ENVIRONMENTAL AND ENGINEERING CONSIDERATIONS IN DESIGNING COASTAL WATER INTAKES

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INTRODUCTION

Water intakes developed for coastal use often require special design considerations to ensure the incorporation of engineering features which are compatible with environmental protection. Due to the severity of the coastal zone environment, cooling water intakes for power generating facilities typically incorporate one of two possible designs:

1. A shoreline (surface) intake which could incorporate jetties, breakwaters, or inlet channels for wave protection and, when necessary, for retardation of sedimentary processes, or

2. An offshore, submerged intake connected via tunnel or pipeline to an onshore screen/pumphouse.

Naturally, protection of structural integrity is of primary concern in designing and locating such intakes. Therefore, physical or hydraulic conditions are required to enhance plant reliability which may be adverse from an environmental viewpoint. As a result, it is often necessary to integrate additional provisions into intake designs which will mitigate potential adverse impacts resulting from plant operation.

During the mid to late 1960s, as the size and number of power plants began to dramatically increase in the United States, various agencies responsible for protecting fish and wildlife were becoming increasingly alarmed that sport and commercial fisheries were being adversely affected by thermal discharges (Krenkel and Parker 1969). In response to this concern, various state and Federal regulations were promulgated to limit the effects of thermal discharges on aquatic biota. Various engineering options were developed to limit thermal effects. These options ranged from simply limiting the rise across the condenser, and therefore the ultimate temperature at the point of discharge, to employing various means of closed-cycle cooling, particularly at sites where water availability was limited (Parker and Krenkel 1969).

It became apparent in the early 1970s that, in addition to addressing the effects of thermal discharges on aquatic biota, consideration would have to be given to limiting the effects associated with withdrawing large quantities of water in cooling water intakes. In 1972, the Federal Water Pollution Control Act Amendments established requirements to ensure that large water withdrawals would not have significant impacts on various fish and invertebrate lifestages (e.g. eggs, larvae, and juveniles). Mortality of these organisms in circulating water systems may occur as a result of entrapment in intake structures, impingement (of larger lifestages) on screening equipment designed for condenser protection, or entrainment (of smaller life stages) through the system. Regulatory concern over the past decade has led to extensive research efforts in an attempt to resolve these problems. As a result, a variety of innovative technologies have been developed which can be integrated into the design of coastal intakes for organism protection without jeopardizing plant reliability (ASCE 1982). Three such designs are described in this paper.

INTAKE DESIGNS

The design of a coastal intake is largely dictated by site-specific physical, hydrologic, and environmental conditions. In areas of limited water depth, wave action, and littoral sediment transport, dredged canals protected by parallel jetties are often used to ensure an adequate water flow while minimizing problems resulting from sedimentation and wave forces. Where deeper water is available in near-shore areas, submerged intake structures connected to a shoreline pumping station via tunnels or pipes can offer protection from wave action and icing problems. In both cases, embayment areas are created which can cause mortality among aquatic organisms. Therefore, protection systems may be required to minimize organism losses.

Canal Intakes with Jetties

Engineering Design

A nuclear power plant in New York withdraws approximately 37 m^3s^{-1} from Long Island Sound for cooling and service water purposes. Initially, two alternatives were available for withdrawing water from Long Island Sound; a submerged offshore intake structure connected by pipeline to an onshore screenwell or an onshore intake structure.

For the offshore alternative, two locations were evaluated; 457 m and 1707 m offshore. These locations were selected on the basis of bottom topography and the fact that recirculation from an offshore discharge diffuser would be minimized. Based on a comparison of the offshore alternatives to an onshore location, the offshore locations were not selected. The offshore alternative operational and maintenance costs were substantially greater than an onshore location. Biofouling control in the long submerged inlet pipes would necessitate the use of large quantities of chlorine or a flow reversal scheme to elevate temperatures in the inlet pipe to 46°C for extended periods of time. It was deemed that utilization of these biofouling control methods for either of the offshore locations would present problems in complying with environmental criteria. Another disadvantage of the offshore intake schemes is the inability to easily retrofit fish protection facilities to the system should an increased level of protection be required in the future.

