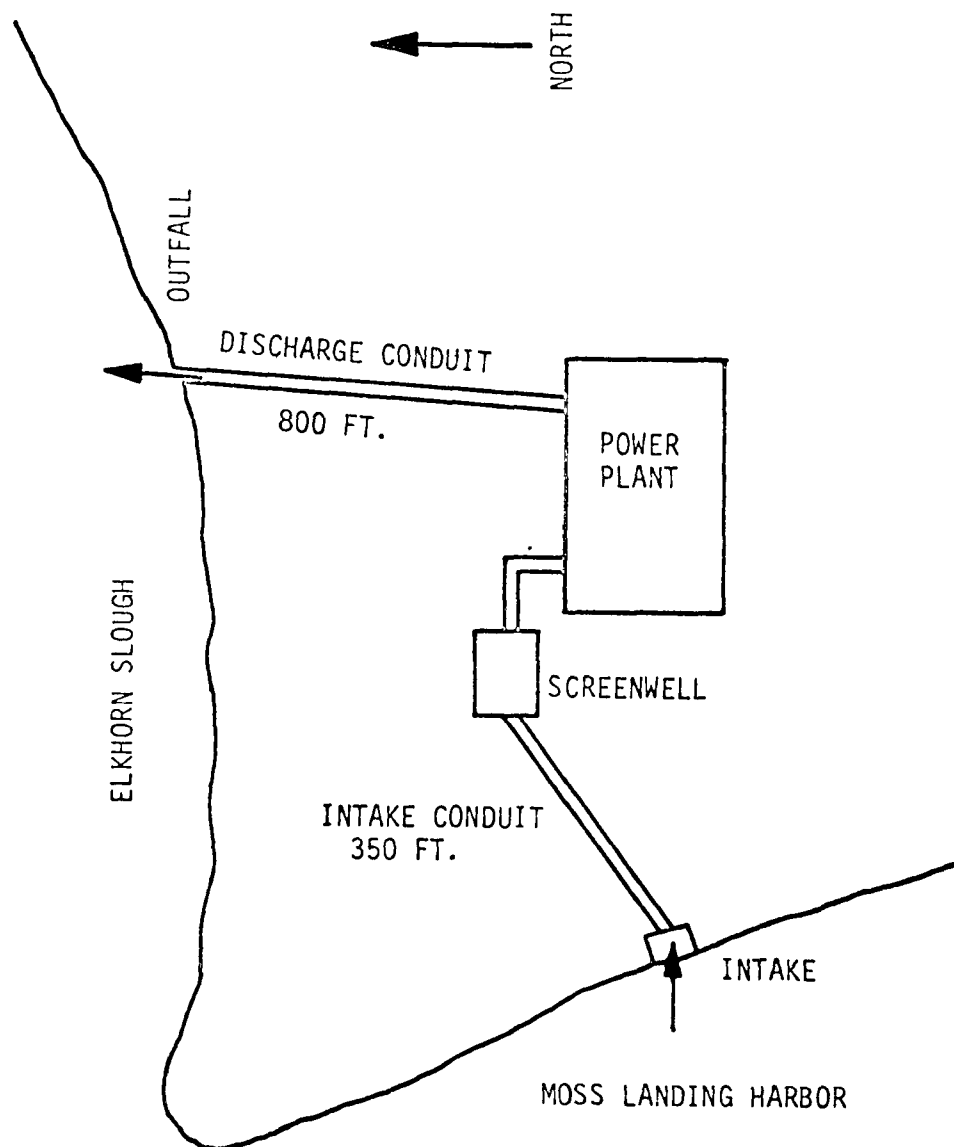
The technical aspect of the avoidance of recirculation is a subject beyond the scope of this study. Note, however, that the subject would involve an analysis of the existing water currents, the stratification of the warm water and the dilution and dispersion characteristics of the discharge structure.

There are a number of ways in which recirculation can be avoided. Two of these are shown in Figures II-2 and II-3. Figure II-2 shows the location of two intakes and discharges at plant no. 5502. The methods used at this plant to prevent recirculation is to locate the intake a considerable distance off-shore and locate the discharge at the shoreline. Figure II-3 shows the location of the intake and outfall for plant no. 0608. This plant avoids recirculation by withdrawing water from one body of water and discharging to another body of water. Other



LOCATION OF INTAKE AND OUTFALL - PLANT NO. 5502

FIGURE II-2



LOCATION OF INTAKE AND OUTFALL - PLANT NO. 0608

FIGURE II-3

ways of avoiding recirculation are to separate intake and outfall by a sufficient distance, the construction of a physical barrier between the intake and outfall, and the excavation of a channel for the intake or outfall or both. Prevention of recirculation also requires adequate vertical separation of intake and discharge. This is important in a stratified water body such as a lake. Vertical separations of between 20 to 60 feet have been used at some locations.

From the standpoint of the effect of recirculation on fish attraction, it should be noted that proper location of the inlet point both with regard to site location and water depth, is an important design element to be considered.

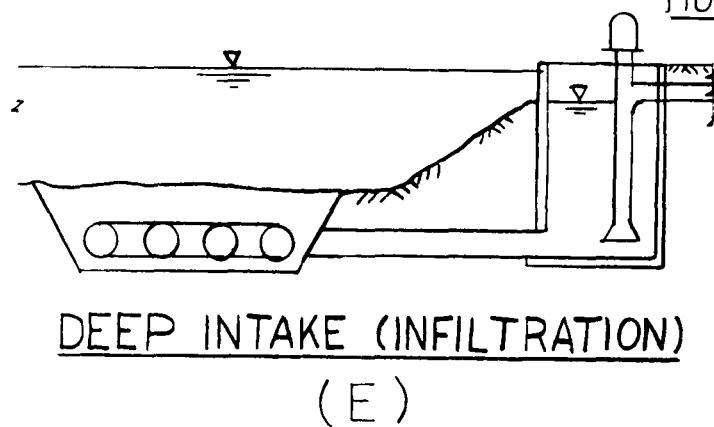
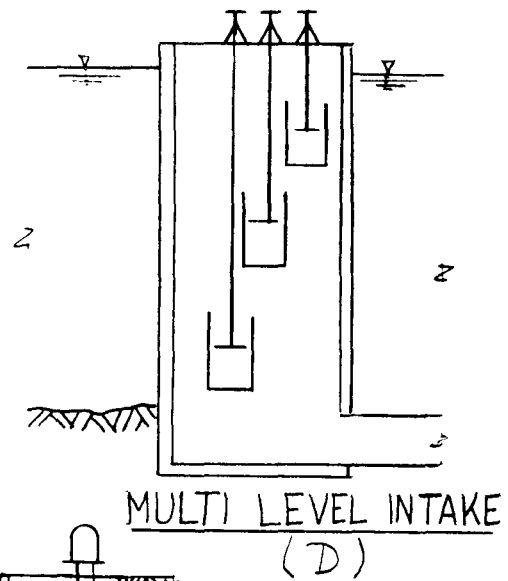
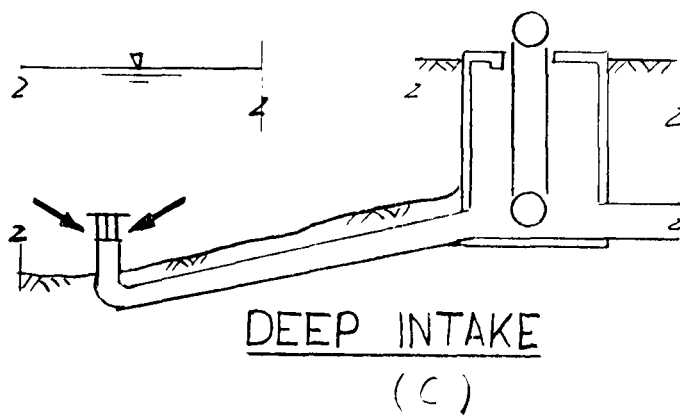
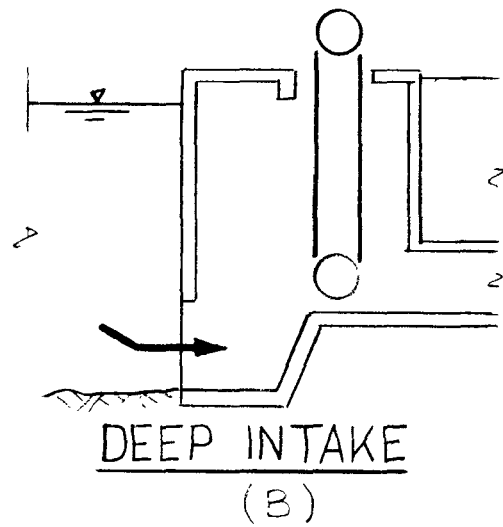
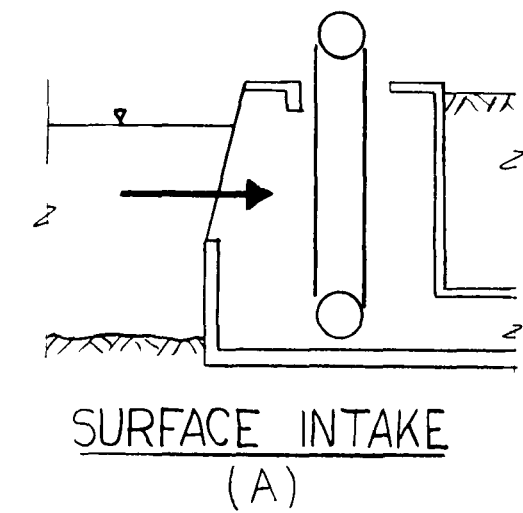
#### Intake Location with Respect to the Shoreline

As mentioned above and shown in Figure II-1, there are three basic orientations of intakes with respect to the shoreline. The difference between them is the relative position of the water inlet with respect to the shoreline. The intake at the top of the figure has the inlet flush with the shoreline. This intake may also be called a shoreline intake or a bankside intake. The middle intake has the inlet located offshore with a conduit leading to the shore. The offshore inlet may be only a pipe opening as shown, or may include water screening facilities and pumps. The third type of intake uses an open channel inlet (generally excavated) leading to an inland water screening facility. This latter type of intake may also be referred to as an onshore intake.

Each of these different intake orientations may be used for any type of water source (river, lake, estuary, or ocean). The flush inlet and the offshore inlet offer alternate means for withdrawing water in areas where aquatic population may be minimal. The third scheme (open channel) may have desirable attributes from an aesthetic point of view, but often creates a problem due to fish which collect in open channels. This aspect will be discussed in the design section of this report.

#### Intake Location with Respect to Water Depth

From the biological standpoint, the depth at which water is taken can be a major factor regarding damage to aquatic organisms. In some locations, it may be desirable to draw surface water only as shown in Part A of Figure II-4. At other locations, it may be better to draw deep water as shown in Parts B and C of the figure. A complicating factor is that the desirable water supply depth may vary seasonally or even diurnally, making multilevel intakes environmentally attractive. A typical multilevel intake is shown in Part D of the Figure. For water sources where the biologic community is extremely sensitive to intake currents, a deep intake of the infiltration type might be best as shown in Part E of the figure.



INTAKES DRAWING FROM DIFFERENT WATER LEVELS

FIGURE II-4

### Aquatic Environmental Considerations in Intake Location

The location of the intake should also reflect the knowledge of the various members of the aquatic community. The location should be selected to minimize the impact of the intake on the identified species. In general, the intake location should include the following:

- avoidance of important spawning areas, fish immigration paths, shellfish beds or any location where field investigations have revealed a particular concentration of aquatic life.
- selection of a depth of water where aquatic life is minimum. This depth may change seasonally or diurnally.
- selection of a location with respect to the river or tidal current where a strong current can assist in carrying aquatic life past the inlet area or past the face of screens (if the flush mounted type of setting is used for example).
- selection of a location suited to the proper technical functioning of the particular screening system to be used. For example, the still experimental louver and horizontal screen installations have limiting requirements relative to water level variations and intake approach channel configurations which will influence their locations with respect to the source of water.

The application of the above presupposes that sufficient biological investigation has been conducted to establish sensitive areas and important species. The previous section of the report outlined the type of data required in the procedure for biological data gathering. These data are essential for proper intake location. Furthermore, when returning bypassed fish and other organisms, they should be delivered to a hospitable situation.

### Intake Location with Respect to the Balance of the Plant

Some organisms may undergo damage in the passage from the intake to the plant and on the return between the condenser and the discharge structure. The extent of the damage is proportional to the temperature and pressure changes and the time of travel between the shore and the plant. Since the time of travel is related to the distance between the intake and plant, it would be desirable, in cases where incremental damage due to this effect would be significant, to locate the intake as close to the plant as possible. This consideration applies even more to the location of the outfall with respect to the plant. Relocation of an existing intake with respect to the balance of the plant could be very costly in many cases.

## SECTION III

### DESIGN

#### Introduction

This section of the report is organized to describe the various components which comprise an intake structure. The components described include screening devices, trash racks and fish handling and bypass equipment. This organization is utilized to provide an understanding of the function and configuration of these components. Following this, the description of components will be assembled into complete descriptions of intake designs, with recommendations developed for each type of design. The section is presented in five parts as follows:

- Screening Systems Design Considerations
- Behavioral Screening Systems
- Physical Screening Systems
- Fish Handling and Bypass Facilities
- Intake Structure Designs

#### Screening Systems Design Considerations

By far the most important design consideration for screening systems at intake structures is the velocity through the screens. Intake velocities are usually measured in two ways as follows:

Approach Velocity - Velocity in the screen channel measured immediately upstream of the screen face.

Net Screen Velocity - Velocity through the screen itself. This velocity is always higher than the approach velocity because the net open area is reduced by the screen mesh, screen support structure and debris clogging.

Velocity considerations should be based on the approach velocity since the net screen velocity is constantly changing with debris loading in the waterway. Another important design consideration is the selection of the screen mesh size. This should be based on both fish size and debris loading considerations.

Other environmental factors to be considered in designing intake water screens can also affect the configuration of the intake structure itself. These factors include proper location of screens to avoid zones of entrapment, and good hydraulic design to insure uniform flow over the entire screen face. This latter element is influenced by the design of the hydraulic passages both upstream and downstream of the screen. The downstream design also includes the location of pumps.

### Approach Velocities

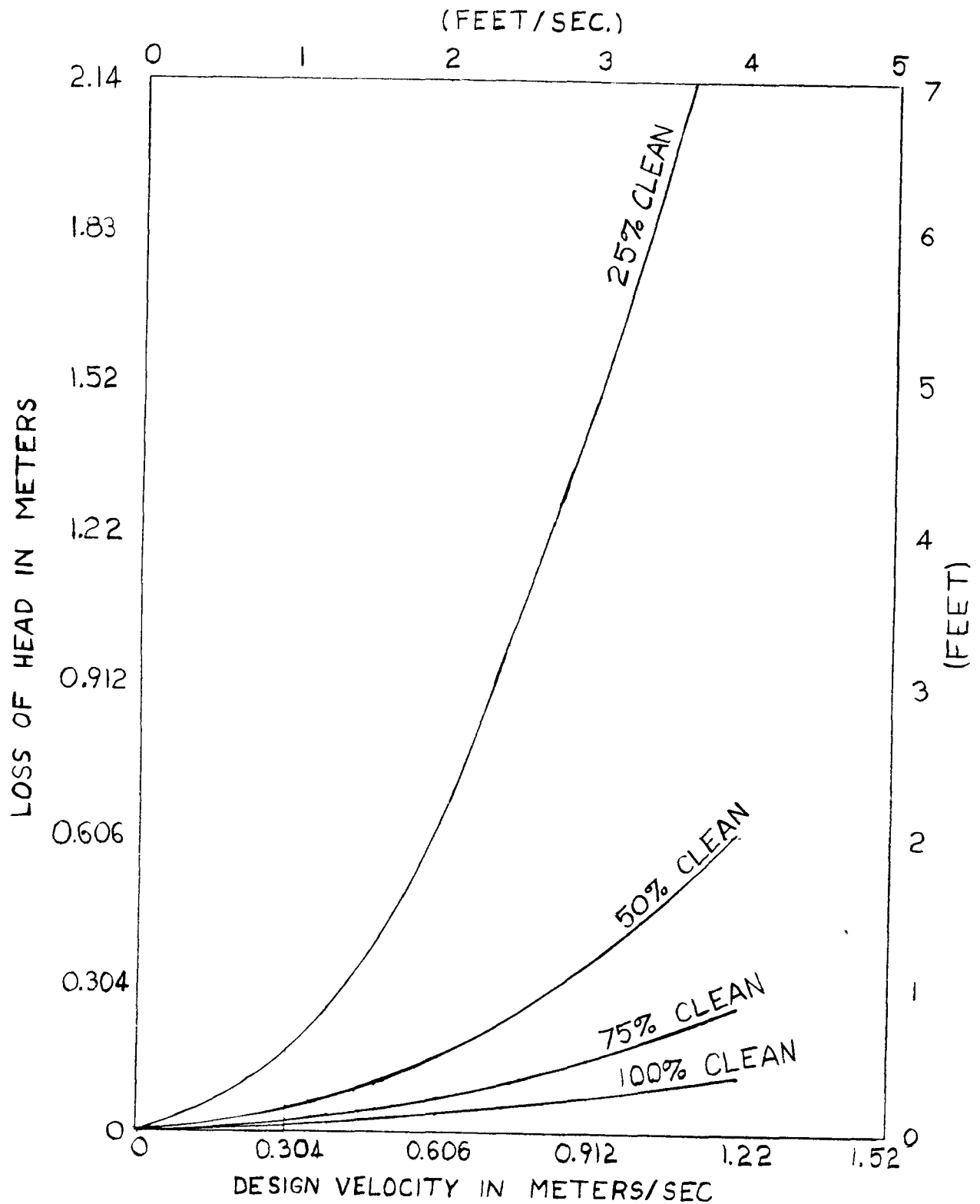
Most existing water screens at intake structures have been designed solely on debris removal considerations. The design criteria is usually that a relatively low head loss be maintained across the screen at the lowest water level anticipated. Typical velocities through the screen mesh fall in the range of 0.61 to 0.762 meters per second (2.0 to 3.0 feet per second) which would correlate to screen approach velocities in the range of about 0.24 to 0.335 mps. (0.8 to 1.1 fps) or higher.

Hydraulic head loss is an important design consideration since it controls the pressure loading on all moving parts of the screen. Thus lowering the head loss across the screen lowers the operating cost of the screen and increases screen life. Head loss increases as the square of the approach velocity, and becomes even greater as debris clogging causes increased turbulence across the screen and reduces the net screen area. The effect of these factors on head loss is shown in Figure III-1. This plot is based on 0.95 cm (3/8") galvanized wire mesh. Screen velocity which is related to screen opening is also important because of its impact on impinged organisms. Physical damage to impinged organisms will increase in proportion to the velocity through the screens.

Many intermittently operated traveling screens are designed to be actuated under a maximum head loss of 1.52 meters (5 ft). Some traveling screens operate continuously at a lower head loss, generally 0.3 to 0.61 meters (1.0 to 2.0 ft). Some traveling screens are rotated once every 4 to 8 hours for 5 to 10 minutes for low head losses, rotated more often for incrementally higher head losses, and run continuously at high speed for the highest head losses. Many powerplant intakes include a pump trip-out to shut off the circulating water pumps automatically when the head loss exceeds 1.52 meters (5 ft) or when the downstream water level drops to some predetermined level. In the absence of such a trip-out provision, head differential across the screen will rapidly increase to the point of screen collapse and possibly damage to the pumps.

Another important design feature of traveling water screens is the rate of screen travel when operating. Screens that are not intended for continuous operation are designed for a single operating speed of 3.05 meters per minute (10 fpm), although speeds as low as 0.61 meters per minute (2 fpm) and as high as 6.1 meters per minute (20 fpm) have been used at particular locations. For continuous screen operation (rarely





LOSS OF HEAD THROUGH TRAVELING  
WATER SCREENS 0.95 cm (3/8") OPENING

FIGURE III-1

used at powerplant intakes) or for use under varying flow conditions, two speed screens are used, 0.76 and 3.05 mps (2.5 and 10 fps) being the usual speeds. Screens are generally operated once per shift and are rotated automatically in response to water level differential across the screen face. The importance of considering operational frequency and screen speed characteristics in minimizing impingement effects will be covered in the subsequent section on operation and maintenance of intake structures.

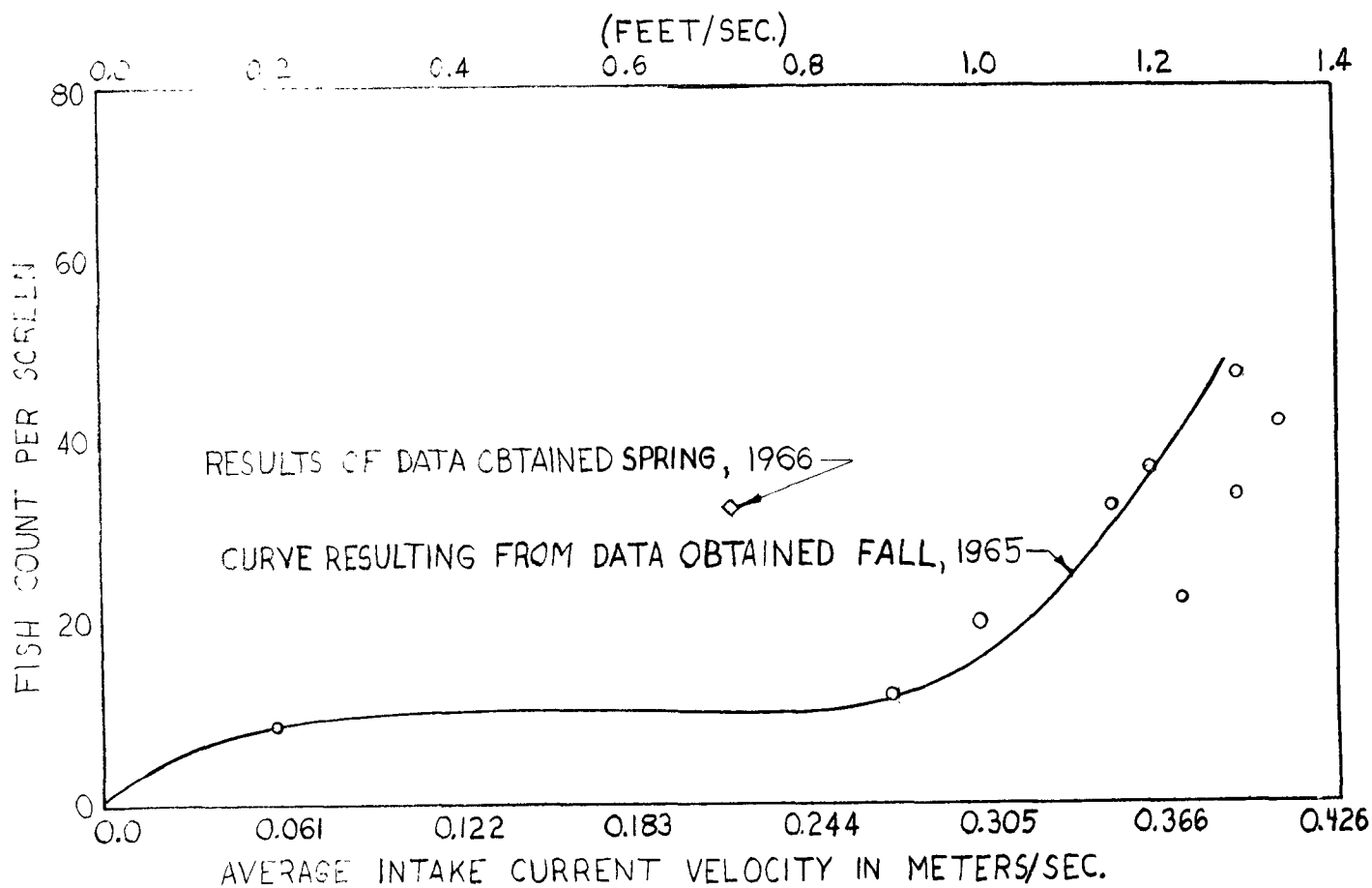
Much of the reported research would indicate that considerably lower approach velocities than the 0.24 to 0.335 mps (0.8 to 1.1 fps) range shown above may be required to protect against impingement of certain species of fish. Table III-1 provides a tabulation of fish swimming capability of various species taken from Reference 21. The table shows that fish swimming ability is a function of both fish size and the ambient water temperature. An inspection of the lower levels of swimming capability within each species shows that approach velocities of considerably less than 0.305 mps (1 fps) may be desirable.

Figure III-2 shows the results of additional studies of the impact of approach velocities on fish impingement. These studies were conducted at a major nuclear plant in the Northeast and reported in Reference 8 G. The involved species were the white perch and striped bass. The figure shows a marked increase in impingement above intake velocities of approximately 0.24 mps (0.8 fps). It is important to note that this study was not done during the critical winter months when fish swimming ability would be at its lowest.

Figure III-3 shows the results of another study which was reported in Reference 24. This figure shows the swimming ability of young salmon. The effects of both size and temperature on swimming ability are significant. Note, however, that the mean cruising speed for all sizes is a relatively low 0.15 mps (0.5 fps) for the colder winter temperatures. Oxygen level, as well as temperature, may be a determining factor in fish-swimming ability. The selection of the design approach velocity should conservatively reflect the degree to which the conditions of the laboratory fish-swimming tests correspond to the conditions of the intake considering that the natural behavior of the fish and their escape response are based upon a complexity of factors. Furthermore, it should be recognized that the approach velocity would influence the ability of fish to avoid the intake screen if there is not already a horizontal current to move them from the intake. A further significant parameter could be the current at the screen itself which would determine the ease of escape of a fish once impinged and also the extent of damage to the fish while impinged.

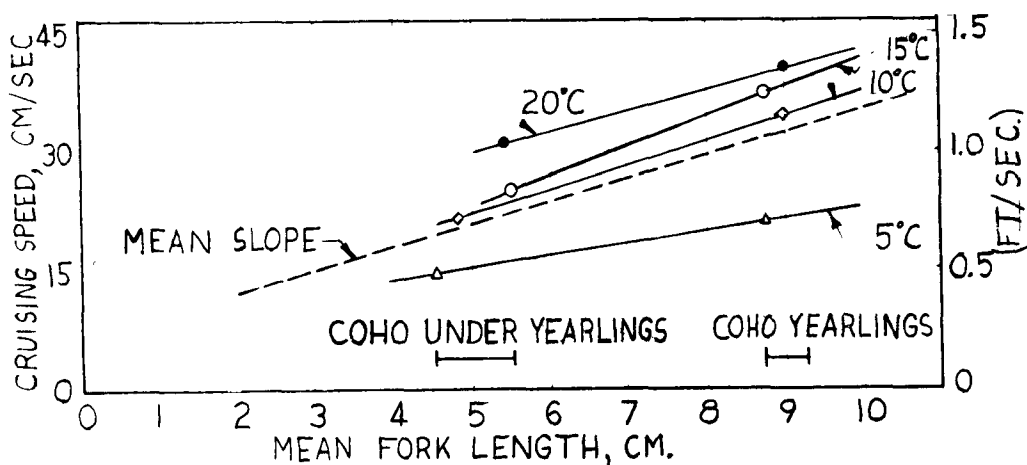
TABLE III-1 FISH MAXIMUM SWIMMING SPEEDS

Fish	Size Range		Water Temp.		Maximum Speed	
	cm	inch	C	F	all - best mps	all - best fps
White Perch	7.9 - 8.4	3.1 - 3.3	5	41	0.16 - 0.25	0.52 - 0.81
	6.1 - 7.1	2.4 - 2.8	10	50	0.19 - 0.23	0.63 - 0.77
	3.0 - 4.3	1.2 - 1.7	24	75	0.12 - 0.30	0.4 - 1.0
	3.3 - 4.7	1.3 - 1.8	27	80	0.15 - 0.30	0.5 - 1.0
	5.1 - 6.8	2.0 - 2.7	27	80	0.22 - 0.40	0.7 - 1.3
	4.1 - 5.1	1.6 - 2.0	32	90	0.22 - 0.40	0.7 - 1.1
	5.1 - 6.8	2.0 - 2.7	32	90	0.28 - 0.43	0.9 - 1.4
Striped Bass	3.0 - 4.8	1.2 - 1.9	24	75	0.18 - 0.33	0.6 - 1.1
	3.0 - 4.8	1.2 - 1.9	27	80	0.18 - 0.40	0.6 - 1.3
	5.1 - 6.4	2.0 - 2.5	27	80	0.33 - 0.43	1.1 - 1.4
Stripped Bass	1.9 - 3.8	0.75- 1.5	-	-	0.28 - 0.43	0.9 - 1.4
	0.25- 7.6	0.1 - 3.0	-	-	0.55 - 0.88	1.8 - 2.9
	7.6 -14.0	3.0 - 5.5	-	-	0.49 - 0.88	1.6 - 2.9
King Salmon	3.0 - 3.8	1.2 - 1.5	-	-	0.28 - 0.52	0.9 - 1.7
	3.0 - 4.8	1.2 - 1.9	-	-	0.15 - 0.46	0.5 - 1.5



INTAKE VELOCITY VS FISH COUNT

FIGURE III-2



MEAN CRUISING SPEED FOR UNDER YEARLINGS AND YEARLING COHO SALMON FOR FOUR LEVEL OF ACCLIMATION

FIGURE III-3

## Effective Screen Length and Uniform Velocities

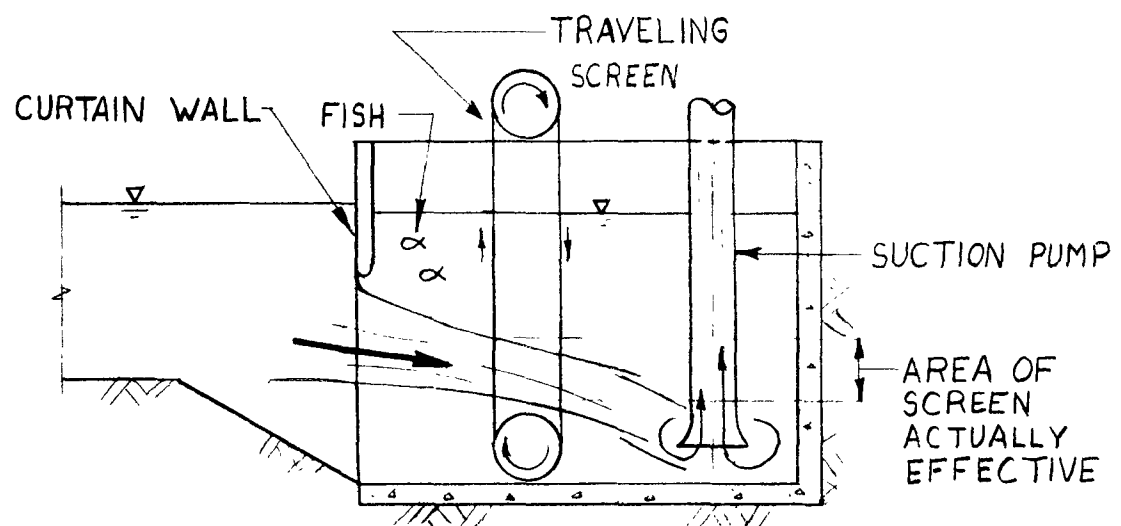
It is important to determine the effective dimension of screen below the water line to be used in calculating the approach velocity. Not all of the screen length below the water line contributes effectively to screening. The effective length of screen is influenced by both the hydraulic design of the intake and by bottom effects related to the screen boot, boot plate, etc. Another important consideration in determining the effective screen length is the effect of upstream protrusions, particularly the effect of curtain walls installed to select intake waters from the top or bottom layers of the water body. The effect of walls on the effective screen area is shown in Figure III-4. The illustration shows a wall installed to limit draft to the lower levels of the water body. The wall limits the flow through the screen area to a relatively narrow band at the bottom of the screen as indicated on the figure. If walls are installed, only the effective screen area should be used to determine the approach velocity. Walls can also be undesirable when they create dead spaces where fish can accumulate and from which they may not be able to escape.

Another important design consideration is the uniformity of velocities across the full face of the screen. An example of poor hydraulic design is shown in Figure III-5. The sketch shows large variations in channel velocities which greatly reduce the effectiveness of the screen. To eliminate these undesirable conditions, the relative locations of pumps, screens and any upstream protrusions should be carefully studied. The standards of the Hydraulic Institute recommend screen to pump distances. However, these are based on pump performance criteria only. Any radical departure from standard intake design should be modeled to establish the actual screen velocity and the extent of any localized variations.

## Selection of Screen Mesh Size

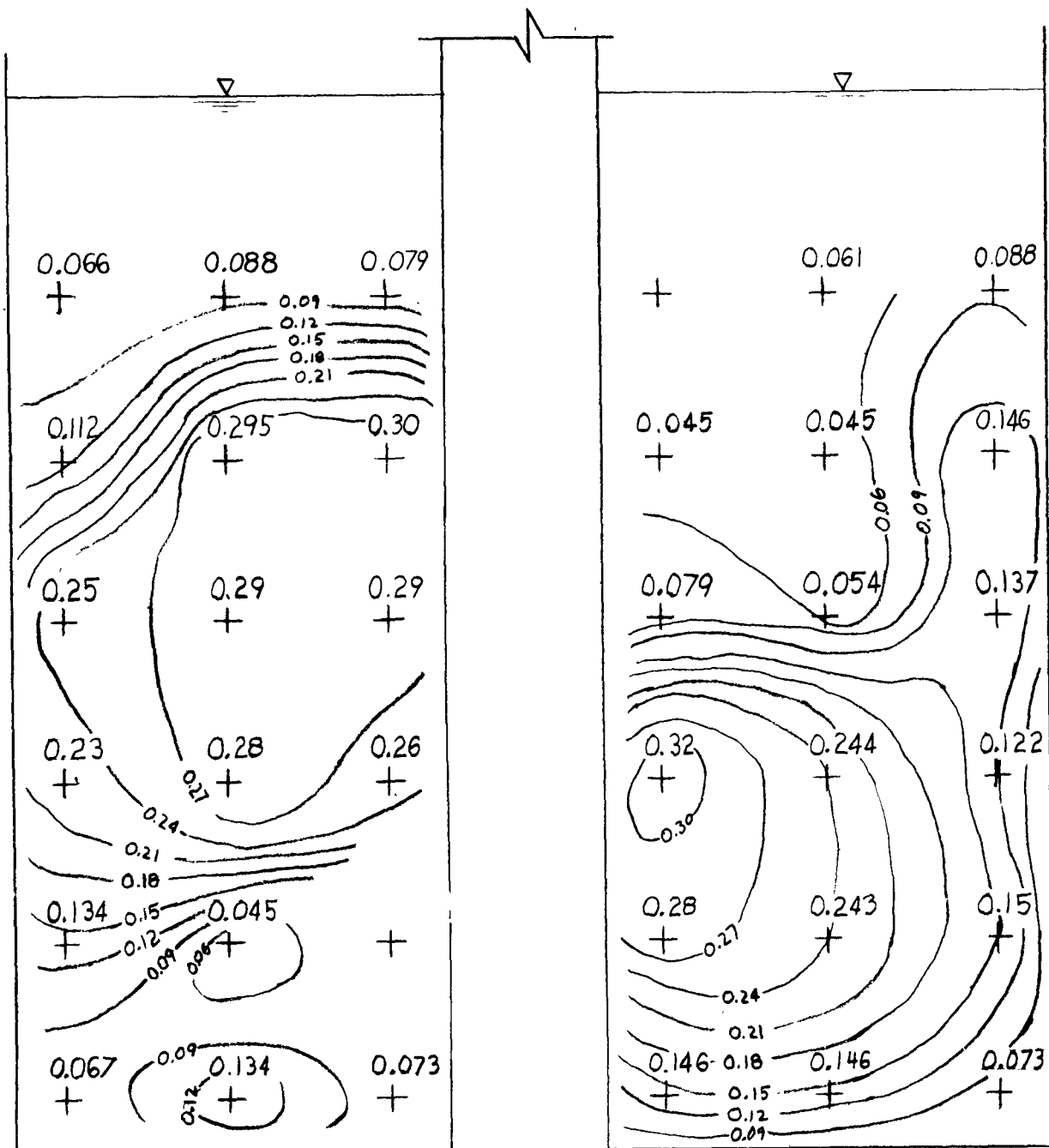
The selection of screen mesh size is generally based on removal of trash that could clog condenser tubes. A generally accepted rule of thumb for selecting the screen mesh size is that the clear openings in the screen should be limited to about half the diameter of the heat exchanger tubes. The powerplant industry has become fairly standardized on a 0.95 cm (3/8") mesh size (equivalent to 1.9 cm (3/4") ID tubes) even though longer condenser tubes are used in many condenser designs.

The effect of screen mesh size on the performance of screens is quite significant as shown in Table III-2. The data were supplied by a leading screen manufacturer. The table shows that the screen efficiencies (ratio of net open areas of the screen to total channel area) decrease rapidly as the mesh size decreases. The table also shows that using alloy metals in place of galvanized metals will increase the screen efficiency as will the use of wider and deeper screens. Alloy metals are generally used to inhibit corrosion in high salinity waters, such as experienced in ocean or estuarine intakes, or in other corrosive waters. PVC screen mesh is also used. The effective area is less than



EFFECTIVE SCREEN AREA

FIGURE III-4



**NOTES:**

1. VELOCITIES SHOWN IN METERS/SEC.
2. MEASUREMENT MADE BETWEEN DEICING LOOP PIPE AND BAR RACKS IN MARCH 1970.
3. MEASUREMENT MADE DURING THROTTLED CIRCULATING WATER FLOW, AT 30% OPEN.

**UNDESIRABLE INTAKE WELL VELOCITY PROFILES**

**FIGURE III-5**

TABLE III-2

TRAVELING WATER SCREEN EFFECIENCIES

Clear Opening Size		Wire Selection				Screen Basket Width Meter (Ft)													
cm.	in.	Material	Diameter		W&M	0.61	0.91	1.22	1.52	1.82	2.13	2.44	2.74	3.05	3.35	3.64	3.96	4.26	
			cm.	in.	Ga.	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
0.32	1/8	Alloy	0.12	.047	18	.322	.431	.436	.438	.440	.441	.442	.442	.443	.444	.444	.445	.445	
		Galv.	0.16	.063	16	.334	.361	.365	.367	.368	.369	.370	.370	.371	.371	.372	.372	.373	
0.48	3/16	Alloy	0.12	.047	18	.511	.522	.527	.530	.533	.534	.534	.525	.536	.537	.537	.538	.539	
		Galv.	0.16	.063	16	.445	.457	.462	.465	.467	.468	.468	.469	.470	.471	.471	.472	.473	
0.63	1/4	Alloy	0.12	.063	16	.510	.451	.526	.530	.532	.533	.534	.535	.535	.536	.536	.537	.538	
		Galv.	0.20	.080	14	.459	.469	.474	.476	.478	.479	.480	.481	.482	.483	.483	.484	.485	
0.95	3/8	Alloy	0.20	.080	14	.543	.555	.560	.564	.566	.567	.568	.569	.570	.571	.571	.572	.573	
		Galv.	0.27	.105	12	.488	.498	.503	.506	.508	.509	.510	.511	.512	.513	.513	.514	.515	
1.28	1/2	Alloy	0.27	.105	12	.546	.558	.566	.567	.569	.570	.571	.572	.573	.574	.575	.575	.576	
		Galv.	0.34	.135	10	.496	.506	.512	.515	.517	.518	.518	.519	.520	.521	.521	.522	.523	
1.58	5/8	Alloy	0.27	.105	12	.587	.600	.606	.609	.612	.613	.614	.615	.616	.617	.618	.618	.619	
		Galv.	0.34	.135	10	.541	.552	.558	.561	.563	.565	.565	.566	.567	.568	.568	.569	.570	

Alloy wire: Copper, stainless, monel, etc. - greater corrosion resistance permits use of smaller diameter wire, improves efficiencies.



for wire mesh for a given screen size. Thus if mesh velocity is a limiting criteria (rather than screen approach velocity) the total screen area must be greater.

Some work has been done toward establishing screen mesh size as a function of the size of fish to be screened. Reference 24 reports the following empirically derived relationships:

$$M = 0.04 (L-1.35) F; 5 \leq F \leq 6.5$$

$$M = 0.03 (L-0.85) F; 6.5 \leq F \leq 8.0$$

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

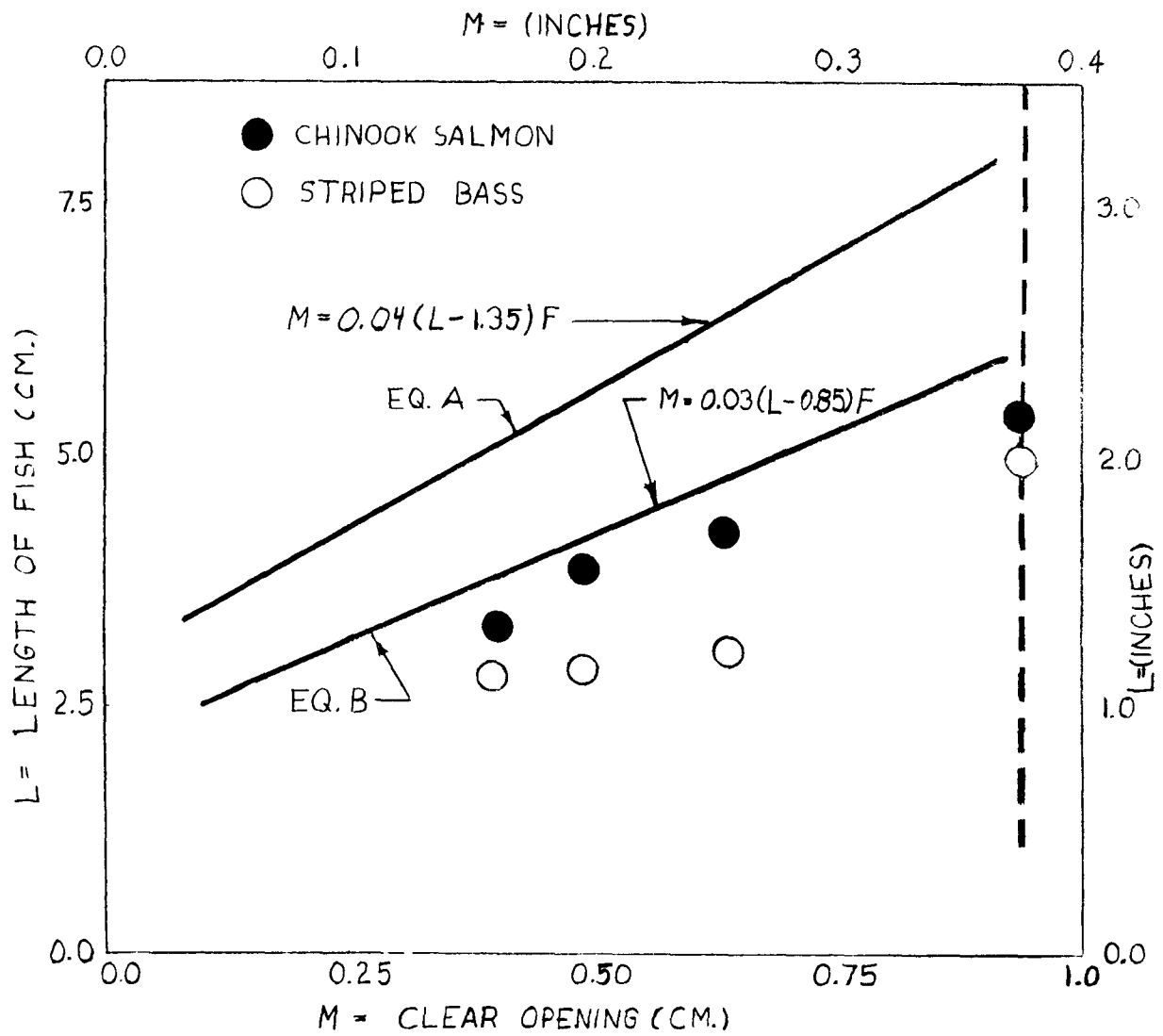
Some results of these investigations are noted in Figure III-6 along with data from earlier experiments conducted by Kerr. <sup>24</sup> These curves were developed on the basis of relatively few species and numbers of fish and therefore a specific recommendation based on these relationships cannot be made. However, the work does establish a framework for consideration of additional data as it becomes available.

### Behavioral Screening Systems

#### General

A behavioral screening system (behavioral barrier) employs one of several stimuli to cause fish to move in a desired manner, and, in so doing, avoid entrapment at an intake structure. The various types of stimuli tested have included: light, sound, electric fields, air bubble currents, and several types of stream flow direction and velocity change mechanisms. Most systems have been designed to repel fish away from a physical barrier and relatively little work has been done on systems designed to attract fish away from the danger zones.

Behavioral screening systems rely on the swimming ability of the various species to avoid the artificial stimuli. Swimming ability is related to fish size within a species and is quite variable between different species of fish. Swimming ability is significantly affected by temperature with markedly reduced swimming ability demonstrated in the colder winter months. Most behavioral systems become ineffective upon the arrival of a higher priority stimulus, such as a predator. For



SCREEN MESH SIZE SELECTION  
(based on length of fish)  
FIGURE III-6

these reasons, most behavioral systems have not demonstrated consistent high level performance.

In addition, all behavioral systems require a passageway to allow the fish to move away from the stimulus. The location and configuration of the required passageway is often more difficult to develop than the behavioral barrier itself. The following discussion traces the development of several of the behavioral screens in an attempt to establish their applicability in intake design.

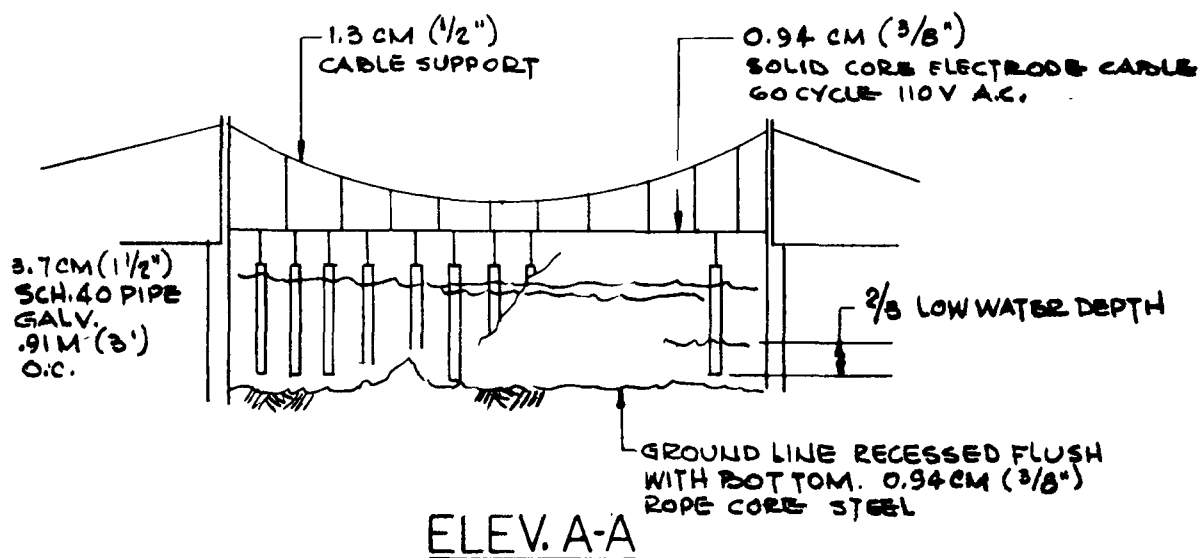
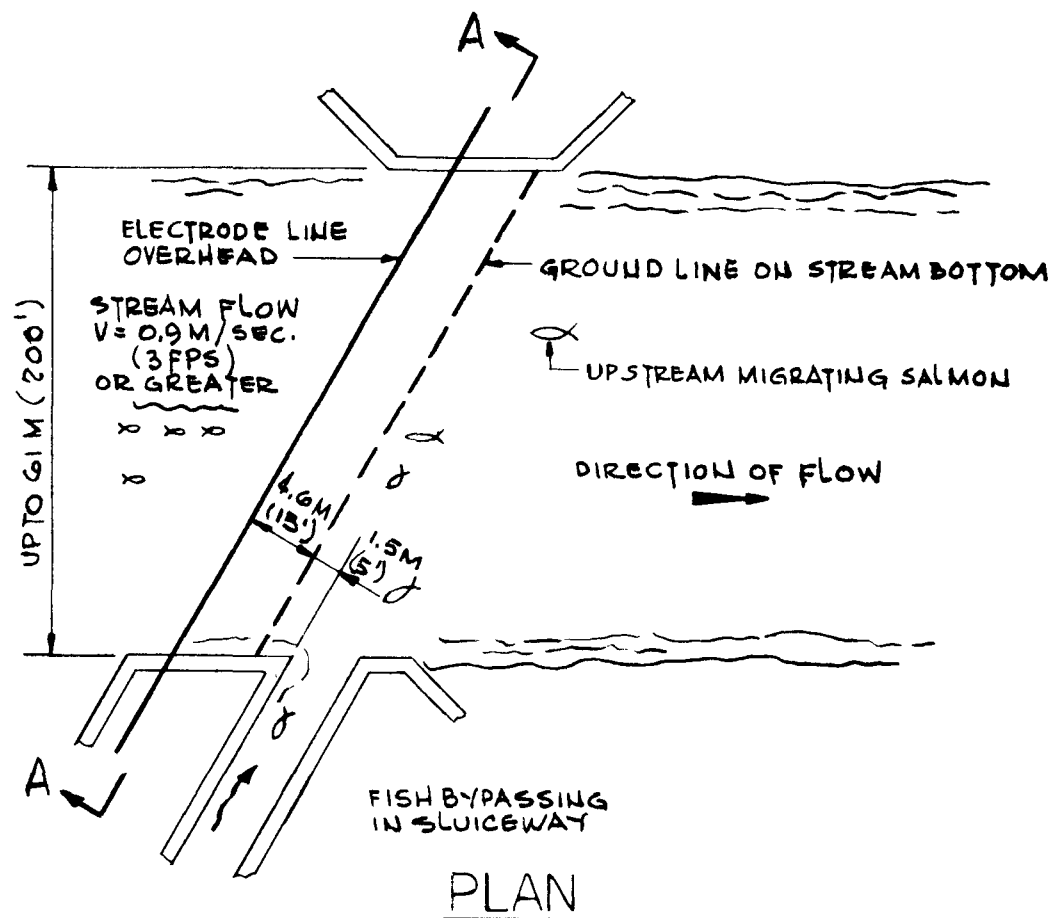
### Electric Screens

The basis of the electric screen approach is described in Reference 18 and is shown in Figure III-7. Immersed electrodes and a ground wire are used to set up an electric field which repels fish swimming into it. The important design parameters in electric screening are the spacing of electrodes, the separation between rows of electrodes, the voltage applied to the system, the pulse frequency, the pulse duration, and the electrical conductivity of the water. Typical design parameters for both test systems and full-scale systems are shown in Table III-3. The data for this table were taken from Reference 13. Most of the test systems established by the former U. S. Fish and Wildlife Service (now the U. S. Bureau of Sportfish and Wildlife) were applied to repel (and divert) upstream migrating fish (adult fish). In most waters, but particularly in brine or salt waters, conductivity can vary widely with stream flows, tidal changes and storms, thus creating a need for proper adjustment of the electric screens to maintain the electric potentials desired.

