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Guidelines for Minimizing Entrainment and Impingement of Aquatic Organisms at Marine Intakes in British Columbia

Habitat Management Division
Department of Fisheries and Oceans
Vancouver, British Columbia V6B 5G3

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GUIDELINES FOR MINIMIZING ENTRAINMENT AND IMPINGEMENT OF AQUATIC ORGANISMS AT MARINE INTAKES IN BRITISH COLUMBIA

by

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ABSTRACT

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The loss of aquatic organisms at marine water intakes through entrainment and impingement can have a potentially severe impact on marine resources. Planktonic organisms are particularly vulnerable to such losses and include juvenile stages of crustaceans and eggs and larvae of herring, hake, cod and other fish species. Recent proposals in British Columbia for industrial and mariculture facilities requiring seawater intakes, indicate an urgent need for suitable guidelines to protect marine resources; the main concern is to minimize the incidental capture at the intakes of aquatic organisms. This document presents guidelines and criteria for the siting and design of marine intakes in British Columbia.

Factors which affect the incidental capture of aquatic organisms at intakes include abundance, distribution, size and behaviour of the organisms in the vicinity of the intake, as well as intake siting and design characteristics. The intake specifications presented include intake location, elevation off the bottom, water velocity, flow volume, screen mesh size, open area in the screen and screen mesh material. A literature review which provided the basis for the guidelines is included in the appendix section.

RÉSUMÉ

Fedorenko, A.Y., 1991. Guidelines for minimizing entrainment and impingement of aquatic organisms at marine intakes in British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2098: 86 p.

La perte d'organismes aquatiques aux prises d'eau de mer causée par l'entraînement et l'empiétement peut avoir des conséquences sérieuses sur les ressources maritimes. Le planoton, les jeunes crustacés et les oeufs et les larves de hareng, de merluche, de morue et d'autres espèces de poisson sont particulièrement vulnérables. Les projets d'installations industrielles et aquicoles nécessitant des prises d'eau de mer mis de l'avant récemment en Colombie-Britannique font ressortir l'urgence d'énoncer des lignes directrices en vue de protéger les ressources marines; le principal objectif est de restreindre la capture accidentelle d'organismes aquatiques. Ce document renferme des lignes directrices et des normes relatives au choix d'un emplacement et à la conception des prises d'eau de mer en Colombie-Britannique.

L'abondance, la répartition, la taille et le comportement des organismes aux environs d'une prise d'eau, de même que l'emplacement et la conception des prises d'eau de mer, sont autant de facteurs déterminant l'ampleur des prises accidentelles. Les caractéristiques définies pour les prises d'eau comprennent l'emplacement, leur distance au-dessus de fond, la vitesse du dourant, le volume d'écoulement, la taille des mailles des crépines, les brèches dans celles-ci et le matériau dont elles sont faites. Une étude documentaire qui a servi de base aux lignes directrices est incluse dans l'annexe.

INTRODUCTION

Entrainment and impingement of fish and other aquatic organisms, such as macroinvertebrates and fish eggs and larvae, at water intake structures may create potentially serious losses of these organisms. Entrainment occurs when an organism is drawn into a water intake, while impingement occurs when an entrapped organism is held in contact with the barrier. The severity of the impact on the aquatic resources will depend on the abundance, distribution, size and behaviour of the organisms in the vicinity of the intake, as well as on intake location, depth, pumping rate, screen mesh size and other features.

The impacts of entrainment and impingement may be considerable for large-sized facilities. For example, conventional 1,000 megawatts (MW) fossil fuel and nuclear power plants require cooling water at a rate of approximately 50 and 75 m^3/sec, respectively (Hanson et al. 1977a). Entrainment of fish eggs and larvae is a potentially large source of environmental impact resulting from water withdrawal, particularly for power plants with once-through cooling systems (Weisberg et al. 1986). Estimates of 179 million fish larvae and juveniles entrained per year at the Connecticut Yankee Power Plant, and 250 million eggs and larvae entrained per year at the Oyster Creek Power Plant illustrate the potential severity of the impact (Hanson et al. 1977a).

In British Columbia, no studies on entrainment in seawater intakes have been conducted because the region has no nuclear power plants and few operating marine intakes for other industries. However, recent proposals for industrial and mariculture facilities requiring seawater intakes, indicate an urgent need for suitable guidelines to protect marine resources. The guidelines are particularly important in view of the large herring spawning populations that are found in the intertidal and subtidal British Columbia waters (i.e. zones affected by tides and zones below the tidal influence) where potential seawater intakes may be sited.

During the last several decades, guidelines have been developed, especially in eastern North America, to reduce impingement and entrainment of aquatic organisms. Those guidelines include proper siting of the intake and selection of appropriate design features and screening systems.