On the basis of this evaluation, an onshore intake system was selected and is shown in Figure 1. It consists of the following:

(a) A 488 m long canal, 122 m of which extends beyond the mean low water (MLW) shoreline, with a 24 m bottom width at elevation -3.7 m MLW. It was not possible to select an onshore intake without a canal because of the rise and fall of the tide. It was also necessary to protect the canal with jetties to avoid the almost continuous dredging that would be necessary to prevent it from becoming filled with sand. The jetties are constructed to an elevation of 3 m MLW. The jetties were constructed of irregularly-shaped core stone blocks weighing from 1.8 to 7.2 MT. The canal sides are covered by a 0.8 m layer of core stone but the bottom consists of the naturally occuring sand, which will allow periodic dredging to remove accumulated sand.

    The canal has been designed to discourage fish entrapment by keeping the average velocity less than 0.3 ms^{-1} at MLW and 0.15 ms^{-1} at MHL.

(b) A screenwell, as shown in Figure 2, which is divided into four bays, with each bay supplying water to a service water (0.55 m^3s^{-1}) and a circulating water (9 m^3s^{-1}) pump. The flow passes through trash racks and traveling water screens which are designed for fish protection.

Organism Protection

Due to the need for jetties at this Long Island Sound site, an embayment resulted between open water and the cooling water intake screenhouse. The presence of this embayment raised regulatory concern that fish might become entrapped in the intake screenhouse and impinge on the traveling screens, a process which results in mortality unless protective measures are taken. For this reason, a novel fish collection system was incorporated into the screenwell design to allow for the safe removal and return of impinged fish to the Sound.

As shown in Figure 3, the collection system consists of a series of vertical, traveling water screens modified from the conventional design to include fish lifting buckets and a low-pressure spraywash to gently rinse collected fish into a trough for return to the Sound. The screens have the capacity to operate continuously to minimize the time of impingement, collection and removal.

Fish which enter the intake screenwell and impinge on a screen are carried by the screen to the water surface. At this point, they drop into a fish-lifting bucket containing approximately 5.0 cm of water. These buckets are attached to each screen panel at 0.61 m intervals.