Typically, salmon respond to the screen in the following manner. They swim upstream against the flow, enter the electric field and jump violently back away from it, retreating several hundred feet downstream. After several attempts and shocks they approach more slowly and follow the angled electric field to the safe passageway provided. If they are immediately stunned, the downstream current will carry them safely away from the screen.

The electric screen has the advantage of flexibility and may be applied intermittently during time of need for intake protection. The major disadvantages of the electric screening system are as follows:

- . Cannot be used to screen downstream migrants.
- . Cannot be used to screen a mixture of sizes and species because of different reactions that are size and species related.
- . Cannot be used in estuarine or ocean waters because of high electrical losses.



## TYPICAL ELECTRIC FISH FENCE

FIGURE. III-7

TABLE III-3  
ELECTRIC SCREEN APPLICATIONS  
SUMMARY OF DESIGN DATA

Location	Specie	Barrier Description	Source Voltage (Volts)	Pulse Frequency (Pulses/sec)	Pulse Duration (Milli/sec)	Performance
*Pacific Northwest	Squawfish	2 rows 0.46m (18") apart	60	2	10-30	good
*Pacific Northwest	Salmon fingerlings	5.0cm (2") $\phi$ electrodes in parallel rows @ 40° angle to flow	NA	8	40	68% diverted
*Pacific Northwest	Salmon fingerlings	5.0cm (2") $\phi$ tubular aluminum electrodes @ 0.51m (20") spacing in parallel rows	210	3-4	20-40	82% diverted
*Idaho	Squawfish	NA	140	10	50	80% diverted
San Diego (water intake)	Mixed	NA	500-900	2-3	10	effective for large fish
Indiana (Power-plant #1809)	Perch	2 parallel rows 0.45m (18") apart 0.30m (12") spacing between electrodes	300-600	1-5	NA	effective
N. Y. (Power-plant #3608)	Fresh water game fish	3.2cm (1¼") $\phi$ electrodes @0.3m (12") spacing in rows spaced 0.91m (3') apart	120	Continuous	Continuous	effective

\* Test systems

- . Can be dangerous to both humans and animals because of the high voltages used.

The Fish and Wildlife Service terminated its research on electric screens in 1965. Over fifteen years of concentrated research had failed to solve many of the major problems of electric screening systems. Several utilities have investigated the problem in depth and some research is still being conducted, but not much success has been shown to date for downstream-migrant fish. In summary, electric screens, while not generally successful, may work in some situations.

#### Air Bubble Screens

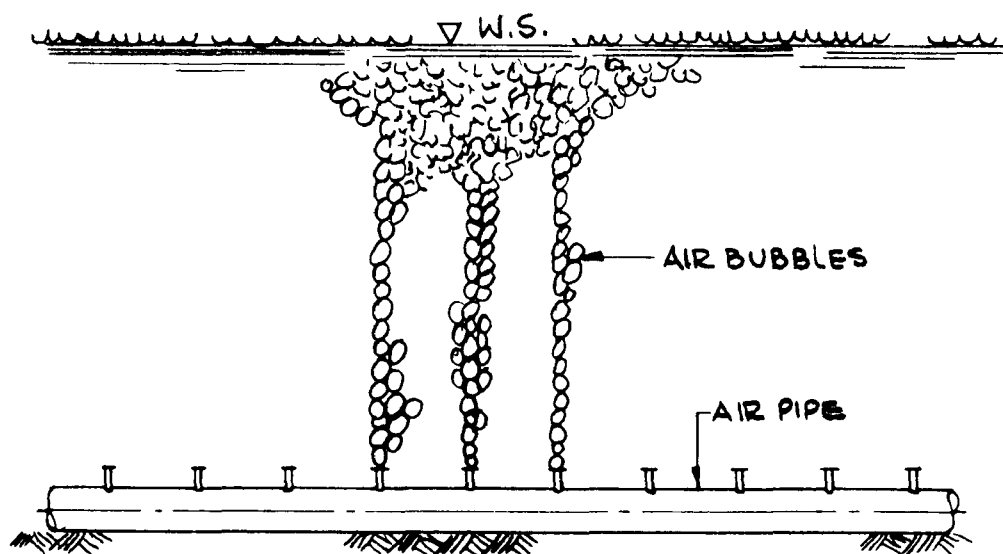
The fish response employed by an air bubble screen is avoidance of a physical barrier. In its simplest form, the bubble barrier consists of an air header with equally spaced jets arranged to provide a continuous curtain of air bubbles over the entire stream cross section, as shown on Figure III-8.

Historically it was also felt that the sensory mechanism involved in utilizing the air bubble screen was entirely visual. This led to the conclusion, long held, that the screen was not useful at night. More recent findings of experiments conducted by a leading manufacturer, Reference 30, tend to refute this belief. Design and performance data at two existing power stations are also presented. In one case the screen was successful and in the other unsuccessful.

The laboratory tests referred to were conducted at the Edenton National Fish Hatchery in North Carolina. The experiments were conducted with striped bass and shad, 80mm to 250mm in length.

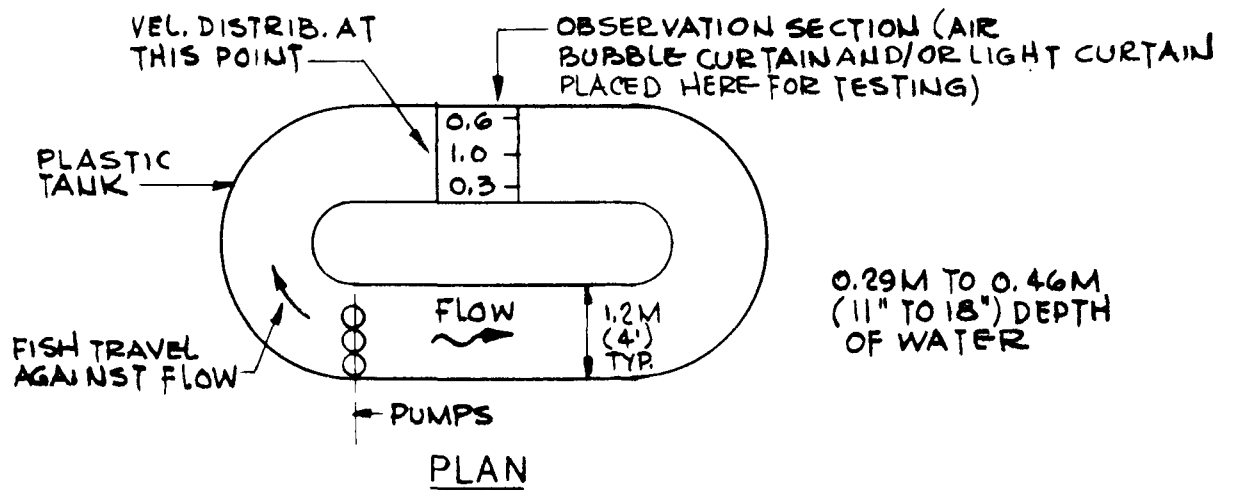
The test channel used is shown in Figure III-9. The results of the tests are reported in Reference 30 and are summarized as follows.

- . When the air bubble curtain was placed entirely across the 1.2m (4') channel, the fish would not pass through in any of the tests, even when attempts were made to chase them through the curtain.
- . Temperature does influence the performance of the barrier. The tests were conducted at 10°C, 4.5°C and 0.8°C (50°F, 40°F, and 33.5°F). The bubble barrier was a complete success at 10°C (50°F) and at 4.5°C (40°F). At 0.8°C (33.5°F) the fish were lethargic and simply drifted through the barrier with the current. This limitation would be shared with all systems which rely on swimming ability of fish to escape an intake.
- . This particular bubble barrier appeared to be as successful in complete darkness as well as in daylight. This tends to refute the



AIR BUBBLE SCREEN  
TO DIVERT FISH FROM WATER INTAKE

FIGURE III-8



CHANNEL TO TEST EFFECTIVENESS OF AIR BUBBLE SCREEN  
AT NORTH CAROLINA FISH HATCHERY

FIGURE III-9



long held conclusion that these systems will not work at night. It also indicates that sensory mechanisms other than visual are involved, and that future work is required to define fish response to this type of situation.

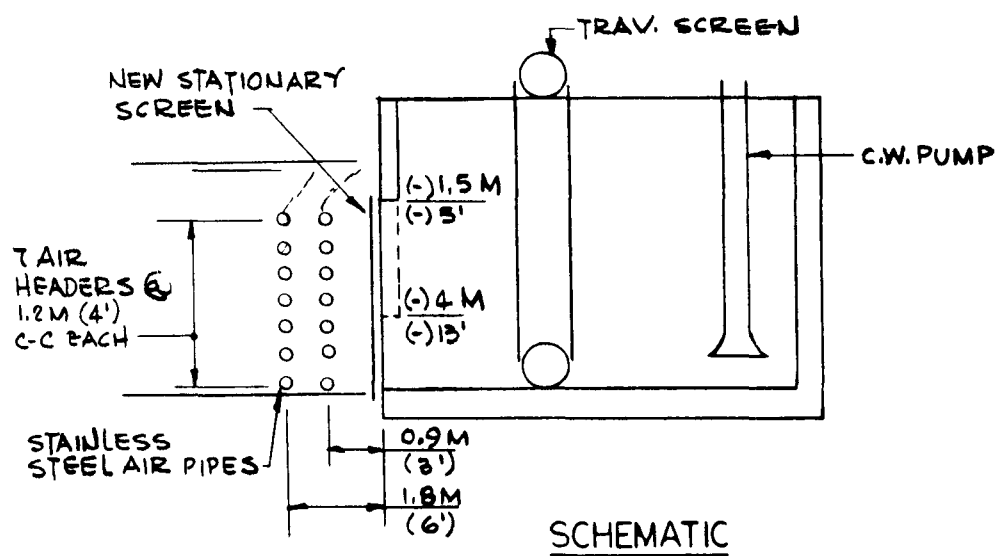
- . The air was injected through 0.08 cm (1/32") round holes at 2.5 cm (1") spacing. At 5.0 cm (2") to 7.5 cm (3") spacing the fish would pass between the rising bubble columns.
- . When the bubble system was placed 5.0 cm (2") off the floor, fish would not pass under it. When placed any further off the floor of the channel, the fish would pass unimpeded under the curtain.

A successful application of an air bubble screen was reported in Reference 13. The system was installed at a powerplant intake (plant no. 5521) on Lake Michigan in Wisconsin. The principal fish species involved was the Alewife, a variety of herring which is a heavily schooling fish having a length between 15 and 20 cm (6" and 8"). The plant has an average cooling water flow of some 18.3 m<sup>3</sup>/sec (290,000 gpm). The air bubble barrier extends across the intake channel, well in front of the intake structure in about 3.6 to 4.0m (12' - 13') of water. The air bubble system consists of 2.5 cm (1") diameter PVC lines with holes drilled on 10 cm (4") centers. The total air flow is approximately 0.047 m<sup>3</sup>/sec (100 cfm) at 413.7 KN/m<sup>2</sup> (60 psi). The air is supplied by a conventional compressor drawing 15,000 to 19,000 W (20 - 25 hp). The optimum air flow was measured at 0.01 m<sup>3</sup>/min (0.36 cfm) per 0.3 m (1 foot) of air header at 413.70 KN/m<sup>2</sup> (60 psi).

Prior to the installation of the air bubble screen, there had been several shutdowns of the plant caused by schools of Alewives jamming the screens and shutting off the flow of cooling water. Since the installation of the screen, there has been only one or two shutdowns of this type during more than four years of operation. The major purpose of the air bubble screen is to repel schools of fish rather than to stop all individuals. The operation of the bubble system at this plant has been equally successful at night as in daylight. The operation of this system was considered so successful that another utility located on Lake Michigan is installing a similar system at a new nuclear station. (plant no. 5519)

The performance of a similar system installed at a major nuclear station in the Northeast (plant no. 3608) was exactly opposite of that described above. The species involved at this plant were the striped bass and white perch. When the plant first went on line, there was a serious loss of larger fish on the screens. A series of modifications were made in an attempt to reduce the loss. The modifications are shown in Figure III-10 and consisted of the following:

- . Removal of eight feet of the original curtain wall to reduce the intake velocity. Average velocity over the face of the screen



BUBBLE SCREEN INSTALLATION AT PLANT NO. 3608  
TO REPEL FISH FROM WATER INTAKE

FIGURE III-10

before the modification was about 0.30 m/s (1 fps). After making the change, the summer average velocity was 0.18 m/sec (0.60 fps), and the winter average velocity was 0.048 m/sec (0.15 fps).

- . The installation of a fixed screen mounted flush with the front face of the intake to allow the fish to swim to the right or left to escape entrapment. This modification also eliminated the entrapment zone between the face of the screen and the existing vertical traveling screen.
- . The installation of an air bubble system in front of one of the four bays of the intake. The bubble system consisted of two vertical rows of horizontal bubbler pipes. The first row was located three feet in front of the intake and the second row was located six feet in front of the intake. Each row of bubbler pipes has seven horizontal pipes in a four foot center to center spacing. Air was discharged through 0.08 cm (1/32 inch) opening at 1.3 cm (0.5 inch) center to center spacing. The first tests were run with 0.424 m<sup>3</sup>/s (900 cfm) of air which was far too large a quantity. The surface of the water in front of the intake rose by as much as one foot in violent churning action. The entrained air caused vibration problems in the pumps. The quantity of air was subsequently reduced to 0.189 m<sup>3</sup>/s (400 cfm) which is the design value used in modifying all bays. The total cost for modifying both intakes at this plant in the manner described was approximately \$1,000,000.

The results of these modifications are as follows:

- . The intakes now impinge fish of a smaller size (50 to 100 mm) rather than the larger sizes that were entrapped before the modification.
- . The effect of the air apparently was to reduce the number of fish entering the bay equipped with the bubble system, but the number of fish entering the remaining three bays increased.
- . During July 1972 tests, the test engineers were able to discern no improvements in fish entrapment during the daytime; at night the fish being trapped in the bay equipped with the bubble system appeared to be significantly greater than in the bays with no bubbler.
- . The bubble barrier did appear to be effective in controlling ice in front of the intake during freezing conditions. This fact makes the bubble system attractive as a possible replacement for the hot water recirculation systems which are currently being used to control ice at many existing installations. The problems associated with hot water recirculation have been discussed in an earlier section.

In summary, the air bubble system may have some application at certain types of intakes. The system appears to be most effective in repelling

schooling fish. However, the mechanism of bubble screening is not sufficiently well understood to recommend its adoption generally.

### Behavioral Systems Employing Changes in Flow Direction

The propensity of most species of fish to avoid abrupt changes in flow direction and velocity has been demonstrated on several occasions. This ability of fish to avoid horizontal change in direction and velocity is the principle on which the louver fish diverting system is based. On the other hand, fish are generally insensitive to changes in vertical flow characteristics. This indifference of most species to vertical changes in flow regimen is the principle upon which the "fish cap" intake is based.

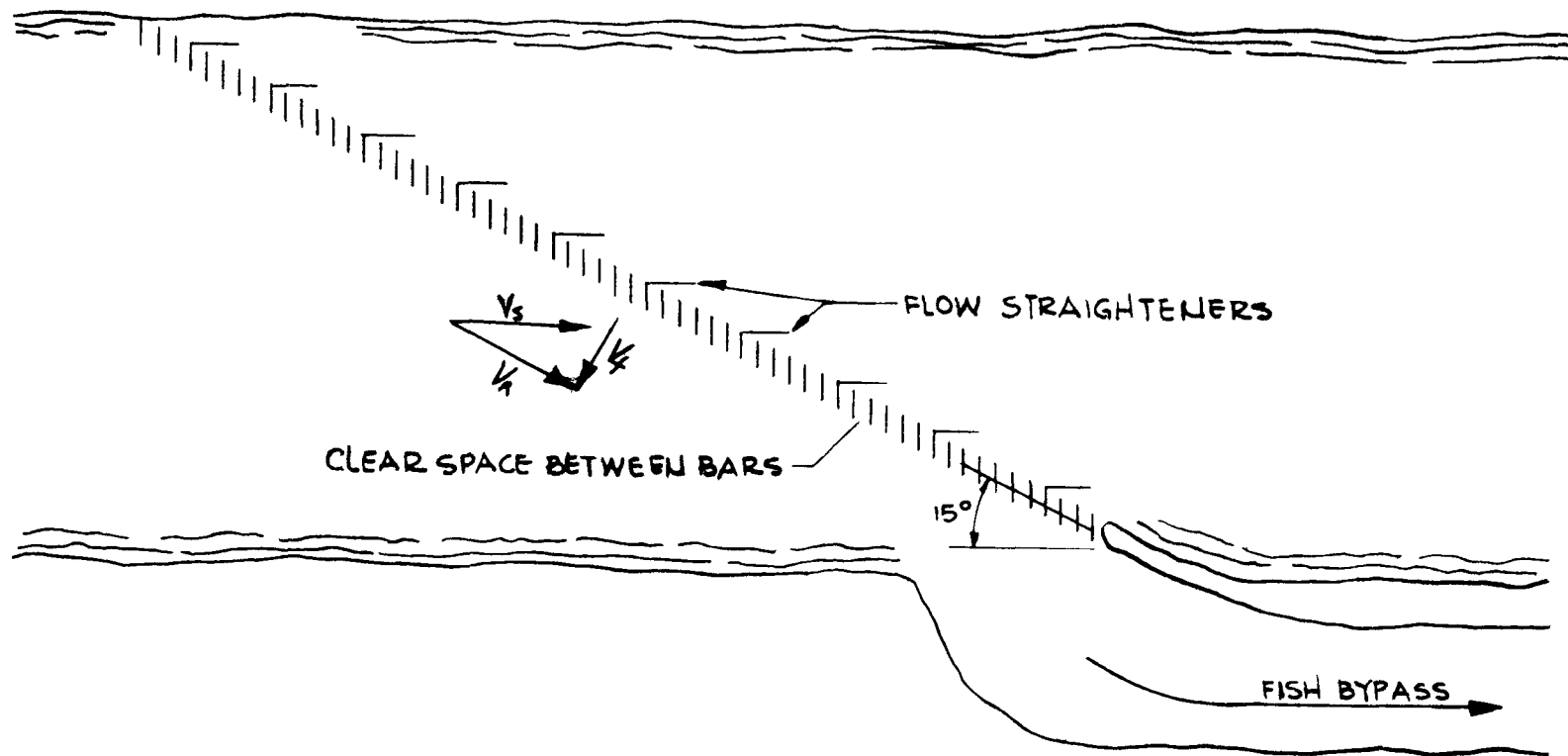
#### Louver Barrier

The principle of the louver diverter is illustrated in Figure III-11. The individual louver panels are placed at an angle of  $90^\circ$  to the direction of flow and are followed by flow straighteners. The abrupt change in velocity and direction form a barrier through which the fish will not willingly pass if an escape route is provided. The stream velocity is shown in the figure as  $V_s$ . Upon sensing the barrier the fish will orient himself perpendicular to the barrier and attempt to swim away at a velocity  $V_f$ . The resultant velocity  $V_R$  carries the fish downstream roughly parallel to the barrier to the bypass located at the downstream end of the barrier. The controlling parameters in the design of the louver system are the channel velocity  $V_s$ , the angle of inclination of the barrier with respect to the channel flow ( $10^\circ$  to  $15^\circ$  recommended) and the spacing between louver panels which is related to the fish size.

Most of the current performance data on the louver design have come from tests of two prototype installations at an irrigation intake operated by the California Department of Fish and Game in the Sacramento-San Joachin delta of California. <sup>24</sup> The Delta intake is shown on Figure III-12. The facility is designed for a flow of  $170 \text{ m}^3/\text{s}$  (6,000 cfs), and was tested at approach velocities to the louver of 0.46 to 1.08 m/s (1.5 - 3.5 fps) with bypass velocities of 1.2 to 1.6 times the approach velocity.

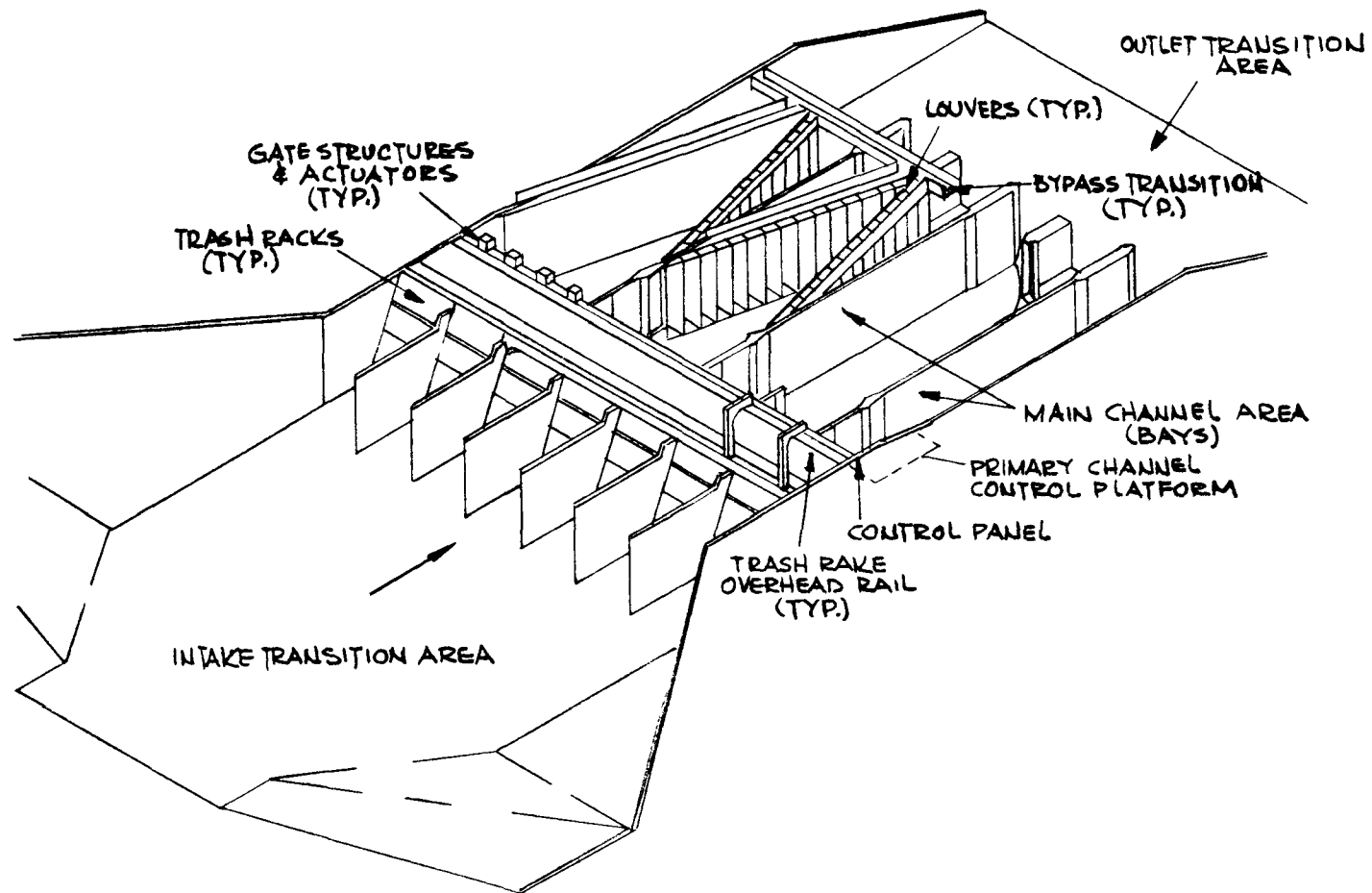
The efficiency of the louver system drops severely with increase in velocity through the louvers. For velocities of 0.46 to 0.61 m/s (1.5 - 2 fps), efficiency was 61% with 15 mm fish and 95% with 40 mm fish. When the velocity was increased to 1.08 m/s (3.5 fps), efficiency was 35% for 15 mm (0.6 in) fish and 70% for 40 mm (1.6 in) fish. The following conclusions were reached as a result of these tests.

- . Efficiency increases markedly with fish size.



LOUVER DIVERTER-SCHEMATIC

FIGURE III-11



DELTA FISH FACILITY PRIMARY CHANNEL SYSTEM

FIGURE III-12

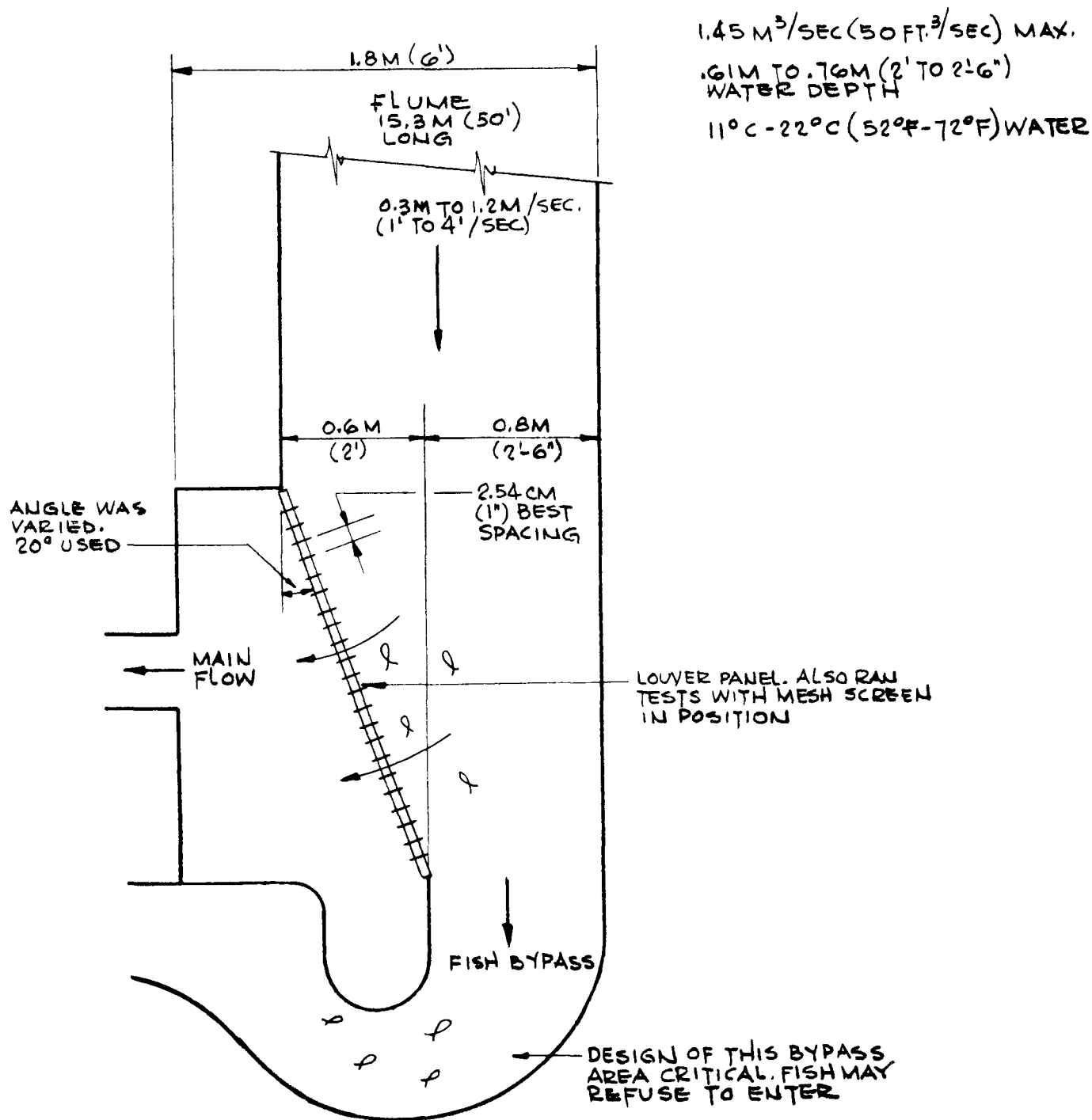
- . Efficiency increases with lower channel velocities.
- . Addition of a center wall improves the efficiency, giving the fish a wall to swim along if he wishes.
- . Very careful design is required to take account of the many variables, such as bypass ratios, guide walls, approach velocity, louver angle, etc. Each application would most likely require extensive model testing to define optimum design parameters, for the species of concern at the temperature anticipated for each size to be dealt with.
- . Individual louver misalignment did not have much effect. In fact, efficiency even improved with a deviation from the exact alignment.
- . Swimming capacity is length related.

The major disadvantages of the fixed louver system are the following:

- . The shallow angle of louvers with respect to the channel flow requires a rather long line of louvers which will increase the cost of the intake.
- . The louver system does not remove trash. A second set of conventional screens are required downstream of the louvers for trash removal. The performance of the louver may be adversely affected in streams with a heavy trash load.
- . A rather complex fish handling system is required to safely return fish to the water source.
- . Water level changes and flow variations must be kept small to permit maintenance of the required flow velocity.

In an attempt to overcome some of these limitations, additional studies were conducted at a major power station in Southern California (plant no. 0618). Of the major fish types studied, the anchovy of about 130 mm (5.2 in) in length was the most delicate. Another sensitive fish (200 mm (8.0 in) in length) was the queen fish. The strongest and toughest fish included white perch and croakers. A sketch of the test flume is shown in Figure III-13 and results reported in Reference 32 were as follows:

- . The louver efficiency increased with flow up to 0.61 m/s (2 fps) which was considered optimum.
- . The bypass design is very important. The optimum bypass velocity was determined to be 1.08 m/s (3.5 fps), a ratio of 1:1.5 with channel velocity.



PLAN

TEST FLUME AT PLANT NO. 0618

FIGURE III-13



- . A 2.5 cm (1") louver spacing gave good results. Increasing the louver spacing to 4.5 cm (1.75") reduced efficiency significantly.
- . The louvers should have a 20° or less angle with flow direction. Increasing this angle markedly reduced louver efficiency.
- . The louver system worked as well at night as during the daytime.

The experience gained in these tests is being used to design a new intake for a major nuclear installation (plant no. 0629). A sketch of this intake is shown in Figure III-14.

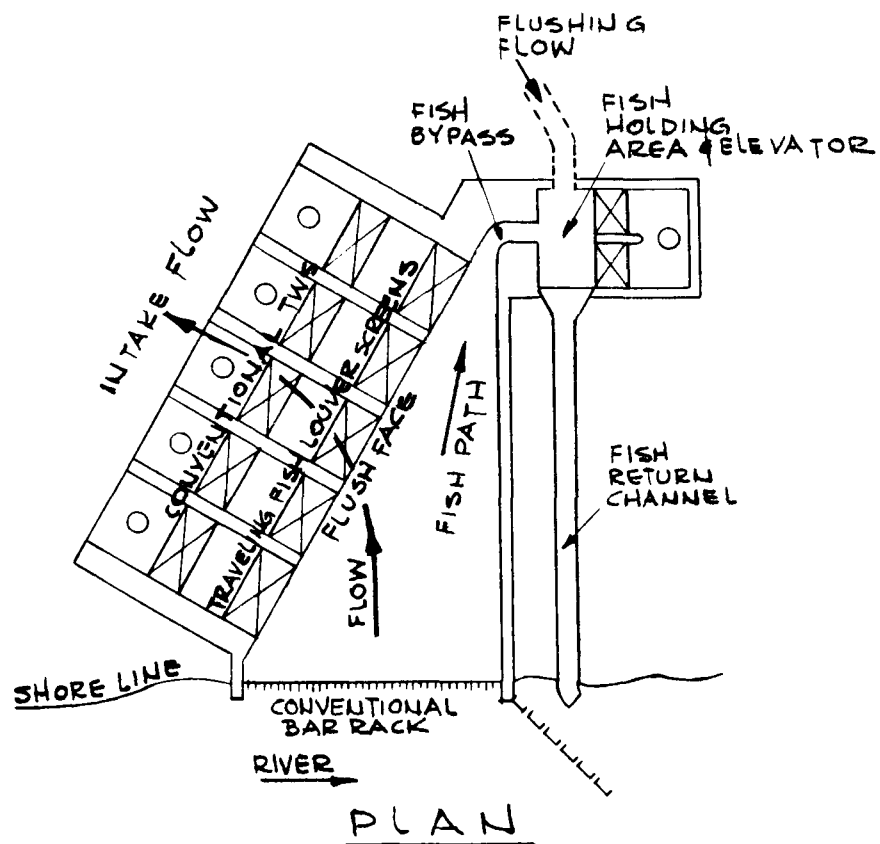
The intake employs the louver principle described above. The louvers are mounted on frames similar to the conventional water screens. Instead of the fixed louver system, the louvers are rotated in a manner similar to a traveling bar screen used in municipal wastewater treatment. A water jet system washes any material from the louvers as it passes over a standard trash trough. Behind these vertically traveling louvers is a standard vertical traveling fine screen similar to that used at most powerplant intakes. The louvered frames are so mounted that the front of the frame is flush with the walls supporting the entire mechanism so that fish may move unimpeded down the face of the louver vanes. The louver vanes serve as trash racks.

A very important element of the intake is the guide vane system upstream of the louver faces. These vanes insure that the flow does not turn before it reaches the louver.

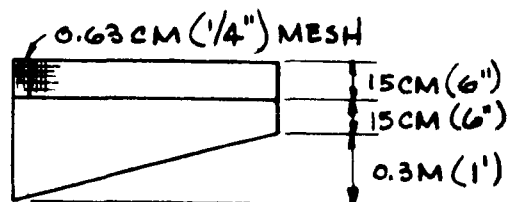
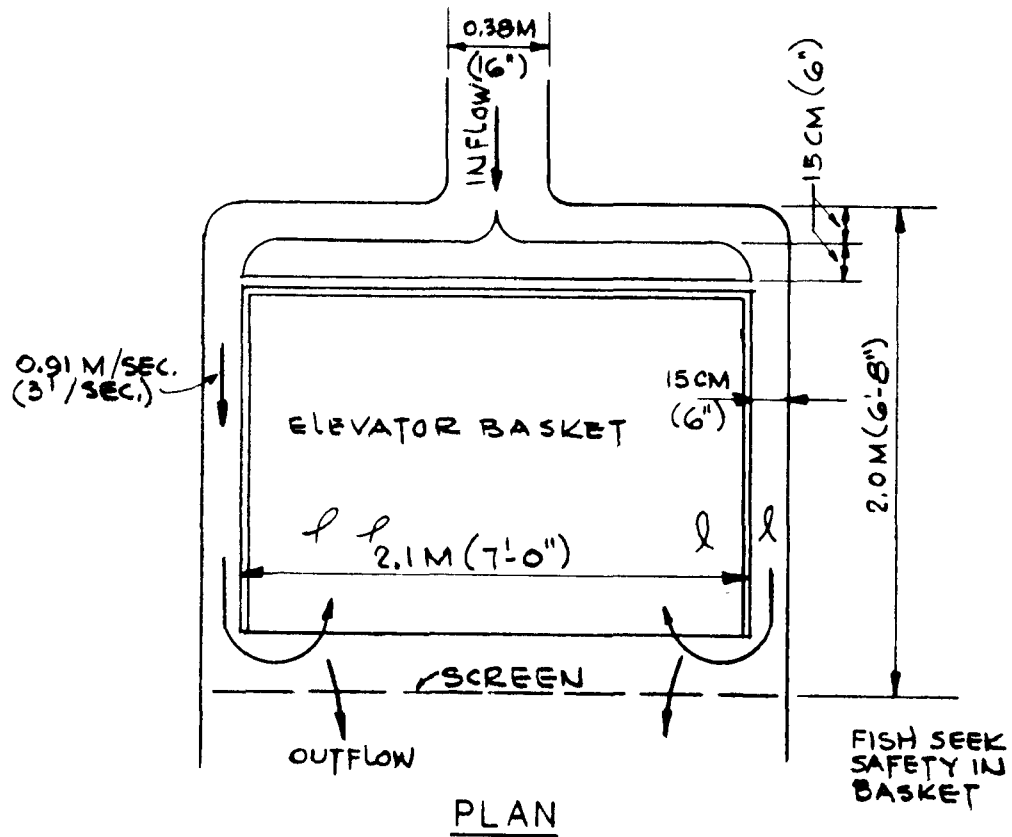
Fish moving down the face of the louvers enter a bypass. The bypass itself has a unique fish lifting system, Figure III-15, which lifts the fish up several feet, where they can be dropped into a channel for their return to the sea. Supplementary water is also pumped into this channel.

A very substantial amount of model testing was required to develop this intake. The model work included the test flume, the test set up for the lifting basket and all its flow mechanisms, the detailed intake structure itself and the detailed bypass system.

While it will be several years before performance data on this intake will be available, its successful operation would represent a large step forward in intake design. The louver principle has been demonstrated both in model and in large prototypes and should have a significant impact on future design of intakes. The cost of installing this type of intake will be substantially higher than those of a conventional intake.



INTAKE STRUCTURE - PLANT NO. 0629,  
TO DIVERT FISH BY LOUVER SCREENS AND RETURN THEM DOWNSTREAM  
FIGURE III-14



BOTTOM DESIGNED TO OPEN UP WHEN ELEVATOR DESCENDS. PICKS UP FISH MILLING AROUND AREA

FISH ELEVATOR FOR FISH BYPASS - PLANT NO. 0629

FIGURE III-15

## "Velocity Cap" Intakes

The operation of a velocity cap is shown in Figure III-16. It is based on laboratory studies which show that fish do not respond to vertical changes in direction, whereas they show a marked ability to avoid horizontal changes in velocity. By placing a cover over the top of an intake, the flow pattern entering the pipe is changed from vertical to horizontal. As shown in the illustration, the cap has a rim around its edge to prevent water sweeping around the edge and to provide more complete horizontal flow at the entrance.

Velocity caps have been used since 1958, when one was installed at a ocean-sited power station in California (plant no. 0623). Several other plants in Southern California have adopted the concept since then. One problem with the utilization of the velocity cap is that it is difficult to inspect, since it is under water. Frequently, the only sign that the cap is not working properly is an increase in fish on the screens.

## Other Behavioral Systems

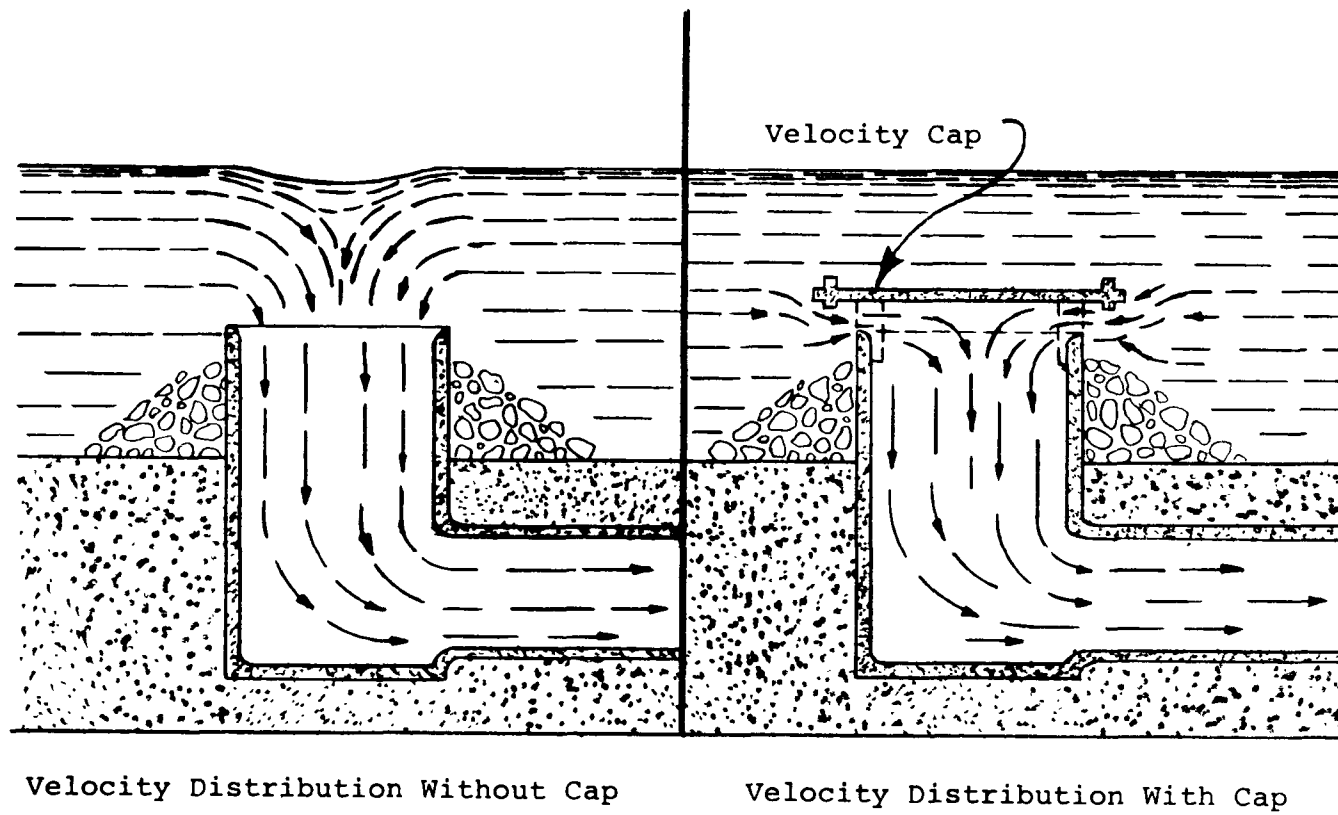
Other behavioral mechanisms have been experimented with in conjunction with fish diversion. These include sound barriers, light barriers and several types of fish attraction systems. The types of experiments conducted in regard to these systems have generally been more crude than those discussed earlier. Consequently, the results are generally less conclusive indicating that considerably more formal investigation is required before these systems can be fully evaluated.

### Light Barriers

The same test flume shown in Figure III-13 and discussed in Reference 30 was also used to test a light barrier system. Upon approaching a light barrier placed across the full width of the flume for the first time during the test, the fish would mill around for 3 to 5 minutes before passing through. On subsequent trips around the flume, they would hesitate less and less until the time for each circuit was reduced to that which existed without the light source. This indicates that the fish rapidly become acclimated to light which renders such a barrier useless. Other experiments with the same apparatus using light in conjunction with a bubble curtain were also unsuccessful. It was concluded from these tests that light had no effect from a practical standpoint. As far as could be determined, there are no existing intakes where a light barrier is functioning successfully. Light also has the adverse effect of attracting fish under certain circumstances and has resulted in the complete shutdown of plants.

### Sound Barriers

Fish have been shown to respond to sound of high intensities and low frequencies, but become accustomed to constant sound levels. It has



OPERATION OF THE VELOCITY CAP

FIGURE III-16

been shown that minnows respond to frequencies up to 6,000 Hz and catfish to 13,000 Hz or only slightly less than the 15,000 Hz band considered normal for humans. Other fish respond to frequencies up to only 1000-2000 Hz and are less sensitive to sound intensity. This high variability to sound among different species is a major drawback to this type of system.

There have been many attempts to direct fish around intake structures using sound barriers. A recent installation at a major nuclear station in Virginia (plant no. 5111) employed rock and roll music broadcast at relatively high intensities under water. This type of music was selected because of its multi-frequency nature and because it is non-repetitive. The conclusion was that the system appeared to be at least partially effective. However, due to the many species and sizes involved and the diversity of responses, it was decided to install a mechanical system to reduce the fish entrapment problem. The sound system will continue in use while the mechanical system is being installed. A discussion of the proposed mechanical system is contained in another section of this report.

#### Applicability of Behavioral Screening System

In summary, none of the behavioral systems have demonstrated consistently high efficiencies in diverting fish away from intake structures. The systems based on velocity change appear to be adequately demonstrated for particular locations and species, at least on an experimental basis. More data on the performance of large prototype systems at powerplants will be required before the louver system can be recommended for a broad class of intakes. The velocity cap intake might be considered for offshore vertical intakes since it would add relatively little to the cost of the intake and has been shown to be generally effective in reducing fish intake to these systems.

The performance of the electric screening systems and the air bubble curtains appear to be quite erratic, and the mechanisms governing their application are not fully understood at the present. These types of systems might be experimented with in an attempt to solve localized problems at existing intakes, since the costs involved in installing these systems is relatively small.

No successful application of light or sound barriers has been identified. It appears that fish become accustomed to these stimuli, thus making these barriers the least practical of the available behavioral systems on the basis of current technology.

## Physical Screening Systems

All cooling water intake systems employ a physical screening facility to remove debris that could potentially clog the condenser tubes. Such facilities range from simple stationary water screens to filter beds. This sub-section will consider only mechanical screening mechanisms. In general, these mechanical screens have been developed to protect the powerplant from debris, rather than to protect aquatic life.

In other sections intake facilities are reviewed as a whole, with further consideration of the installation and operation of some of the mechanical systems discussed here. Also reviewed in other sections is the important area of fish repulsion systems based on the behavioral characteristics of fish.

The following mechanical screening devices are the principal types which are either in common use or have been suggested for use in powerplant circulating water systems, both in the United States and abroad.

1. Conventional vertical traveling screens
2. Inclined traveling screens
3. Fixed screens
4. Perforated pipe screens
5. Double entry, single exit vertical traveling screens
6. Single entry, double exit vertical traveling screens
7. Horizontal traveling screens
8. Revolving drum screens - vertical axis
9. Revolving drum screens - horizontal axis
10. Rotating disc screens

Most of the types of revolving drum and rotating disc screens are commonly used in powerplants outside the United States and have been supplied by European manufacturers. They have not been used in the United States, with the exception of a few experimental screens which will be discussed.

### Conventional Vertical Traveling Screens

By far the most common mechanically operated screen used in U. S. powerplant intakes is the vertically rotating single entry band type

screen mounted facing the waterway. A catalogue cut of this screen is shown in Figure III-17. Figure III-18 is a schematic drawing showing the principal operating features.

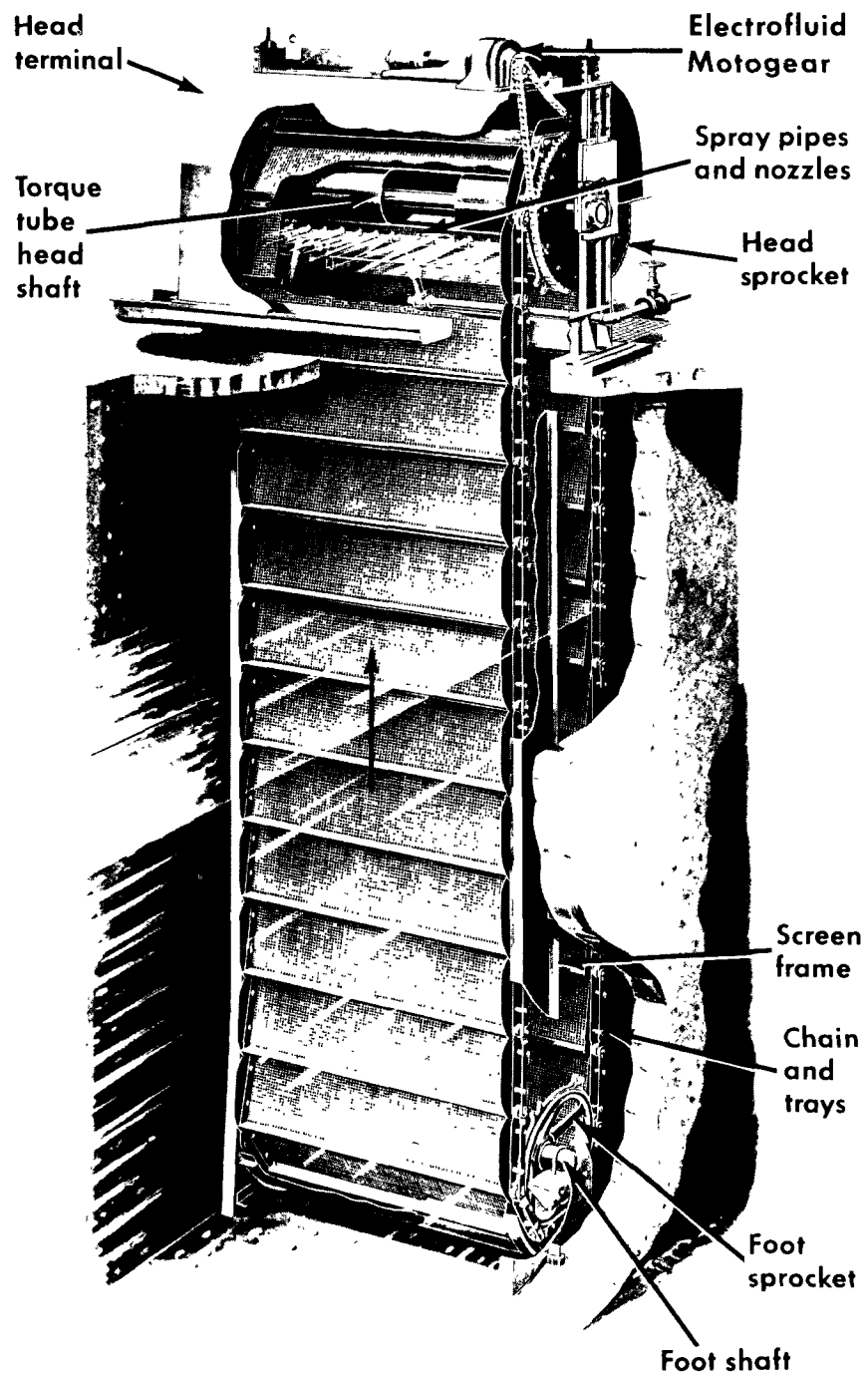
The screen mechanism consists of the screen, the drive mechanism and the spray cleaning system which requires a means for disposal of the waste materials removed from the screen. The screen is attached to an endless chain belt which revolves in the vertical plane between two sprockets. The screen mesh is usually supplied in individual removable panels referred to as "baskets" or "trays". A continuous band screen is also available but is not often used. The entire assembly is supported by two or four vertical steel posts. Longer and wider screens usually require the stronger four post box structure for support.

The screen washing system consists of a line of spray nozzles operating at a relatively high pressure 550 to 827 KN/m<sup>2</sup> (80 - 120 psi). The washing system may be located at the front or the rear of the screen, or both. The usual location is in front as shown in Figure III-18. The quantity of water required for spray cleaning is in the order of 0.372 m/s (98.42 gpm) per meter (3.28') of screen width. It is supplied either by booster pumps taking suction from the circulating water pump discharge or by separate vertical shaft pumps. The disposal of the debris is usually accomplished by discharging the screen wash waters from individual screens to a common disposal trough located at the floor on which the screen is mounted. The trough drains either to a debris storage compartment or directly back to the waterway. If a debris storage compartment is used, the water is allowed to drain from the bottom of the compartment and the remaining refuse is periodically removed to a land disposal area. Both the drive shaft and the screen wash system are enclosed in a removable housing to protect the drive components and to contain the high pressure water spray.

The conventional vertical traveling screen has several advantages. It is a proven off-the shelf item and is readily available. It performs efficiently over a long service life and requires relatively little operational and maintenance attention. It is applicable to almost all water screening situations. It is available in lengths up to about 30 meters (100') and 15 cm (6") increment widths up to 4.26 meters (14'). The system adapts easily to changing water levels. The screen is relatively easy to install. Major components of the system, including supports, baskets, drive mechanisms, and spray systems are standardized. Special materials for corrosion protection and greater durability are also available.

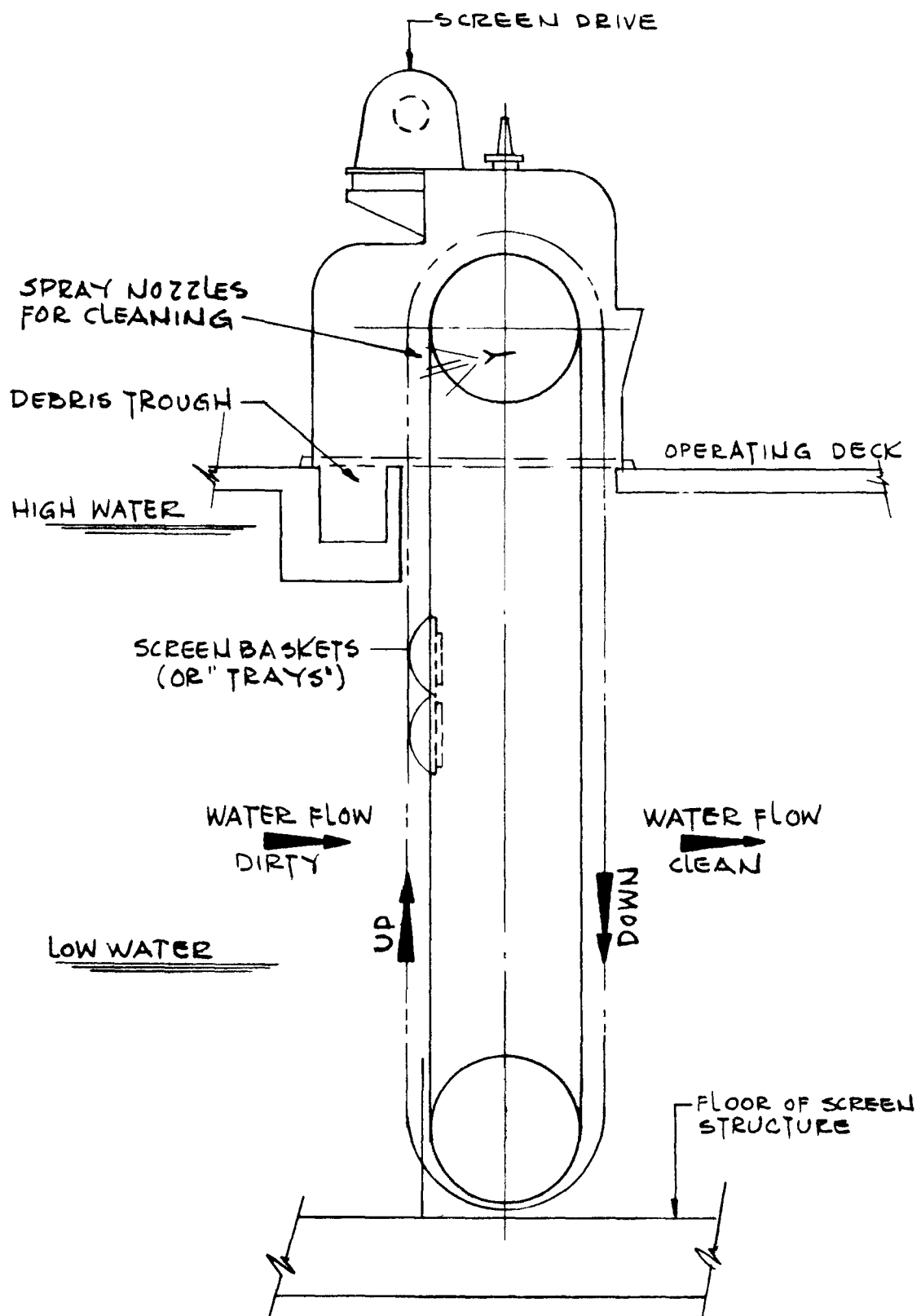
The system as presently used has several undesirable features that can cause adverse environment impact. The most important of these is the fact that any fish impinged on the mesh of the screen will probably be destroyed. This effect results from both the design of the system and the way it is operated. Most traveling water screens are operated intermittently, not continuously, and fish are pinned against the screen





CONVENTIONAL VERTICAL TRAVELING SCREEN

Figure III-17



CONVENTIONAL VERTICAL TRAVELING SCREEN

FIGURE III-18

for extended periods of time. When the screens are rotated the fish are removed from the water and then subjected to a high pressure spray, both of which may be lethal. Any fish surviving these hazards will be destroyed in the subsequent refuse disposal operations, if the refuse is not returned to the waterway.

The above discussion suggests the following possible avenues for correcting some of the environmental defects of the conventional traveling water screen:

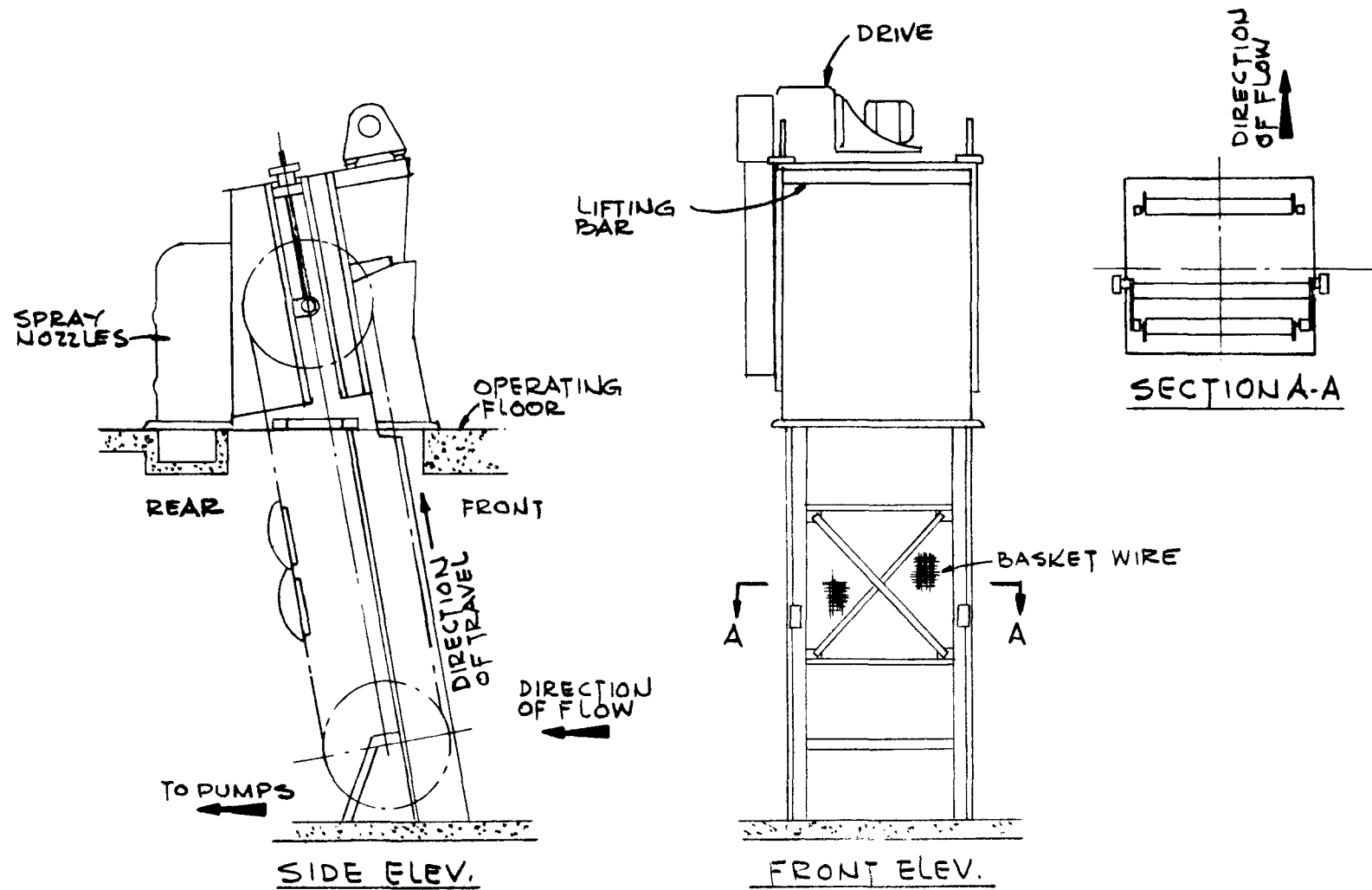
- a. reduce impingement time by continuous operation of the screen.
- b. provide a path for rapid and safe return of fish to the waterway.
- c. mount the screen so as to provide fish escape passages to either side, a feature discussed in the section concerning overall intake design.

The current design of traveling water screens and the screen structures themselves would not require radical changes to adopt the first two corrective measures. Several intake designers and screen manufacturers have proposed modifications of this type in past years and at least one major nuclear station (plant no. 5111) is modifying its screen baskets and operational procedures to provide fish protection. These modifications are discussed in a subsequent portion of this report.

#### Inclined Screens

Two basic types of inclined screens are available. The first, shown in Figure III-19, is merely an adaptation of the conventional vertical traveling screen. It is used at installations where the debris loading is extremely heavy and is of a nature that does not readily adhere to the screen. The downstream inclination of the screen (usually 10° to vertical) allows debris falling off the lip of one basket to be caught in the following basket rather than falling back into the waterway. Also, by inclining the entire screen frame, debris being lifted from the channel is supported more fully by the ascending basket lips and the backward tilted screen wire. This type of screen thus might be advantageous in insuring more rapid removal of fish, shellfish and jellyfish from the waterway for subsequent bypass as discussed above. The number of installations using this screen is relatively small and the system has the same advantages and disadvantages as the vertical traveling screen. The cost of this screen would be slightly higher than that of the vertical screen, due to the longer screen well required, the use of two rows of spray nozzles and other minor variations from the conventional vertical screen.

The second type of inclined screen has been designed specifically with fish protection in mind and has significantly different design features



TRAVELING WATER SCREEN

FIGURE III-19

than the conventional vertical traveling water screen. This type of system is shown in Figure III-20.

It is still in the experimental stage, but such a screen has been used successfully in Canada to divert downstream migrating fish and its performance is reported in Reference 21. This system employs a fixed screen inclined downstream at an extreme angle to the vertical. The rear portion of the screen is bent horizontally over the fish collection trough. The screen is cleaned by a continuous chain flight conveyor similar to that used in conventional water and wastewater sedimentation practice. The differences are the orientation of the collector above the screen and the conveyor flights which are made of a pliable brush material rather than solid metal. By orienting the screen and cleaning mechanism in this manner the fish can be slowly herded up the screen and kept immersed in water until it is dumped gently into the bypass trough. This design avoids many of the pitfalls of impingement on vertical traveling screens. The fish is not really impinged in the real sense of the word. He never leaves his normal habitat of water and is not subjected to the extreme pressures of the conventional system spray water.

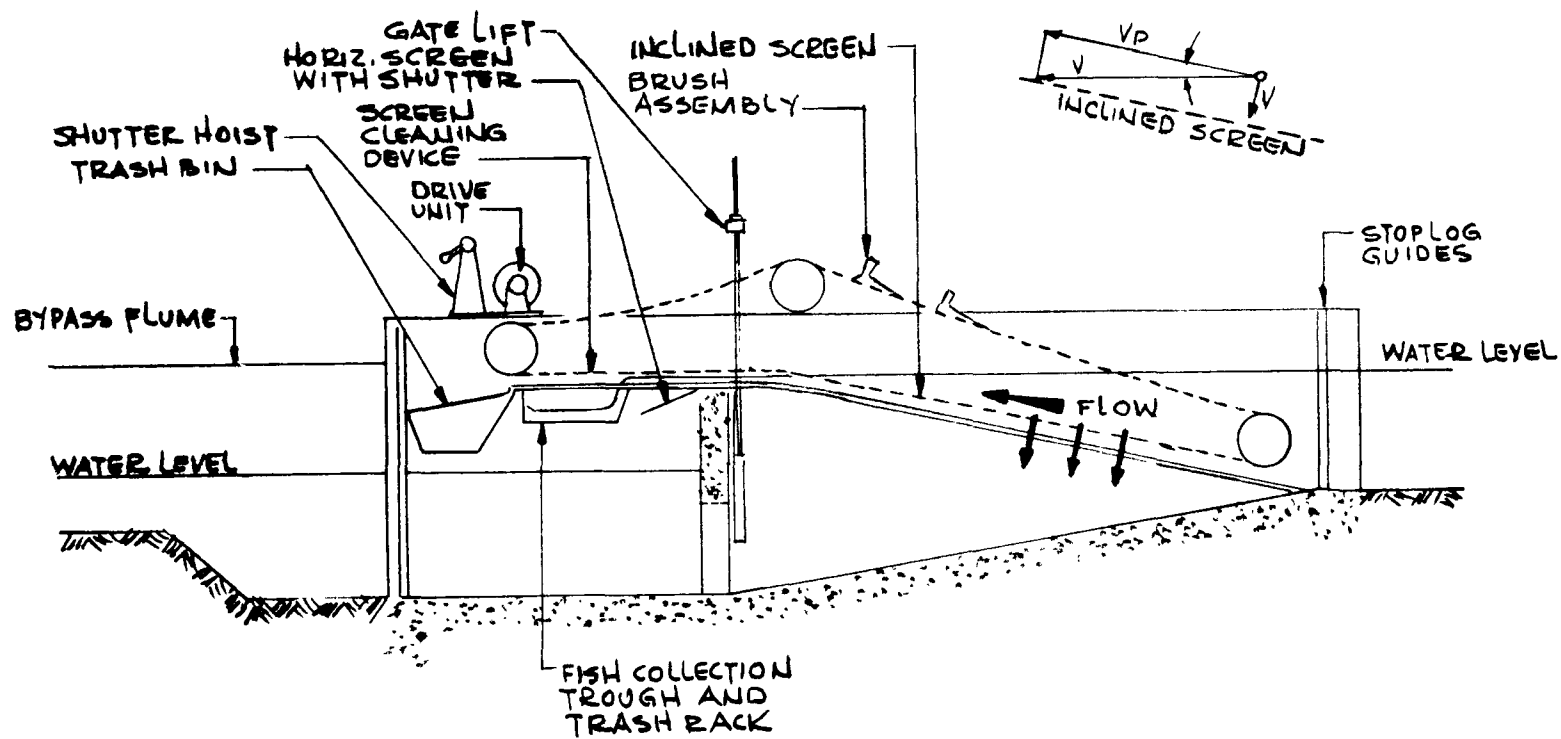
The system has some important limitations. It is very sensitive to fluctuations in water level, since the water level variation at the horizontal section of screen must be limited to a few inches; a level control mechanism such as the slide gate shown in Figure III-20 is thus required. Another disadvantage is that the cost of the intake structure for this type of screen would be significantly increased. The shallow angle of placement with respect to the incoming flow causes the length of the intake channel to be several times longer than that required for the vertical traveling screen of the same screening capacity.

The application of this type of system, as well as several others to be discussed, is limited in many areas because of the regulations of cognizant water quality control agencies. Reference here is to the common policy which prohibits the subsequent discharge of any debris after it has once been removed from the waterway.

As can be seen from Figure III-20, the method of diverting fish to the bypass trough also allows for the discharge of the debris back to the receiving water. Prohibition of this debris discharge would also result in the prohibition of safe fish return. It is apparent that the same comment applies to the discharge from the conventional traveling screen previously discussed. However, in certain cases fish can be separated from the debris.

### Fixed Screens

This term is applied to a number of different types of screens, some of which are permanently anchored below the waterline of intake structures



INCLINED PLANE SCREEN WITH FISH PROTECTION

FIGURE III-20

and others, the more common, which can be moved but are not capable of continuous travel. Taken together "fixed" screens, (or "stationary" screens), constitute the second largest group of physical screening devices presently found in powerplant intakes. Examples of two types of screening systems in this category are shown in Figure C-III-21. Note that both types of screen would not be used at the same intake and are only shown on the same figure for convenience.

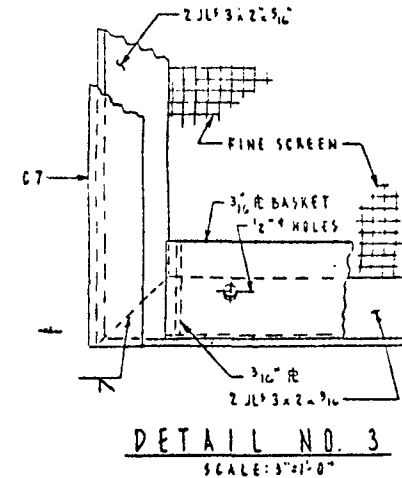
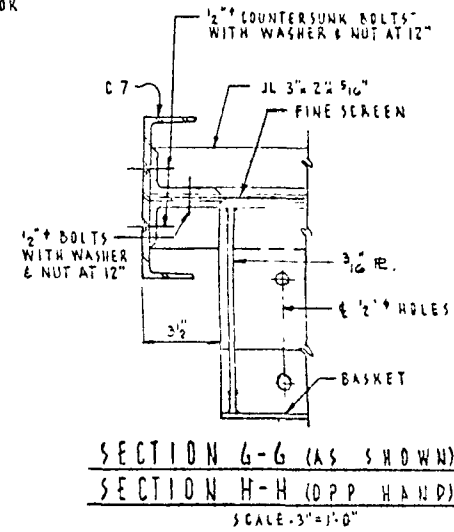
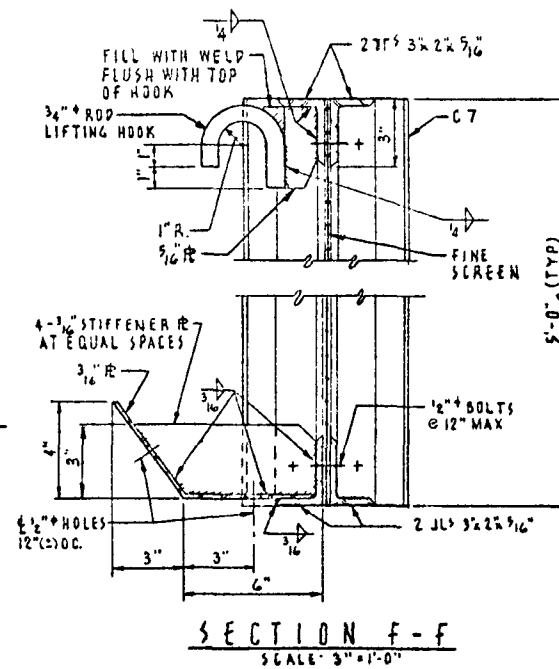
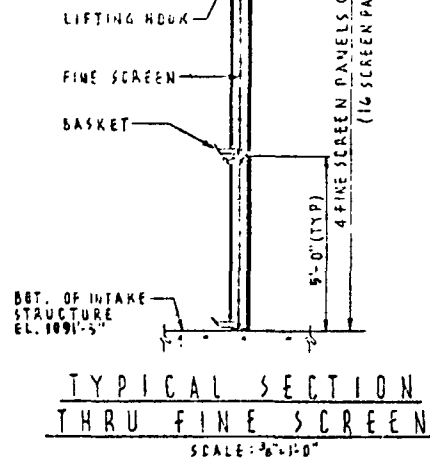
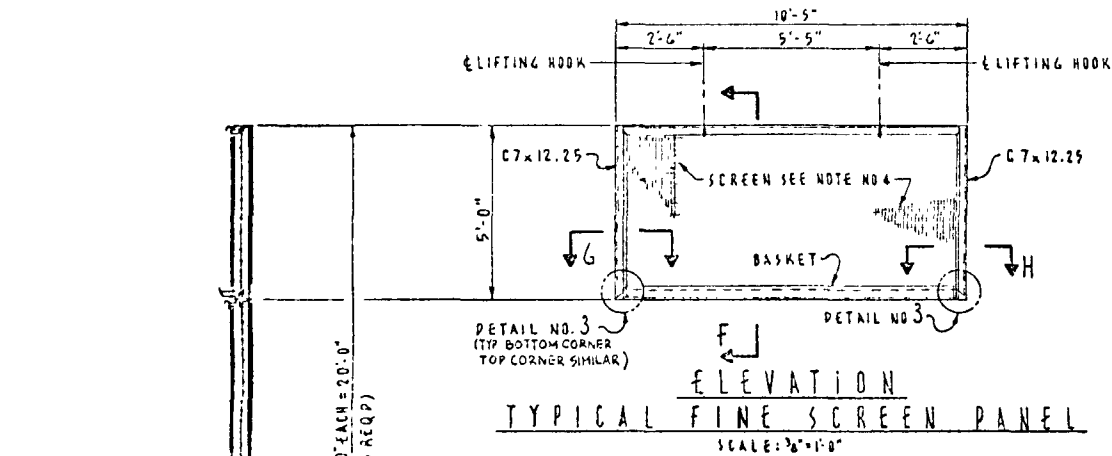
The first type of screen is mounted upstream of the pumps in vertical guides to allow them to be removed to a position above the water line. Figure III-21 shows a relatively sophisticated installation wherein two rows of screens are provided to permit one to remain in service while the other is being changed. In addition, each row is divided into two sections in a manner which allows removal of the lower section without removal of the upper section. Some debris and fish can be sucked into the pump during the process of changing screens. The screen guides are sometimes extended above the deck to hold the raised screens in place for cleaning. Figure III-22 is a sketch showing typical fabrication details of such a screen.

Another fixed screen type involves attaching a cylindrical screen to the pump suction bell, also shown in Figure III-22. The cleaning of this type of screen is very difficult; it may be done by dewatering the bay, with the use of divers or by backwashing through the pump, all methods being unsuited to the continuous pump operation required at powerplants.

The bulk of fixed screens are found on smaller and older plants. Some newer plants located on water bodies that have small debris loadings have also installed this type of screen. The only advantage over a conventional traveling water screen is a savings in the cost of the mechanical equipment and in maintenance costs for the screens, screen drives, spray wash pumps, etc. Operating costs may be higher if frequent manual cleaning is required.

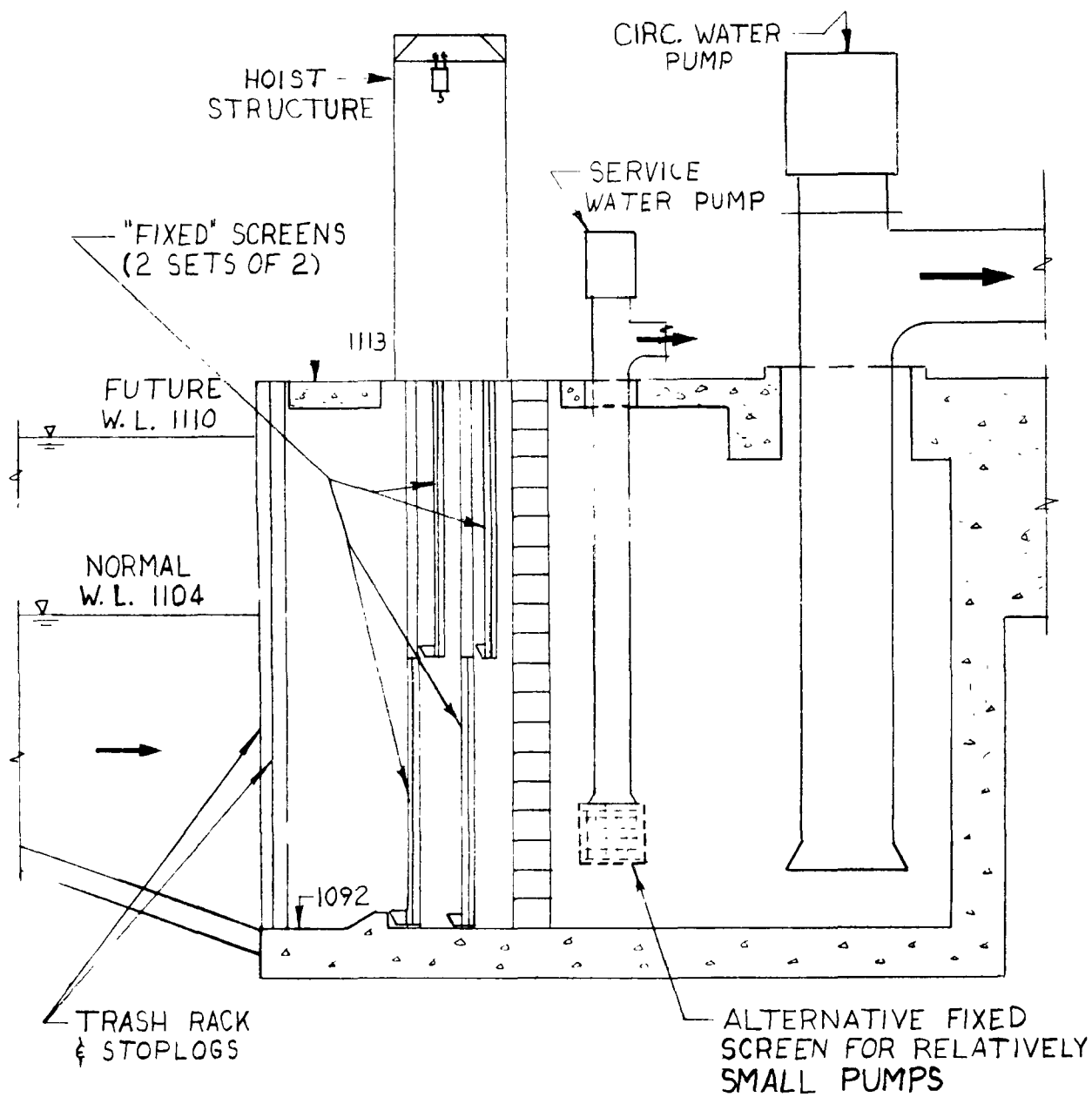
Fixed screens have serious drawbacks, both from a plant operation standpoint and an environmental standpoint. First, operators must be immediately available to raise and clean the screens when a limiting head loss occurs (as signalled by a differential level alarm, for example). Secondly, no matter how light the debris load may normally be, the possibility always exists that a sudden heavy debris or fish load could completely clog the fixed screen, causing plant shutdown and possibly collapse of the screens and circulating water pump damage. Because of these factors many fixed screens originally installed for economy reasons have subsequently been replaced with traveling water screens.

From the environmental standpoint the fixed screen involves longer impingement periods between cleaning cycles and increased damage to the impinged fish because of greater velocities across the increasingly clogged screen. The crude methods employed to clean fixed screens is also damaging to fish.



### FIXED (STATIONARY) SCREEN DETAIL





FIXED (STATIONARY) SCREENS  
(SCHEMATIC ONLY)

FIGURE III-22

## Perforated Pipe Screen

Figure III-22A shows a type of "fixed screen" with characteristics significantly different from the fixed screens discussed above. The screen consists of a perforated pipe placed in the waterway and oriented in such a manner that the passing current will sweep debris downstream. There are several installations of this type in service. They have to date been designed for debris handling service without respect to fish protection. However, it appears quite possible that this type of screen may be very effective in reducing fish mortality.

Model tests are currently underway for one nuclear powerplant makeup water intake to develop optimum perforation velocity, size and shape, all specifically to provide maximum fish protection. Additions to the inside of the pipe, such as sleeves, may be made to produce equal velocities through the perforations. Very low approach velocities can be achieved with a reasonable total length of perforated pipe, divided into several individual pipes if necessary. In this manner large quantities of water may be handled at what may be substantially less cost and greater fish protection effectiveness than presently used conventional screens.

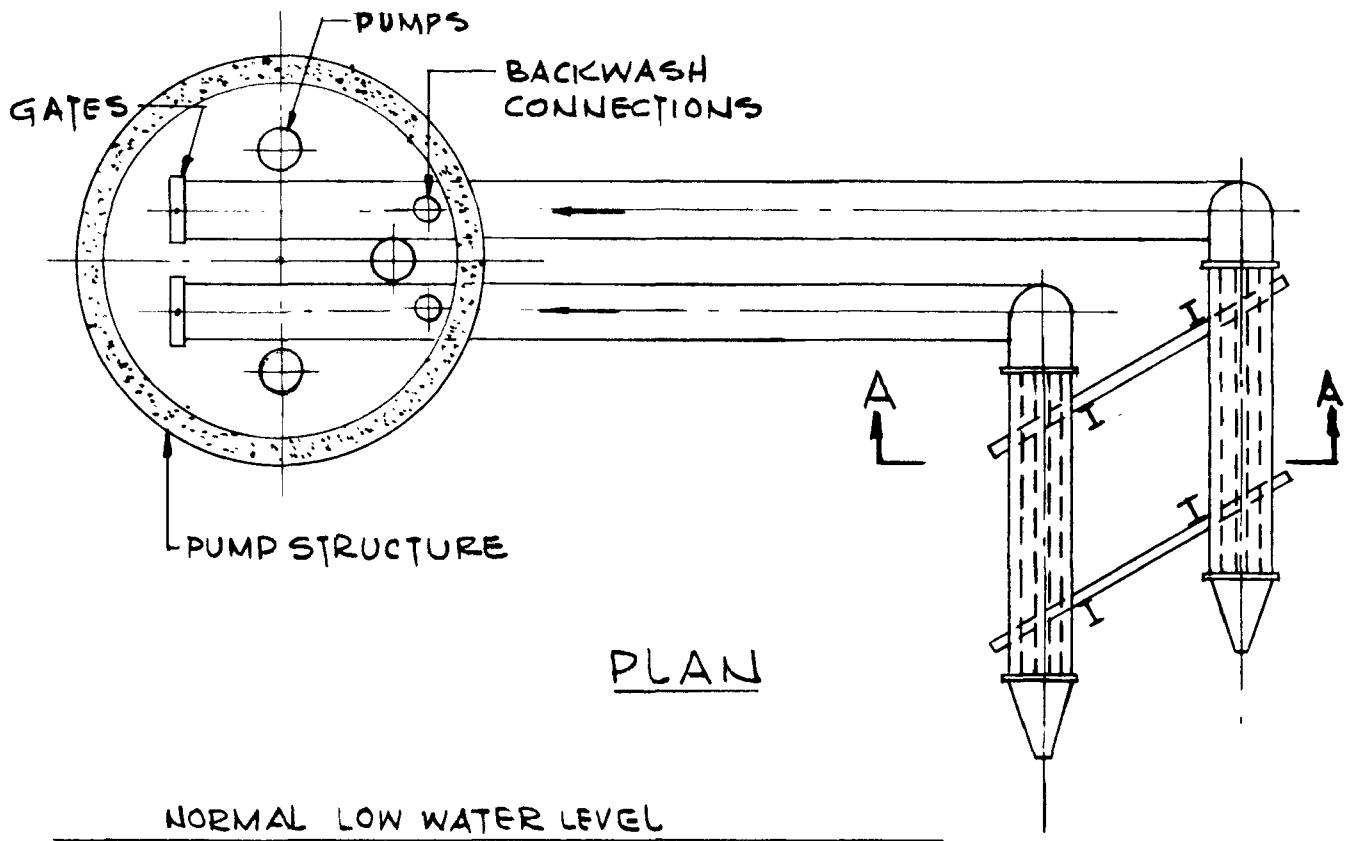
Backwash provisions may be included as shown in Figure III-22A, but a review of existing installations has indicated that these provisions have not been extensively needed.

## Double Entry, Single Exit Vertical Traveling Water Screens

Figures III-23, III-24, and III-25 show two types of installation for a vertical traveling screen which takes water from both sides and passes it out through one end of the screen, thus doubling the screening area for a given width of screen. Although this unit appears similar to the conventional traveling screen there are significant differences.

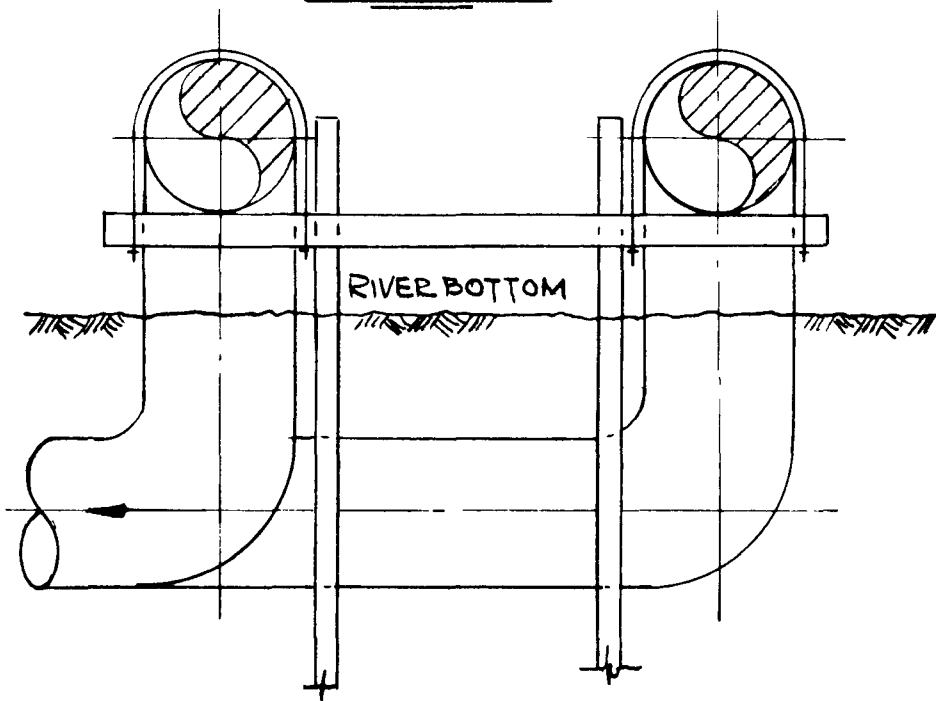
Figures III-23 and III-24 show the most common mounting of this type of screen. The unit is turned so that the approach flow is parallel to the faces of the screen. It is mounted in a concrete screen well. Water enters through both the ascending side and the descending side of the screen, thus utilizing both sides for water cleaning. For a given theoretical mesh velocity the screen will have twice the capacity of the conventional screen. There is no possibility of debris carry over to the pump side, since incomplete cleaning will simply result in returning the debris to the incoming water for recycling.

There are several drawbacks to this type of installation, however, and from both the operational and environmental points of view it appears to be inferior to the conventional screen. Some of these objections are as follows:



PLAN

NORMAL LOW WATER LEVEL



SECT. A-A

PERFORATED PIPE SCREEN  
(IN RIVER CHANNEL)

FIGURE III-22A

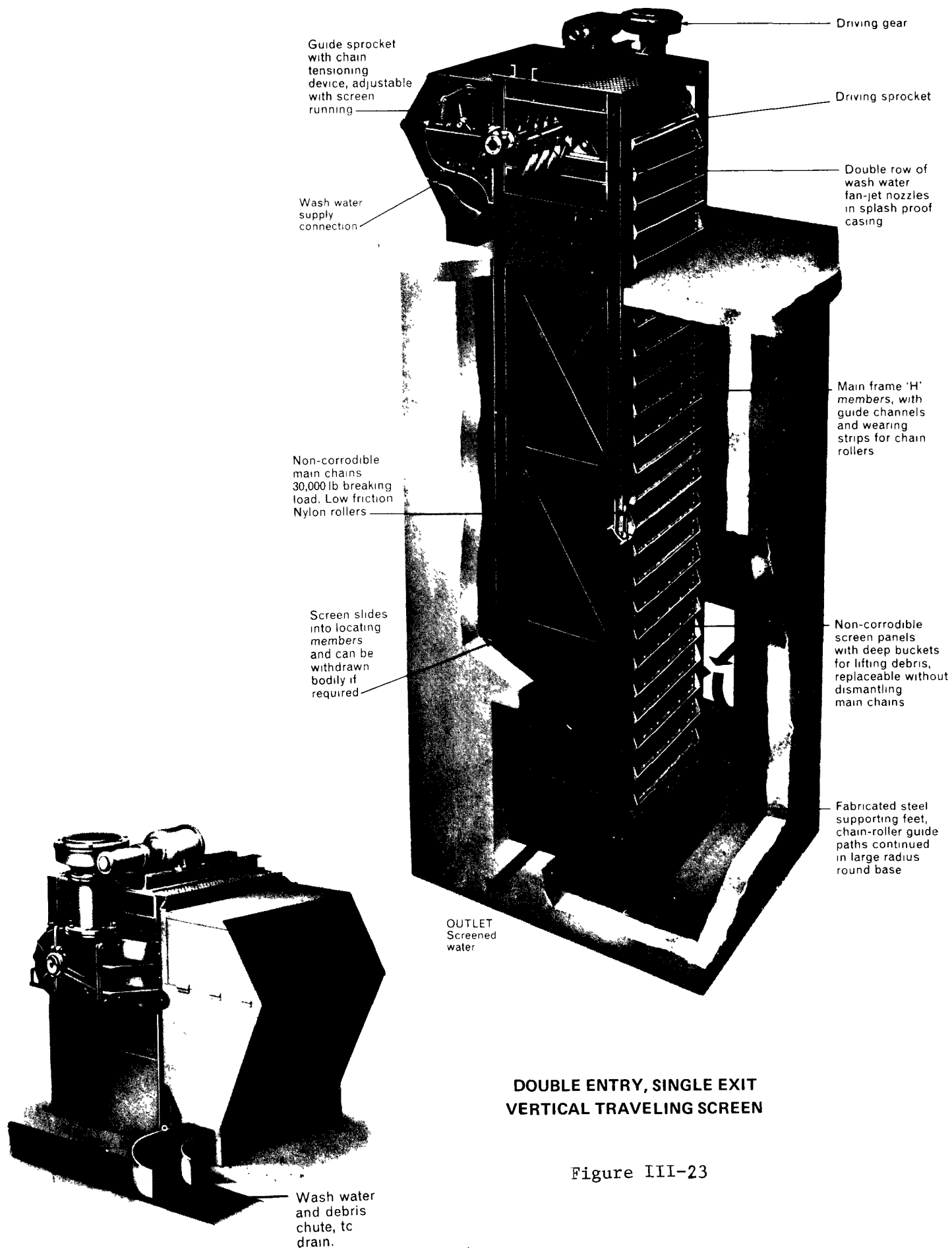


Figure III-23

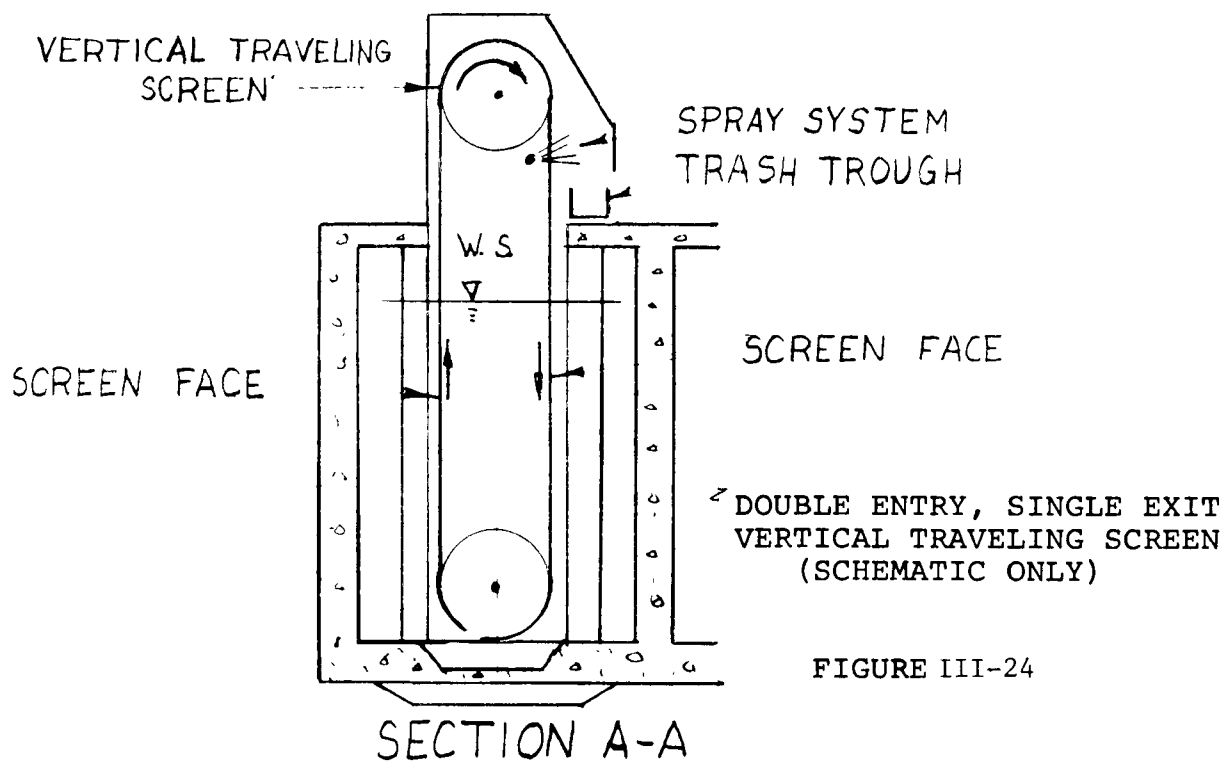
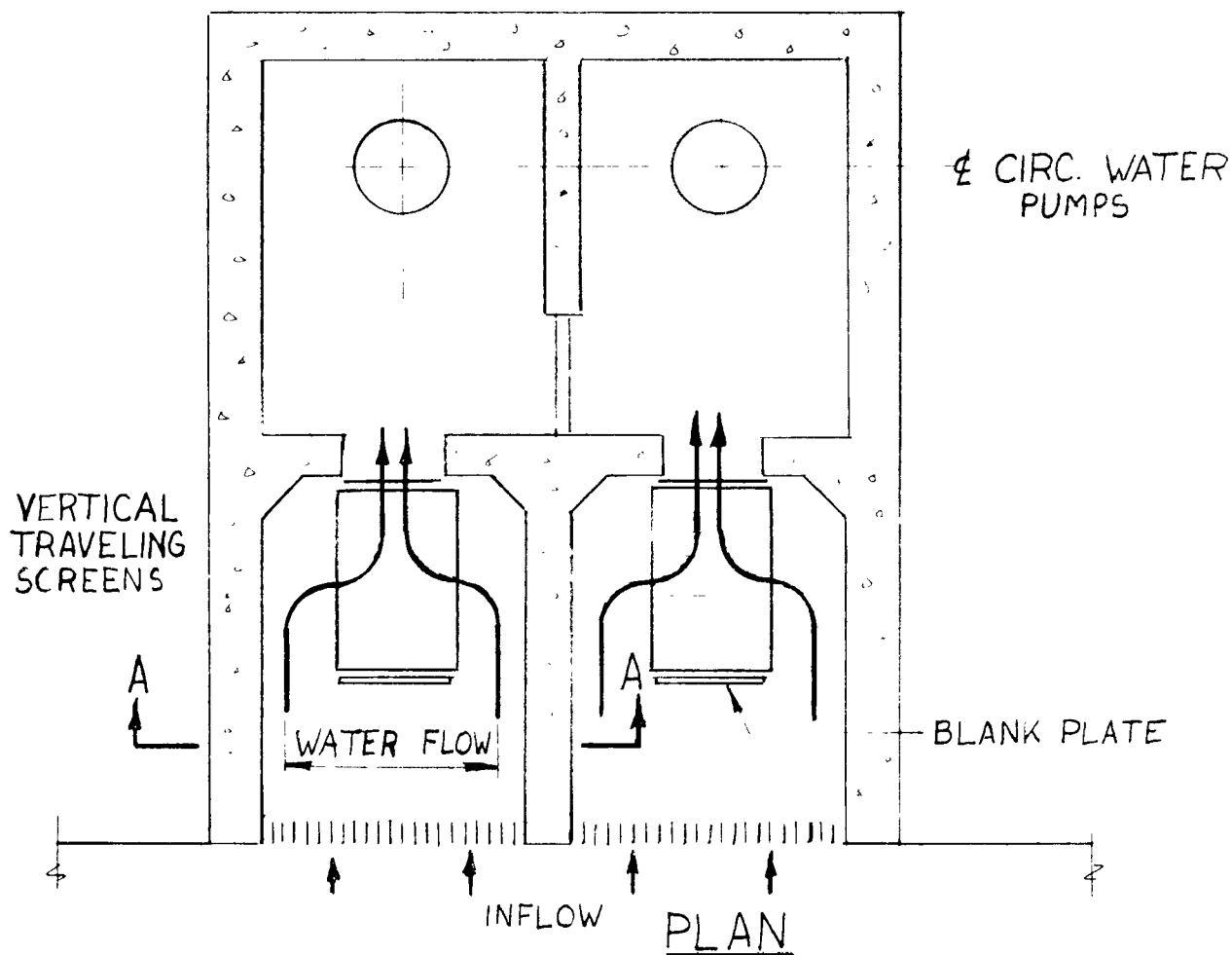
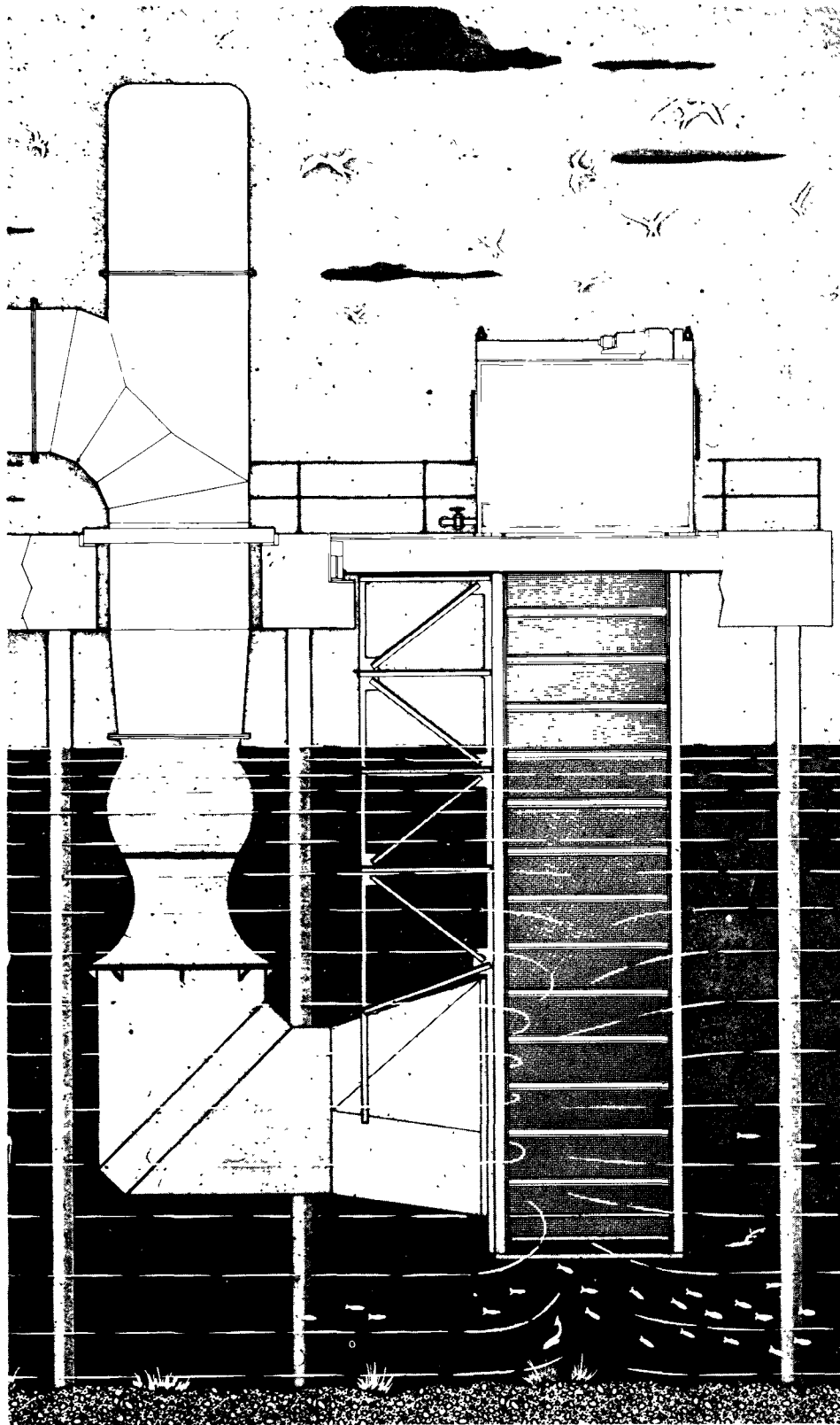


FIGURE III-24



**DOUBLE ENTRY SINGLE EXIT  
VERTICAL TRAVELING SCREEN  
OPEN WATER SETTING**

Figure III-25

a. If the double entry screen is to handle twice the flow volume, as suggested by the manufacturers, it will have to handle twice as much debris as the single entry screen. At the same rate of screen travel debris clogging will occur much more quickly.

b. The clean screen face is first introduced to the flow at the water surface. The debris picked up by the descending baskets must then be pulled down and through the boot section. Debris thus collected on the descending run blocks the screen for the entire cycle. This is in contrast to the single entry screen which presents a clean basket to the flow and usually does not encounter the majority of the debris until just before it lifts out of the water.

c. Since head loss increases on an exponential basis with the degree of blockage of the screen wire, the dual flow screen will have to be designed to operate under higher head losses. Higher head loss design requires both a structurally stronger screen and a higher horsepower drive.

d. The double entry screen mounted as in Figure III-22 requires abrupt changes in water flow direction as it passes through the screen. This will result in nonuniform flow across the screen face, with high localized velocities, additional system head loss and possibly enough turbulence to upset pump operation.

e. The common setting shown in Figure III-22 does not provide any escape route for fish other than to swim back out of the channel. Definite fish trap areas result at both faces of the screen.