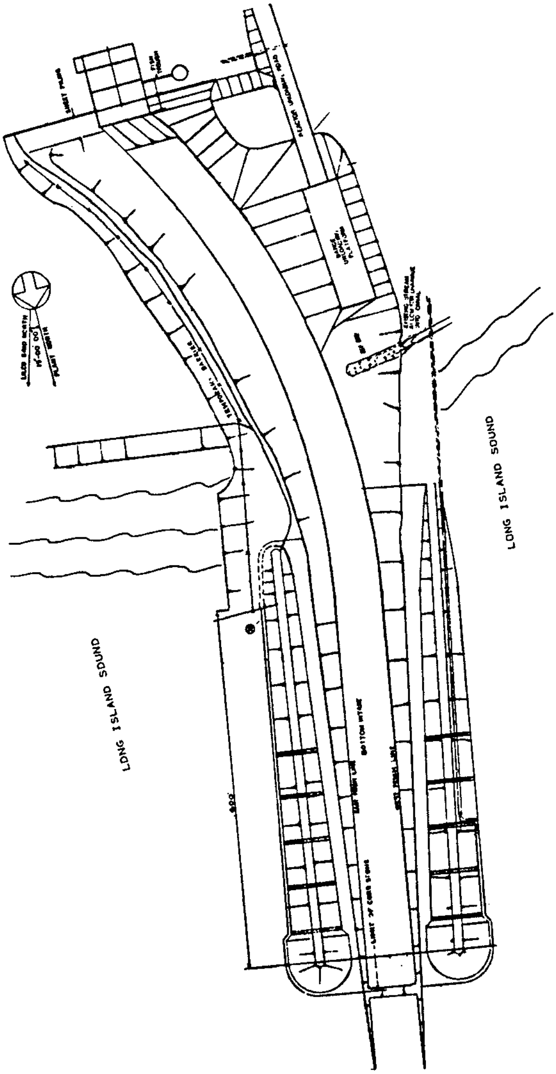


FIGURE 1 ONSHORE INTAKE SYSTEM WITH JETTIES

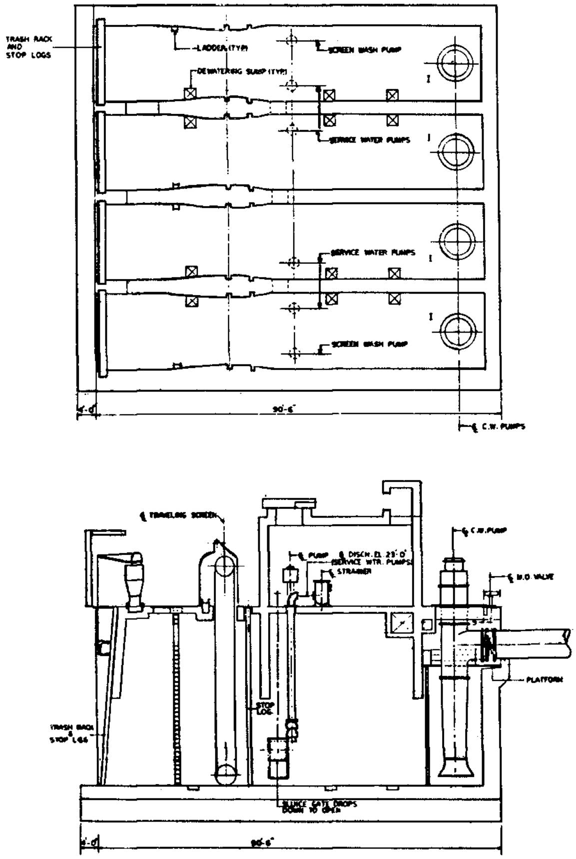


FIGURE 2 INTAKE SCREENWELL WITH MODIFIED, FISH PROTECTION SCREEN

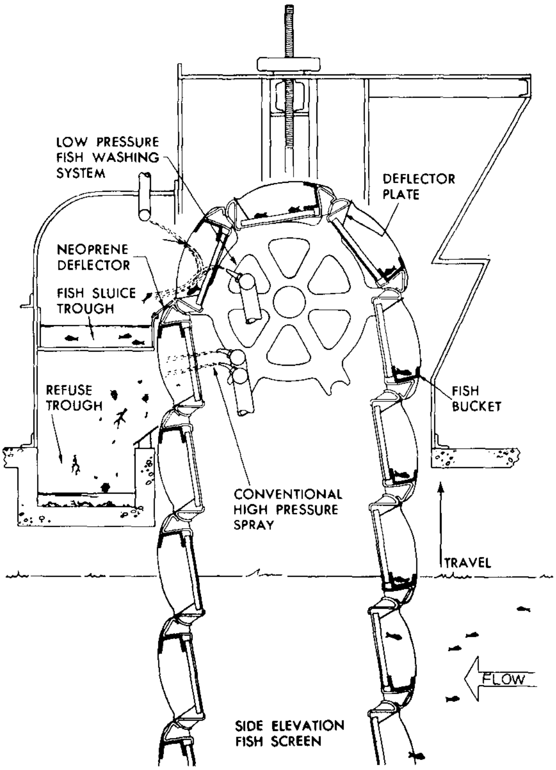


FIGURE 3 MODIFIED THROUGH-FLOW TRAVELING SCREEN WITH FISH BUCKETS

Containing the fish in water prevents them from flipping off the screen and becoming reimpinged on the submerged screen area.

At the operating deck level, a low-pressure spray (less than 1.4 kg cm^{-2}) rinses the contents of the lifting bucket into a return trough. A high-pressure spray is located above the low-pressure spray to rinse remaining debris from the screen mesh into a separate debris trough.