This type of screen is frequently used outside the United States and is also offered as a standard item by one U. S. manufacturer.

Figure III-25 shows an environmentally promising alternative mounting for the double entry screen. Here the screen is mounted on a platform and is surrounded by water on all sides.

There is no confining concrete structure which might trap fish. This is a major asset from the point of view of fish protection. The screen has some of the mechanical drawbacks of the mounting shown in Figures III-23 and III-24. In addition, the pump suction piping will cause non-uniform flow through the screen mesh since abrupt flow direction changes must take place to get the water to the pump. Not shown in Figure III-25 are trash racks and associated structure which will probably be needed to protect the screen from heavy debris. Even with such added facilities, however, the total cost of the screen and pump installation for the open type mounting may well be less than for an installation using either conventional traveling screens or the screens mounted as shown in Figures III-23 and III-24.

It might be noted here for reference that the principle of the "Open" type of screen mounting typified in Figure III-25 is also a feature of one of the alternative mountings of a European drum screen shown in Figure III-38, the pump suction piping is similarly attached to the screen frame itself, allowing open water to surround the screen, thus avoiding fish trap areas.

#### Single Entry, Double Exit Traveling Screens

Figures III-26 and III-27 show a screen type which reverses the flow path shown for the double entry screen previously discussed. Water enters through an opening in one side of the screen frame and exits to both the right and left through the ascending and descending screen faces. Debris is removed from the screen baskets into a trough on the inside of the screen by both gravity action and sprays. There is no possibility of carrying debris over into the "clean" side of the system. None of these European designed double exit screens is presently in operation in the United States, but they are on order for at least two major U. S. powerplants.

The advantages and disadvantages of this design are similar to those for the double entry screens previously discussed. One potential fish protection feature of the screen shown in Figure III-27 is a substantial debris, water and fish holding trough for each section of individual curved screen basket. Fish might be less likely to flip out of the trough back into the incoming water and thus would not be "recycled" in the manner which is objectionable on unmodified conventional traveling screens.

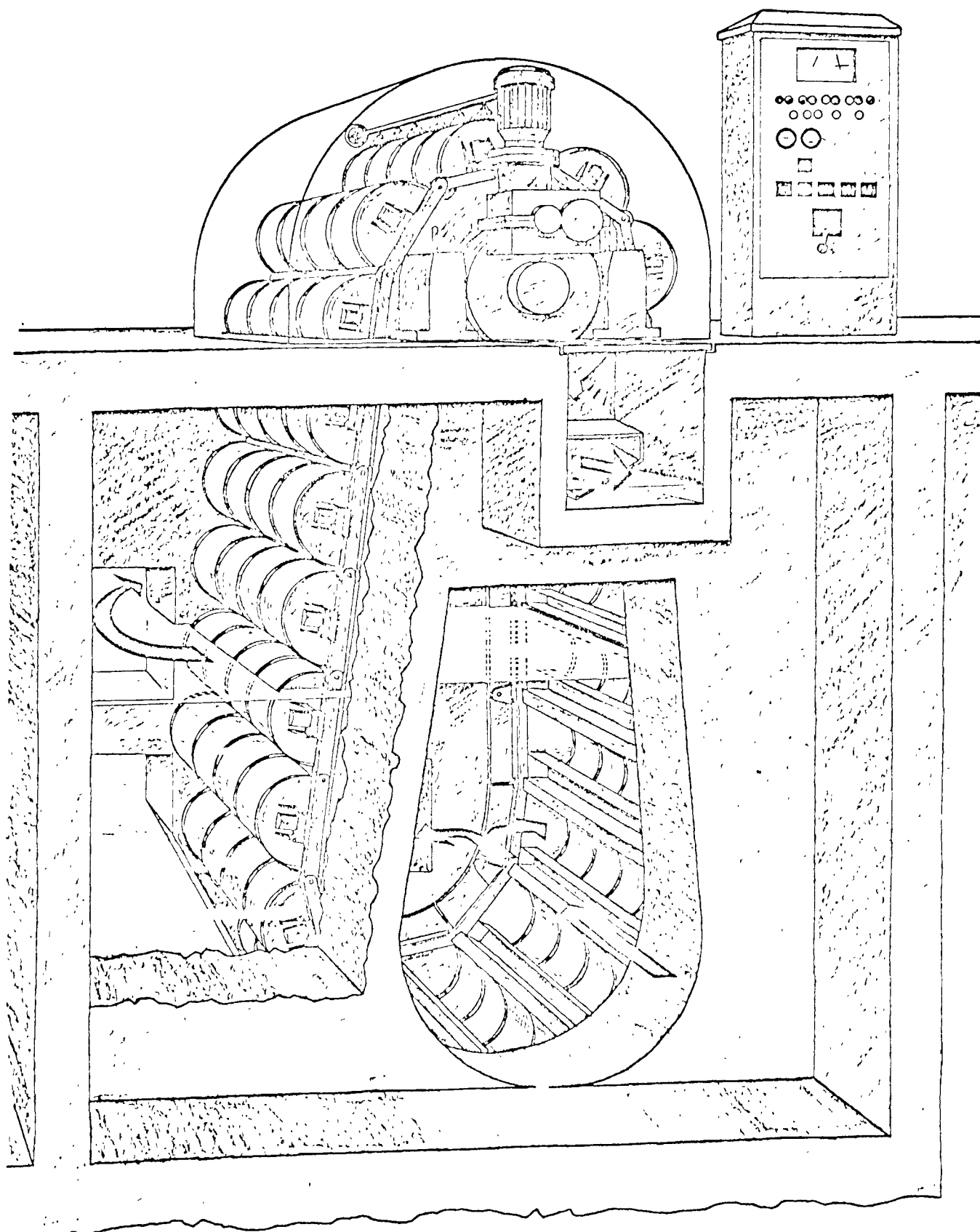
Neither this screen nor any of the other vertical traveling screens were developed with fish protection in mind. Thus they have the inherent and obvious environmental drawbacks which have been highlighted in the previous discussions.

#### Horizontal Traveling Screen

Figure III-28 shows the principle of the horizontal traveling screen, a device specifically developed to protect fish. It elicits a behavioral response from the fish similar to the louver diversion system discussed elsewhere in this report. The horizontal screen, which is still in the experimental stage, is the single major advance in mechanical screening technology in the last decade. It was initially developed by the U. S. Fish and Wildlife Service in Oregon. Later financial and technical support has come from several utilities and a commercial screen manufacturer.

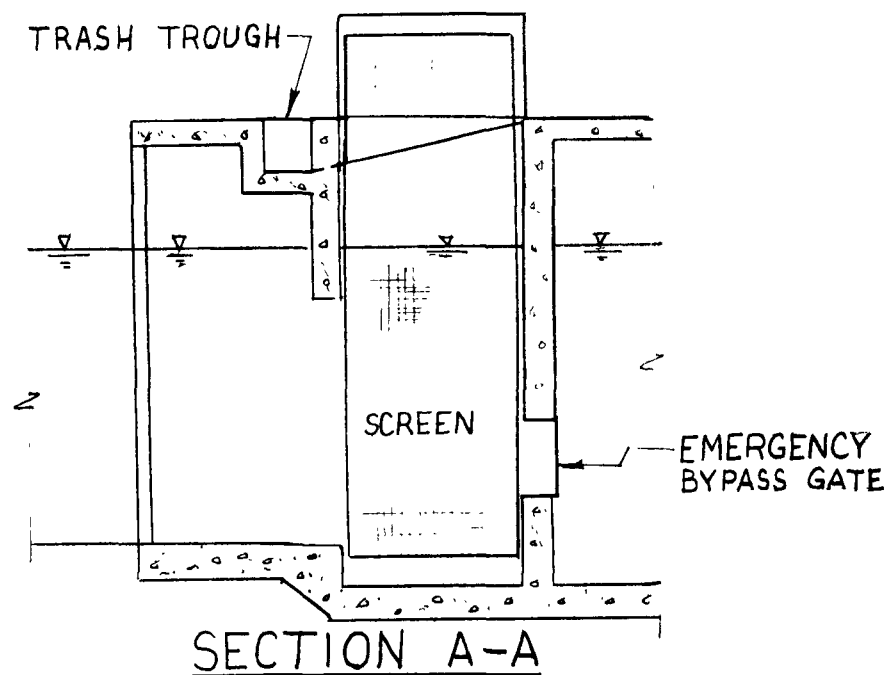
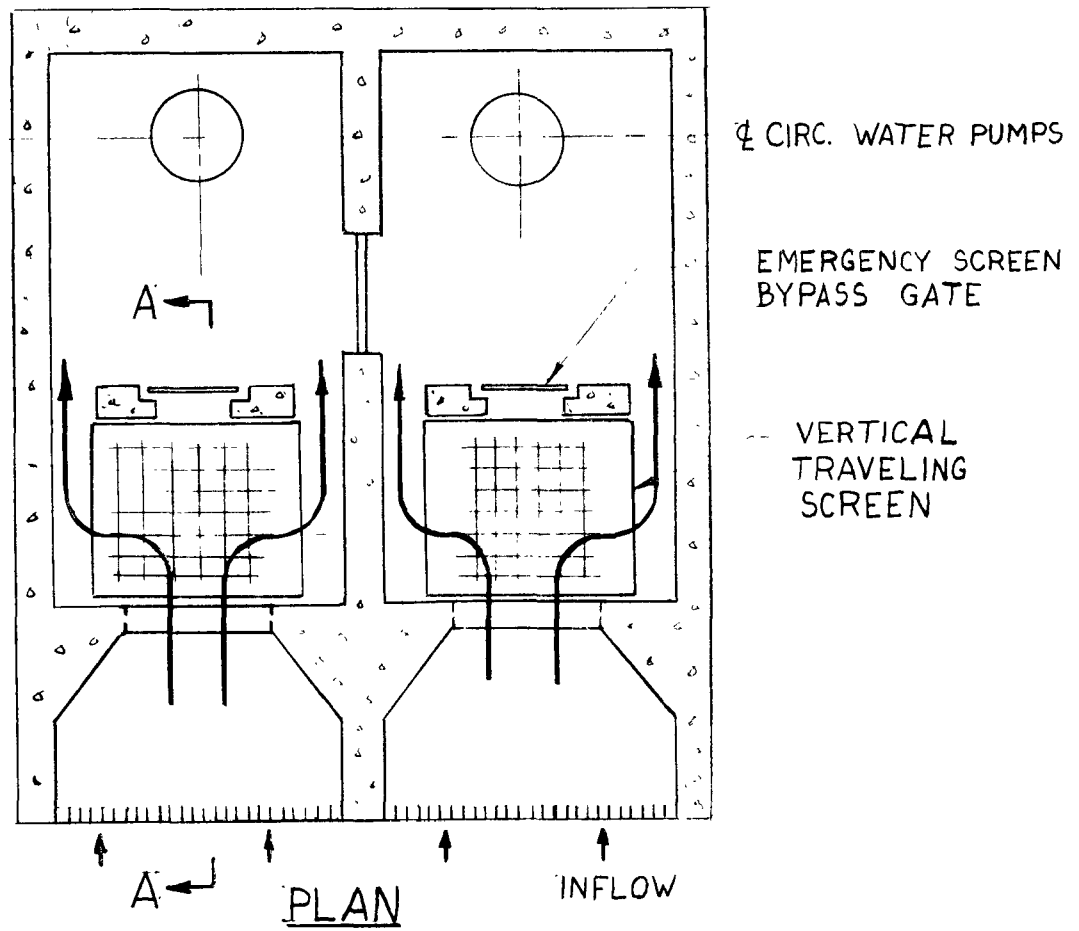
As shown schematically in Figure III-28, the horizontal traveling screen rotates horizontally at a sharp angle to the incoming water flow. The





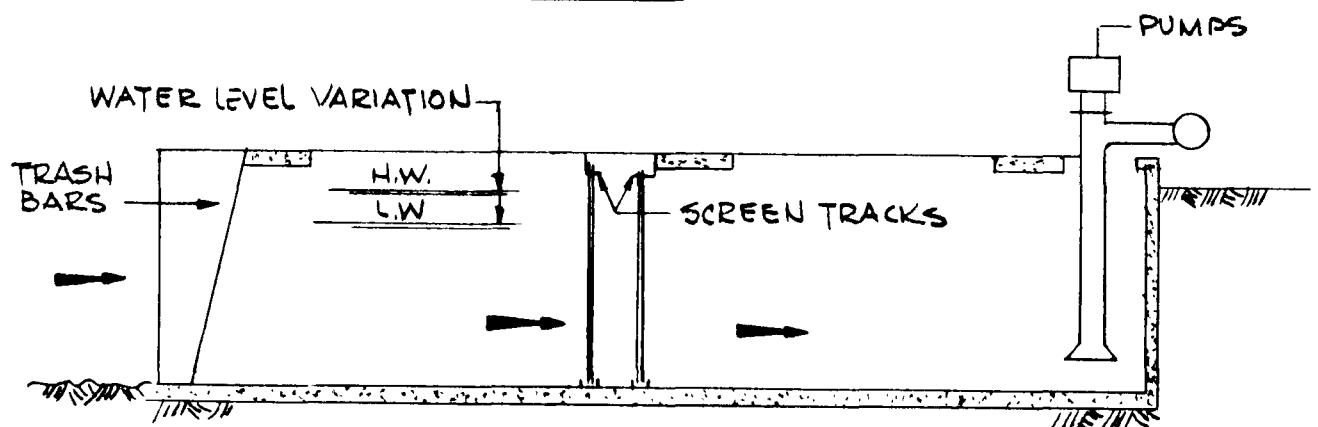
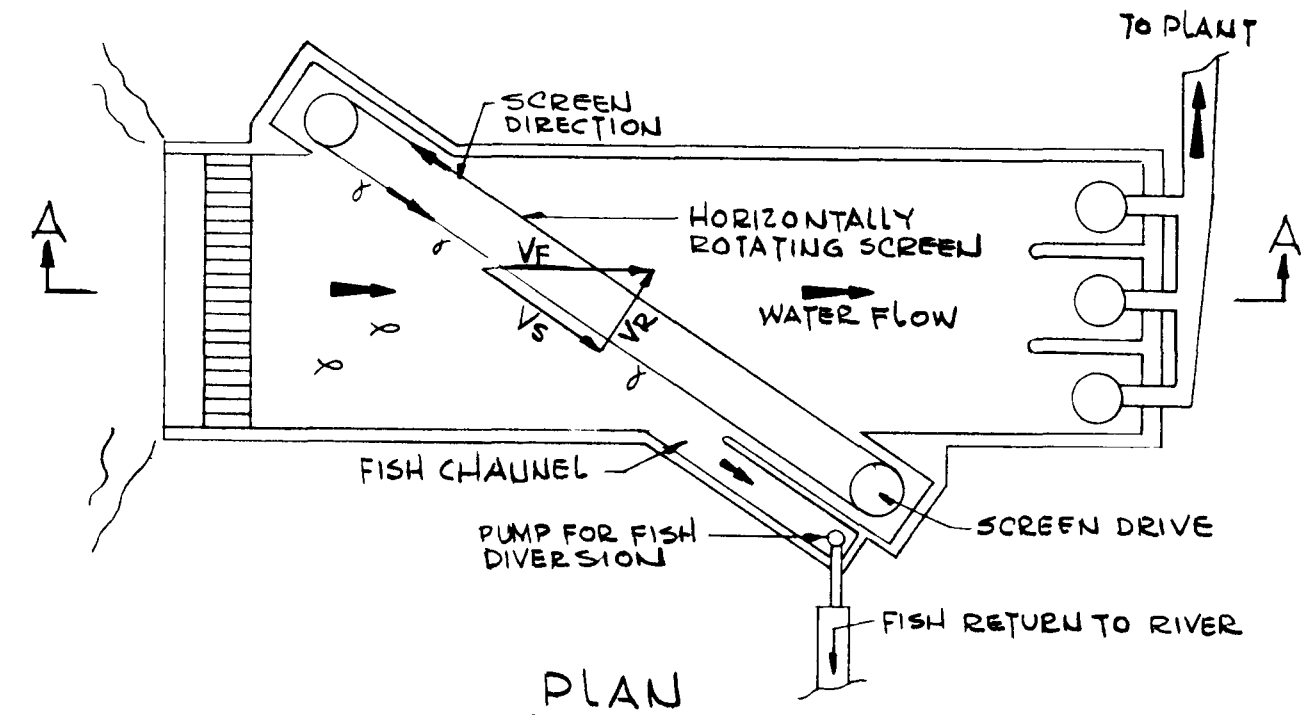
SINGLE ENTRY, DOUBLE EXIT  
VERTICAL TRAVELING SCREEN

FIGURE III-26



SINGLE ENTRY, DOUBLE EXIT VERTICAL TRAVELING SCREEN

FIGURE III-27



HORIZONTAL TRAVELING SCREEN  
(SCHEMATIC ONLY)

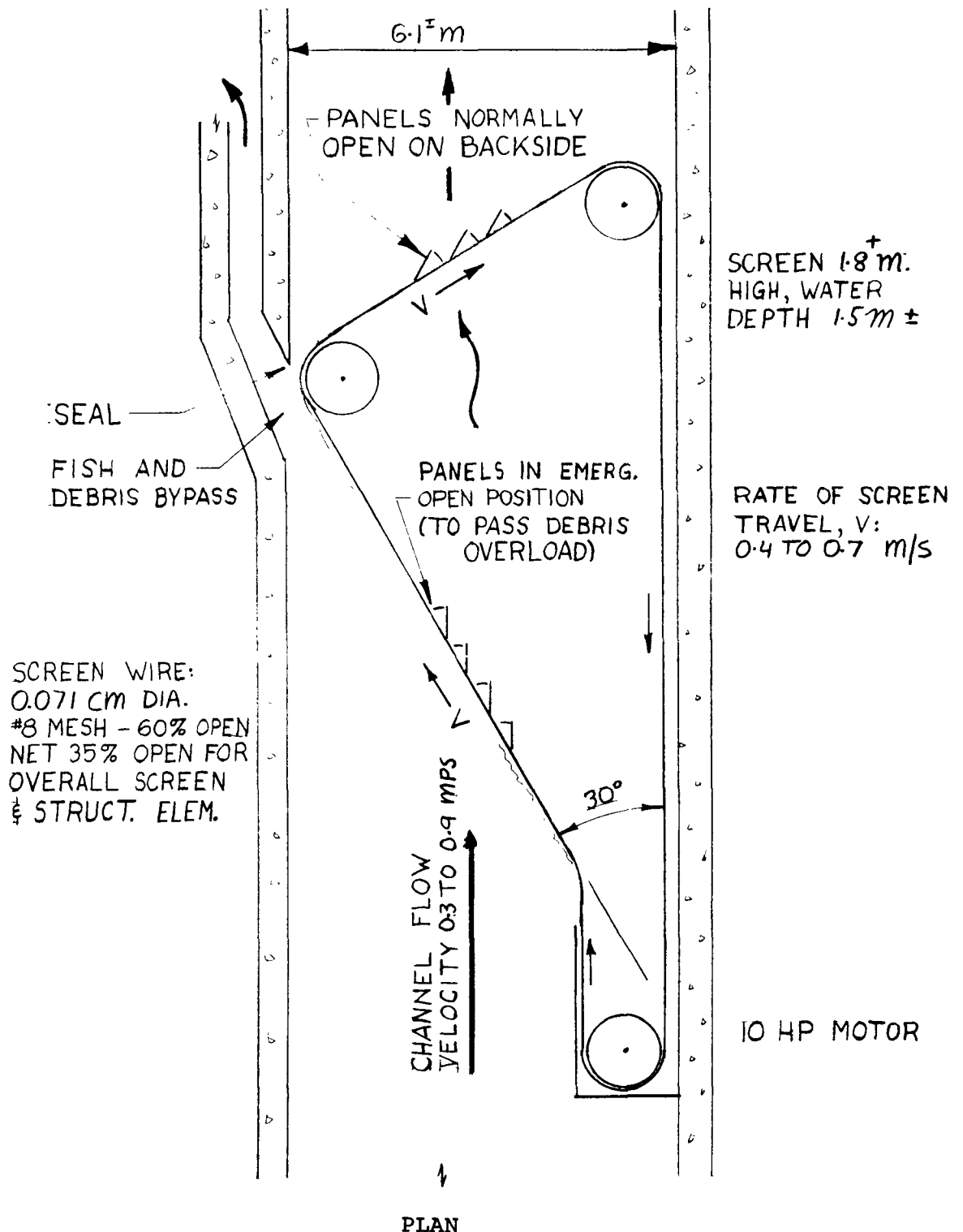
FIGURE III-28

principle is to guide fish to a point where a bypass channel can carry them to safety. It has been very effective. Upon sensing the screen, a fish will orient himself perpendicular to the screen and attempt to swim away from it along  $V_R$ . This he is able to do since the component of the channel velocity opposing his effort ( $V_R$ ) is small. In this orientation the fish is swept downstream along the face of the screen by the component of channel velocity which is parallel to the screen ( $V_S$ ). When he reaches the end of the screening leg he moves into the bypass channel for safe passage back to the waterway. The size of fish that is effectively screened can be reduced by reducing the angle of inclination of the screen with respect to the channel flow direction. However, as this angle is reduced the size of the screen increases for the same flow rate, increasing the cost of the intake. Some small percentage of fish will become impinged on the screen, but they will be released at the bypass and will also not be pressed as tightly against the screen as they would be in a vertical screen.

The latest experimental version of this screen (designated Mark VII) is shown schematically in Figure III-29. It is located on the Grande-Ronde River near Troy, Oregon and was designed in cooperation with a major commercial screen manufacturer. Although this screen and its predecessors have undergone extensive tests the manufacturer and knowledgeable intake designers estimate that it is at least two generations of experimentation away from installation at a major steam electric powerplant. Application of this screen to a large industrial intake at this time would require extensive and costly research.

Some of the problems are as follows:

- a. The screens operate continuously and at very high rates of speed compared with vertical screens. For the Mark VII screen the rate of travel is variable from 0.4 to 1.2 m/s (80 - 240 fpm) as compared with a usual maximum of 0.05 m/s (10 fpm) for the vertical screen. All components of the mechanism are thus subject to severe wear. Reliable, long life components have not been developed.
- b. Water level differential due to clogging must be limited to avoid collapse of the screen. Either the pumps must be tripped to stop flow or the screen panels must be designed to spring open. This latter solution was used in the Mark VII screen. If the panels thus open they will release fish and debris and supplementary conventional traveling screens will be required downstream of the horizontal screens to protect the cooling water system.
- c. The horizontal screen cannot accommodate significant variations in water depth in its present stage of design. Effective performance hinges on suitable approach water velocities.



MARK VII HORIZONTAL TRAVELING SCREEN  
(SCHEMATIC ONLY)

FIGURE III-29

d. The maximum screen panel height is about 6.1 meters (14 feet) due to the same general structural limitations that control the maximum width of a vertical traveling screen.

e. Due to lack of gradient in the incoming water screen, it is difficult to obtain sufficient bypass velocity without the use of supplementary pumps in the bypass system.

f. Debris as well as fish must be handled on the bypass system, thus required additional water cleaning facilities.

g. Screens would have to be redundant to permit continuous full load operation during screen maintenance shutdowns. The size of the installation will thus become very large and costly compared with a vertical screen facility.

h. Debris and bed load tend to jam lower tracks.

Figure III-30 is a schematic version of a possible variation of the horizontal screen setting. This location and orientation would utilize the velocity of the passing water to carry the fish to safety and remove trash.

The principle of angling the water cleaning facilities to the incoming flow is further developed in other sections, with respect to the louver system of behavioral guidance and the concept of placing conventional traveling screens at an angle to the flow.

#### Revolving Drum Screens - Vertical Axis

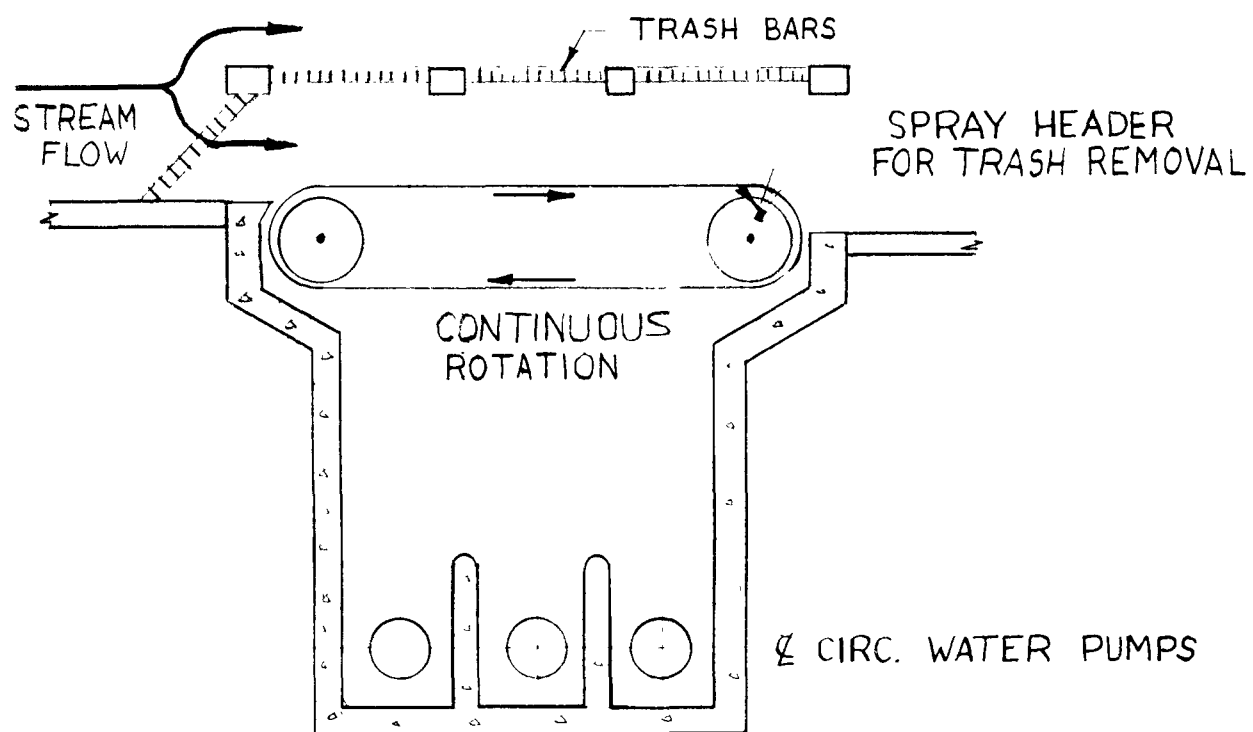
At least two types of vertical axis revolving drum screens are in use in U. S. water intakes, but not in facilities connected with industrial cooling water systems.

a. The vertical drum revolving in an opening in front of the pumps as shown schematically in Figure III-31.

b. The vertical drum revolving around the pump itself as shown in Figure III-32.

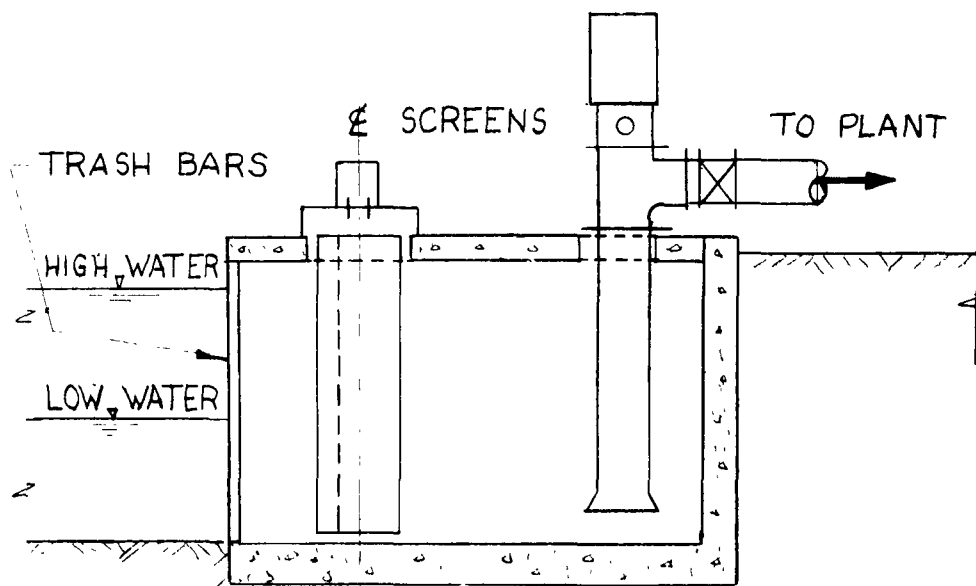
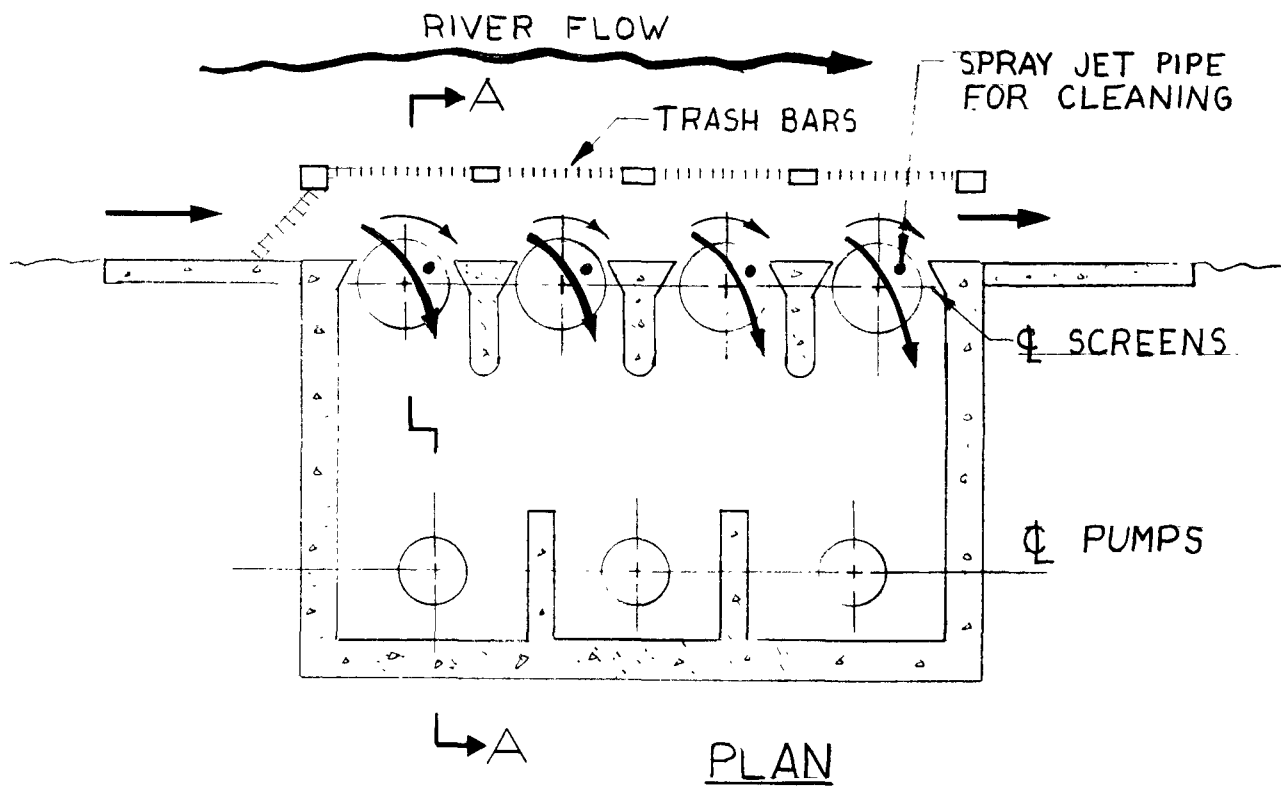
The screen mesh is placed on a vertically revolving drum. Water level variations can be handled without difficulty. A vertical jet spray system can be mounted inside the drum to wash off debris. However, no convenient way has been developed to move the debris away from the screen face area.

Figure III-31 shows the drums lined up in such a manner that a passing river flow will carry away debris and would also carry fish to safety. Obviously the reliable performance of this system will depend on a



SCHEMATIC PLAN  
ADAPTATION OF HORIZONTAL TRAVELING SCREEN

FIGURE III-30

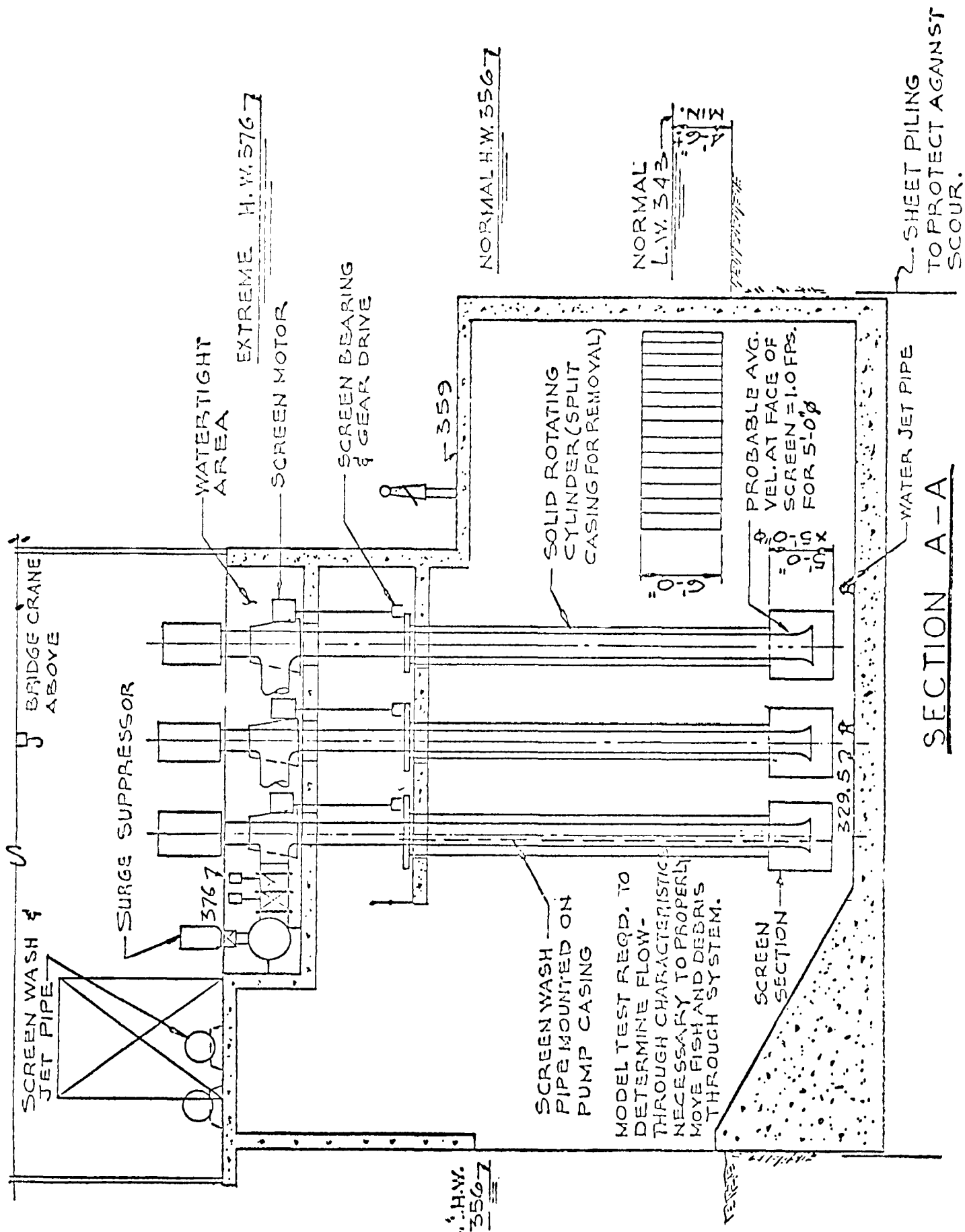


### SECTION A-A

**REVOLVING DRUM SCREEN - VERTICAL AXIS  
SCHEMATIC**

**FIGURE III-31**





VERTICAL AXIS REVOLVING DRUM SCREEN

FIGURE III-32

strong one directional passing current, which is a feature severely limiting the locations where the screen would be effective. Without such passing flow the debris would simply pile up in front of the screens. Fish would be scraped or jetted off only to impinge on the same or adjacent screens.

Figure III-32 shows the screening element encircling the pump and revolving around the pump. One major screen manufacturer has supplied such screens for relatively small,  $0.19 \text{ m}^3/\text{s}$  (3,000 gpm), powerplant auxiliary pumps. Another version has been independently developed and used for an irrigation water intake by the Prior Land Company of Pasco, Washington. Although this system is experimental and has been in operation for only about a year it has served Prior Land's special needs. The system has had mechanical difficulties, however, and required major overhaul during the non-irrigation season. Modifications and new designs are underway. A vertical spray washing system has been installed, but no satisfactory provisions have been made to carry the debris away once it has been washed from the face of the screen.

The screen enveloping the pump must be large in diameter compared with the bell in order to achieve an acceptable low screen velocity. Only a small vertical section of the screen will be effective since the flow lines into the pump bell traverse only a limited area of the surrounding waterway.

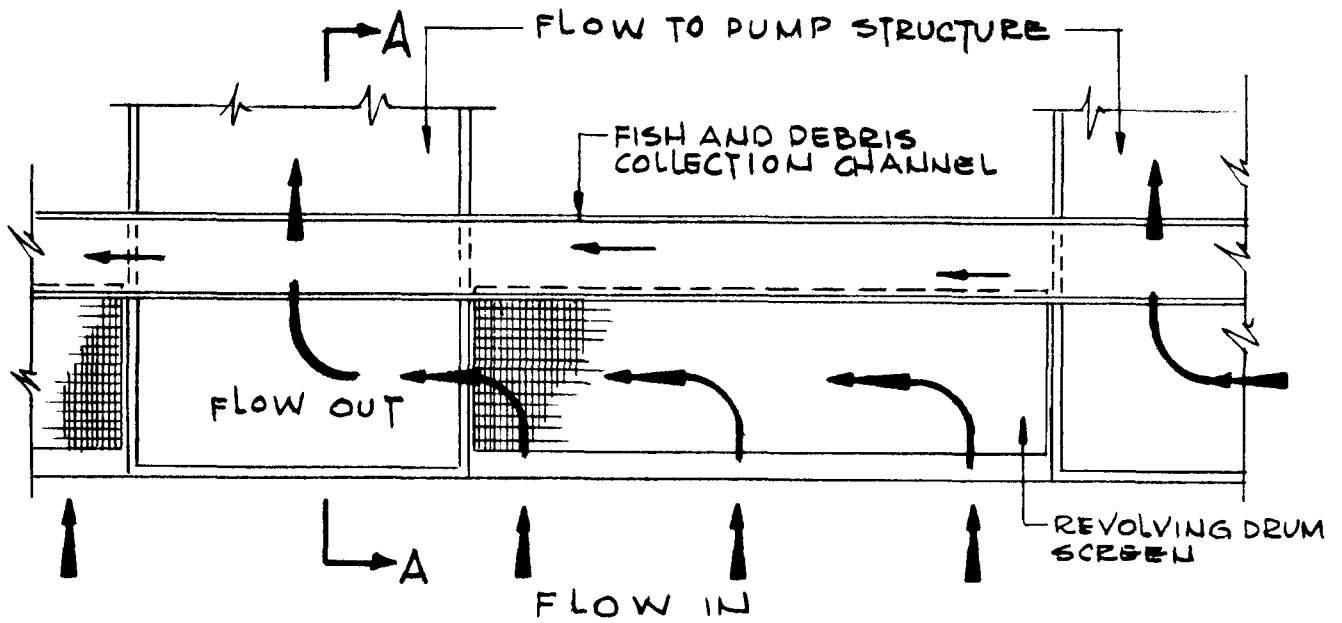
The vertical drum screens described here are not sufficiently developed to provide protection to fish and appear to be of marginal effectiveness in handling any but very light debris loads.

#### Revolving Drum Screens - Horizontal Axis

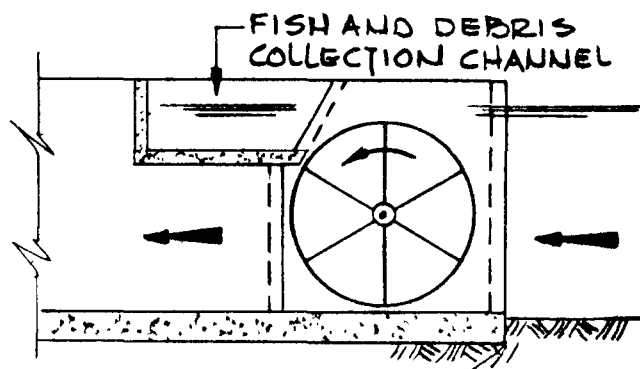
Horizontal axis revolving drum screens are widely used throughout the world. There are many variations functioning in quite different ways. In the United States, however, they have had practically no application and are not supplied as a standard design for the water quantities required in powerplants.

A simple drum installation is shown in Figure III-33. This type of screen is placed with its longitudinal axis horizontal across the intake channel. The screening media is located on the periphery of the cylinder. The screen rotates slowly with its exposed upper surface moving downstream just below the water surface. Because it operates in this manner it can be used to separate fish from the water flow with minimum impingement, if mesh approach velocities are low. Debris is not removed efficiently.

The important design parameters for the drum screen are mesh size, drum diameter, drum rotation velocity, and velocities through the screen. The velocities through the screen are difficult to control since



PLAN



SECTION A-A

REVOLVING DRUM SCREEN HORIZONTAL AXIS

FIGURE III-33

portions of the screen are alternately moving with and against the intake flow. The horizontal drum screen as shown is also sensitive to water level changes.

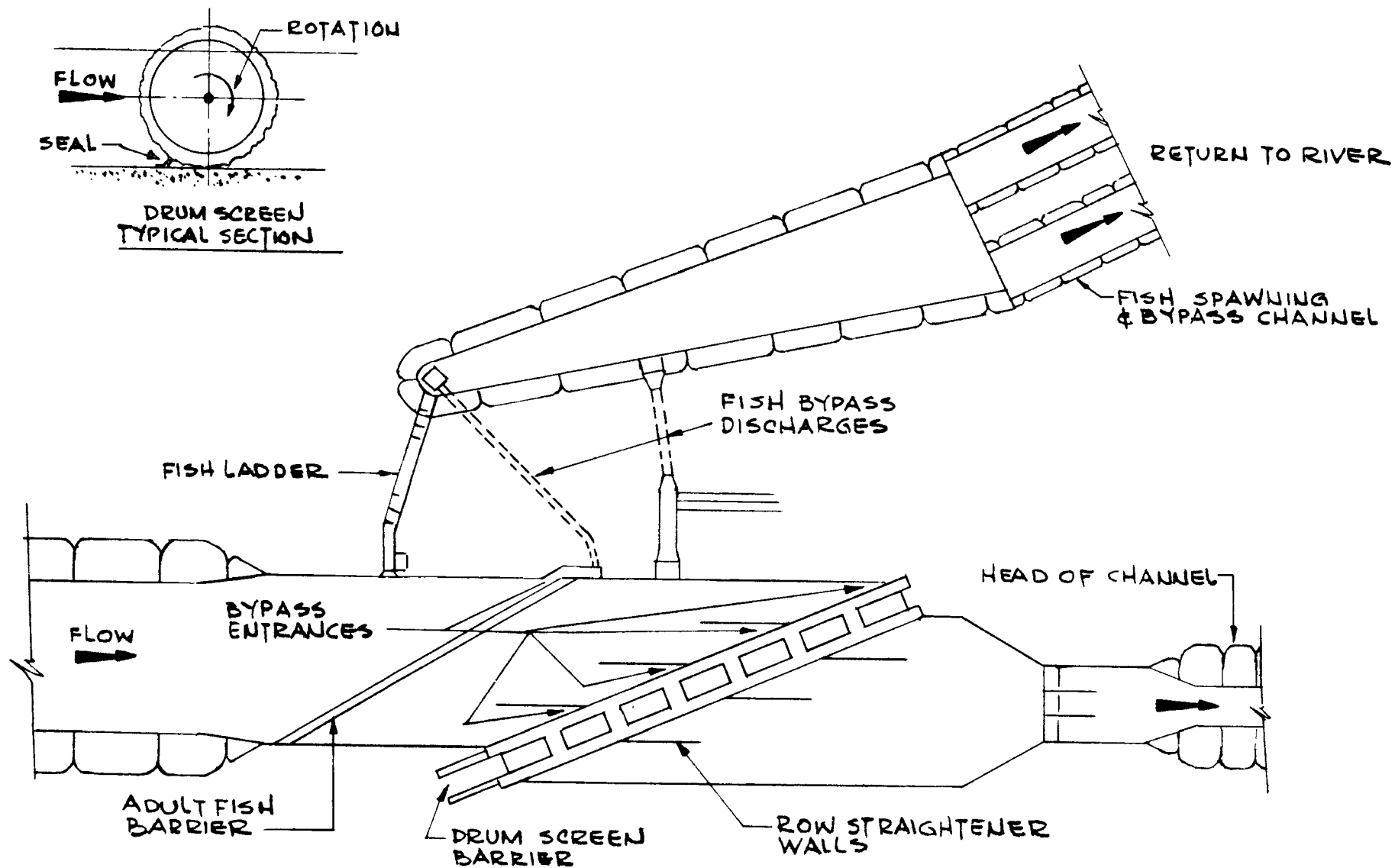
Drum screens may be designed as impinging or non-impinging depending upon the size of the fish to be separated and the velocity of the screen and the rate of flow in the channel. The impinging design is not preferable because of possible damage to the fish while on the screen. It is also difficult to remove the fish subsequent to impingement. High pressure sprays have been used but these can also damage fish.

No drum screen was found to exist at a U. S. powerplant. Several horizontal drum screens have been used to divert fish from irrigation canals. A major installation of this type is the fish bypass structure of the Tehama-Colusa Irrigation Canal operated by the U. S. Bureau of Reclamation, shown on Figure III-34, taken from Reference 21. Since the water is used for irrigation, debris removal is not as important as at a powerplant or other industrial intake. Note that the drum screen is placed at an angle to guide fish to a downstream bypass similar to horizontal screens and louver diverters. A supplementary pumping system would be needed to produce the desired bypass flow. There is also a problem in obtaining good seals at the bottom and against the side walls.

The advantages of the illustrated drum screen over the conventional traveling water screens include the decreased number of moving parts and the possibility of utilizing more than half of the total screen mesh as effective screen area. However, an industrial intake designed on the pattern of Figure III-34 would cost considerably more than the conventional intake.

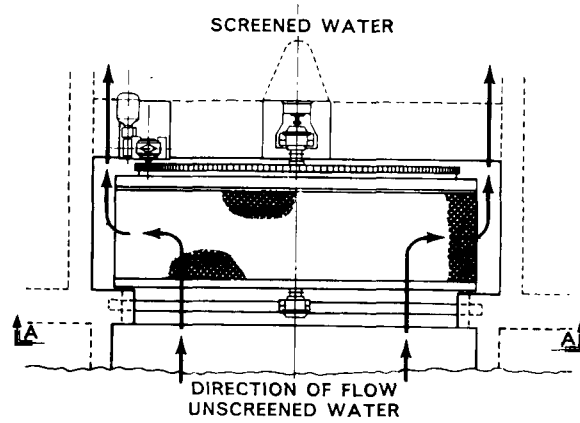
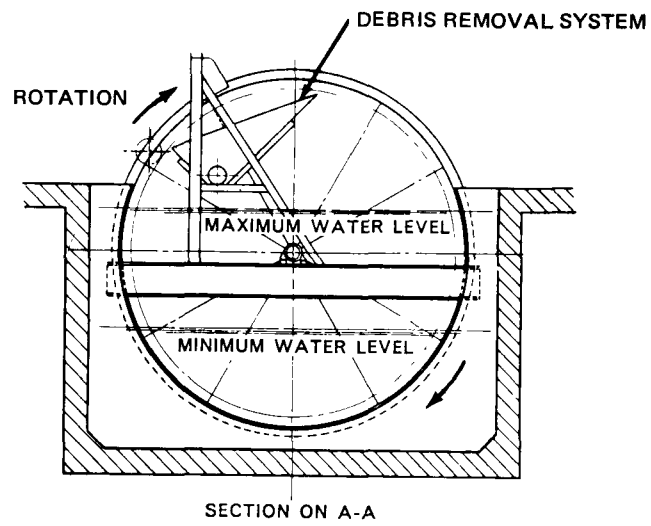
In European practice the term "drum screen" covers a much broader range of designs. For the purposes of this brief review the terms "drum" and "cup" are generally interchangeable, depending on each manufacturer's specific definition. Many of these are used extensively in major powerplant intakes and are highly regarded for their effectiveness in water cleaning and their serviceability. None has been designed, however, with the welfare of fish in mind. A few appropriate modifications have been made to lessen environmental impact, but in general this facet of water screening has not been given much attention. The following types are readily available and often used:

- a. Figure III-35, single entry cup screen, where the water enters at the end (side) of a large rotating drum and passes out through screen mesh on the periphery. It is limited in size to about 9 m (30') in diameter because of the cantilever nature of the shaft support.
- b. Figures III-36 and III-37, double entry cup screen, where the water enters the rotating drum from both ends (sides) and passes out



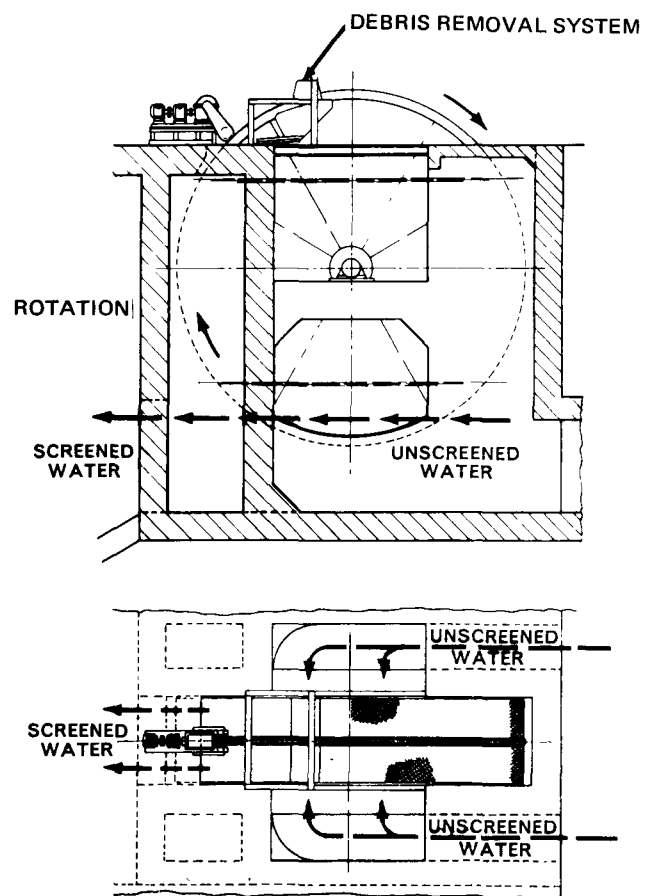
FISH BYPASS STRUCTURE

FIGURE III-34



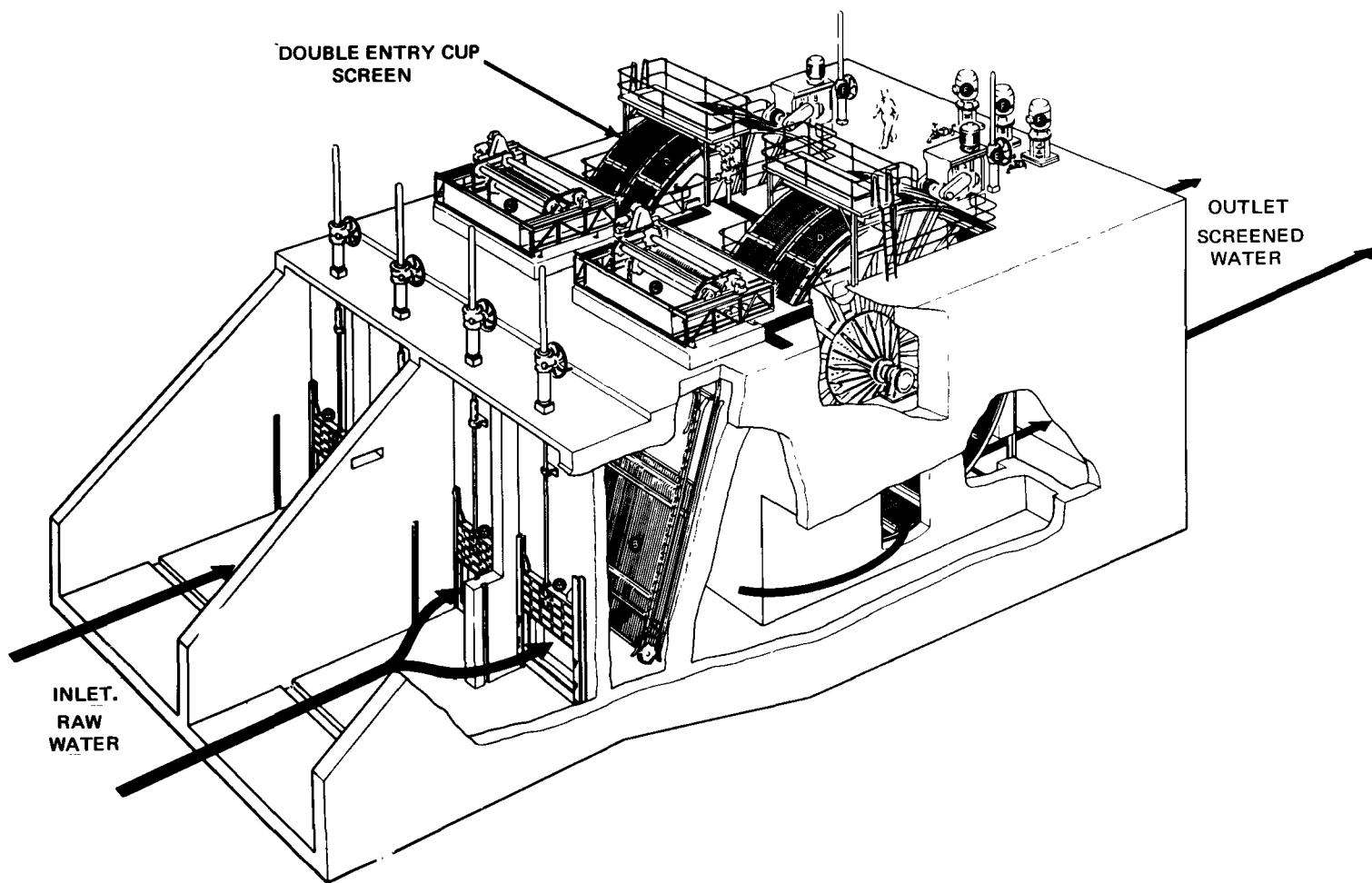
**SINGLE ENTRY CUP SCREEN**

Figure III-35



**DOUBLE ENTRY CUP SCREEN**

Figure III-36



**SCREEN STRUCTURE WITH  
DOUBLE ENTRY CUP SCREENS**

Figure III-37



through the mesh on the periphery. These screens have been made as large as 18.3 m (60') in diameter. Efforts have been made to provide oversize debris lifting buckets to carry fish in water up to the debris removal system and trough at the top of the drum travel.

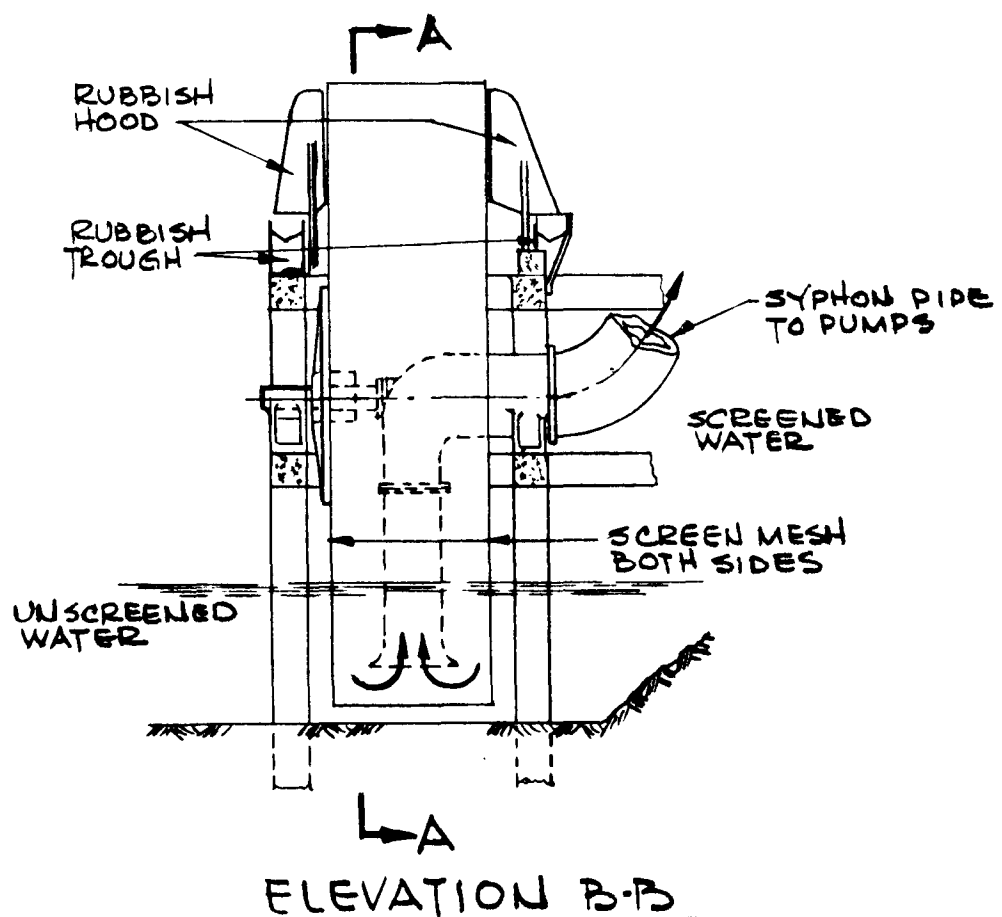
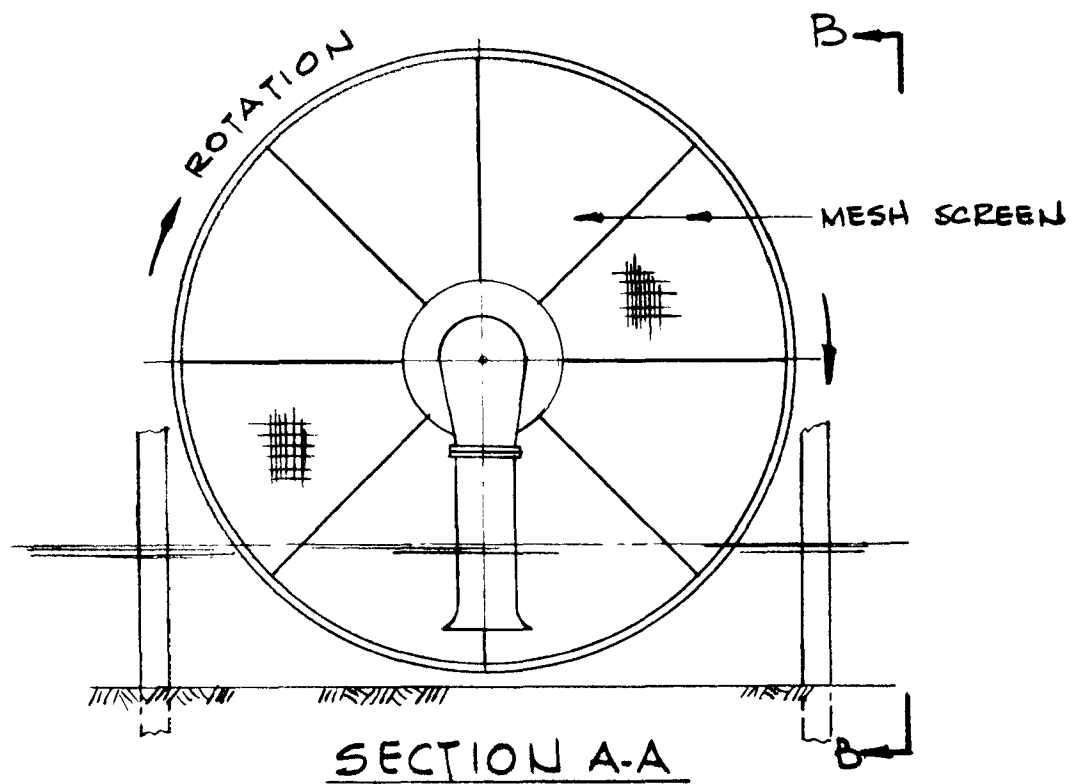
c. Figure III-38, a double entry drum screen where the screen mesh covers the ends (sides) of the drum and the periphery is closed. Water enters the sides and also leaves one side through a pipe around which the drum rotates. This screen rests on piers without a surrounding concrete structure, a mounting which permits water flow around all sides and which thus provides escape routes for fish. In this respect the setting is similar to the double entry vertical traveling screen offered by a U. S. manufacturer and shown in Figure III-25. Screens of this type cannot be cleaned efficiently because of the tendency for the debris to fall back into the raw water as the screen rises.

The structure required to mount drum or cup screens is substantially larger and more costly than the vertical traveling screen structure designed to handle the same quantity of water under the same conditions. They are reputed to be easier to maintain (the horizontal shaft is located above normal water level), there are fewer mechanical parts and there is no possibility of carryover of debris into the circulating water system.

#### Rotating Disc Screen

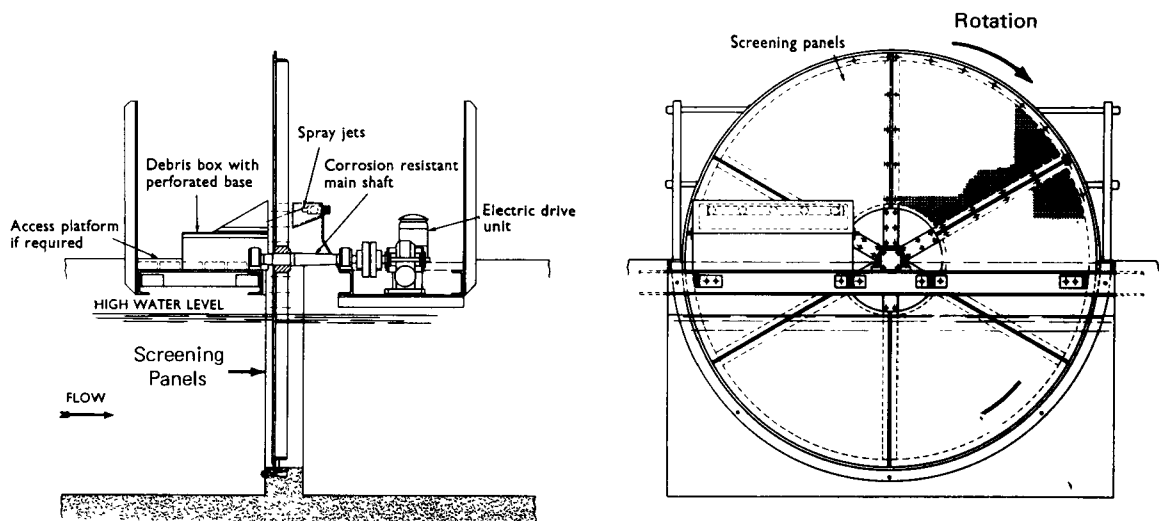
Figure III-39 shows a typical rotating disc screen, a type which is suitable only for relatively small flows and small water level variations. The screen mesh covers a flat disc set at right angles to the water channel. The disc rotates around a horizontal axis, bringing the dirty screen face above water where high pressure sprays wash the debris into a trough similar to that used for conventional traveling screens. It has a minimum number of moving parts and is thus inexpensive to buy and maintain. The circular screen shape makes inefficient use of available area of the incoming water channel. No more than about 35% of the total screen face is being used at any one time.

Such a screen has no advantage over other common screens from the fish protection point of view. It also has most of the drawbacks, including probability of fish impingement, the need for high pressure sprays to remove fish and debris and the need for a very large screen structure to limit screen approach velocities to those now being considered for fish survival.

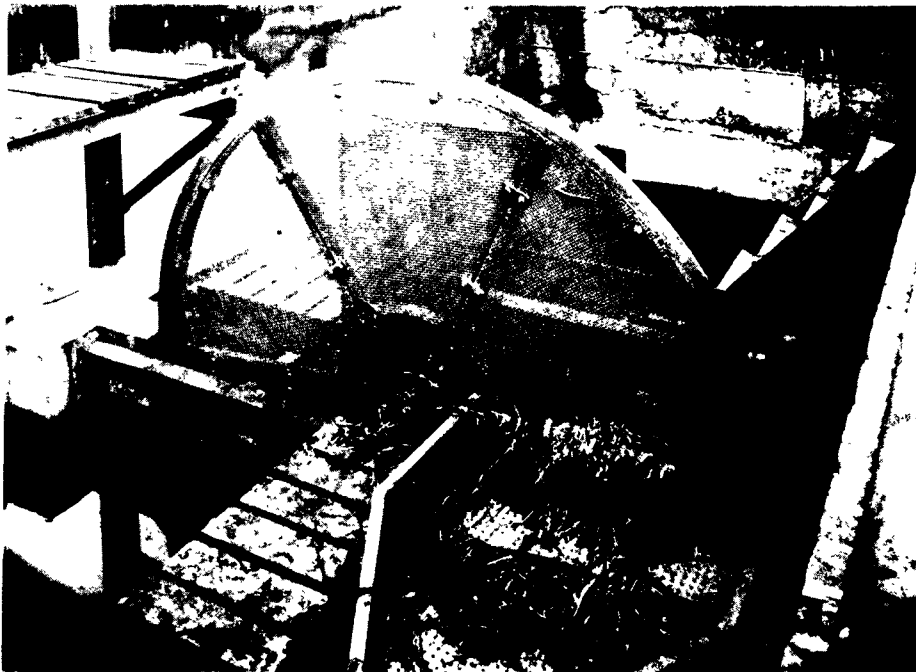


DOUBLE ENTRY DRUM SCREEN OPEN WATER SETTING

FIGURE III-38



**ROTATING DISK SCREEN  
BASIC ELEMENTS**



**ROTATING DISK SCREEN  
IN OPERATION**

**Figure 111-39**

## Miscellaneous Mechanical Screens

Water treatment plants, sewage disposal facilities and various industries requiring service water employ many other configurations of mechanical screens, strainers and filters. Many are designed for much smaller water flows than are required for powerplant circulating water systems. As with most of the screens described in this section they were designed specifically to produce screened water, not to protect fish. Consequently, they do not have features we feel are worth considering for incorporating into facilities being designed with fish protection as a major criterion.

## Fish Handling and Bypass Facilities

In addition to the screening device, other types of systems can influence the design of intake structures. The need for fish bypass systems in conjunction with some of the screening systems has been discussed in previous sections. Fish handling and bypass equipment can also be used to return impinged fish back to the waterway. Relatively little work has been done on developing these facilities for incorporation into existing industrial intakes. Most of these types of facilities have been installed at irrigation diversions operated by the U. S. Bureau of Reclamation and the State of California. A great deal of work has been done in the Pacific Northwest in diverting salmon around hydroelectric impoundments. As more powerplant intake designers become aware of the need for fish handling and bypass facilities, they will have a greater impact on the intake configuration employed.

Fish bypass and handling facilities of interest include the following:

- fish pumps
- fish elevators
- "crowding devices"
- bypass conduit
- modifications to vertical traveling screens

## Fish Pumps

Fish pumps have been used for many years. The rotary type of pump with open or bladeless impellers seem to cause the least amount of damage to fish. However, all rotary pumps are not necessarily suitable for pumping all types of fish.. The use of hydraulic eductor pumps was thought to be ideal for fish pumping. However, fish passing through such eductors encounter high pressures which seem to cause more damage than mechanical pumps <sup>13</sup>.

## Fish Elevators and "Crowding Devices"

Several types of bucket elevators have been tested in elevating fish on a batch rather than a continuous basis. One such system was tested at the Tracey Pumping Station by the National Marine Fisheries Service in conjunction with the horizontal traveling screen. This system is shown in Figure III-40. The fish are first concentrated over the lower bucket by use of a crowding device and then raised and dumped into the fish trough for bypass. This type of system might be quite useful at intakes where fish might congregate in quiescent zones created by such things as curtain walls and other intrusions into the screen channel.

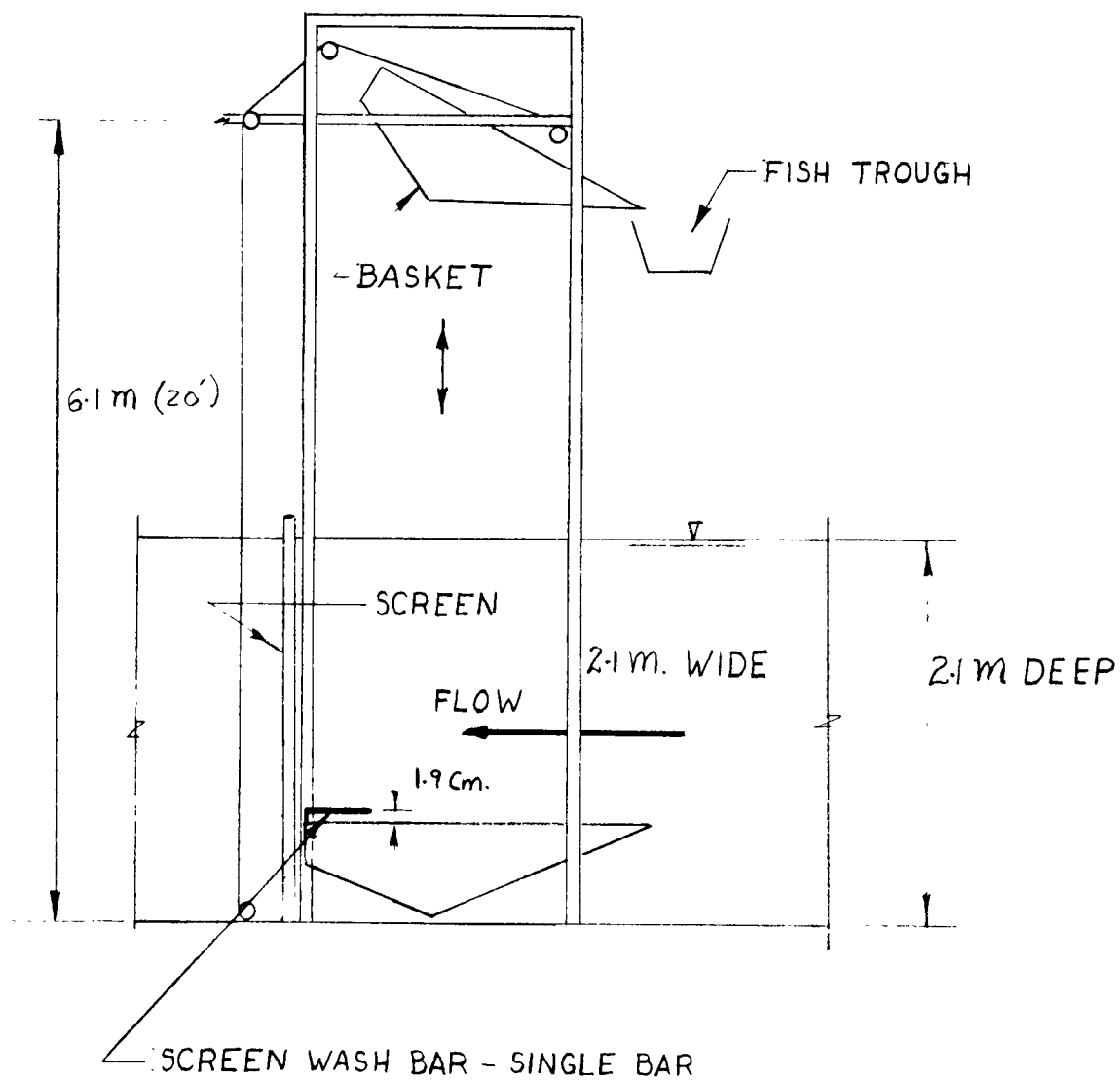
## Fish Bypass and Transport Facilities

After being concentrated and removed from the screen well, the fish require a means of conveyance back to a hospitable environment the waterway. The design of the bypass system should minimize the time that the fish is out of water and insure safe and rapid return to the waterway at a location sufficiently removed from the intake to prevent the recirculation of fish and reimpingement. Once the fish have been raised to an elevation above that of the waterway they can be discharged to a trough or pipe for gravity return to the waterway. Care must be taken in the design of the fittings and elbows of the discharge conduit to prevent undue stress on the fish. Furthermore, discharge of fish should be made to a hospitable environment.. Considerable experience in designing and operating long fish bypasses for both upstream and downstream migrant salmon has been obtained in the Pacific Northwest. The technology exists for these types of systems. Where conditions do not permit direct hydraulic conveyance, fish can be trucked back to the waterway. Trucking fish over long distances does not seem to cause unacceptable mortalities. Both trucking and airlift have been used for seeding waterways with fish. Reference 13 has some suggested criteria for trucking fish.

## Modification To Existing Traveling Water Screens

The fish bypass facilities described above were intended to remove fish from the intake structure to prevent impingement. An interesting example of modifying an existing traveling water screen to bypass impinged fish is described below.

The installation is a major nuclear station on the eastern seaboard (plant no. 5111). The station is located above the river and 2.7 kilometers (1.7 miles) from the intake. Water is pumped from the river into the "high level" canal from which it flows by gravity to the screens located at the plant. Apparently juvenile fish pass through the pumps and become entrapped in the canal for subsequent impingement on the screens. The first modification made was to connect the screen waste flow to the plant discharge canal using a 45 cm (18") polyethylene



FISH BASKET COLLECTION SYSTEM

FIGURE DII-40

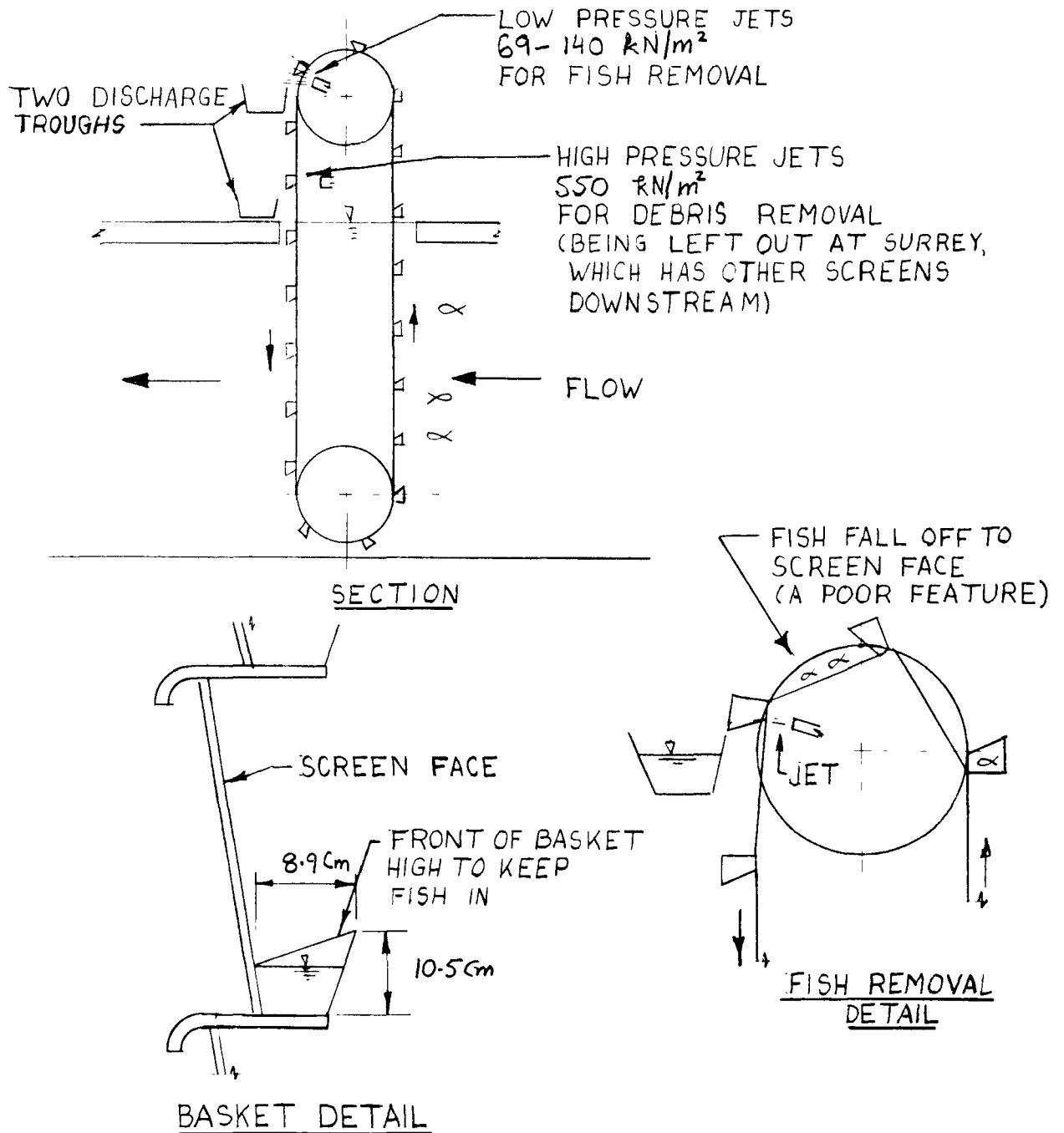
pipe. Tests made on the system in this condition, showed that this transport system minimized mortality when the screens were operated continuously during the cold water period but that damage was above acceptable levels during the summer. Mortality was primarily caused by high screen wash water pressure and by recycling of fish at the air-water interface of the screen front. It was concluded that "recycling" was a higher mortality factor in the summer than in the winter because the more active fish would flip back into the water after the screen basket cleared the water surface and be reimpinged. This would be repeated until the fish were dead or weak enough to remain on the narrow lip until the basket reached the wastewater stream.

The modifications are shown schematically in Figure III-41. They consisted of bolting a 10 gauge steel trough on the lip of the conventional screen baskets. The troughs were positioned to maintain a minimum of 5 cm (2") of water depth during the time of travel between the water surface and the head shaft sprocket. The new screens are designed to be continuously operated, thus reducing the time of any possible impingement of fish on the screen to two minutes or less.

The screen wash system was also modified to minimize damage caused by the standard high pressure jets. As the screen travels over the head shaft sprocket, the fish will be spilled onto the screen surface. On further rotation, fish will slide down the screen and be deposited into a trough of running water for transport back to the river away from the intake structure. A low pressure screen wash system has been incorporated into the design to aid in removing crustaceans and returning them to the river.

Since these modifications are only now being installed at the plant, no data on the performance of these modifications are available. No prior model testing was performed and a prototype will be used to verify the capabilities of the system. If reasonable efficiencies in bypassing fish safely are obtained, this type of system might be utilized to modify other intakes where impingement is a problem. The system could be installed on most existing conventional intakes, and the cost is roughly 30% of the initial screen cost plus the cost of the bypass line. The intake is not substantially changed.

One disadvantage of this system may be a lack of acceptance on the part of some of the regulating agencies. We noted a problem regarding discharge of debris after it has been removed from the waterway. As can be seen from the figure, there is no way to avoid discharging a portion of the debris in the fish bypass channel. Stringent restrictions may prevent the use of this system at many locations.



MODIFIED VERTICAL TRAVELING SCREEN

FIGURE III-41



## Intake Structure Designs

In addition to special biological considerations, the size and shape of an intake structure should be determined to a large extent by the following factors:

The quantity of intake flow

The type of screening system used and allowable water approach velocity

The relationship of the intake to the water source

Miscellaneous factors such as need for storm protection, avoidance of excess sedimentation, ice control

Since most existing powerplant intakes employ the conventional traveling water screen they will be referred to as "conventional" intakes, implying that they are equipped with such a screen.

### Conventional Intakes

There are three general classification of conventional intake structures based on the relationship of the intake to the water source. These are as follows:

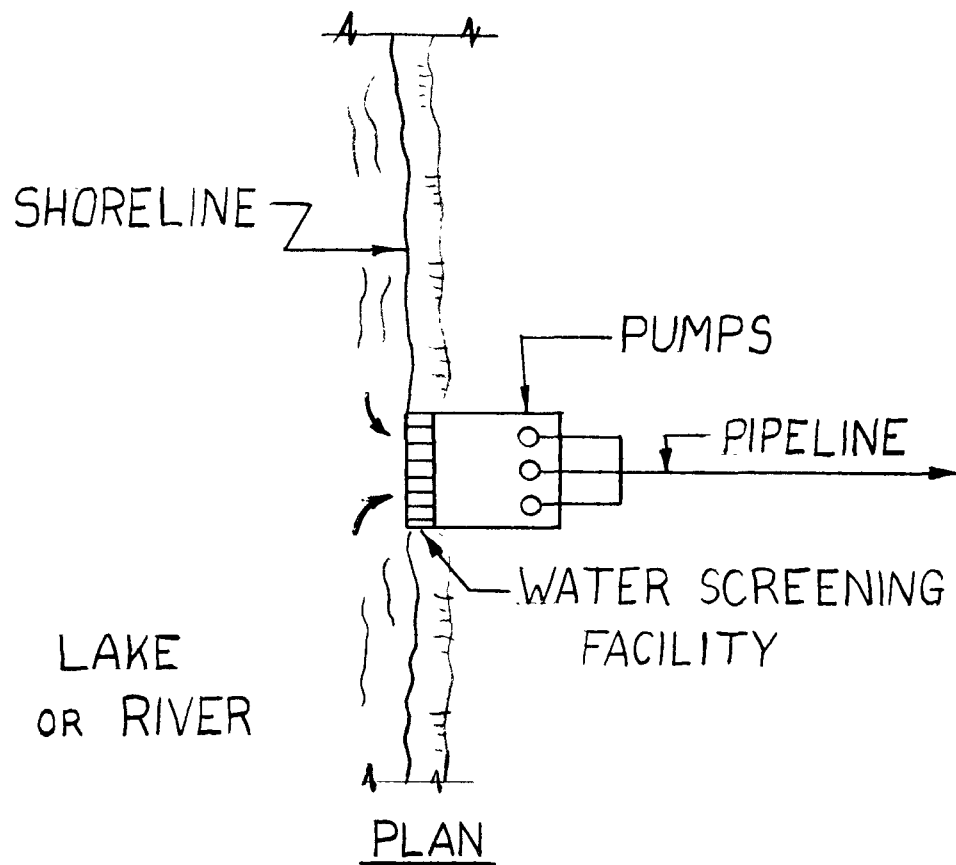
Shoreline intake

Offshore intake

Approach channel intake

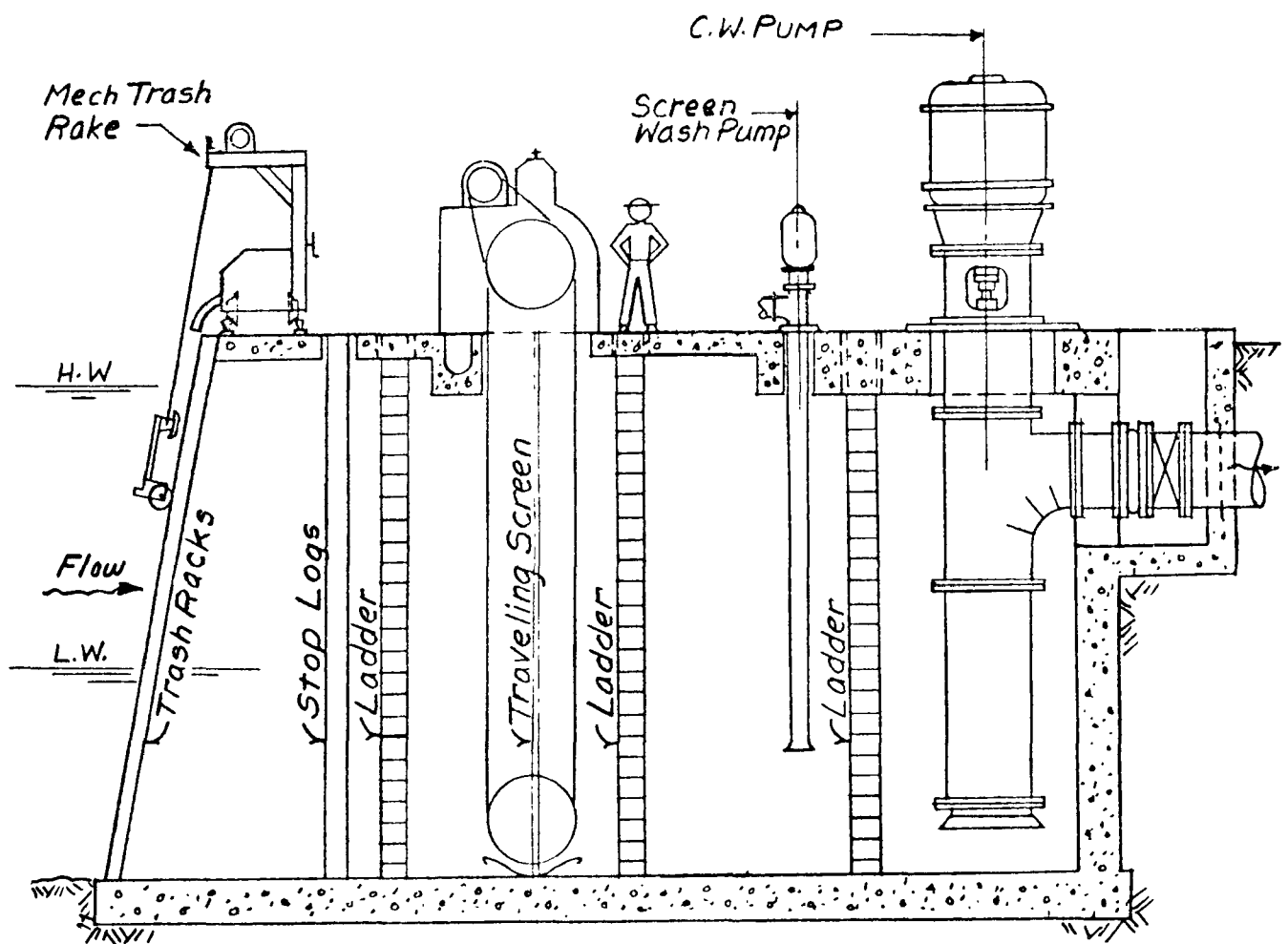
### Shoreline Intake

The most common intake arrangement is the combination of inlet, screen well and pump well in a single structure on the edge of a river or lake. The best designation for this installation is "pump and screen structure", to clearly distinguish it from individual structures also commonly used. A plan view of this type of structure is shown in Figure III-42. A cross section of the shoreline structure is shown in Figure III-43. Note that the water passes (in order) the trash rack, the stop log guide and the traveling water screens on its way to the pumps. This type of structure is used where the slope of the river bank is relatively steep and there is relatively little movement of the water edge between high and low water. A variation of shoreline structure design is shown in Figure III-44. Here a skimmer wall is used to insure drawing in of cooler lower strata waters. Curtain walls, used primarily to protect trash racks and screen from logs and ice, can also be used to draw in cooler water.



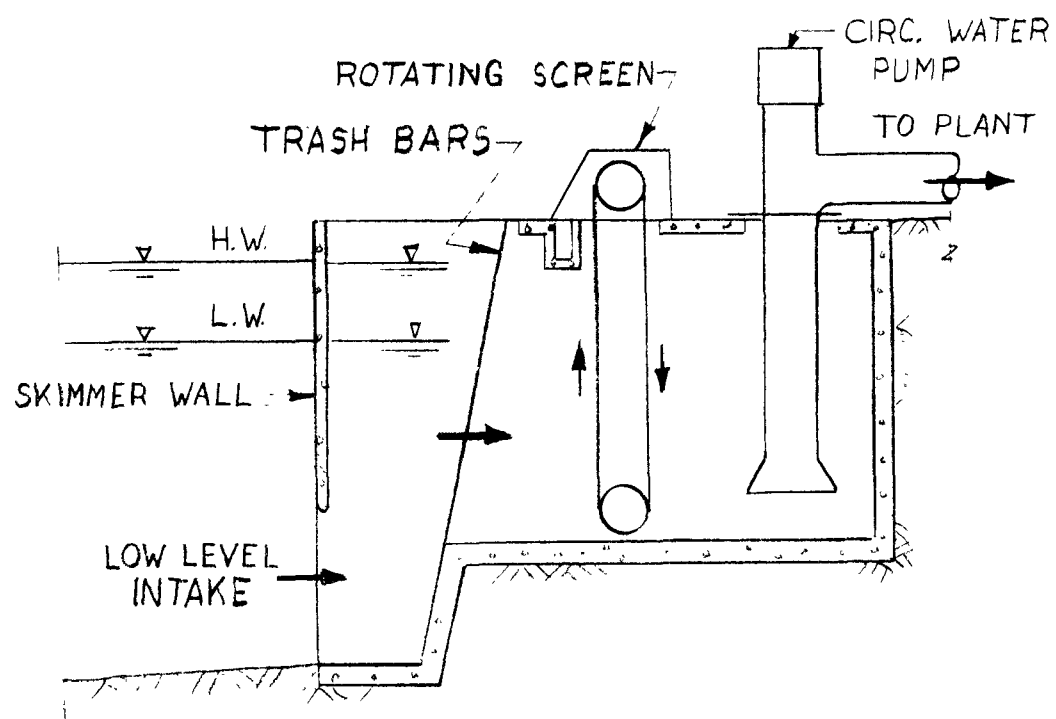
SHORELINE PUMP AND SCREEN STRUCTURE

FIGURE III-42



CONVENTIONAL PUMP AND SCREEN STRUCTURE

FIGURE III-43



PUMP AND SCREEN STRUCTURE WITH SKIMMER WALL

FIGURE III-44

## Offshore Intake

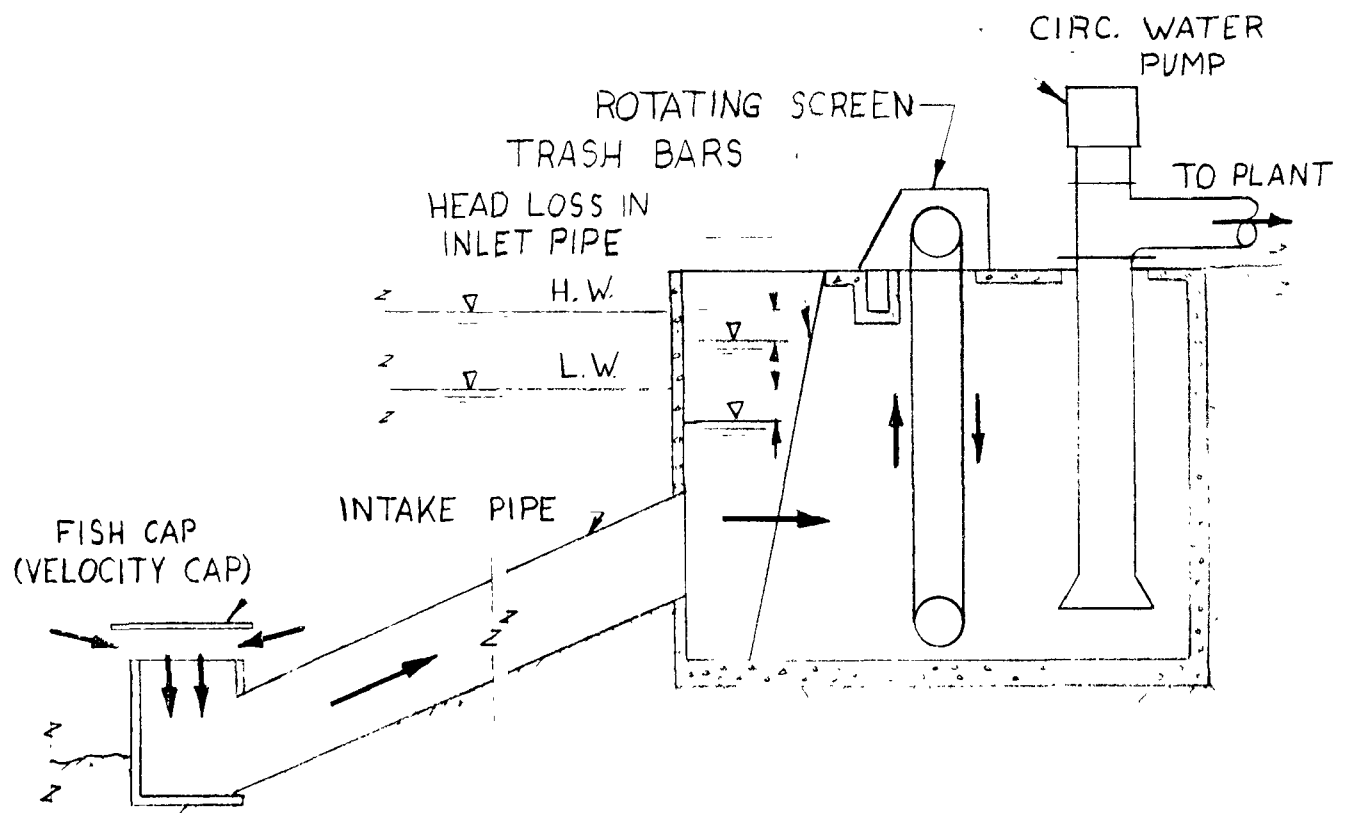
The offshore design separates the inlet from the pump well. This type of intake is used where there is a significant lateral movement in the waterway between high and low water where there is a particular technical or environmental reason for utilizing the water supply at a distance from shore. Figure III-45 and III-46 show two similar concepts of such an intake. The design shown in Figure III-46 employs a siphon. The term siphon here refers to a gravity pipe placed above the level of the water and thus flowing under vacuum. The provision of fine screening facilities at the conduit inlet offshore is often impractical because of construction difficulties, because of the navigational hazards it presents or because of difficulty of access for operation and maintenance. Therefore, the fine screens are usually located in a shore structure as shown in both Figure III-45 and III-46. Flow velocities are commonly rather high (say 1.5 to 3.0 mps) in the inlet pipeline to reduce its cost and most species of fish would not be able to escape entrapment in the system after entering it. Therefore a considerable amount of interest centers on the inlet structure as the place to guard against fish entrapment in an offshore intake. Since offshore intakes can have screens onshore, diversion weirs or crowders can be used as a second line of control to remove fish prior to possible interaction with the screen.