The fish trough transports recovered fish back to Long Island Sound at a suitable distance from the intake to minimize recirculation.

This system has only recently become operational and fish survival data is, unavailable at this time. However, other power plants incorporating this system have been in operation for several years. The biological data obtained at these sites clearly demonstrates the effectiveness of the modified screen concept.

The first collection screen system installed in the U.S. is at Virginia Electric Power Company's Surry Nuclear Station in Virginia. An 18 month biological evaluation of this system showed that the average initial survival of 58 species of fish after recovery from the screen was about 93 percent (White and Brehmer 1976).

Similar studies were conducted with a fish collection screen at Boston Edison Company's Mystic Station (Stone & Webster 1981). In these studies, all fish recovered from the screen were held for 96 hours after collection for observation of latent effects resulting from the collection and removal process. Initial survival rates were similar to those observed at the Surry Station for fish species common to both sites. However, latent survival varied by species, as expected. For example, the relatively hardy flounder showed nearly 100 percent survival under all conditions tested. On the other hand, fragile species, such as herring and smelt, displayed survival rates under optimal condition in the range of approximately 50 to 65 percent.

These studies, along with other studies conducted at power plants throughout the United States, indicate that the modified fish collection screen system is a viable and effective means of protecting fish entering intake screenwells.

Offshore, Submerged Intakes

Engineering Design

At a power plant on Lake Ontario, wave action and severe icing conditions that result in ice packing along the shore necessitated the withdrawal of cooling water (20.5 m^3s^{-1}) from a submerged (9.1 m) intake structure connected to an onshore screenhouse in a 305 m long tunnel.

As a result of regulatory requirements, provisions had to be incorporated into the design of this system to protect fish which may be drawn into the intake. In this case, the species of concern were fragile and could not survive collection on a screen. Therefore, an innovative fish diversion system was incorporated into the design of the screenhouse. The design consists of primary and secondary fish diversion and pumping systems which together act to divert fish into a small bypass flow which ultimately returns the fish to Lake Ontario via a pipeline.

Figures 4 and 5 illustrate the screenwell arrangement incorporating angled flush mounted screens leading to the bypass. Fish entering the screenwell pass through 7.6 cm spaced trashracks and guide along the angled screens into a 15.2 cm wide bypass. Each bay is equipped with two 3 m wide screens angled 25° to the direction of the flow. The screens are separated by 1 m wide concrete piers and have been modified so that the screen baskets are flush with the piers and opening of the bypass to allow fish to easily guide along the face of the structure. Upon entering the bypass, fish are carried to a secondary angled screen and diverted to a pipeline which returns them to the lake.

Although debris loading tends to be low, the bypass was designed so that it can be manually cleaned by raking or, if necessary, flow can be reversed to free any material which passes through the trashracks and becomes lodged in the bypass. Bypass flow is designed such that the ratio of the screenwell approach velocity to the bypass entrance velocity is 1:1, a condition that yields high fish diversion efficiencies. Approach and bypass velocity is approximately 0.3 ms^{-1}, resulting in a 0.15 ms^{-1} velocity at the screenface. A jet pump provides the energy to induce the required bypass flow and return fish back to the lake in a submerged pipeline.

Organism Protection

The design of this system for fish protection was developed as a result of several years of investigation in the laboratory. (Taft and Mussalli 1978). These laboratory studies demonstrated that the angled screen system is 100 percent effective in diverting a wide variety of fish species to bypasses. Subsequent to diversion, test fish were held for 96 hrs for observation of delayed mortality. In all cases, mortality was low (less than 5 percent), thus yielding overall system efficiency values in excess of 95 percent.

The full-scale angled screen system on Lake Ontario has been in operation for over two years. Although published results are not presently available, ongoing studies indicate that diversion efficiencies are generally high for all fish entering the plant including species which had not previously been evaluated.

Intakes with Fine Screening

Organism Protection

In the previous two examples of coastal intake designs, engineering design requirements dictated the need for biological protection. At a power plant on the coast of Florida, the need for organism protection necessitated an engineering design study to develop an organism handling system. Due to regulatory concern over the loss of small

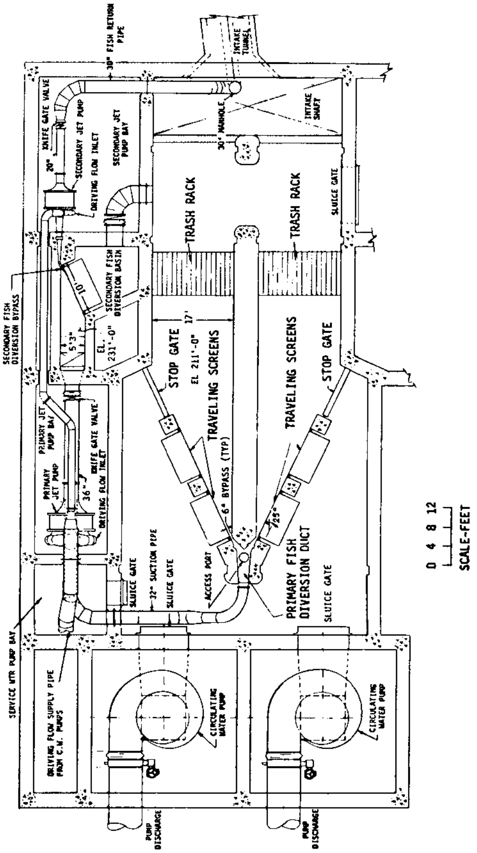


FIGURE 4 ANGLED TRAVELING SCREENS AT LAKE ONTARIO POWER PLANT

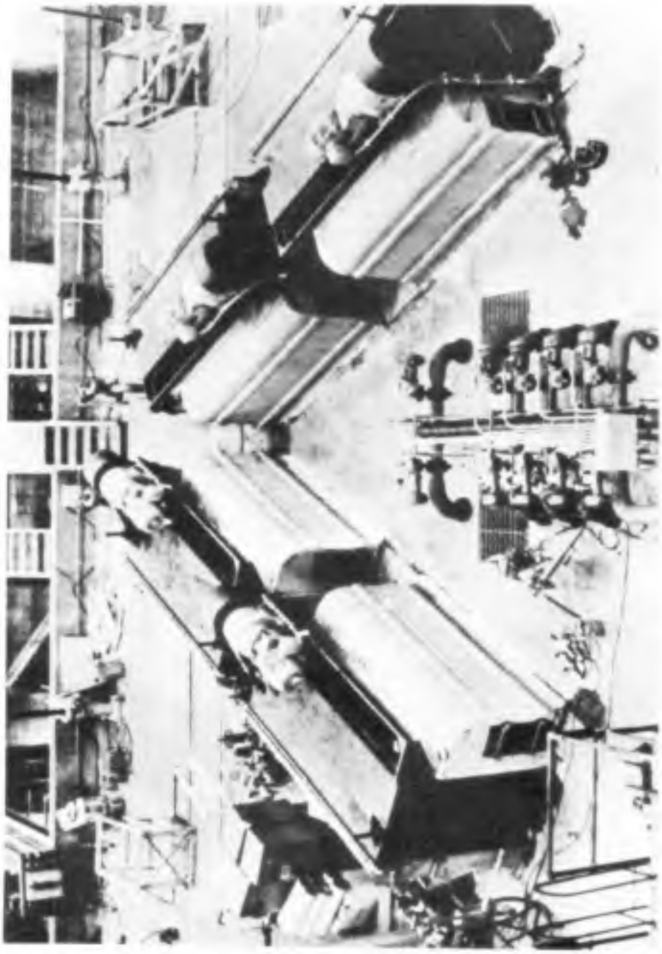


FIGURE 5
OSWEGO STEAM STATION - UNIT 6 ANGLED SCREEN INTAKE
DESIGNED AND CONSTRUCTED BY STONE & WEBSTER

organisms (the earliest life stages of various fish and invertebrate species) at this station, a major research program was conducted to optimize the design and operation of a unique collection screen system.