## Approach Channel Intake

In this type of intake, water is diverted from the main stream into a canal at the end of which is the screening device. This type of intake is shown in Figure III-47. Channel intakes have often been used to separate the plant intake and outfall for the control of recirculation effects, to permit location of the pump structure where it can more easily be constructed or to reduce total system friction losses and costs by replacing high friction, high cost pipe with low friction, low cost canals. It may also be used to remove the intake from the shoreline for aesthetic reasons which are discussed elsewhere. Fish will tend to congregate in these approach channels and thus increase the incidence of entrapment at the screens. A modification of the approach channel concept is shown in Figure III-48, where the screen structure has been placed at the entrance to the channel and becomes essentially a shoreline intake, without the fish entrapment hazards inherent in the channel scheme. However, care must be taken with the shoreline intake to avoid velocities which could increase impingement.

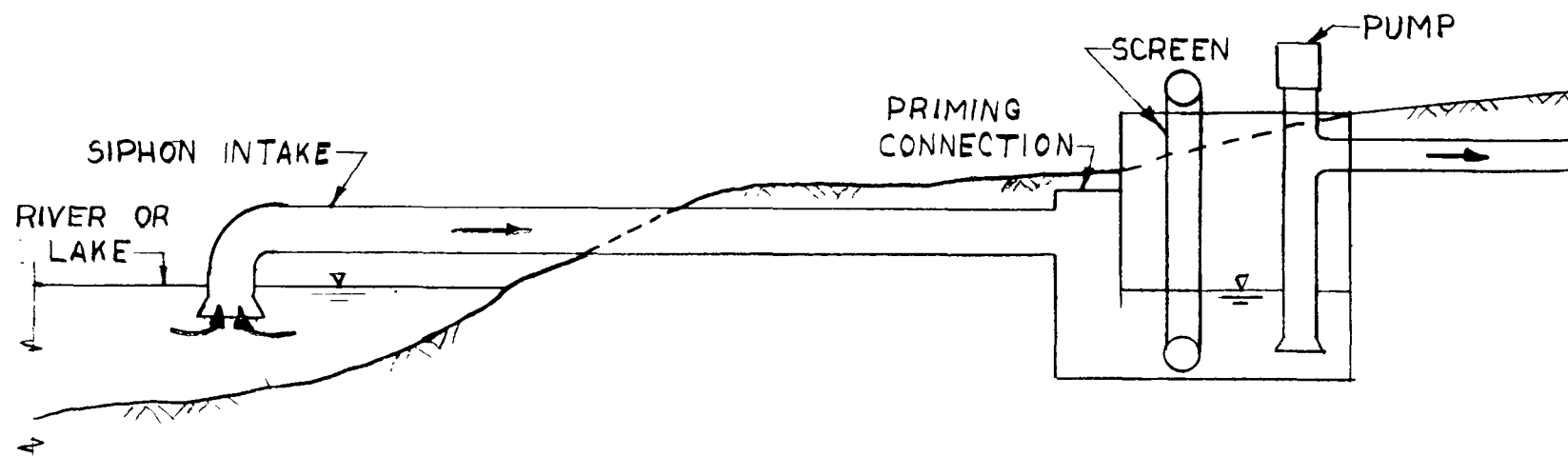
## Conventional Intake Design Considerations

In addition to special biological considerations, other important considerations in the design of conventional pump and screen structures are the following:



PUMP AND SCREEN STRUCTURE WITH OFFSHORE INLET

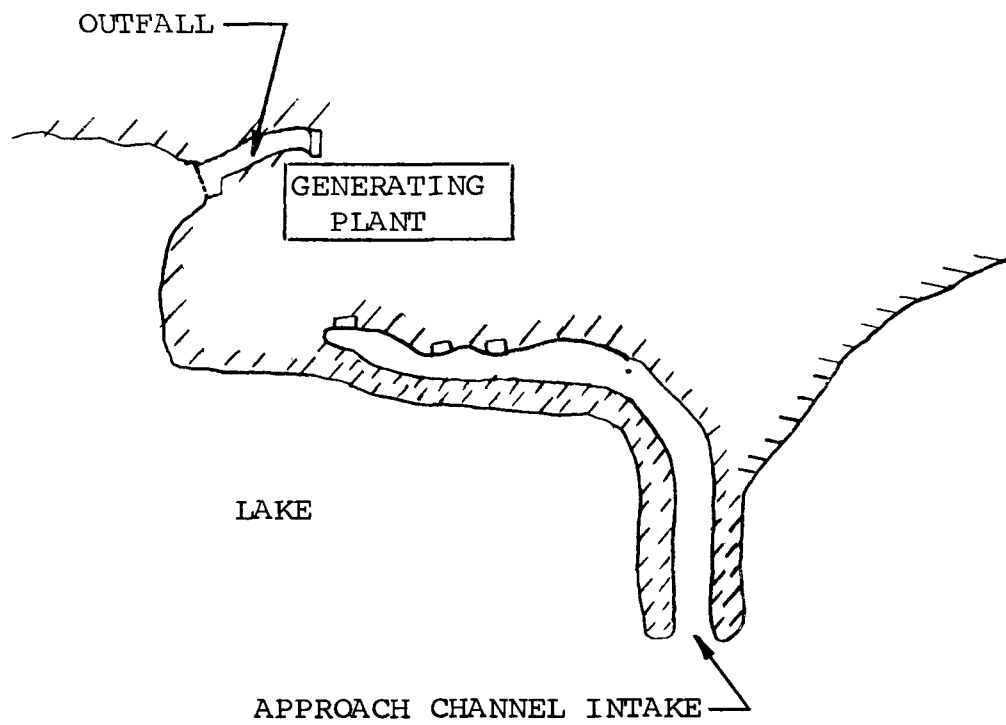
FIGURE III-45



PROFILE THROUGH WATER INTAKE

SIPHON TYPE

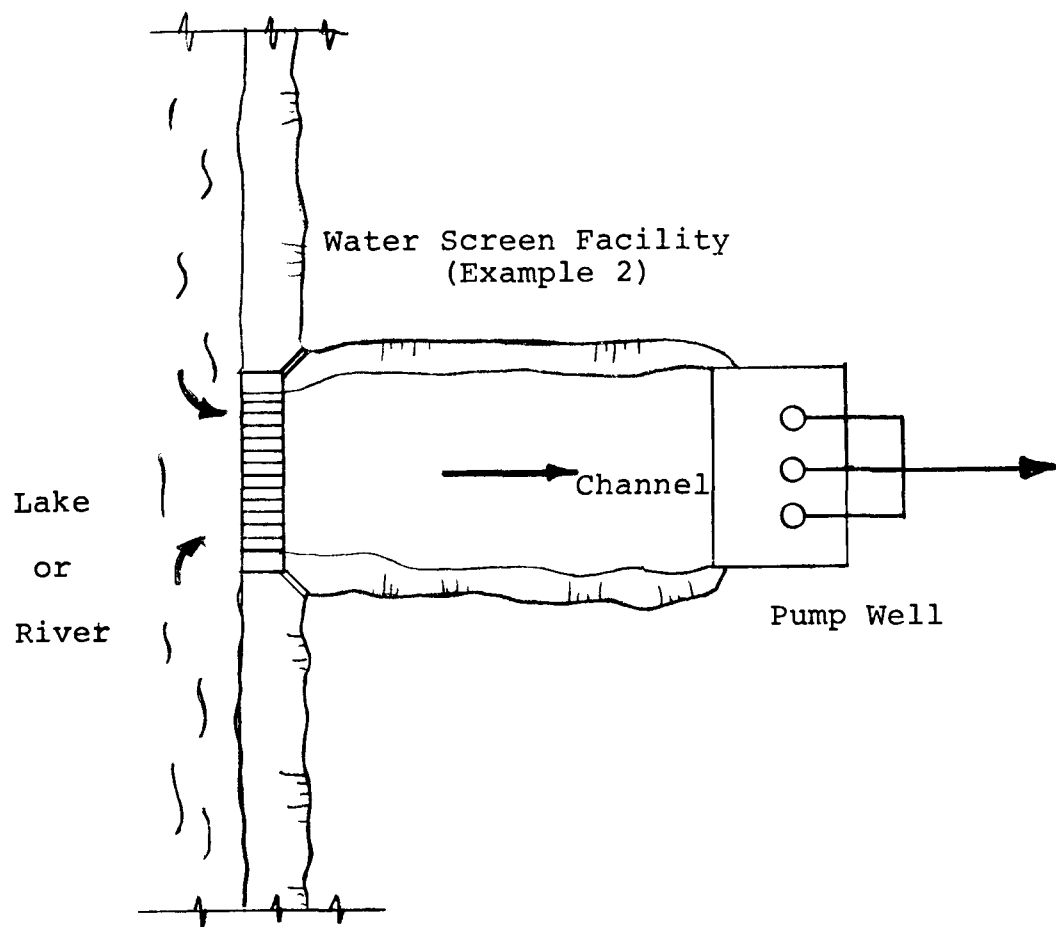
FIGURE III-46



APPROACH CHANNEL INTAKE

FIGURE III-47





SCREEN LOCATION - CHANNEL INTAKE

FIGURE III-48

Water level variations

Inlet design

Screen placement

Screen to pump relationships

Flow lines to the pump and the pump chamber configuration

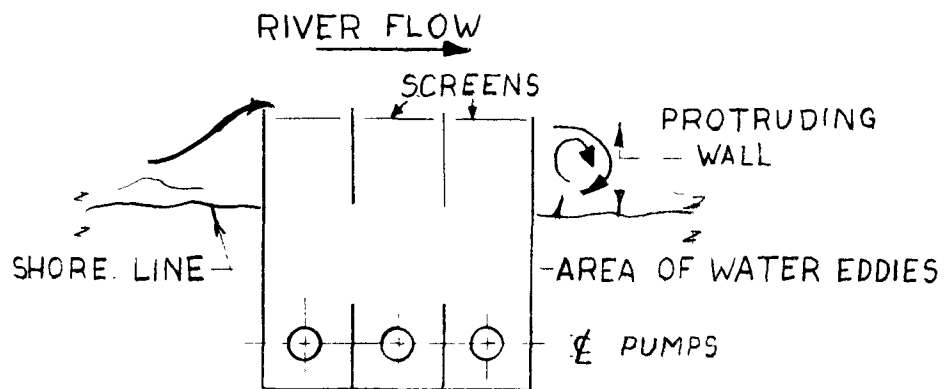
Ice control provisions

Access to the structure for operation and maintenance

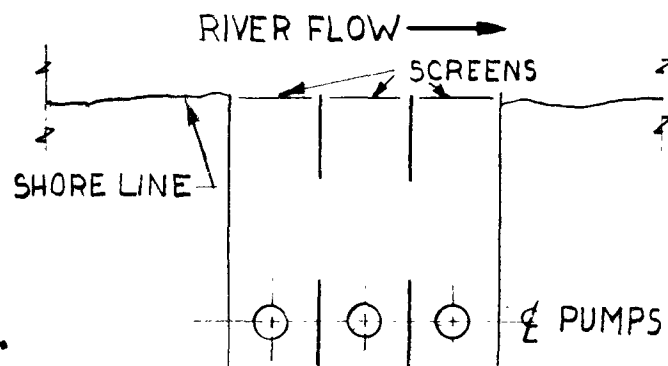
Inlet safety design considerations will be different for each of the three classifications of conventional intake structures. For the shoreline intake an important consideration is to avoid significant protrusions into the waterway. This is shown diagrammatically in Figure III-49. The top sketch shows an example of undesirable intake design where the side walls of the intake structure protrude into the waterway and create eddy currents on the downstream side of the intake. Fish are sometimes found concentrated in these areas, a situation which may increase the possibility that they will become entrapped in the intake. The bottom sketch shows a more suitable design with no portion of the intake structure protruding into the flow. Of course, this would not be significant at structures drawing water from a lake shore location where cross flow velocities are negligible.

#### Screen Placement

Most conventional intakes are designed with the traveling water screens set back away from the face of the intake between confining concrete walls. As shown in the top sketch of III-50, this creates a zone of fish entrapment between the screen face and the structure entrance. Small fish will not swim back out of this area. The bottom sketch of the same figure shows an alternative screen placement with screens mounted flush with their supporting walls. The trash rack facility is so designed that there is an open passage to the waterway directly to both left and right of the screen face. In this design, there is no confining screen channel in which the fish can become entrapped. Figures III-51 and III-52 show two recent designs of "flush" mounted screen structures. The first is the screen and pump for a major fossil-fueled plant in the Northeast (plant no. 3601). Figure III-52 is the pump and screen structure for a major fossil-fueled plant on the west coast (plant no. 0610). Note that the screens are mounted flush with the shoreline in each case and that fish passageways are provided in front of the screens. In these designs there is no provision for stop logs to permit dewatering the screen wells. Extending the screen support walls to provide stop log guides would defeat the "flush" mounting principle.



POOR DESIGN



GOOD DESIGN

### SHORELINE INTAKE STRUCTURE

FIGURE III-49

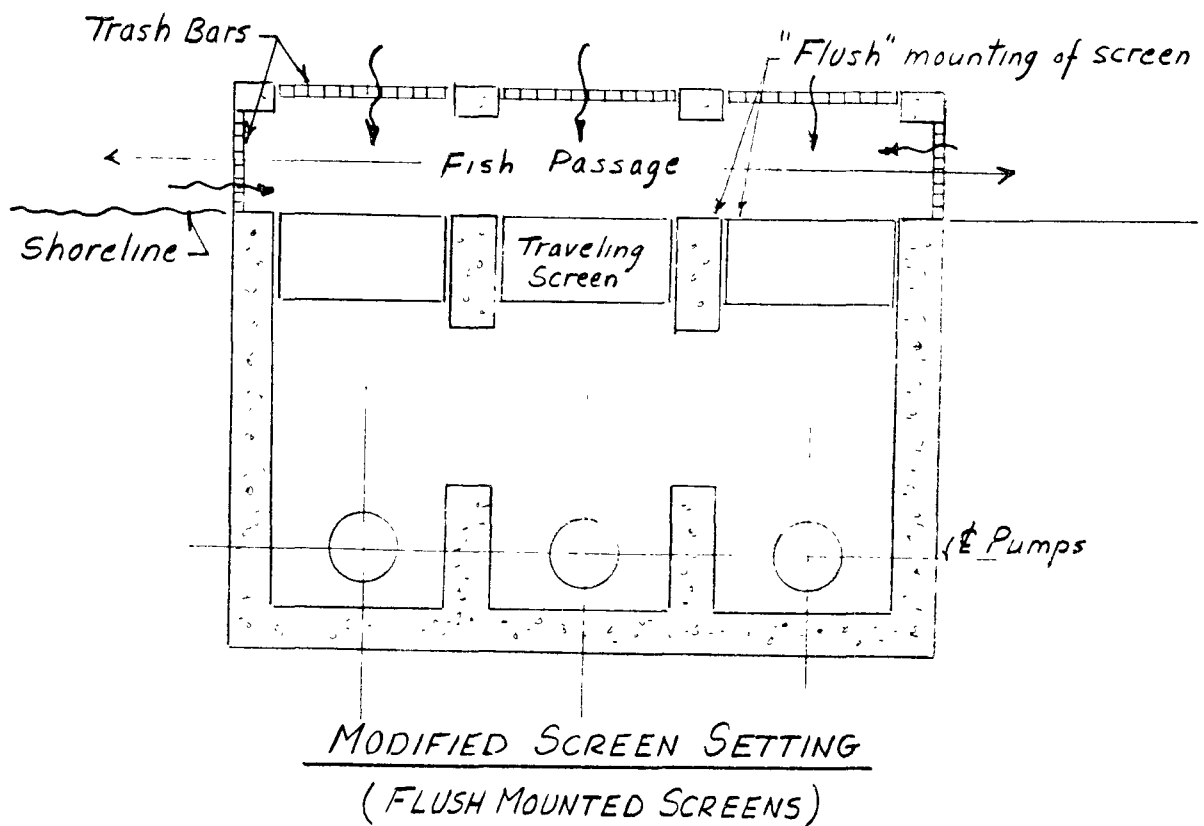
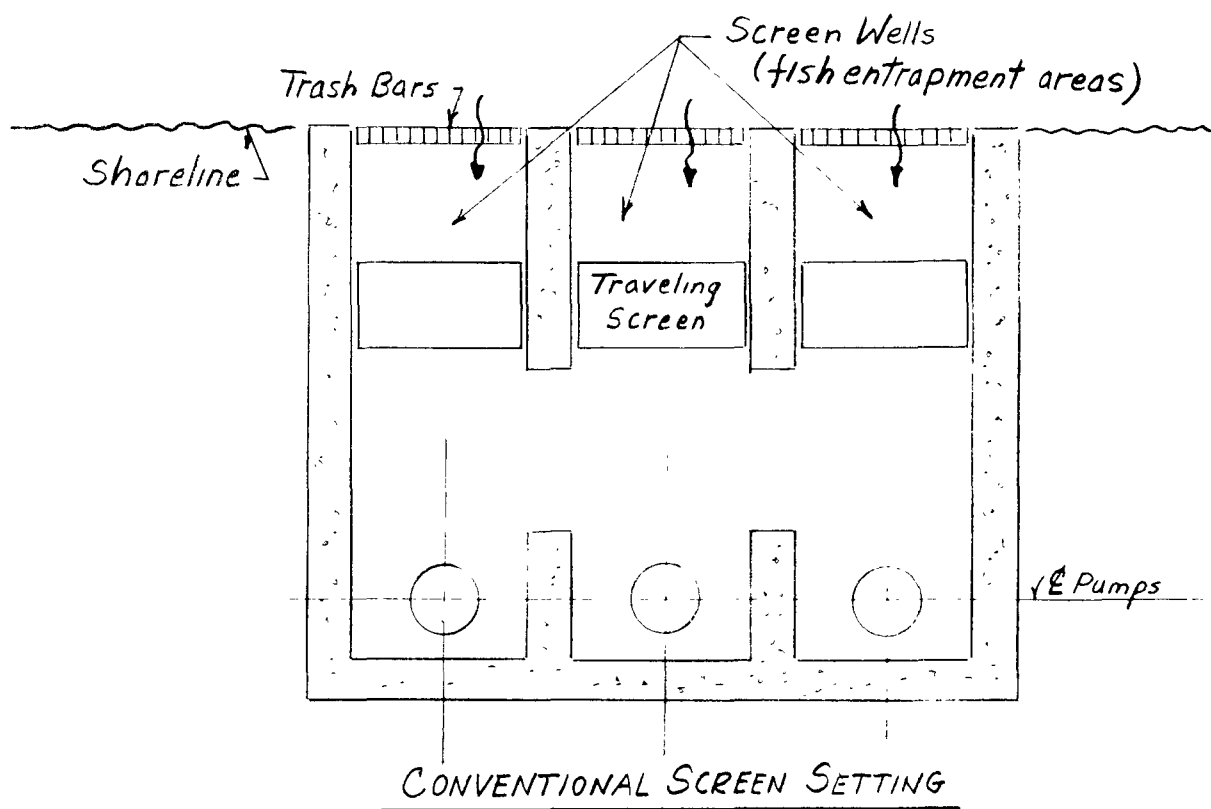
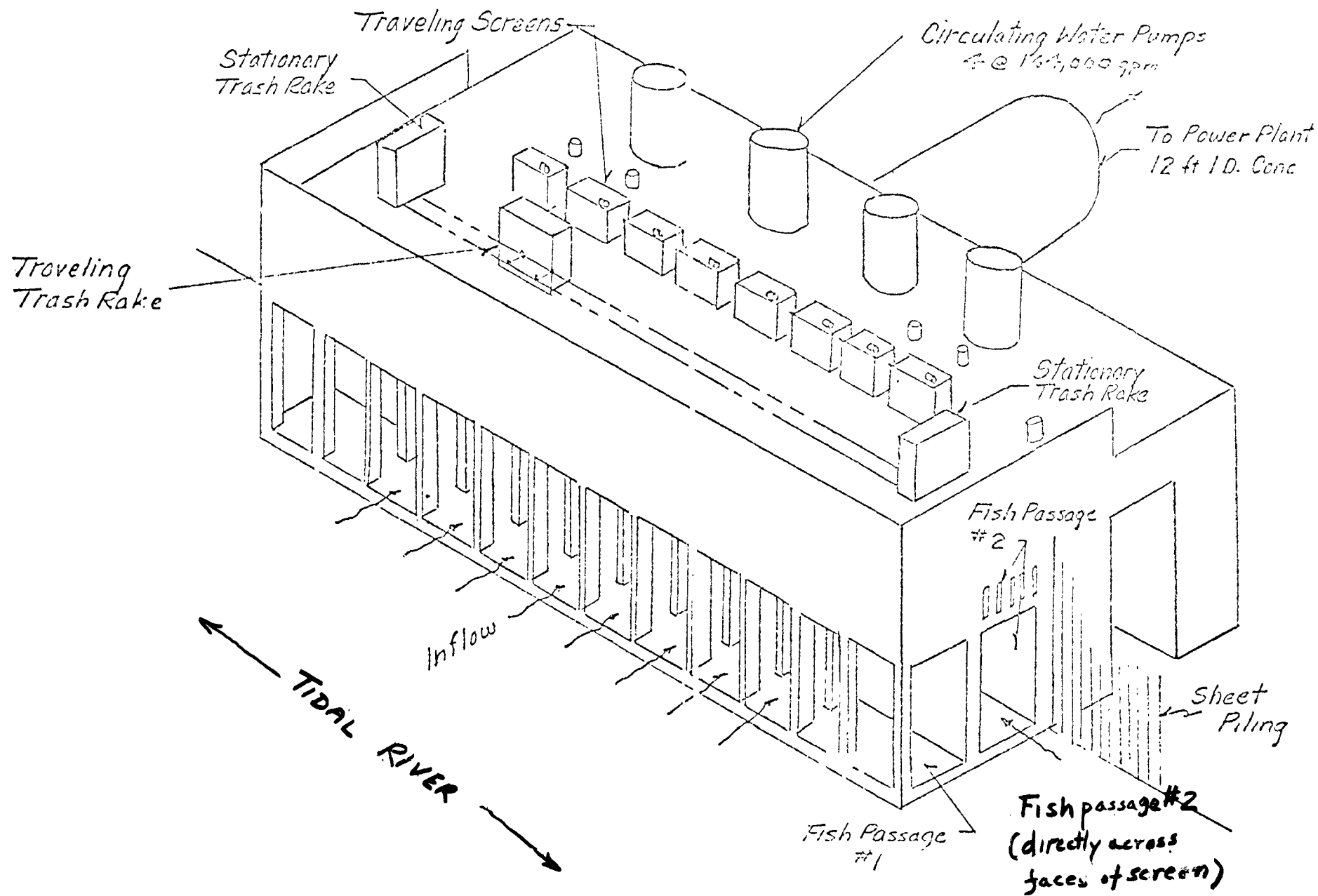
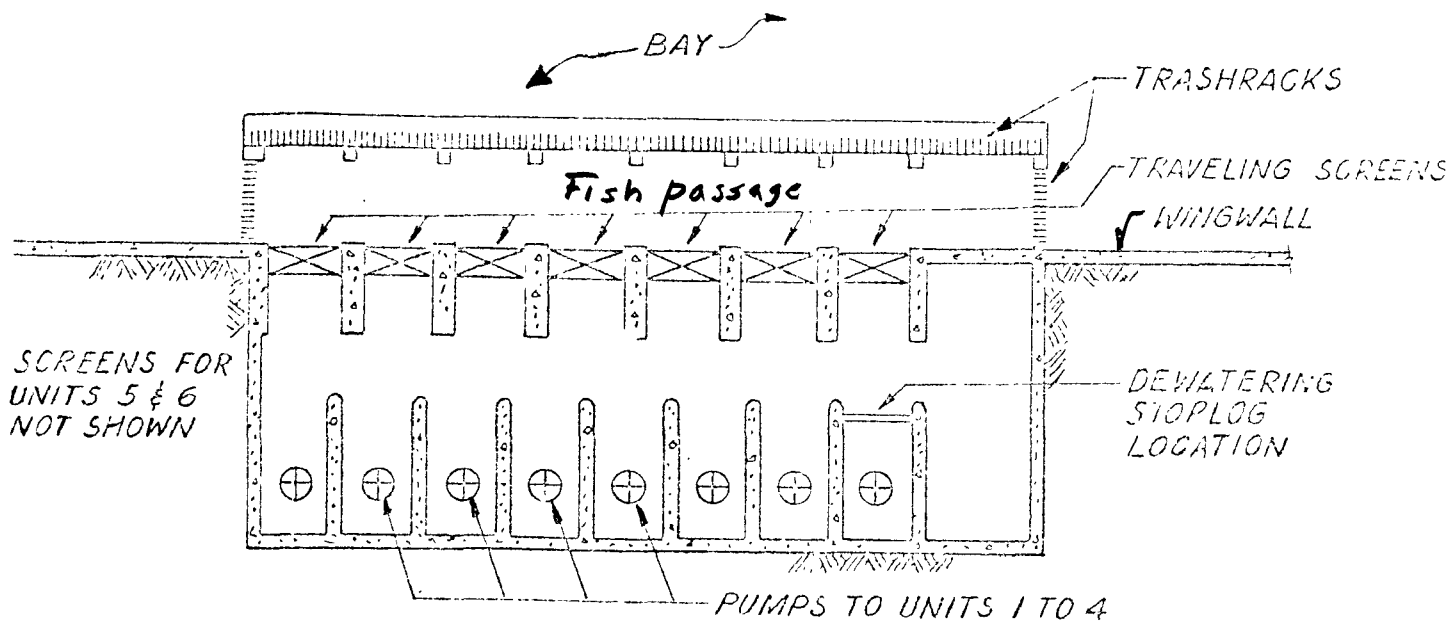


FIGURE III-50

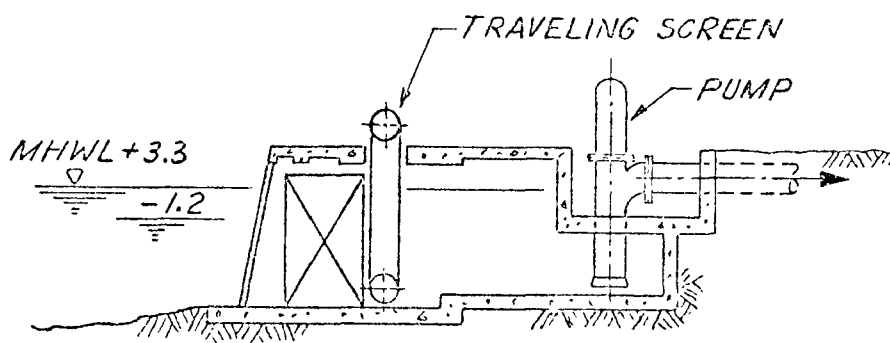


PUMP AND SCREEN STRUCTURE

FIGURE III-51



SECTION - PLAN



SECTION-ELEVATION

**PUMP AND SCREEN STRUCTURE**

**FIGURE III-52**

Where channel sections leading to the screens cannot be avoided due to some unusual condition, proper design of the screen supporting piers can reduce the fish entrapment potential of the area. This design consideration is shown in Figure III-53. In Figure III-53A an example of incorrect pier design is shown. The pier which protrudes into the flow presents a barrier to fish movement. They cannot make the turns required to escape the screen. Figure III-53B shows a much more suitable design. With the extended portion of the pier eliminated, the fish can move sideways and rest in the relatively still water near the face of the pier.

#### Maintaining Uniform Velocities Across the Screens

It is essential in good screen structure design for environmental protection to maintain uniform velocities across the entire screen face. When flow is not uniform across the screen, the potential for fish impingement is increased.

Figure III-54 tabulates a typical run of a model test series made for a major plant in the northeast (plant no. 3601). The variation in velocities is evident. Flow distribution in many existing intakes is much less uniform than indicated in Figure III-54.

There are several ways in which a non-uniform screen velocity can be created. Figure III-55 illustrates some of the factors which create non-uniform velocities in the screen area. Sketch A of Figure III-55 shows the condition when water approaches the screen structure at an angle. Flow tends to concentrate at the downstream side of the water passage entrance and in some cases may even flow backwards on the upstream side. Sketch B shows the effects of curtain walls projecting into the water passage. Curtain walls similar to that shown here are frequently used to reduce the intake of surface debris or to confine the entering water to a lower and normally cooler strata. The result is not only the creation of non-uniform velocity conditions at the screens, but also the creation of a dead area where fish may become entrapped. They will not usually swim back to safety under the wall. Sketches C and D show the effects of pumps or downstream water passages so located that water is drawn from a limited horizontal or vertical strata as it passes through the screens. Pumps or gravity exit pipes may be too close to the screen or may be offset from the screen center. Hydraulic Institute standards recommend a minimum distance from screen to pump, but this distance is established for suitable pump performance, not for best utilization of the screen area.

The obvious result of the poor distribution of flow through the screens is the creation of local areas of flow velocities much higher than the calculated average design velocities. Entrapment of fish is thus increased.

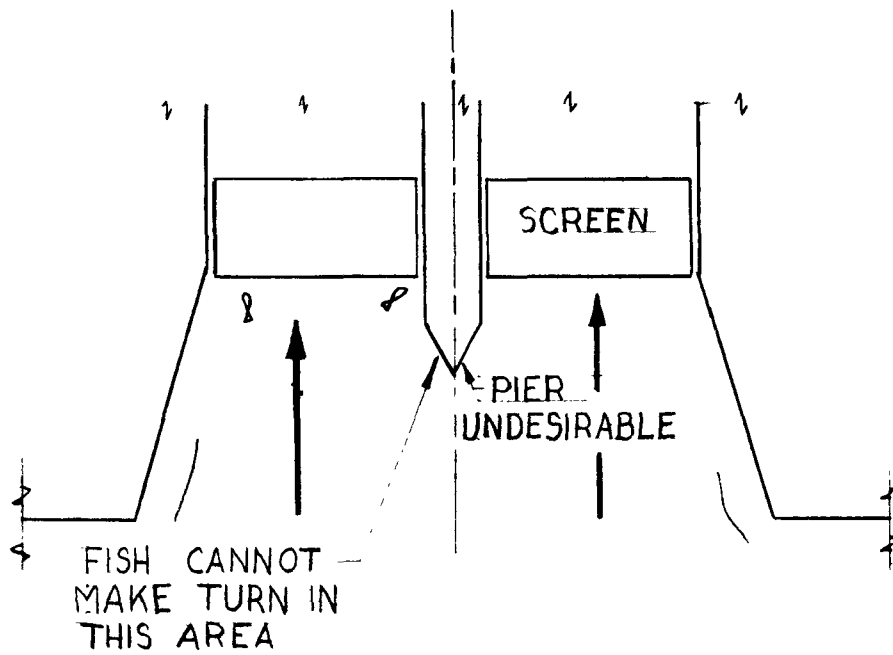


FIGURE A

UNSATISFACTORY DESIGN

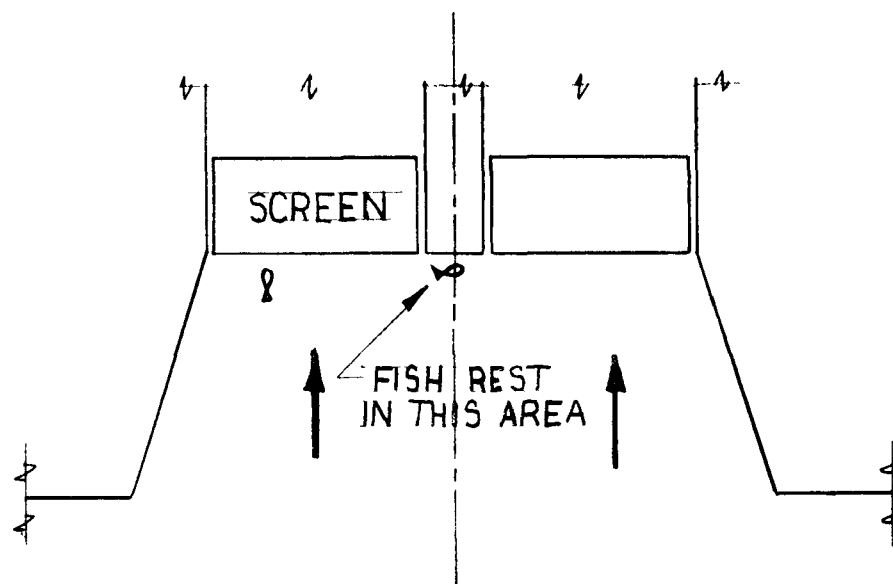


FIGURE B

IMPROVED DESIGN

# PIER DESIGN CONSIDERATIONS

FIGURE III-53



Velocity measurements ( In ft/sec ) at entrance  
of pump Bay No. 3 for the following conditions:

Pumps 1, 2 and 3 In operation; 2 ft/sec river  
flow with the water level of 0', and full wall  
openings.

First cross-section ( upstream from the trash-rake )

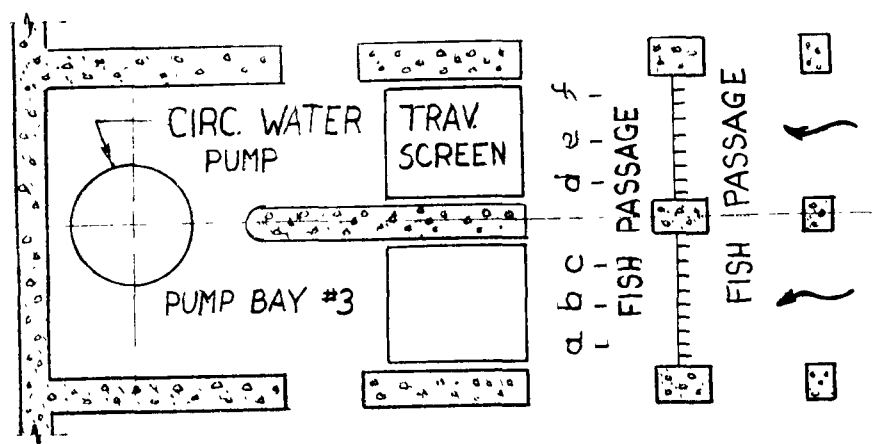
	(a)	(b)	(c)	(d)	(e)	(f)
Near Bottom	0.34 ↑	1.06 ↓	1.12 ↑	0.74 ↓	0.95 ↓	0.75 ↑
Mid-Depth	0.45 ↑	0.93 ↑	1.02 ↓	0.89 ↓	0.75 ↓	0.83 ↑
Near Surface	0.57 ↓	0.67 ↑	0.33 ↑	0.41 ↑	0.31 ↑	(nil)

Second cross-section ( in the fishway )

	(a)	(b)	(c)	(d)	(e)	(f)
Near Bottom	0.39 ↓	0.57 ↑	0.99 ↑	(nil)	0.75 ↑	0.73 ↑
Mid-Depth	(nil)	0.57 ↑	0.95 ↑	(nil)	0.90 ↑	0.80 ↑
Near Surface	0.62 ↑	0.68 ↗	0.87 →	0.77 →	0.95 →	0.72 →

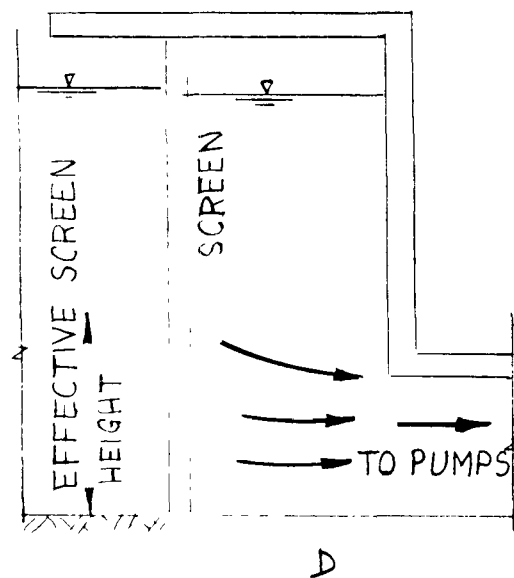
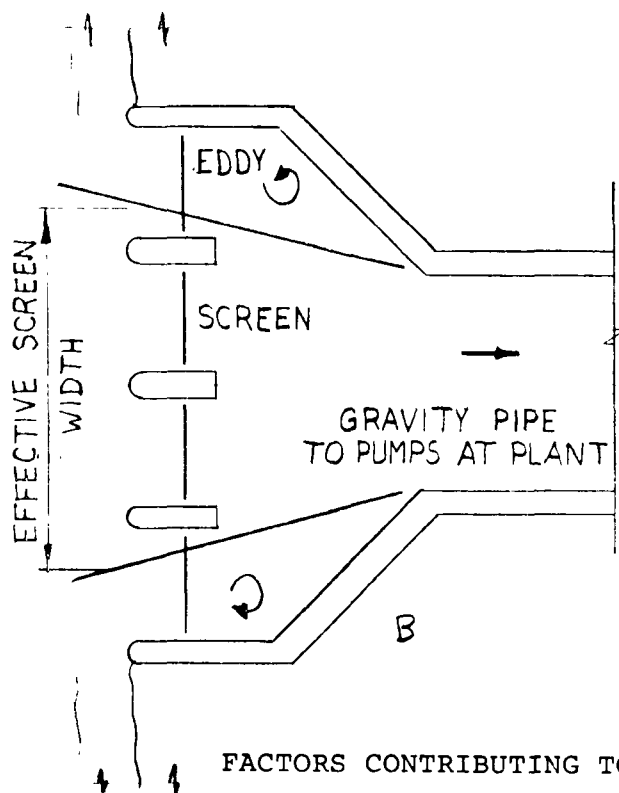
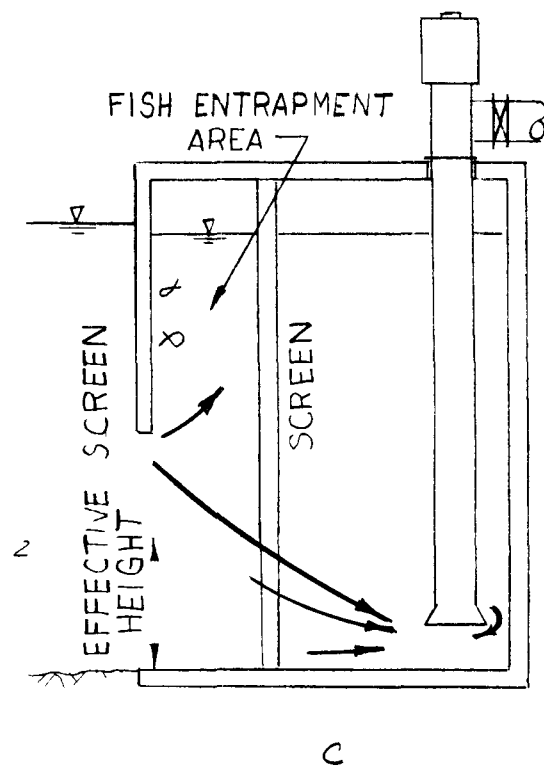
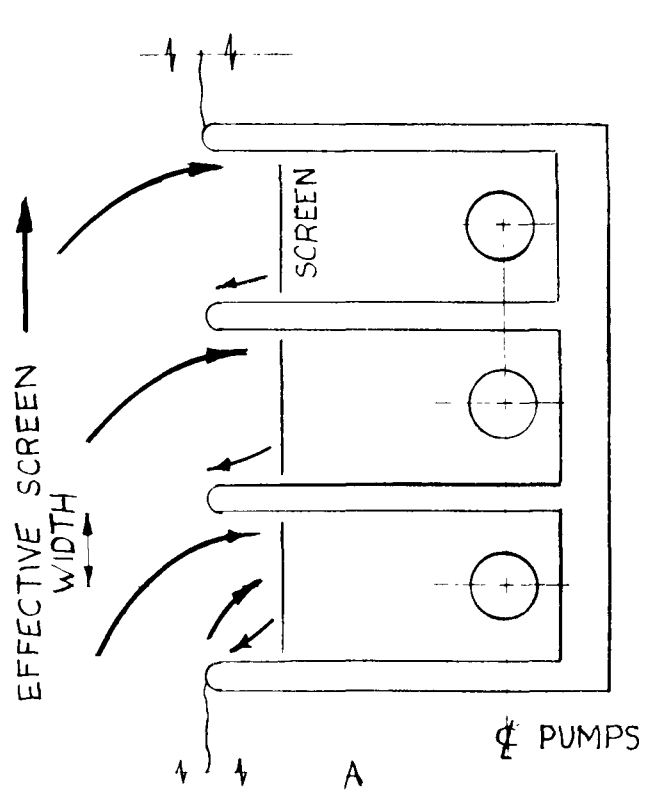
Third cross-section ( downstream from the screen )

	(a)	(b)	(c)	(d)	(e)	(f)
Near Bottom	0.68 ↑	0.84 ↑	0.80 ↑	0.60 ↑	0.74 ↑	0.67 ↑
Mid-Depth	0.80 ↑	0.95 ↑	1.06 ↑	0.67 ↑	0.80 ↑	0.81 ↑
Near Surface	1.20 ↑	1.01 ↑	0.47 ↑	0.63 ↑	0.63 ↑	(nil) ↑



SCREEN AREA VELOCITY DISTRIBUTION

FIGURE III-54



FACTORS CONTRIBUTING TO POOR FLOW DISTRIBUTION

FIGURE III-55

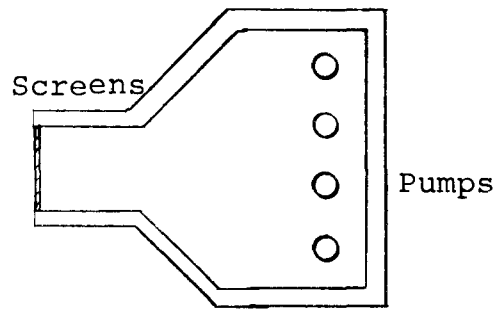
One basic consideration in initial layout of the structure is the matching of the pumps to the screens. Figure III-56 illustrates four intake variations to accommodate pumps of a wide range of sizes. Sketch A is an intake for several small pumps served by one screen. The shape is produced by the fact that the flow required by the pump is so small that only a minimum sized screen is required. Sketch B is a one pump - one screen arrangement common for medium size pumps up to about 100,000 gpm. Beyond this pump size the physical limitations on the screen size (14 foot trays or baskets are the maximum commercially available) requires the use of multiple screens per pump. Sketches C and D illustrate possible combinations. Care must be taken to locate the screen with respect to the pump in a manner which will properly utilize the entire screen surface. If a very low screen velocity is required for a very large pump installation, the length of structure required for the screens may be greater than that which will be hydraulically suitable for the pumps. Such a requirement could result in the configuration shown on Figure III-57.

#### Pump Runout and the Effect on Screen Settings

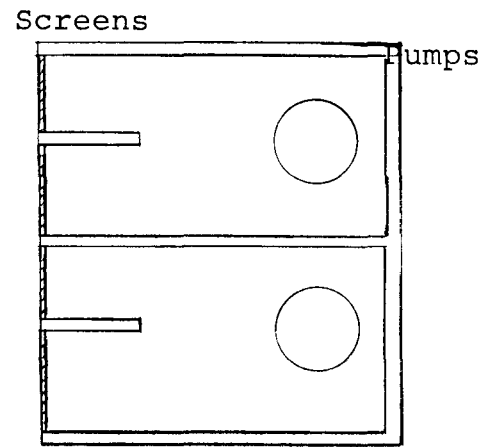
Sketch A of Figure III-58 shows a typical one screen per pump intake. If the screen is sized for the design flow of the pump, the screen velocities will substantially increase during periods when only one pump is in operation. This is the result of the "runout" characteristics of the pump which tends to pump more water as the total system flow and head losses decrease. As much as 40% flow increase might be expected. Operation in this manner is common in those areas where winter water temperatures are much lower than summer temperatures. We may then expect an increase in screen velocity during those cold water periods when lethargic fish might be least able to resist the flow. Consequently, if this type of setting is used, the screens must be designed for the expected runout flow of the pump.

An alternative to the individual bay setting shown in Sketch A is to place the pumps as shown in Sketch B of Figure III-57. In this case, an open chamber is located in the side wall between the pumps and the screens. The operating pump may thus utilize a part of the screen area normally used for an adjacent pump. Field and laboratory tests show that only a small part of the adjacent screens are effectively utilized in this situation, but that a small part will be sufficient to compensate for the increase in pump flow if the screens and pump are properly located.

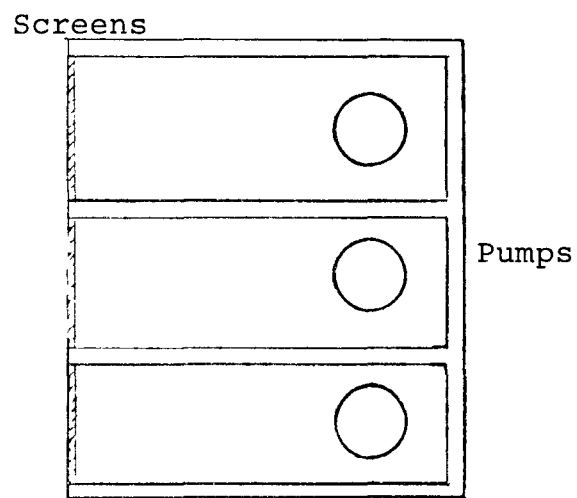
An intake of the latter type will be larger and more costly than the former. Maintenance procedures may be complicated by the fact that the central bay cannot be dewatered and also the dewatering of individual screen and pump bays becomes more complex.