A full-scale, prototype system was constructed on site to permit both engineering and biological evaluations. The system consisted of a dual-flow (no-well) traveling screen, modified to incorporate 0.5 mm screen mesh (Figure 6) to exclude small life forms, special organism lifting lips and a very low-pressure spraywash system for rinsing collected organisms into a trough. Screens were also operated continuously to minimize the time that organsims would be impinged on the mesh.

Two years of research was conducted with the fine-mesh prototype screen. Results of biological studies indicated high survival rates for many of the organisms of concern at this site. For example, crab and shrimp larvae generally showed latent survival rates in excess of 85 percent, with many approaching 95 to 100 percent. Similarly, fish eggs collected from the screen showed hatching rates generally greater than 90 percent and subsequent, 48-hr larval survival rates ranging from about 82 to 100 percent (Taft, Horst, and Downing 1981).

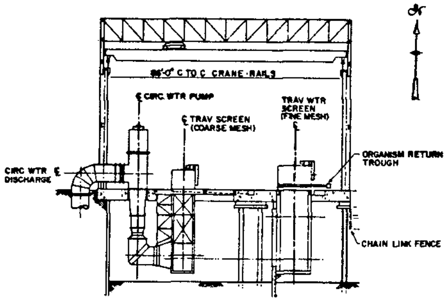
Engineering Design

The field studies demonstrated a high biological efficiency of this organism collection system. As a result, two generating units are being equipped with fine-mesh screens (Figure 7). Each unit will be equipped with 3 screens to handle 15.3 m^3s^{-1}. The stringent design criteria required for organism protection (very small mesh size, continuous screen operations) necessitated detailed engineering design evaluations and studies to ensure reliable operation.

Due to the requirement for fine screening at this site, unique operation and reliability questions arose which had not previously been addressed. A major concern and focus of the developmental studies was the potential for greatly increased clogging due to the use of 0.5 mm mesh, and subsequently pressure drop, over that experienced with conventional 9.5 mm mesh. Consequently, a head loss monitoring program was conducted as part of the overall prototype system evaluation. The results of this program showed that, even under conditions of moderate loadings of jellyfish (ctenophores), head losses could be maintained at levels less than 10 cm.

In order to ensure reliable screen operation in actual application, features were incorporated to prevent clogging, including continuous operation capabilities and screen spray systems. The screens will be equipped with variable speed motors to accommodate various debris loadings and will be completely sealed to minimize organisms losses (Mussalli, et al 1981).

FIGURE 6 FINE-MESH SCREEN TEST FACILITY



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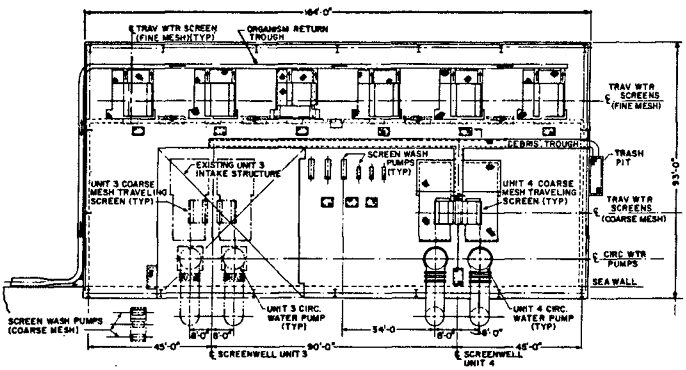

PLAN

FIGURE 7 FLORIDA FINE-MESH SCREEN INTAKE

CONCLUSIONS

The selection of a design for a coastal water intake depends on several factors. Consideration has to be given to the topography and geology at the site, severity of wave action and potential for icing, the types and quantities of debris that may be encountered, and regulatory concern as to the types of aquatic organisms that have to be protected.

These three cases demonstrate how environmental concerns related to the engineering of cooling water systems in coastal zones can be addressed and resolved through careful study and the development of innovative design concepts.

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