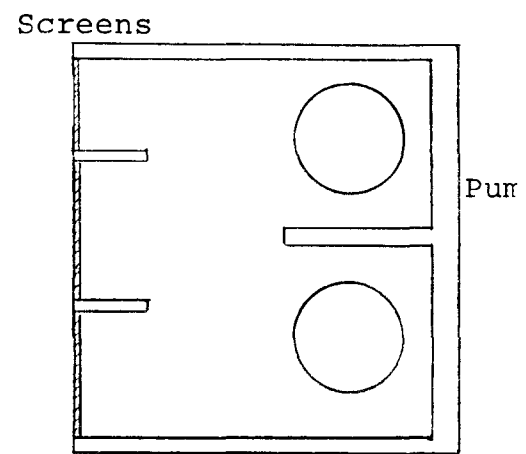
A



D



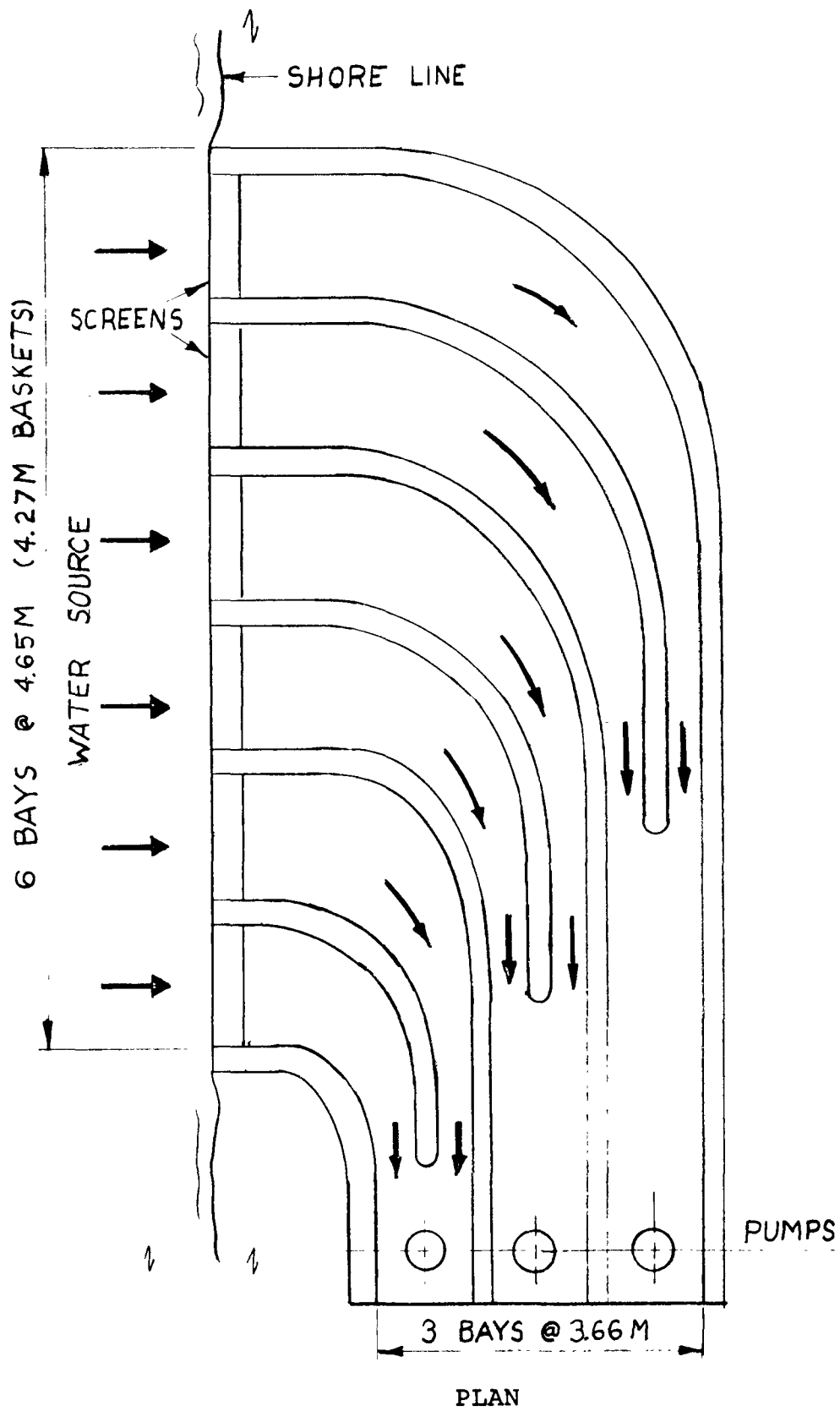
B



C

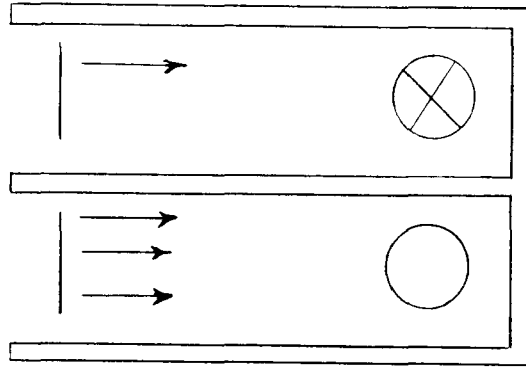
# PUMP/SCREEN RELATIONSHIPS

FIGURE III-56

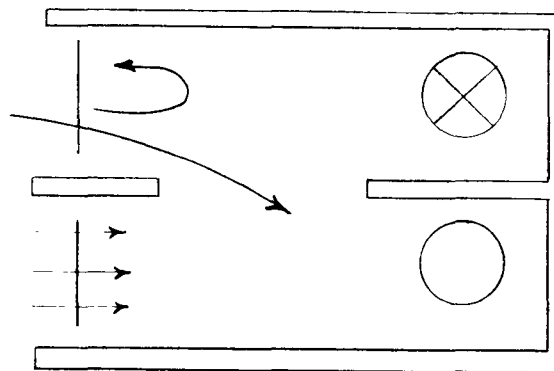


PUMP AND SCREEN STRUCTURE FOR LOW INTAKE VELOCITIES

FIGURE III-57



A



B

EFFECT OF PUMP RUNOUT

FIGURE III-58

## Design of Ice Control Facilities

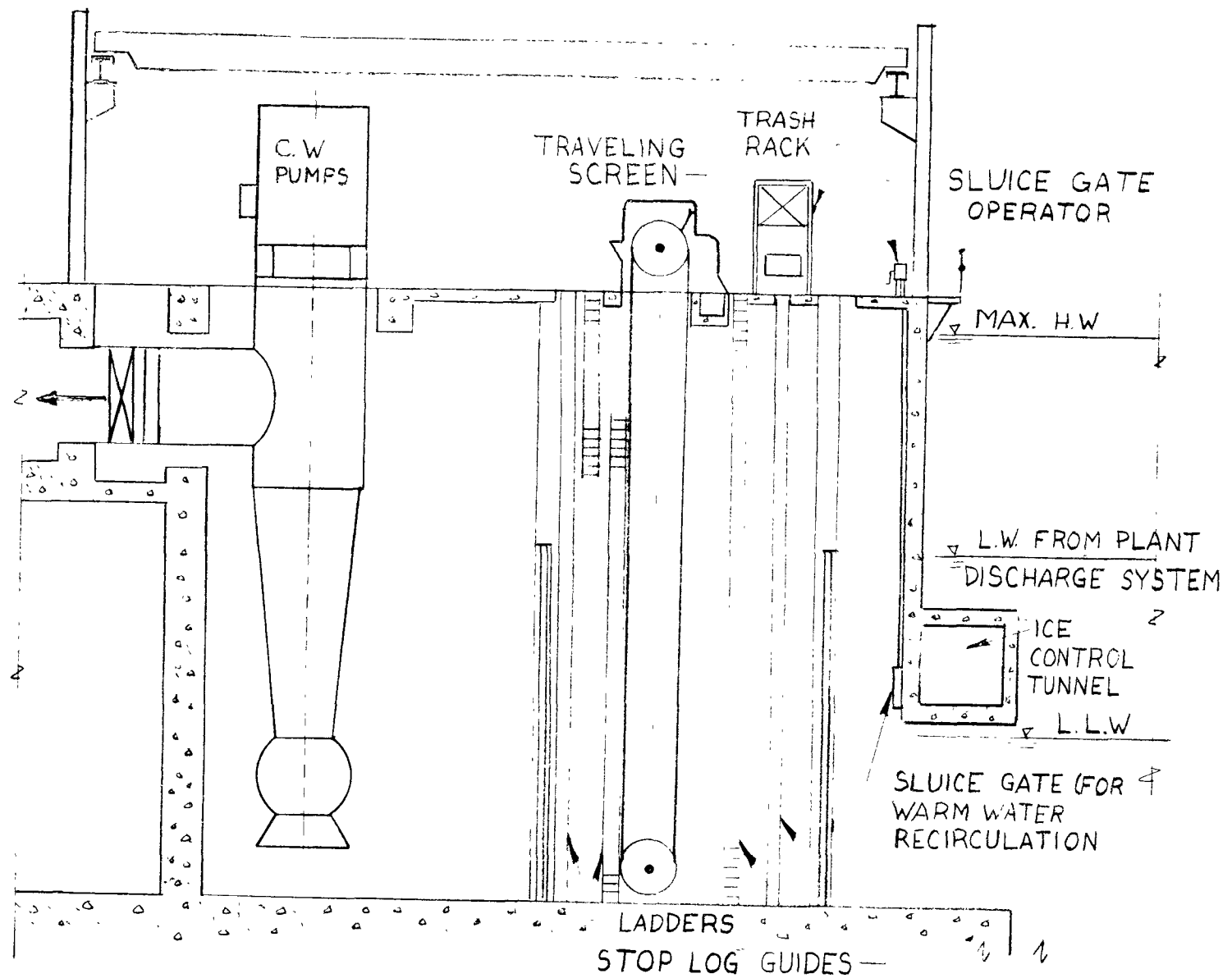
Most powerplant intakes located in the northern latitudes must have some provision for ice control during the winter months. Sheet ice and "frazil" ice ("needle" ice) can cause flow blockage at the intake. The system most frequently used to control the ice problem is the recirculation of a portion of the warmed condenser water back to the intake. Figure III-59 shows a cross section of a powerplant intake with the ice control header and discharge ports located upstream from the screens. A variation of this method would be to recirculate only intermittently to minimize fish retention at the intake area. The sketch shown is for a major nuclear plant located on the Mississippi (plant no. 3113). Other ice control systems that have been tried have been less successful. In particular, several attempts to use an air bubble curtain (similar to that described in the section on behavioral screening) to control ice have not been completely effective. Other methods of ice control are to place the intake well below the water surface, or, for sheet ice, to agitate the water surface with propellers or similar devices. The problem with the use of the recirculation system for ice control is that it has been shown that fish concentrate in warmer water in the winter time, thus increasing their possible interaction with the screen. It has also been shown that fish are lethargic in the cold water periods and cannot swim well against the intake flow. These two factors can combine to make the traditional warm water recirculation system less than desirable from an environmental standpoint.

It is suggested that traditional warm water recirculation systems be avoided. While the feasibility of other ice control systems is yet to be proven at major powerplant intakes, there does not appear to be any technical limitations to the development of alternate ice control systems.

## Non-Conventional Intakes

Non-conventional intakes vary considerably from conventional intakes in that they will use methods for separation of water and debris other than the screening devices and/or screen mountings previously mentioned. The non-conventional intakes to be described in this section include the following:

- Open setting screen
- Filter type intake
- Perforated pipe intake
- Radial well intake



PUMP AND SCREEN STRUCTURE WITH ICE CONTROL FEATURE

FIGURE III-59



## Open Setting Screens

Figures III-25 and III-38 show two screens which have been mounted on platforms and connected directly with the pumps which they serve. One is the double entry, single exit vertical traveling screen, the other the double entry drum screen of European design. Both of these screening systems have open water completely around them, thus eliminating fish entrapment areas. A second advantage of these systems, and the original purpose for which they were developed, is the elimination of costly concrete screen wells. Most such installations would require some type of trash rack protection which is not shown on the figures.

Flow distribution through the screen faces may not, however, be suitably uniform. The areas nearest the inlet to the pumps will tend to have higher flows and velocities and may therefore result in undesirable fish impingement. This objection might be overcome with internal dividers and increased screen sizes, but no information is available that indicates that such measures have been utilized.

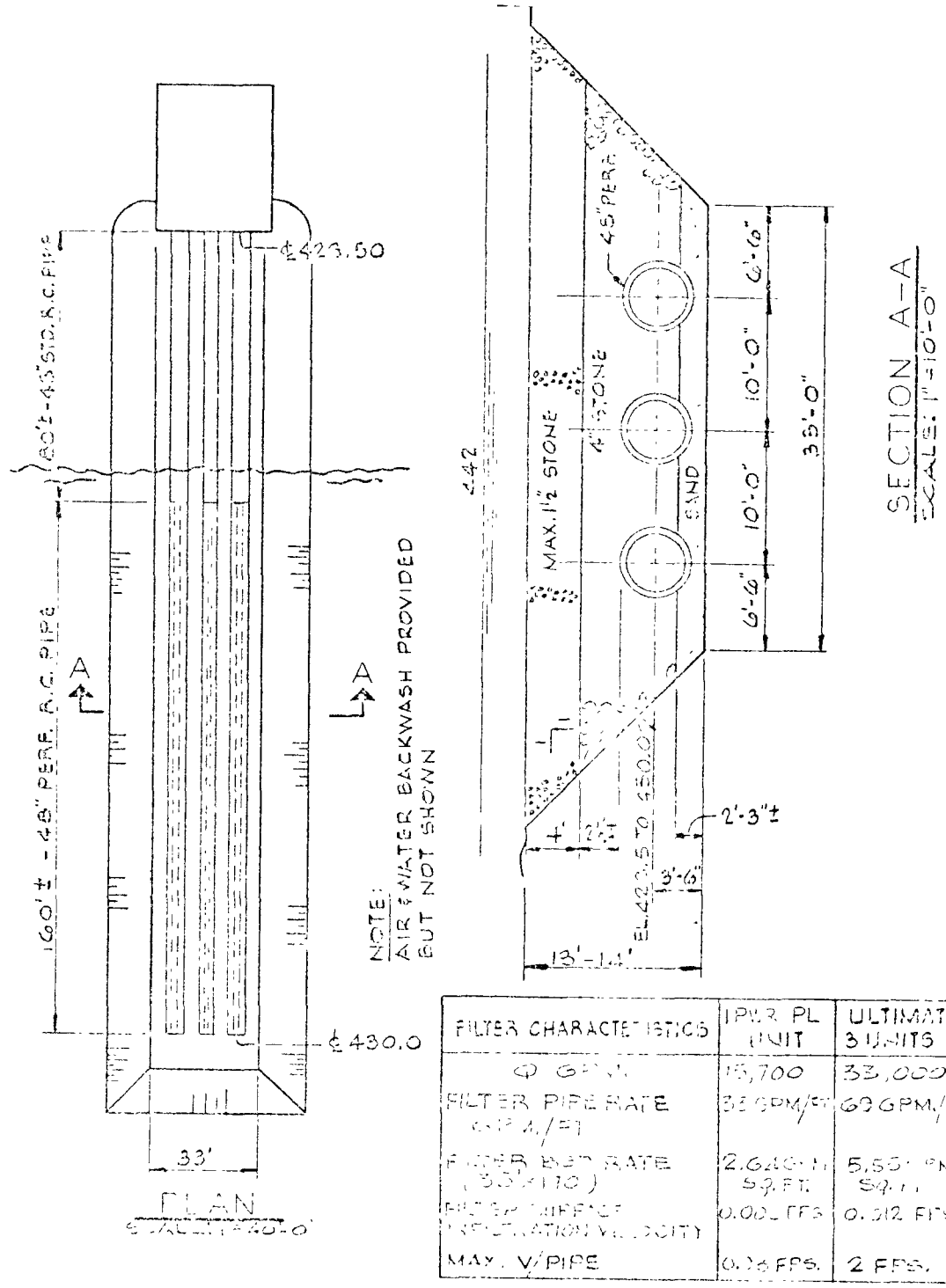
A similar system is being used at plant no. 1229 located on the southeast coast. The system has performed reliably for several years.

## Filter Type Intake

Many types of filter intakes have been developed on an experimental basis and some have been installed in relatively small scale applications for powerplants. The essential feature of all these schemes is the elimination of mechanical screens. The water is drawn through a filter medium such as sand and stone. Such an intake is capable of being designed for extremely low inlet velocities and can be effective in eliminating damage even to small fish. Planktonic organisms can also be protected to some extent.

Figure III-60 is a sketch of a stone filter in use since late 1971 to screen makeup water for a large powerplant in the northeast (plant no. 4222). The sketch shows the original filter. It has since been modified several times in attempts to improve its performance. It still has a tendency to clog and cannot yet be considered reliable. Figure III-61 is a somewhat more complex design developed but not used for the makeup water of a large powerplant in the Northwest (plant no. 5309).

A preliminary filter design has been developed for the entire circulating water flow to serve a major powerplant in the Northwest (1,500 cfs). This system employs precast concrete filter modules in seven separate filter sections, each capable of being isolated for maintenance. The entire filter complex would be about (450 x 260 feet) in plan. Fairly complex piping, water control and pump facilities complete the system.



INFILTRATION BED INTAKE - PLANT NO. 4222

FIGURE III-60

Another filter system concept which has been used with some success in relatively small intakes is the "leaky dam" which consists simply of a stone and rock embankment surrounding the pump structure. Water must flow through the "dam" to reach the pumps. The dam thus acts as a screen. Very low water passage velocities can be achieved and the danger of fish impingement is reduced. Very small fish can, however, pass through the openings in the stone. A major problem for this system in waters containing suspended matter would be clogging. Practical backwashing facilities have not been developed. An intake system of this type has been operated at powerplant no. 5506 since late 1972. It has been reported to be 70-75% effective in screening out fish.

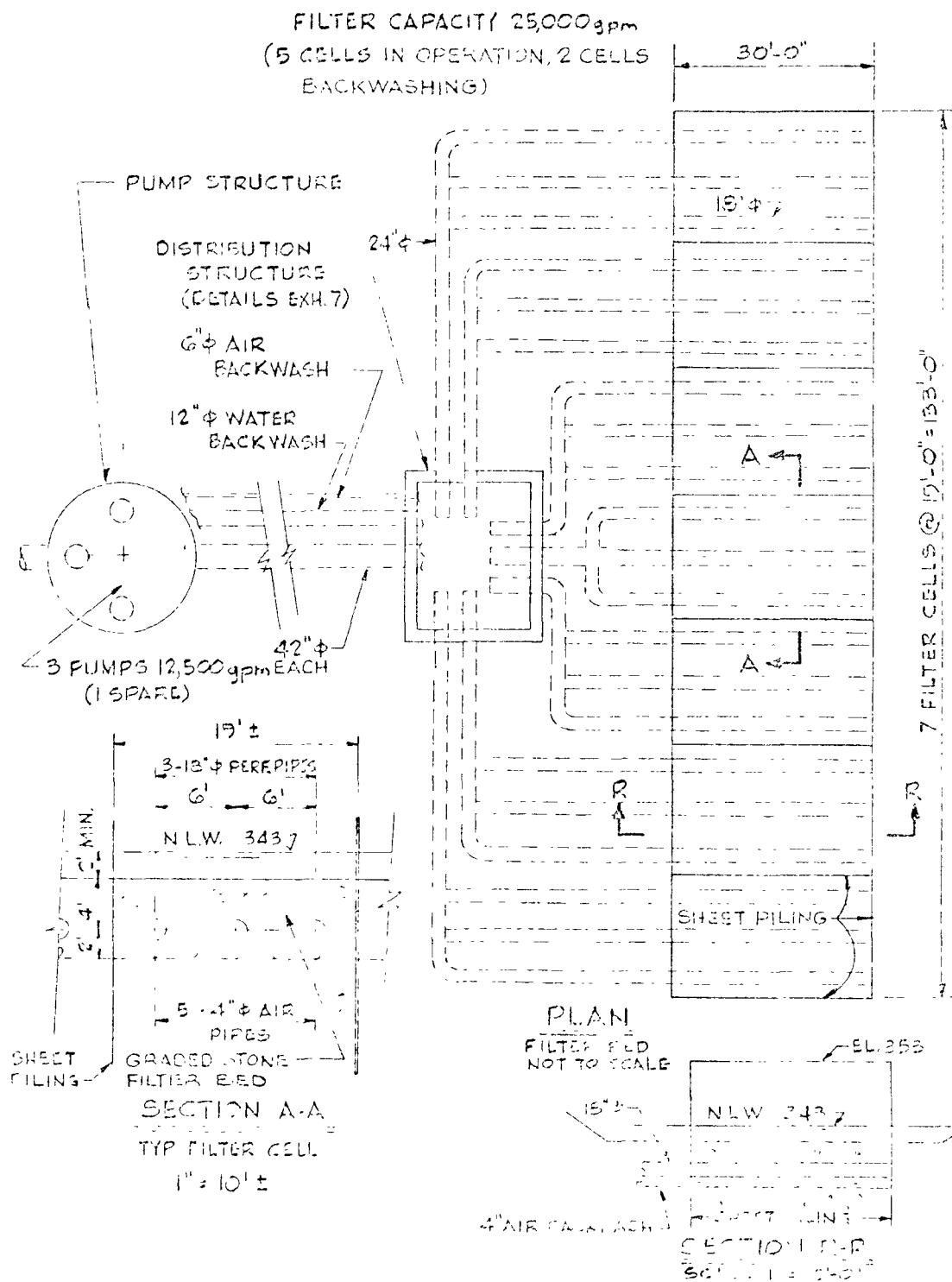
Although these filter intakes would appear to be ideal from an environmental point of view, they have many disadvantages. The clogging problem is foremost. In turbid waters such clogging would rule out the filter use. Backwashing facilities will be needed in even relatively clear water. The backwashing procedure will temporarily raise the turbidity of downstream waters and thus may be in conflict with limitations on turbidity. To date no large scale filter system has been developed and proved reliable in operation. The cost of such a system will be substantially higher than for a comparable conventional screen facility.

#### Perforated Pipe Intake

A typical perforated pipe intake is shown in Figure III-61 and III-62. This concept has been discussed in detail under "fixed screens" elsewhere in this report. The figures show a preliminary design being considered at this time for the makeup water system of a major steam electric powerplant in the Northwest (plant no. 5309). The concept can be expanded to handle substantially greater quantities of water than the 25,000 gpm to be passed through the illustrated intake. See the previous discussion for a review of the advantages and disadvantages of this scheme.

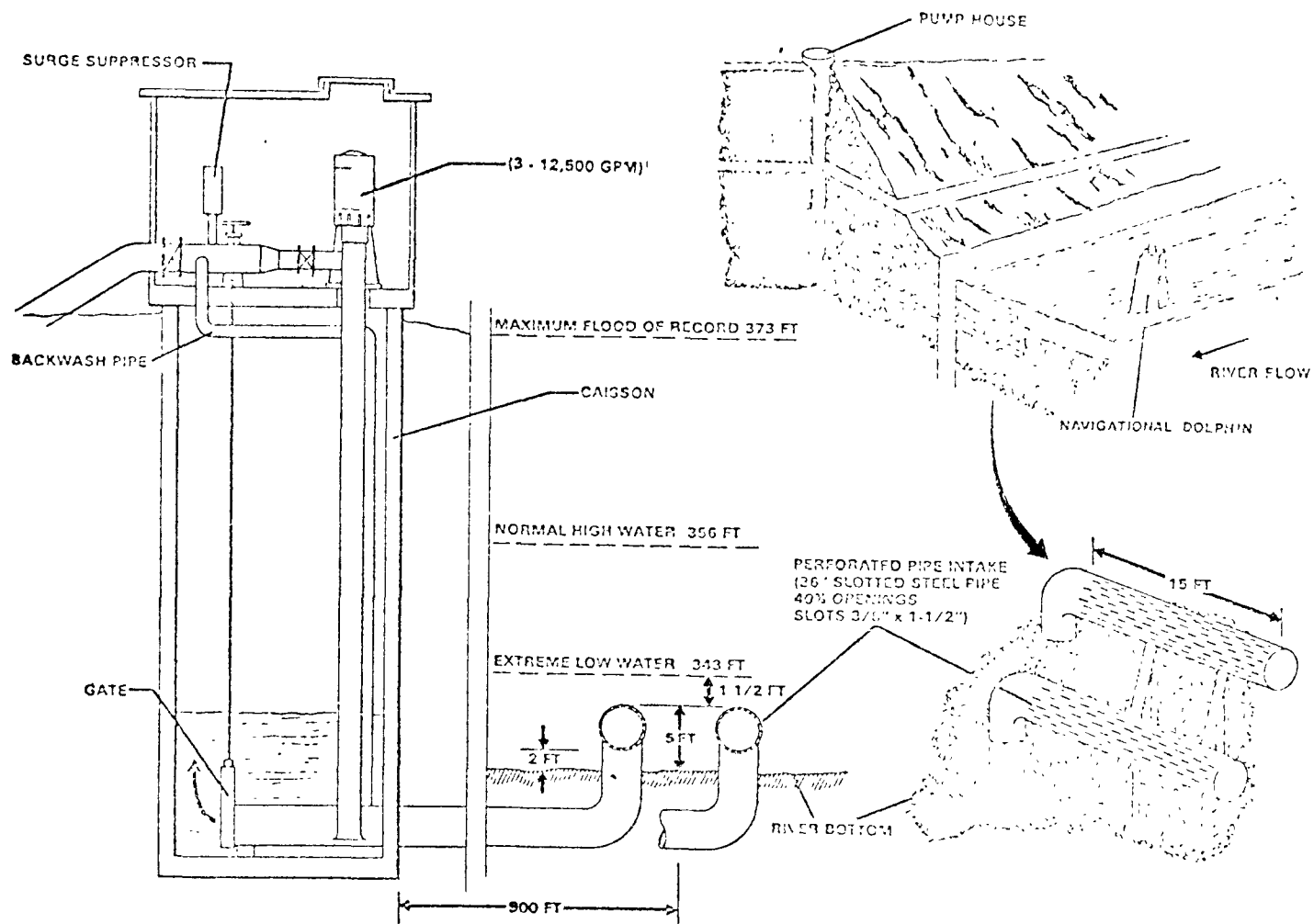
#### Radial Well Intake

The radial well intake is an infiltration type utilizing natural in-place pervious material as contrasted with the artificially prepared filter beds discussed above. Slotted pipes are jacked horizontally into sand and gravel aquifers beneath the river bed. These pipes are connected to a common pump well. This is an intake which has been frequently used for obtaining highly filtered industrial and municipal water. The radial well intake is shown in Figure III-63. This type of intake can only be successful where suitable water bearing permeable material is found. It provides a degree of screening which far exceeds the requirements for cooling water supplies. It has the advantage of being the most environmentally sound intake system because it does not



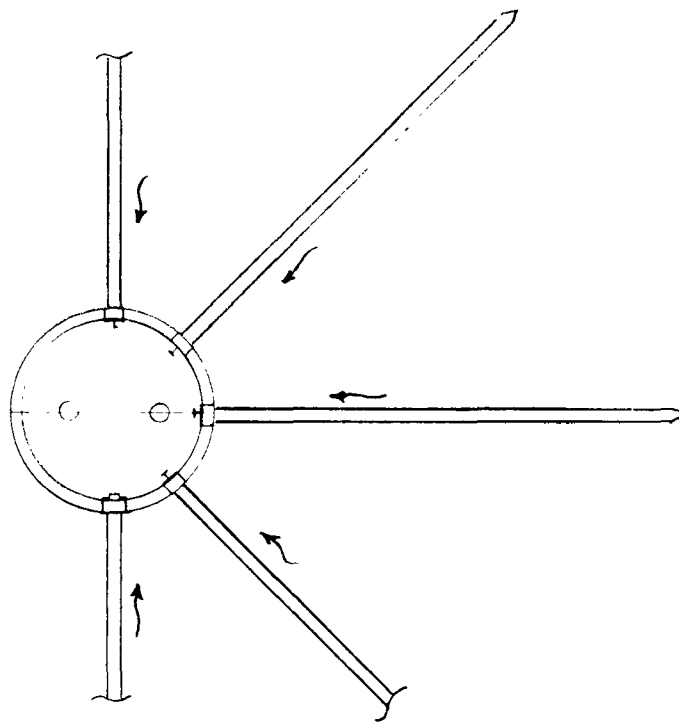
INFILTRATION BED INTAKE - PLANT NO. 5309

FIGURE III-61

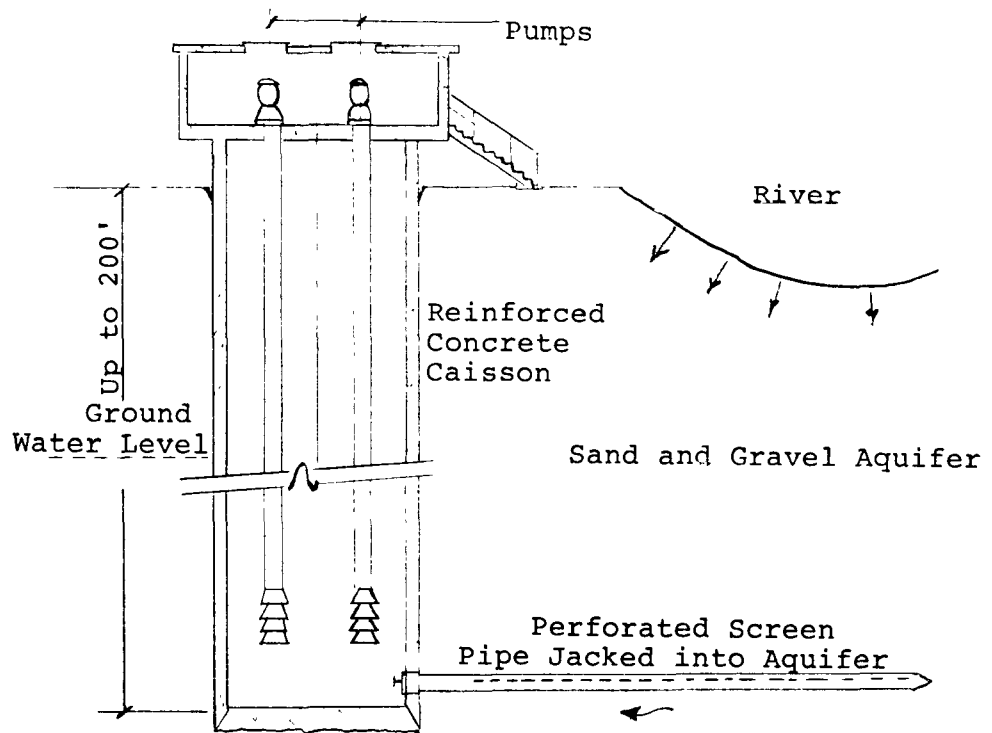


PERFORATED PIPE INTAKE

FIGURE III-62



PLAN



Section

RADIAL WELL INTAKE

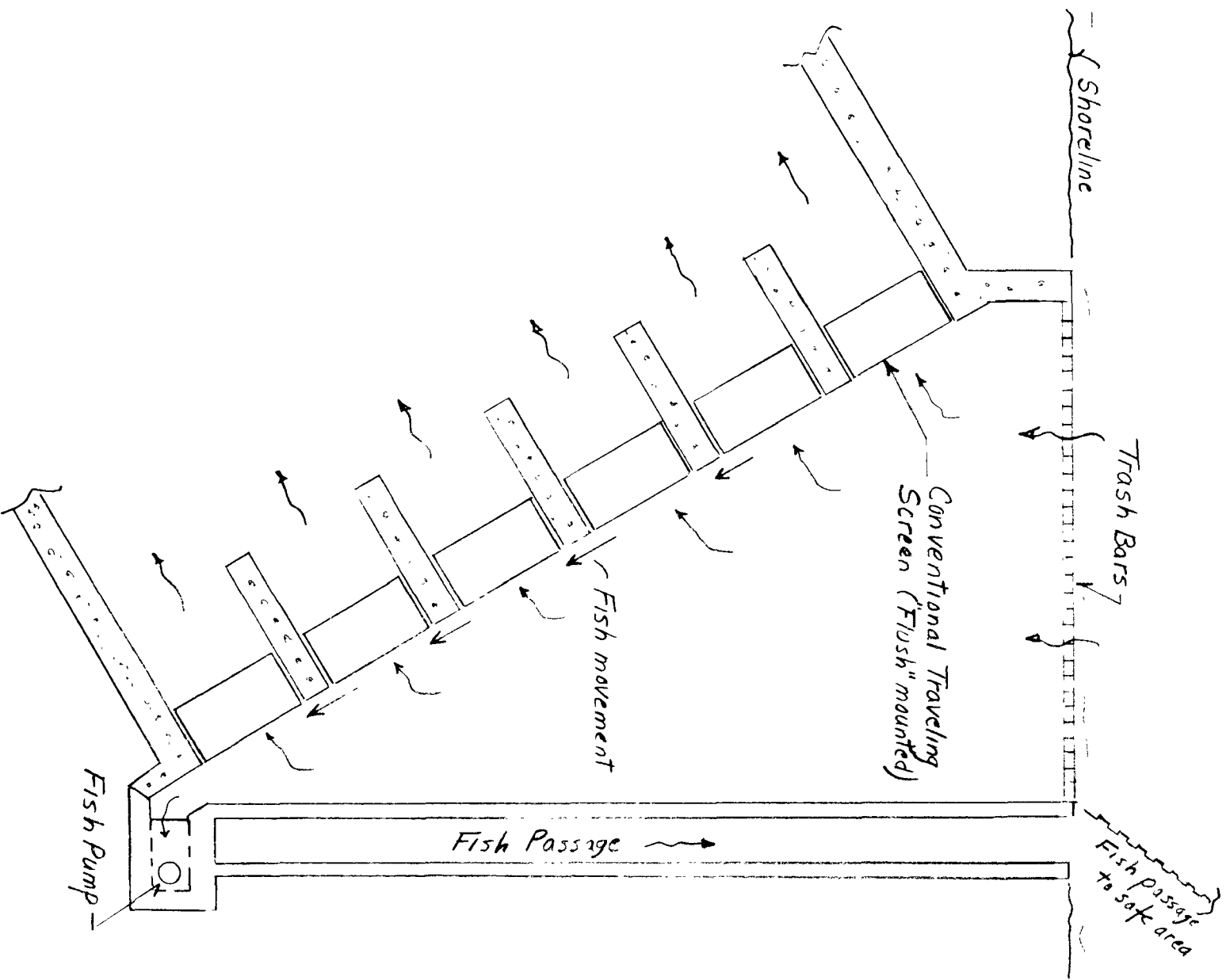
FIGURE III-63

have any direct impact on the waterway. It would be competitive in cost with conventional small intakes of the same capacity. However, for very large capacity requirements, several individual widely scattered cells would be required and the cost would be substantially greater than for a conventional intake. Radial well intakes have been in service for over 35 years and have been reliable.

### Behavioral Intakes

The wide variety of behavioral intakes has been discussed elsewhere in this report. They represent a substantial departure from "conventional" screen facilities. Such intakes include horizontal screens, louvers, air bubbles, sound, etc., and combinations of these features with each other and with more conventional facilities.

Conventional intakes themselves can be modified to take advantage of fish behavior. For example, angling conventional screens to the incoming water flow can guide fish to bypasses in the same manner as the horizontal screen and the louvers. Figure III-64 is a sketch of such an installation. The total facility will be substantially more costly than the more conventional setting due to the orientation of the screens and the need for providing fish bypass facilities (including fish pumps and auxiliary water cleaning equipment). Hydraulic studies can be made to develop guide walls both in front of and behind the screens to assure a reasonably uniform flow through screens.



# ANGLED CONVENTIONAL TRAVELING SCREENS

FIGURE III-64



## SECTION IV

### CCNSTRUCTION

#### Introduction

The adverse environmental impact associated with the construction of cooling water intakes results from three factors. The first of these is that the intake may occupy a finite portion of area in the bed of the source water body. To the extent that this occurs, there will be a loss of potential habitat and a displacement of the aquatic populations that reside at that location. In addition, modifications to a larger area surrounding the specific intake location, resulting from construction activities and changes in existing topography can create permanent disruptions in the biological community.

The second factor is the impact on the ecosystem of increased levels of turbidity resulting from the construction of the intake structure and any associated inlet pipes and approach channels. Turbidity levels can also be increased as the result of erosion of inadequately protected slopes of excavations and fills created during the construction operations.

The third factor concerns the location of disposal areas for the materials excavated during construction. If spoil disposal areas are located within the confines of the source water body, further permanent disruptions of the existing aquatic species can result. If these spoil banks are not adequately stabilized, increased levels of turbidity may persist for an indefinite period. Adequate protection and stabilization of spoil areas located above the waterline are also required to prevent long term erosion of these materials which can contribute to increased turbidity levels.

Of the three factors mentioned above, the first will not significantly impact the environment in most cases and will be discussed briefly. The remaining two factors can create serious short term and long term problems if not properly controlled.

#### Displacement of Resident Aquatic Organisms

The impact of the physical size of the intake on the displacement of the resident biological community is a function of the size of the intake. Offshore intakes which require long conduits placed in the waterbody will be more disruptive to the resident species than shoreline intakes. The species that will be most effected by the construction of the intake are the benthic organisms. The impact of construction activities in this regard is expected to be small since in no case will the intake occupy more than a small percentage of the total area of the source. All water sources will be able to adjust rapidly to the loss of habitat

area and to reproduce the small portions of the important organisms lost. If the locational guidelines proposed are followed, the impact of this aspect of intake structure construction will be minimized.

### Turbidity Increases

Increased turbidity can result from the construction of intake structures in several ways. First, increased turbidity can result from physical construction activities conducted below the water level of the source. Such activities as dredging, pipe installation and backfilling, and the installation and removal of coffer dams and related facilities can create significant increases in turbidity unless these activities are carefully controlled. The turbidity created by the physical construction of intakes will normally be limited in duration to the extent of the construction schedule. The impact of this type of turbidity increase on the source ecology is dependent upon the particle size distribution of the sediment, the sediment transport characteristics of the source, and the location of the important organisms with respect to the intake construction activities.

There are a number of construction techniques that can be employed to reduce the turbidity increases associated with these activities. Excavation and dredging activities can be conducted behind embankments or coffer dams to contain potential sediment discharges. Care must be exercised to limit the turbidity increases due to the construction and removal of these facilities. Onshore construction can be performed with natural earth plugs left in place to prevent the discharge of material to the source. Construction can be scheduled to take advantage of low water periods and periods of reduced biological activity in the source. Some sources will expose a large portion of the flood plain under low water conditions allowing much of the intake structure to be constructed in the dry area. Construction should also be scheduled around important spawning periods, feeding periods and migrating periods to reduce impact to these functions.

The control of dewatering activities can also be important. The discharge of soil materials from dewatering activities can be limited by the use of holding ponds or filtration equipment prior to discharge of this water to the stream.

All material excavated or dredged in the construction of intakes should be placed above the water line where possible. The laying of conduit should be scheduled to minimize the amount of time that the trench is open. As soon as the conduit is placed, the trench should immediately be backfilled and the surface of the trench smoothed over to prevent erosion of the trench materials.

Long term turbidity increases can result from the entrainment of material from spoil areas located either below the waterline or erosion of material placed above the waterline. In addition, erosion of

excavations and fills that are permanent parts of the intake can also add turbidity that will persist long beyond the completion of construction activities. Adequate stabilization of these fills may be required which may necessitate rip-rap slope protection and seeding of fill areas.

#### Disposal of Spoil

The disposal of spoil within navigable waters is controlled by the U.S. Army Corps of Engineers. The disposal of spoil from excavation and dredging activities can displace and destroy important benthic organisms. The disposal of spoil in known fish spawning, nursery, feeding areas, shellfish beds and over important benthic populations can cause permanent loss of important biological species.

## SECTION V

### OPERATION AND MAINTENANCE

#### Introduction

The environmentally related performance characteristics of a cooling water intake structure will be primarily established by the location and design criteria discussed in the previous sections. While most adverse environmental impact will result from the operation of the intake, relatively little can be done by the application of appropriate operational measures to significantly reduce such adverse environmental impact. This results from the fact that during operation the intake is the passive portion of the cooling water system, which simply supplies the water demand of the plant. The only portions of the intake structure that can be "operated" are the pumps and the screens. Only a small degree of improvement of adverse environmental impact can be effectuated by controls placed on these facilities.

The development of a continuing enforcement and performance monitoring program might be of some value in determining desirable operating conditions.

Maintenance is an aspect of intake structure operation which has direct environmental impact. Good maintenance will require an effective program of preventive maintenance for both above water and below water portions of the intake.

#### Operation

Many conventional traveling screens are operated once during each eight hour shift. During periods of high debris loading in the water source, screens may be operated more frequently and in some cases continuously. Pump operation is directly controlled by the water demand from the plant. Little flexibility in the operation of either of these systems is possible.

#### Screen Operation

The data available on screen operation suggest that, under certain conditions, continuous operation of the screens can reduce impingement effects. This is due to the fact that, with continuous screen operation, fish are impinged for a shorter period of time. One of the primary reasons for this is that fish typically tend to fight a situation which they recognize as perilous such as being impinged on a screen or being lifted out of water. The longer a fish is allowed to fight such a situation, the more likely it is to damage itself.

Continuous screen operation to reduce impingement effects is only applicable where fish separation and bypass systems are available. The number of installations having this capability is small. Continuous screen operation will shorten screen life and increase maintenance costs to some degree.

#### Pump Operation

Control of pump operation has been used at certain intakes (Plant No. 3608) in the northern latitudes to reduce impingement effects during the winter months. This type of control involves the reduction of the volume of water pumped during these cold water periods. Pump flows can be reduced without detrimental effect on plant performance if water temperatures are low enough to compensate for the reduced volume of cooling water.

Since fish swimming ability for many species is drastically reduced at low water temperatures, such a flow reduction in the winter period can effectively reduce fish impingement. The best way to reduce water intake volumes is to reduce the pump speed. This can only be done where pumps have variable speed drives. Unfortunately, most circulating water pumps do not have variable speed capability. Another way to reduce the intake volume is to shut down a pump. This will cause increased velocities through the remaining screens because of the pump runout factors noted in the design section of this portion of the report.

On new structures the value of a reduced number of pumps operating in winter should be evaluated and considered in the overall initial design.

#### Performance Monitoring

For several reasons, the development of a continuing performance monitoring program in conjunction with the operation of intake structures would be helpful. First, the data developed on the performance of various intake systems under different regional conditions could be used to develop a base on intake performance. Second, it would allow the effectiveness of individual intake guidelines to be determined and periodic updating of individual requirements where desirable.

The following type of data would be included:

- Source water temperatures
- Stream flows (where applicable)
- Screen operation schedules
- Cooling water flow
- Number, types and condition of important organisms impinged, entrained, and bypassed.

## Maintenance

An effective preventive maintenance program can be developed for both below water and above water portions of the intake structure.

The maintenance of the above water portion of the intake will basically consist of the maintenance of the mechanical equipment associated with the intake. This equipment includes primarily the screens and screen drives, the trash racks and supporting equipment.

Suggested preventive maintenance procedures are normally supplied by the manufacturer of the various systems. This program will consist of regular lubrication schedules for all moving parts and a firm inspection program to check key wear points, particularly screen basket lugs, headshaft lugs, carrying chains, etc. Inspection of the spray wash system should also be made on a regular basis with particular emphasis on the condition of the spray nozzles. The water screen should be tested for binding and misalignment on a monthly basis by operating the screen for several revolutions with the test shear pin left in place. Adequate maintenance procedures also require the stocking of a spare parts inventory because of long lead times which generally exist on spare parts deliveries. The suggested list of spare parts will generally be supplied by the equipment manufacturer.

Preventive maintenance of the portion of the intake below the water line is also important and also often neglected because it usually requires the dewatering of the individual intake bays and/or use of divers. Below water maintenance should include visual inspection of footwells and footwell bushings on an annual basis. This may require a diver if the well cannot be dewatered or the screen raised. In addition, periodic below water inspection of the intake can reveal the extent of the following adverse conditions as noted in Reference 76:

- Silt accumulation in front of the structures which can effect intake hydraulics.
- Undermining of the base of the structure which might cause subsequent collapse of the structure.
- Deterioration of stop log and screen guides.
- Spalling concrete which may expose reinforcing bars and weaken the structure.
- Damage to pump impeller and fittings which can lead to pump failure.

## SECTION VI

### CCST DATA

#### Introduction

This section contains cost data relative to cooling water intake structures. The section is organized to first present current costs for the construction of the several types of conventional intake structures commonly used by industrial establishments. This is done to establish a baseline against which the additional costs associated with the implementation of the control measures can be compared. Following the development of this baseline cost data, estimates are made of the costs associated with the certain intake structure control measures.

The cost data contained in this section are capital costs associated with intake structure construction only. No consistent data on operation and maintenance of cooling water intakes were available. Records of these costs are not routinely kept by either the users or the manufacturers of intake structure equipment. The magnitude of costs associated with operation and maintenance of cooling water intake structures are believed to be small.

A further qualification of the data contained in this section is required. The scarcity of detailed data on the constructed cost of intake structures was the major problem area in the development of this document. This lack of data results from the fact that most intake structures are constructed as part of a larger general contract which includes other structures on the site, and in some cases, the complete plant. It is difficult in these cases to separate the portion of the costs that are directly associated with the intake structure either from the bid package or from field records of the cost of construction put in place. It was necessary therefore to synthesize the cost data available from several sources. In doing this, the costs of intakes constructed at different dates and in different geographical areas of the country are combined without normalization of the data with respect to either inflationary factors in the construction market or well established regional cost differences. The cost data presented must therefore be considered to be order of magnitude costs and should be used in this context only.

#### Cost of Construction of Conventional Intake Structures

The cost of conventional intake structures is influenced by both the type of intake and the size of the intake facility. The cost of the major piece of mechanical equipment in the intake, the traveling water screen, contributes a relatively small portion of the total intake structure cost.

## Screen Costs

The costs of furnishing and installing intake water screens are readily available from any of the leading screen manufacturers. Table VI-1 is a tabulation of the cost of 16 conventional traveling water screen installations provided by a leading screen manufacturer during 1971. These costs have been converted to a unit flow basis and the results tabulated in the next to the last column of the table. The approach velocity for each installation is recorded in the last column. The factors that most effect the cost of the screens are the approach velocity and the size of the plant. The total range of screen cost was from \$2,000/m<sup>3</sup>/s (\$0.13/gpm) to \$37,400/m<sup>3</sup>/s (\$2.36/gpm). The effect of approach velocity was pronounced with the average unit cost for installations where approach velocity exceeded 0.3 m/s (1 fps) being \$5,200/m<sup>3</sup>/s (\$0.33/gpm) compared to a cost of \$16,600/m<sup>3</sup>/s (\$1.05/gpm) for installations where the approach velocity was less than 0.3 m/s (1 fps). The variation with the size of flow was even more significant. The cost of large screening units (greater than 6.3 m<sup>3</sup>/s (100,000 gpm) per screen averaged \$3,200/m<sup>3</sup>/s (\$0.20/gpm) as compared to \$17,400/m<sup>3</sup>/s (\$1.10/gpm) for smaller units (less than 3.2 m<sup>3</sup>/s (50,000 gpm) per screen.

## Intake Structure Costs

Estimated cost data for the three different types of intake structures are shown in Figure VI-1. These data were taken from Reference 11 for small powerplants and from estimated costs of individual large plants from various sources. The base year for these cost data is 1971. The figure demonstrates the two important cost impacting factors in conventional intake construction. The first of these is the type of intake used. The offshore intake will cost significantly more in all size ranges than either the shoreline intake or the channel type. The basic reason for this is the cost of excavation and laying of offshore conduit. The cost differences between the channel type of intake and the shoreline intake appear to be small except in the lower size ranges.

The other significant cost factor is the size of the plant. The cost of construction of all three types of intakes are shown to be significantly higher for smaller plant sizes than for larger powerplants. For instance, the costs of offshore intakes are shown in Figure VI-1 to vary from as low as \$3/KW of installed electrical generating capacity for a 1000-MW plant to as high as \$90/KW for plants under 10 MW.

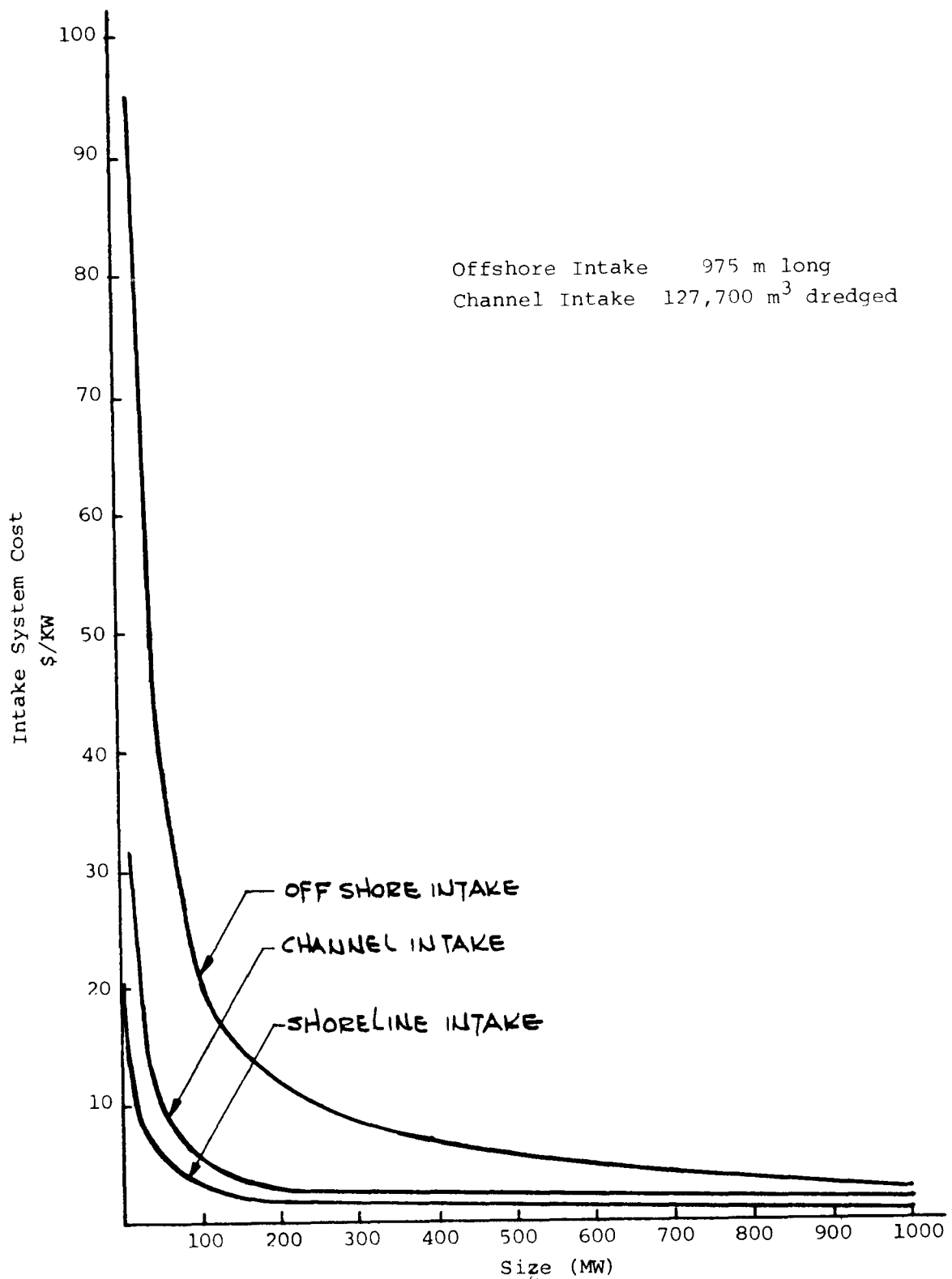
The data contained in the Figure have been standardized on the basis of significant cost factors. The length of pipe used in the development of the curve for offshore intakes was 975 M (3200 ft). Likewise, a constant 127,700 m<sup>3</sup> (167,000 cu yds) of excavation was assumed for all channel intakes. The amount of these items and their costs can vary significantly. Reference 24 shows the costs of three offshore intakes constructed between 1955 and 1958. The cost of installation of the



TABLE VI-1

## COST OF TRAVELING WATER SCREENS (1971)

Plant Code No.	Number of TWS	Basket Size (m)	Centers (m)	Type of Water	Flow per TWS m <sup>3</sup> /s	Design Low Water Depth m	Frame (No Posts)	Approx. Cost \$	Unit Cost \$/m <sup>3</sup> /s	Velocity m/s
4709	6	4.27	17.98	Fresh	11.91	8.53	4	228,000	3,200	0.326
1243	1	1.52	7.01	Fresh	.94	1.68	2	16,000	17,000	0.369
4817	4	2.13	9.75	Salt or Brackish	4.50	5.18	4	120,000	6,700	0.409
N.A.	6	3.05	11.58	Fresh	7.91	6.70	2	144,000	3,000	0.387
4001	4	3.05	10.58	Fresh	5.36	5.49	2	84,000	3,900	0.320
4829	3	3.05	13.72	Salt	8.14	6.25	2	87,000	3,600	0.427
N.A.	2	1.52	5.18	Salt	1.03	2.74	4	33,000	16,000	0.244
2110	1	3.05	31.39	Fresh	4.72	5.79	4	49,000	10,400	0.268
135 1003	8	3.05	10.97	Fresh	3.20	6.19	2	197,000	7,700	0.171
1731	3	3.05	11.89	Fresh	8.63	8.53	2	53,00	2,000	0.332
1002	2	3.05	6.40	Brackish	2.90	3.05	2	30,000	5,200	0.305
0616	1	3.05	9.45	Salt	6.93	4.11	2	29,000	4,200	0.549
0108	3	2.44	19.81	Fresh	2.19	5.33	4	93,000	14,200	0.168
0109	2	2.74	10.06	Fresh	0.69	4.72	2	52,000	37,400	0.052
N.A.	6	3.05	8.84	Salt	1.73	3.35	2	137,000	13,200	0.168
N.A.	1	1.78	11.58	Salt	1.26	2.40	2	23,000	18,300	0.290



COST OF INTAKE SYSTEMS

FIGURE VI-1

offshore piping for these powerplants varied from as low as \$2.16 to \$4.70 per KW installed. Caution is therefore suggested in the use of this figure. Costs of each type of intake can vary considerably from the curves shown.

Additional data on the cost of shoreline intakes are contained in Table VI-2. The Table contains cost data on five cooling water intake structures and four makeup water intake structures constructed after 1965. With the exception of three makeup water structures the cost data contained in the table represent construction actually put in place. The costs of the three makeup water intakes are detailed cost estimates since these plants are now still under construction. The cost data contained in the table are substantially the same as in Figure VI-1. The cost of shoreline intakes runs from between \$1-\$4/KW for the larger size powerplants. The cost differences between makeup water systems and circulation water systems does not appear, from the Table, to be as great on a \$/KW basis as the difference in intake flow volume would indicate. The cost data, on a flow basis, appear to range from \$40 to \$90 per gpm of flow for makeup water intakes and from \$6 to \$30 per gpm of flow for circulating water intakes. For both these types of systems the upper cost ranges are for nuclear powerplants. The nuclear service intakes, although pumping much smaller volumes of water, are becoming as large as the circulating water intakes in order to accomodate backup equipment, provide missile protection and insure operation under maximum probable storm, water flood and drawdown levels. The data presented in Table VI-2 can be compared to the screen cost data on the basis of \$/m<sup>3</sup>/s (\$/gpm). It can be seen that the cost of the screens is a relatively small portion (less 1-2%) of the intake structure cost. The bulk of the cost of intakes are associated structural features, and are relatively independent of equipment costs, at least for conventional intakes.

Typical rule of thumb estimating guides for intakes are the following:

- Water screens cost approximately \$11/m<sup>2</sup> (\$1.00/ft<sup>2</sup>) of screen surface with a range of \$5.50 to \$24.22/m<sup>2</sup> (\$.50 to \$2.25/ft<sup>2</sup>).
- The cost of construction of offshore pipeline can vary from as low as \$500/m (\$150/ft) for small makeup water lines to as much as \$6,600/m (\$2,000/ft) for large makeup water lines.
- The cost of shoreline intakes will average approximately \$11,000/m<sup>2</sup> (\$1,000/ft<sup>2</sup>) based on the cross-sectional area of the screens.
- Shoreline intakes will also vary from between \$140 to \$424/m<sup>3</sup> (\$4 to \$12/cu ft) of structure enclosed beneath the operating deck with a mean of \$212/m<sup>3</sup> (\$6/ft<sup>3</sup>).

TABLE VI-2

## COST OF INTAKE STRUCTURES

Plant Code No.	Intake Flow m <sup>3</sup> /s	Total Cost \$	Unit Cost \$/m <sup>3</sup> /s	Unit Cost \$/kw	Comments		
					Plant Fuel	Intake Type	Year Commissioned
5404	1.26	466,000	369,800	0.40	Fossil	Makeup	1965
5309	1.58	2,000,000	1,265,800	1.82	Nuclear	Makeup	1976
4213	1.58	2,500,000	1,582,300	1.37	Nuclear	Makeup	1975
3407A	2.27	5,000,000	2,202,600	4.17	Nuclear	Makeup	1977
3407	20.79	1,000,000	48,100	1.78	Nuclear	Circulating Water	1965
3805	4.85	400,000	82,500	1.67	Fossil	Circulating Water	1966
Unit 1 3805	5.67	950,000	167,500	2.26	Fossil	Circulating Water	1973
Unit 2 3601A	20.79	4,800,000	230,900	4.00	Fossil	Circulating Water	1972
3113	20.16	8,700,000	431,500	11.18	Nuclear	Circulating Water	1972

## Cost of Implementing Proposed Guidelines

### Locational Measures

The measures which potentially have the greatest cost impact on intake structures are concerned with the location of the intake. In particular, where locational measures involve extensive offshore piping at a site for which a shoreline intake would have otherwise been suitable, the intake cost can be increased significantly. Costs of offshore piping have been detailed above, and it was shown that the cost of this work can increase the intake cost significantly.

### Design Measures

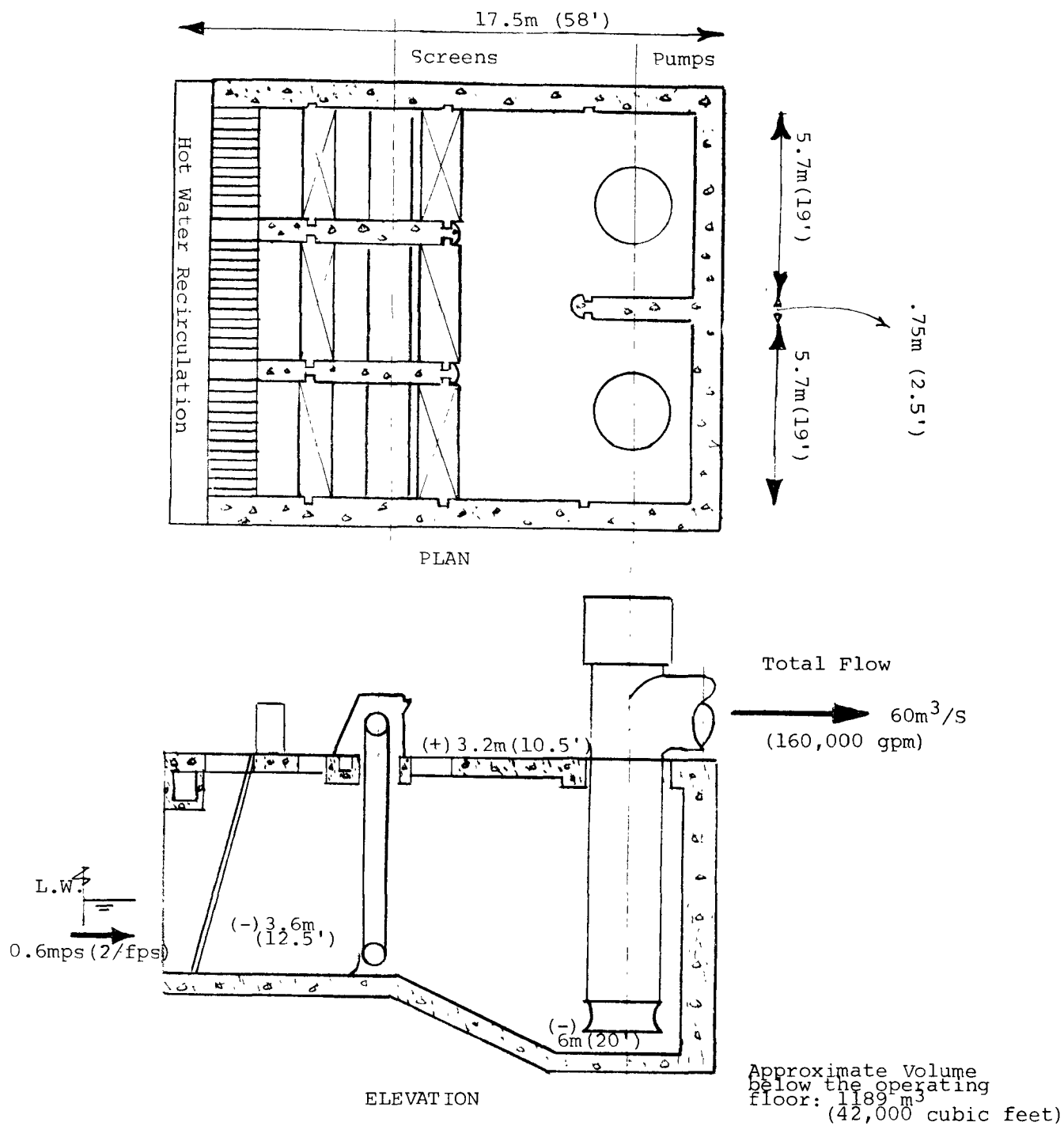
The design measures that will increase costs significantly are those that involve a reduced approach velocity and flush mounting of the screens. The changes that could be involved are shown in Figures VI-2 and VI-3. These figures are based on a certain design of a hypothetical shoreline intake structure without the modifications required. The unmodified design provides an approach velocity of 0.6 m/s (2 fps) with screens set back from the front face of the intake. The modified design employs an approach velocity of 0.15 m/s (0.5 fps) with screens set at the front of the intake and fish passageways provided between the screens and the trash racks. The total intake flow-per-bay is approximately 10.1 m<sup>3</sup>/s (160,000 gpm) at maximum pump runout conditions. The intake would draw an average of 15.8 m<sup>3</sup>/s (250,000 gpm) using two bays with the third bay acting as a spare. This flow is equivalent to the circulating water flow for a fossil-fired plant with a capacity of approximately 300 MW.

The major changes involved include the increasing of the volume of the intake structure below the operating floor from approximately 1190 m<sup>3</sup> (42,000 ft<sup>3</sup>) as shown in Figure VI-2 to approximately 2040 m<sup>3</sup> (72,000 ft<sup>3</sup>) as shown in Figure VI-3. The cost increase involved in making these changes are shown in Table VI-3.

TABLE VI - 3

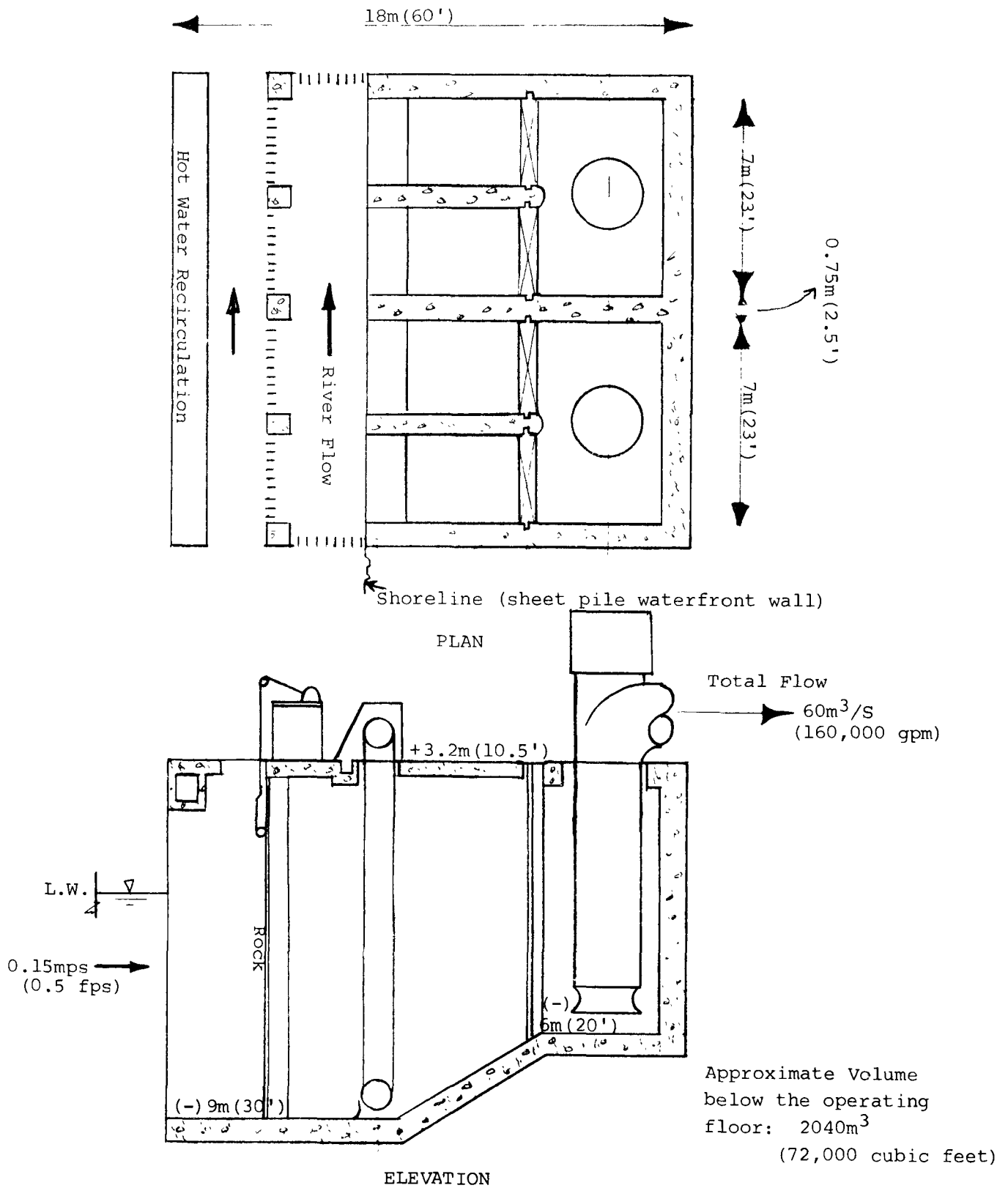
#### COST ANALYSIS - IMPLEMENTATION OF EXAMPLE DESIGN REQUIREMENTS

<u>Facility</u>	<u>Unmodified Intake Cost</u>	<u>Modified Intake Cost</u>
Structure	\$ 189,000	\$ 324,000
Racks	17,000	38,000
Traveling Screens	54,000	80,000
TOTAL	\$ 260,000	\$ 442,000



DESIGN OF CONVENTIONAL INTAKE

FIGURE VI-2



DESIGN OF CONVENTIONAL INTAKE MODIFIED BY RECOMMENDATIONS

FIGURE VI-3

The total cost increase involved in making these changes is shown in the Table to be approximately \$182,000 or roughly 70% of the cost of the unmodified intake.

In addition, the larger structure requires more dredging and the construction of a sheet pile retaining wall upstream and downstream of the intake to provide continuity to the "flush-face" intake, and to facilitate flow through the fish passage between the trash rack and traveling screens. The estimated cost for the additional work (dredging and retaining wall) is \$90,000.

The estimated cost of modifying the traveling water screens to incorporate fish handling and bypass systems as discussed in the design section of this portion of the report is between \$15,000 and \$20,000 per bay depending on the screen size. An equivalent amount could be required to provide the additional screen wash systems and bypass systems required.

#### Costs - Other Measures

There will be additional costs for measures related to construction and performance monitoring. The costs of these measures are indeterminable at this time, but are not believed to be excessive.



SECTION VII  
CONCLUSIONS AND RECOMMENDED TECHNOLOGY  
TO BE CONSIDERED IN EACH CASE

Introduction

This section summarizes the findings of the previous sections on background, location, design, construction and operation and maintenance of cooling water intake structures. The format for this section presents certain conclusions with respect to the various factors involved. The technology discussed herein were prepared to assist in the evaluation of the best technology available for minimizing environmental impacts of cooling water intake structures. As a minimum, the following recommended technology should be considered in each case.

Background

It was concluded that the application of the best technology available on intake structures alone will do little to protect against the entrainment effects on small organisms passing through a cooling system. These effects are better controlled by either controlling the plant intake flow or the design of the cooling water systems. Such measures do not relate to cooling water intakes per se, and therefore are beyond the scope of this report.

It was found that some intakes have been designed without the development of adequate data on the biological community that would be affected by intake operation. Since subsequent measures for location, design and construction can only be made on the basis of this information, this data base should be developed in each case.

Technology - Acquisition of Biological Data

The discharger should provide data on the biological community to be protected. In some cases, depending on the severity of the problems and especially for new steam electric powerplants withdrawing water from sensitive water bodies, the data should consist of, as a minimum, the following:

- The identification of the major aquatic species in the water source. This should include estimates of population densities for each species identified, preferably over several generations to account for variations that may occur.
- The temporal and spatial distribution of the identified species with particular emphasis on the location of spawn-

grounds, migratory passageways, nursery areas, shellfish beds, etc.

- Data on source water temperatures for the full year.
- Documentation of fish swimming capabilities for the species identified, and the temperature range anticipated under test conditions that simulate as close as possible the conditions that exist at the intake.
- Location of the intake with respect to the seasonal and diurnal spatial distribution of the identified aquatic species.

### Location

The proper location of the intake structure with respect to the aquatic environment is far and away the most important consideration relevant to applying the best technology available for cooling water intakes. Care in the location of the intake can act to grossly minimize adverse environmental impacts. It will be difficult and perhaps impossible in certain cases to offset the adverse environmental impact of improper intake location by subsequent changes in either design or operation of the intake structure short of significantly reducing the intake volume.

Therefore, it is critical that the qualifications of the biological and other investigators and the data obtained, especially as a preliminary to the location of a new intake, reflect the significance of the decisions which must rely on the results of the study.

#### Intake Location With Respect to Plant Circulation Water Discharge

The potentially adverse effects of the recirculation of water from the discharge back to the intake have been discussed. Most powerplants will prevent this to maximize plant thermal efficiency. In some cases where this is difficult to do, some recirculation may be tolerated. From the environmental standpoint, recirculation of warm water is undesirable.

#### Technology - Prevention of Warm Water Recirculation

All intakes should be located with respect to the plant discharges in a manner that will prevent, to as great an extent as possible, the recirculation of warm water from the discharge back to the intake.

#### Plant and Vertical Location of the Water Inlet

The location of the water inlet with respect to the temporal and spatial distribution of the resident and migratory aquatic populations is extremely important. Intake configuration can be selected to withdraw

water from any point in the source water body. Inlets can be located to draft water from any elevation in the source.

#### Technology - Location and Elevation of Water Inlet

Water inlets should be designed to withdraw water from zones of the source that are the least productive biologically and contain the lowest population densities of the critical aquatic organisms. This includes both the plan and location of the inlet and the vertical location in the source water body.

In addition, inlets should be located to avoid spawning areas, nursery areas, fish migration paths, shellfish beds or any location where field investigations have revealed a high concentration of aquatic life.

The location of the intake should also be selected to take advantage of river or tidal currents which can assist in carrying aquatic life past the inlet area or past the face of the screens.

#### Intake Location With Respect to the Plant

The incremental impact on entrained organisms is directly related to the transit time between the intake and the condenser. However, all entrained organisms would be lost, anyway, in configured recirculating cooling water systems. Therefore, for other types of cooling water systems the intake should be located close to the plant. This consideration is even more important in the relative location of the outfall structure and the plant.

#### Technology - Location of Intake With Respect to the Plant

For nonrecirculating cooling water systems the intake structure should be located close to the plant.

#### Design

The basic conclusion related to the design section is that there is no generally viable alternative to the conventional traveling water screen available at the present time. Some new screen types have recently been developed that might prove to have generally superior environmental characteristics following an adequate period of testing. Certain of these designs might be superior today at certain sites. It is noted that this is one area in which research and development have not kept pace with the need. Research projects directed toward the development of more effective screening systems could have valuable results. Furthermore, since the configuration of the intake is largely determined by the screening system employed, the conventional intake structure will probably remain substantially unchanged in the near future.

Therefore, most of the design recommendations contained herein are based on the configuration and physical design features of conventional intake structures as previously defined in Section III. It is anticipated that new intake designs will emerge that may have more positive environmental design features than the conventional intake. One of the express overall recommendations is the encouragement of this positive evolutionary process in the technology. As discussed in Section III, some of the new technologies that will influence intake design have already been partially explored. These include the increased use of behavioral barriers such as the louvered intakes; the development of new types of physical screening systems such as the horizontal travelling screen; and the increased use of bypass systems. The present status of these technologies and their very limited use at existing cooling water intake structures does not justify separate recommendations for these types of systems at the present time. However, certain features of the following recommendations may be applicable to these types of systems, as well as to conventional intake structures.

### Approach Velocities

Typical approach velocities to the traveling water screens at existing intakes fall within the range of about 0.24 to 0.33 mps (0.8 to 1.1 fps).

### Technology - Design Approach Velocities

The design approach velocity to the intake water screens should be measured in the screen channel upstream from the screens and be based on the effective portion of the screen face. The velocity measurement should further be based on the lowest water level anticipated. The design approach velocity should be conservatively based on data specific to the design organism(s) at the intake location. These data should include as a minimum:

- The spatial and temporal distribution of the fish by size for each species identified.
- The annual temperature range anticipated at the intake.
- The demonstrated avoidance capability of these species over the full range of temperatures experienced.

It is possible that a low approach velocity could have a more adverse environmental impact than a higher approach velocity.

### Uniform Approach Velocities and Effective Screen Areas

The maintenance of uniform velocity profiles across the screen face is an important feature in effective screen performance. Many factors can influence the velocity gradient at the screen face and it is not a

simple task to eliminate non-uniform velocities. Another important consideration is the determination of the effective area to be used in determining the approach velocity. In many cases, the effective area is significantly less than the full submerged area of the screen.

#### Technology - Uniform Approach Velocities

The discharger should document that effectively uniform velocities will be maintained across the face of the screen at the design conditions. The discharger should also indicate the effective screen area used in the approach velocity calculation. Where there is reason to question this information, hydraulic model testing, as well as velocity profile measurements taken at the intake should be required of the applicant.

#### Selection of Screen Mesh Size

The selection of screen mesh size is generally based on providing a clear opening of no more than one-half of the inside diameter of the condenser tubes. The powerplant industry has generally standardized on 0.95cm(3/8") mesh size. While this criterion may be adequate for keeping foreign objects out of the cooling system, this criteria may not be adequate for proper protection of all aquatic species. A rational design approach for screen mesh selection based on the design organism(s) is contained in the design portion of the report. The data used in this approach are not considered extensive enough for development of a firm recommendation on screen mesh size.

However, this approach may be used in lieu of better data. More information on this aspect of screen design should become available in the future as the biological data required above are developed.

#### Behavioral Screening Systems

None of the available behavioral screening systems have demonstrated consistently high efficiencies in diverting fish away from powerplant or other industrial intake structures. The behavioral screening systems based on velocity change appear to be adequately demonstrated for particular locations and species, at least on an experimental basis. More data on the performance of large prototype systems at industrial plants will be required before the louver system can be recommended for a broad class of intakes. The "velocity cap" intake can be recommended to be considered for all offshore vertical intakes since it would add relatively little to the cost of the intake, and has been shown to be generally effective in reducing fish intake to these systems.

The performance of the electric screening systems and the air bubble curtain appears to be quite erratic, and the mechanisms governing their application are not fully understood at the present. These types of systems might be experimented with in an attempt to solve localized

problems at existing intakes, since the costs involved in installing these systems are relatively small.

No successful application of light or sound barriers has been identified. It appears that fish become accustomed to these stimuli, thus making these barriers the least practical of the available behavioral systems on the basis of current technology.

#### Technology - "Velocity Cap" Intakes

All offshore intakes should be fitted with a "velocity cap" designed to minimize the intake of the design organism(s) that are resident at the individual intake location. The design approach velocity measured at the face of the intake opening should conform to the design approach velocities previously discussed.

#### Physical Screening Systems

It is concluded that the conventional traveling water screen will continue to be widely used at powerplants for the near term, although this system may have some potentially significant adverse environmental features.

Furthermore, the fixed screening systems currently installed at powerplant intakes, have potentially even more damaging environmental characteristics. These systems invariably involve longer impingement periods between cleaning cycles and increased damage to the fish because of greater local velocities across the more completely clogged screen. The crude methods employed to clean fixed screens are also damaging to fish.

#### Technology - Limitation of the Use of Fixed Screens

The use of fixed or stationary screening systems should be prohibited at powerplant intakes. The cost impact of this would be relatively small, since the higher initial cost of rotating equipment will be offset by the reduced labor required for manual cleaning of the screens over the lifetime of the intake.

#### Fish Handling and Bypass Facilities

There is some evidence to recommend that all new intakes should incorporate a fish handling and bypass system which will allow for safe return of important fish species to the water source along with the physical screening system. Unfortunately, the case of fish handling and bypass systems in conjunction with cooling water intakes is not a highly developed technology at the present time. Therefore, a blanket recommendation, requiring these systems at all new intakes cannot be recommended, but this technology should be considered in such case.

The use of fish bypass facilities at existing intakes where fish impingement has been documented may improve the performance of these intakes. These types of facilities may also be desirable in those new intakes where it is not clear that impingement can be avoided. One type of bypass system can be incorporated in the conventional intake using the traveling water screen. This system assumes impingement but minimizes its effect in the following manner:

- Impingement time is reduced by continuous operation of the screens
- It provides a means for a gentle separation of the fish from the screen mesh
- It provides a passageway for safe return of fish to the water way

One installation of this type is presently being installed on a major powerplant intake (Plant No. 5111) and was described in detail in the design section of this report. The basic features of this system are shown in Figure III-41. It is believed that this type of system might have a positive impact on the impingement problem if the performance of this initial installation is successful. However, this system is not sufficiently developed at present to provide a basis for a formal general recommendation. The progress of this type of facility should be closely followed in the future because the system appears to have attractive environmental features.

#### Control of Fouling and Corrosion

Biological fouling of the cooling water system downstream of the intake is usually controlled by the addition of chlorine to the cooling water. The point of application is often the intake structure. The application of chlorine at the intake can adversely affect any subsequent fish bypass system that may be installed. It is, therefore, important that if chlorine is to be administered at the intake it should be added downstream of any such facility. It is noted that the addition of chlorine at this point will seriously affect the survival chances of all entrained organisms, and its use should be carefully monitored and controlled.

Corrosion protection of the screening system is not a design factor of intakes that directly affects the environment. It will be to the advantage of the owner to insure the integrity of screening systems by providing adequate materials for the type of use and water quality of the source.

## Intake Configuration

Of the three conventional intake structure types discussed in the design section of this report, the approach channel type of intake generally has sufficient potential for environmental impact to warrant careful evaluation prior to its use. This type of intake is shown in Figure III-47.

### Technology - Use of Approach Channel Intakes

The use of lengthy approach channel intakes should be avoided where at all possible. Where they are used, the screening facility should be located as close as possible to the shoreline while maintaining a satisfactorily uniform velocity distribution. An arrangement is shown in Figure III-48. The velocity in the approach channel should be limited to the design approach velocity.

There are further considerations in the design of a shoreline intake. In some cases at nuclear powerplants, it may not be practical, for safety reasons, to locate the screen structure or intake on the shoreline. Also, the placement of the intake with respect to the shoreline, should be such as to limit the protrusion of the intake into the stream, except in the case of an ocean site. Protruding intakes cause localized eddy currents that can affect the travel of fish to the intake. An example of this type of design is shown in Figure III-49.

### Technology - Limitation of Protruding Shoreline Intakes

Intakes should be designed to limit the protrusion of the intake sidewalls in the stream.

Another important design consideration for shoreline intakes is the location of the screens within the confining sidewalls of the intake. Most conventional intakes have the screens set back from the face of the intake between confining sidewalls. This type of setting can create undesirable entrapment zones between the trash racks and the screens. The recommended setting is to mount the screens flush with the front face of the intake as shown in Figure III-50. In this type of design, it is also desirable to design the trash racks to allow fish passage in front of the screens. This type of intake is most suited to locations where there is sufficient current in the source to wash the fish past the intake. Two examples of this type of design incorporated in existing powerplants are shown in Figures III-51 (Plant No. 3601) and III-52 (Plant No. 0610).

### Technology - Screen Settings for Shoreline Intakes

The screen settings for all shoreline intakes should provide for mounting the screens flush with the upstream face of the intake. In addition, provisions should be made for fish passageways located between the screens and the trash racks.



## Use of Walls

Walls are often used to select water from the coldest portion of the source. The use of a wall is shown in Figure III-4. Walls not only create non-uniform velocity conditions at the screens, but also create a dead area where fish can become entrapped. Fish will not usually swim back under the wall to safety. It is recommended that this type of construction be avoided.

## Technology - Limitation on the Use of Walls

The use of walls for the purpose of selecting cold water should be avoided. Walls may be used where required to prevent the recirculation of warm water or to select water from biologically safe areas of the source. Both of these factors are contained in previous guidelines.

## Pier Design

Many intakes utilize a pier which protrudes upstream of the screens and serves as a dividing wall between adjacent screen channels. This type of design is shown in Figure III-53, and is not consistent with the concept of flush mounting of screens and should therefore not be used.

## Pump to Screen Relationships

The relationship of the pump capacity to the screen area provided is an important design factor at intake structures. Several intake variations to accommodate pumps of a wide range of sizes is shown in Figure III-56. Care must be taken to locate the screen with respect to the pump in a manner which will properly utilize the entire screen surface. Any mismatch between screen size and pump size can result in undesirable velocity distribution across the screen. Hydraulic Institute Standards recommend minimum distances from screen to pump as well as lateral dimensions of the screen and pump wells. However, these recommendations are based on pump performance criteria and not best utilization of the screen area.

Another important design consideration is the effect on screen velocities under pump run-out conditions. This condition exists where one pump is removed from service and the total dynamic head on the remaining pumps is reduced. Flow through the remaining screens may be increased by as much as 40% above average design conditions.

It is impossible to establish a uniform recommendation that would reflect the different problems that might arise because of the several pump-screen relationships that exist. However, dischargers should be required to show how their designs have allowed for these factors.

## Ice Control Facilities

Most intakes located in the northern latitudes employ a partial recirculation of warm condenser discharge back to the intake to control ice buildup in front of the intake. The potential adverse environmental effects of warm water recirculation have been well documented. Fish will be attracted to the intake in the winter months. At the low water temperatures their swimming capability will be greatly reduced and the possibility of their entrapment in the intake will be increased.

Unfortunately, there is no alternate ice control technology currently available to replace hot water recirculation. Submerging the intakes can create another problem as noted in an earlier section. Air bubble systems have not been proven on large cooling water intakes, although they may become acceptable following a further period of development.

The development of alternate technology for the control of ice at intake structures is one area in which further research should be undertaken. However, until such technology is available the use of hot water recirculation cannot be prohibited. These systems perform an important function at intake structures. For this reason, the recommendation for ice control must be qualified in a manner that does not prohibit this system but encourages the development of alternate technology.

## Technology - Ice Control at Intakes

The use of warm water recirculation for the purposes of controlling ice at intake structures should be limited to those installations where no other means of ice control are available. Where such a system is employed, close control of the quantity of water recirculated and timing of its use (intermittent if possible) should be practiced. The point of application of the hot water should be located to minimize the potential adverse environmental impact that can result from the application of these systems. The applicant is encouraged to seek alternate solutions to the ice control problem. Intermittent operation of ice control could prevent fish accumulations which might occur with a continuous ice control.

## Aesthetic Design

Where the intake structure and the balance of the plant are separated by great distances, the intake structure can have an objectionable physical presence. This will be significant in wilderness areas and in natural and historic preserves. There are various techniques available to blend the intake structure with its surroundings. The intake may also be lowered to reduce its impact. However, this latter approach can increase costs significantly especially where rock excavation is required. Where the plant and intake are located close together, the intake will be dominated by the plant and various architectural treatments can be applied to create an attractive grouping of structures. This latter factor is another reason for locating intakes close to the balance of the plant. Since aesthetic impacts are governed

by location conditions, a general measure for aesthetic design is not recommended.

#### Noise Control

The sound level of large circulating water pumps can be quite high. Again this will be important only where the intake is remotely located from the balance of the plant. The noise level emanating from an intake located close to the plant will be dominated by the noise of the plant. Current practice, however, is to construct intakes, in milder climates, without enclosures. Where intake noise level is a factor, they should be enclosed. Enclosed intakes would not have significant sound levels. A uniform measure is not recommended.

#### Construction

The adverse environmental impact of the construction of cooling water intake structures consists almost entirely of the effects of the aquatic population of the turbidity increases created by the various construction activities. The U.S. Army Corps of Engineers already is responsible for construction in navigable waterways and all intake construction will have to conform to the Corps' guidelines for dredging, disposal of soil, etc.

#### Dredging, Excavation and Backfilling

These activities can cause significant short term increases in the turbidity of the source water. Depending on the particle size, distribution of the excavated materials and the hydrology of the source, the impact of the turbidity increase will be local or widespread. It is believed that a two-fold approach for the control of turbidity increase is required. First an absolute limit should be placed on the level of turbidity increase resulting from these operations. Second, typical requirements, as follows, should be utilized to reduce the impact of individual construction operations.

#### Technology - Turbidity Increase Resulting From Dredging Excavation and Backfilling

The turbidity increase from construction operations on cooling water intake structures should not exceed a specific level of Jackson turbidity units (JTU) set for the particular site. The method and location of the point of measurement should depend on the nature of the aquatic community, the length of the construction program and the hydrology of the receiving water. This acceptable level of turbidity should be based, as a minimum, on existing water quality standards for the classification of the particular water body.

## Technology - Typical Requirements for Dredging, Excavation and Backfilling

- Excavation in low lying areas in the vicinity of the water body should be conducted with natural soil plugs or berms left in place. When these soil plugs are removed, the one furthest away from the stream should be removed first.
- Where excavations are dewatered during construction, no discharge from the dewatering pump should be made to the waterbody unless it conforms to the turbidity standard set forth above; this may require that the said discharges be settled or filtered prior to discharge.
- Materials excavated should be placed above the water line. Suitable slope protection for excavated materials should be provided.
- Underwater excavations for conduit should be scheduled to allow placing of the conduit and the closing of the excavation to be completed as rapidly as possible. Backfill over conduit below the water line should be leveled to prevent sediment transport.
- Where large excavations and dredging operations are required it may be desirable to conduct these operations behind a retaining structure such as an earth embankment or a coffer dam. Care must be taken in the construction and removal of these facilities so that the turbidity limits established above are not exceeded.

The applicable outline specifications contained above should be incorporated in all intake construction where required. The discharger should indicate that these specifications shall be incorporated into the contract documents for the construction of the intake.

## Construction Scheduling

The construction of intakes can often be scheduled in a manner that can reduce adverse environmental impact. In many waterbodies there are significant water level variations during the year. It may be possible to schedule much of the intake construction during low water periods when it can be done above water level. In addition, construction should be scheduled to avoid spawning seasons and migration periods where turbidity increase can harm these functions. The ability to schedule in this fashion requires that the appropriate biological data be made available.

## Technology - Construction Scheduling

The scheduling of intake structure construction should take advantage of low water periods to undertake certain construction work above the water level. Scheduling should also avoid known periods of fish spawning and migration.

## Disposal of Spoil

The disposal of spoil within navigable waters is controlled by the U.S. Army Corps of Engineers. In addition to any requirements that the Corps establish, it is necessary to prevent the disposal of spoil in known fish spawning, feeding areas, shellfish beds and over important benthic deposits. The disposal of spoil in these areas can cause permanent loss of important biological species. In addition, spoil deposits both below the water and above the water should be adequately stabilized to prevent long term turbidity increases due to either water currents or erosion.

### Technology - Disposal of Spoil

The disposal of spoil below the water line should be avoided. In those cases where this cannot be avoided, spoil should not be disposed of in spawning grounds, feeding areas and over important benthic deposits. All spoil deposits should be adequately stabilized to prevent long term erosion.

### Slope Protection for Excavation and Fills

The same considerations governing the stabilization of spoil deposits are also applicable to the protection of slopes of excavation and fills that are a permanent part of the intake.

### Technology - Slope Protection for Intake Excavations and Fills

The slopes of all excavations and fills incorporated in the intake structure shall be adequately protected against erosion and wave action.

## Operation and Maintenance

Although most of the environmental impact may occur during actual intake operation, it will not be possible to effect intake operation significantly once it is placed in service.

Most of the control of adverse environmental impact of intake structures would probably be obtained in the location and design criteria. Some degree of control over impingement effects might be achieved by proper screen operational procedures. Pump operation might also be controlled to reduce environmental impact although the pumps are not a part of the intake structure as strictly defined. It would also be desirable to develop a program for periodic performance monitoring of intake structures.

Maintenance is not an aspect of intake structure operation which has only indirect environmental impact. The discharger should submit in outline form his maintenance program for the intake system.

## Screen Operation

The impact of fish impingement on screens can be reduced by continuous screen operation to reduce the period of time that fish are impinged on the screens. This type of operation to reduce impingement effects is only applicable where fish separation and bypass streams are available. Since the number of installations having this capability is small, no general recommendations on continuous screen operation are made. However, more of these systems may be installed in the future. Continuous screen operation in this manner will shorten screen life and increase maintenance costs.

## Pump Operation

The ability to control pump operation can reduce impingement effects at certain locations during the winter months. Pump flows often can be reduced in the colder winter months with no detrimental effect on plant performance. Since fish swimming ability is reduced during colder temperatures, such a flow reduction may be desirable to reduce fish impingement. Since the pumps are not a part of the intake as previously defined, no measures regarding pump performance are recommended. However, pump controls may be desirable in certain locations.

## Performance Monitoring

A program of performance monitoring of intakes is recommended to establish data on the performance of these systems.

### Technology - Performance Monitoring of Intake Structures

The performance of intakes should be monitored on a continuing basis. The owners of intake structures should periodically submit performance data that consisting of the following:

- Source water temperatures
- Stream flows (if applicable)
- Screen operation schedule
- Cooling water flow
- Number, types, and condition of important organisms impinged, entrained, and bypassed.

### Applicability of Intake Structure Technology

For new sources, no measure other than proper location of the intake in correspondence iwth the intake volumes required should be relied upon.

In many cases an existing establishment may have reason to replace the nonrecirculating cooling water system with an essentially closed recirculating system. The reduction in intake water quantity by installing the closed cooling system should significantly reduce adverse environmental impact resulting from the cooling para like water intake.

Furthermore, intake flow could be reduced during certain time periods to minimize adverse environmental impact.

A stepwise approach to intake modifications is generally recommended for cases where adverse environmental impact must be reduced by this means:

The first step should be to attempt to reduce impact by the modifications of the existing screening systems. The possible modifications that can be applied are discussed in the design section of this report. The performance of this type of modification has not been fully documented because initial installation is presently under construction. However, the cost of in-place modifications of this type are not excessive and they can generally be made while the plant is operating.

The second step should be to increase the size of the intake to reduce high approach velocities. This will require additional screen and pump bays and most likely the replacement of the existing pumps to reduce the flow through each bay. This type of modification could also be done while the structure is kept in service but only where extra screen bays are available.

The third step should be to abandon the existing intake and replace it with a new intake at a different location and incorporating an appropriate design. This could be very costly particularly if an offshore inlet is required. The recommendation of such a change should be very carefully considered. However, a particular discharger may elect to avoid the costs and uncertainties associated with the first two steps and proceed directly to step three.

The time required for the installation of these changes at a steam electric powerplant, for example, will vary from as low as 3-4 months for the modification of an individual screen bay to as much as two years to completely construct a new intake.

#### Cost of Implementation of Intake Structure Technology

The cost of the implementation of the required technology can vary from intake to intake. The costs associated with implementation will be mainly due to the capital costs of the facilities proposed. Operation and maintenance costs are relatively small for existing intakes and the technology will not increase these costs significantly.

#### New Intakes

The cost of intake structures at powerplants is presently estimated to be between \$3 and \$20 (between 2 and 10% of present plant cost) per kilowatt of installed capacity, the lower range being for larger circulation water intakes of the shoreline type. The higher range is

for intakes for smaller service water systems which require extensive offshore piping.

The potentially major cost-impacting measures would be those that require a reduced approach velocity ;and the requirement for flush mounting screens. The implementation of these measures might add as much as 70% to the cost of a bankside intake. For a powerplant this would be equivalent to between \$2 and \$4 per kilowatt of installed capacity. Installing an offshore intake reather than a bankside intake can add considerably more to the cost.

#### Existing Intakes

The cost impact to existing sources can be considerably greater than to new sources. In the worst case, where an entirely new intake is required which requires extensive offshore conduit, the cost should be as great as the \$20 per kilowatt stated above. The impact of this cost on an older plant will generally be more severe than on a newer plant. Since these changes cannot be entirely relied upon to actually reduce adverse environmental impact in any case, these modifications should be carefully considered before implementation.



## SECTION VIII

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SECTION IX

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## SECTION X

### GLCSSARY

#### Agglomeration

The coalescence of dispersed suspended matter into larger flocs or particles which settle more rapidly.

#### Brackish Water

Water having a dissolved solids content between that of fresh water and that of sea water, generally from 1000 to 10,000 mg per liter.

#### Brine

Water saturated with a salt.

#### CFM

Cubic foot (feet) per minute.

#### Circulating Water Pumps

Pumps which deliver cooling water to the condensers of a powerplant.

#### Circulating Water System

A system which conveys cooling water from its source to the main condensers and then to the point of discharge. Synonymous with cooling water system.

#### Closed Circulating Water System

A system which passes water through the condensers, then through an artificial cooling device, and keeps recycling it.

#### Cooling Canal

A canal in which warm water enters at one end, is cooled by contact with air, and is discharged at the other end.

#### Cooling Lake

See Cooling Pond.

### Cooling Pond

A body of water in which warm water is cooled by contact with air, and is either discharged or returned for reuse.

### Cooling Tower

A heat exchange device which transfers reject heat from circulating water to the atmosphere.

### Cooling Water System

See Circulating Water System.

### Crib

A type of inlet structure.

### Critical Aquatic Organisms

Aquatic organisms that are commercially or recreationally valuable, rare or endangered, of specific scientific interest, or necessary to the well-being of some significant species or to the balance of the ecological system.

### Curtain Wall

A vertical wall at the entrance to a screen or intake structure extending from above, to some point below, the water surface.

### Discharge

To release or vent.

### Discharge Pipe or Conduit

A section of pipe or conduit from the condenser discharge to the point of discharge into receiving waters or cooling device.

### Entrainment

The drawing along of organisms due to the mass motion of the cooling water.

### Entrapment

The prevention of the escape of organisms due to the cooling water currents and forces involved.

### Filter Bed

A device for removing suspended solids from water, consisting of granular material placed in horizontal layers and capable of being cleaned hydraulically by reversing the direction of the flow.

### Filtration

The process of passing a liquid through a filtering medium for the removal of suspended or colloidal matter.

### Fixed or Stationary Screen

A nonmoving fine mesh screen which must be lifted out of the waterway for cleaning.

### Floc

Small gelatinous masses formed in a liquid by the reaction of a coagulant added thereto, thru biochemical processes, or by agglomeration.

### FPS

Foot (feet) per second

Foot (feet) - Designated as 1', 2', etc.

### Impingement

Sharp collision of organism with a physical member of the intake structure.

### ID

Inside diameter

### Inch (inches)

Designated as 1", 2", etc.

### Infiltration Bed

A device for removing suspended solids from water consisting of natural deposits of granular material under which a system of pipes collect the water after passage through the bed.

### Inlet Pipe or Conduit

See Intake Pipe or Conduit.

### Intake Pipe or Conduit

A section of pipe or conduit from the pump discharge to the condenser inlet; also used for the pipe leading from the inlet to the screens or pumps.

### Intake or Intake Structure

A structure containing inlet, water cleaning facilities and/or pumps.

### KN

Kilo Newton

### MPS

Meters per second.

### Makeup Water Pumps

Pumps which provide water to replace that lost by evaporation, seepage, and blowdown.

### Mine-mouth Plant

A steam electric powerplant located within a short distance of a coal mine and to which the coal is transported from the mine by a conveyor system, slurry pipeline or truck.

### M<sup>3</sup>

Cubic Meter

### Nominal Capacity

Name plate - design rating of a plant, or specific piece of equipment.

### Once-through Circulating Water System

A circulating water system which draws water from a natural source, passes it through the main condensers and returns it to a natural body of water.

### Powerplant

Equipment that produces electrical energy, generally by conversion from heat energy produced by chemical or nuclear reaction.

### Pump and Screen Structure

A structure containing pumps and facilities for removing debris from water.

### Pump Chamber

A compartment of the intake or pump and screen structure in which the pumps are located.

### Pump Runout

The tendency of a centrifugal pump to deliver more than its design flow when the system resistance falls below the design head.

### PVC

Polyvinylchloride

### Recirculation System

Facilities which are specifically designed to divert the major portion of the cooling water discharge back to the cooling water intake.

### Recirculation

Return of cooling water discharge back to the cooling water intake.

### Saline Water

Water containing salts.

### Second

Abbreviation = s

### Sampling Stations

Locations where several flow samples are tapped for analysis.

### Screen Chamber

A compartment of the intake of pump and screen structure in which the screens are located.

### Screen Structure

A structure containing screens for removing debris from water.

### Sedimentation

The process of subsidence and deposition of suspended matter carried by a liquid.

### Service Water Pumps

Pumps providing water for auxiliary plant heat exchangers and other uses.

### Station

A plant comprising one or several units for the generation of power.

### Stop Logs

A device inserted in guides at the entrance to a waterway to permit dewatering. It can be made up of individual timber logs, but more commonly of panels of steel, timber, or timber and concrete.

### Total Dynamic Head (TDH)

Total energy provided by a pump consisting of the difference in elevation between the suction and discharge levels, plus losses due to unrecovered velocity heads and friction.

### Trash Rack, Trash Bars, Grizzlies

A grid, coarse screen or heavy vertical bars placed across a water inlet to catch floating debris.

### Trash Rake

A mechanism used to clean the trash rack.

### Traveling Screen

A device consisting of a continuous band of vertically or nearly vertically revolving screen elements placed at right angles to the water flow. Screen elements are cleaned automatically at the top of the revolution.

### Turbidity

Presence of suspended matter such as organic or inorganic material, plankton or other microscopic organisms which reduce the clarity of the water.

### Unit

In steam electric generation, the basic system for power generation consisting of a boiler and its associated turbine and generator with the required auxiliary equipment.

### Utility

(Public utility) a company, either investor-owned or publicly owned which provides service to the public in general. The electric utilities generate and distribute electric power.

### Velocity\_Cap, Fish\_Cap

A horizontal plate placed over a vertical inlet pipe to cause flow into the pipe inlet to be horizontal rather than vertical.

### Wet\_Well

A compartment of the pump structure in which the liquid is collected and to which the pump suction is connected.