The present guidelines have been prepared by the Department of Fisheries and Oceans (DFO) and are intended to satisfy certain of the Department's fish habitat management responsibilities. Section 30 of the Fisheries Act gives the Department specific authority with respect to the protection of fish from impingement and entrainment at water intakes. Since any intake withdrawal may result in some level of impingement and entrainment, the intent of the guidelines presented here is to minimize this impact. The guidelines are technical in nature and are intended to assist fish habitat managers and industrial or aquaculture developers in providing protection for marine organisms through environmentally sensitive siting and design of marine intakes, thus ensuring that populations of marine organisms are not adversely affected. The guidelines are restricted to issues of entrainment and impingement of marine organisms and are not intended to encompass other technical issues, social and economic concerns, or concerns that other agencies may have. It is emphasized that the guidelines are not to be interpreted as strict regulations to be adhered to in each and every case. Rather, they provide guidance to developers as to how they can best comply with the provisions of the Fisheries Act. The guidelines may be treated with some flexibility depending on specific circumstances as long as the intended objective of protecting aquatic resources is met.

A literature review which provided the basis for the guidelines is included in the Appendix section. Individuals requiring additional information should consult the reference section of this report. If further questions arise, developers should contact the appropriate DFO Habitat Management personnel early in the planning stage to ensure that the proposed protection measures for aquatic organisms are acceptable.

The appendixed literature review examines impingement and entrainment impacts at marine, estuarine and freshwater sites, with the freshwater intakes being the most commonly encountered examples in the literature. Pertinent information extracted from a given literature source is listed under each text heading by year of publication, from earliest to latest. The review also contains the recommended siting and design criteria developed in other jurisdictions (mostly the eastern United States). Although many of these guidelines are generally directed at the design of intakes for power plant cooling water systems, they are also fully applicable to any industrial or other water intakes where continuous water withdrawal may be necessary (ASCE 1982).

The guidelines for British Columbia presented below are based on the following: the preliminary guidelines drafted by D. Hay and D. Chalmers (MS 1988 DFO memo) and modified by R. Eliasen (MS 1988 DFO memo); the available literature sources; and interviews with research scientists, fisheries biologists and engineers (see Acknowledgements section). It is the Department's intention to assess the effectiveness of these guidelines using data from current and future assessment studies at selected marine intakes in British Columbia, such as the Nanaimo Marine Farms. Based on that review, the guidelines will be modified, if necessary. Each guideline section below is based on the information described in the specified appendix.

GUIDELINES

1. PRELIMINARY STUDIES (Appendix 6 A)

All proposed marine intakes will require a preliminary impact assessment at the proposed site. The scope of the assessment will be established by the DFO Habitat Management biologist and will include some or all of the following factors: life stages of aquatic organisms, such as fish and crustaceans, present in the general vicinity of the proposed intake site; seasonal and diurnal density and distribution of organisms, their migration patterns and location of spawning areas; food sources; salinity (in estuaries) and temperature fluctuations; and other physical conditions, such as current direction and magnitude. Based on the information obtained from these studies, the proposed intake site will be repositioned, if necessary, to meet the criteria defined in the guidelines.

The assessment should be undertaken by a qualified professional and funded by the proponent. Prior to conducting the assessment, the proposed methodology must be reviewed by DFO for completeness of approach. Results of the study must be forwarded to DFO for review and consideration of approval. Post-installation studies to monitor the intake operation may also be required, with the assessment specifications to be determined by the DFO Habitat Management personnel.

2. SITING - GENERAL (Appendix 6 B)

Select intake areas where field studies indicate low abundance of organisms during most times of the year for most species. Greatest concern is for the more vulnerable smaller organisms, such as plankton, macroinvertebrates and fish larvae and juveniles.

Avoid estuaries since they serve as nursery areas for anadromous and marine species.

Avoid subtidal rock reefs with growths of Agarum and other macrophytes since these reefs serve as significant nurseries for juvenile stages of prawns and rockfish. These rock reefs can be readily located by utilizing marine charts.

Avoid siting at or near a protected rocky shoreline habitat (65% of the Strait of Georgia shoreline is rocky). A marine intake positioned at such a site may severely impact rocky intertidal fish larvae which lack the capacity for planktonic dispersal and hence would have a low recovery potential if affected by an intake.

Do not site intakes at or near herring spawning areas that show historical spawning over time. Allow a minimum of 2 km between an intake structure and a documented herring spawning area. Distances less than 2 km could pose a serious risk to herring and other marine fish larvae which have little or no swimming ability.

3. SITING WITH RESPECT TO CURRENTS (Appendix 6 B)

Locate the intake upstream of a spawning area with respect to current direction so that water movement will sweep planktonic larvae away from and not toward the intake (Fig. 1). This action is especially important if the intake depth criterion of 25 m (see below) cannot be achieved since tidal current is higher at shallow depths. Note that some current activity is beneficial at the intake site in order to help reduce impingement of floating debris, such as fragments of kelp, on the intake screens.

4. SITING WITH RESPECT TO SHORELINE TOPOGRAPHY (Appendix 6 B)

Avoid areas with topographical features that promote eddies (e.g. upstream of a peninsula). Such eddies may cause the retainment of marine organisms which consequently will be more vulnerable to an intake placed at that site. Where an irregular shoreline cannot be avoided, place the intake off the end of a land protuberance (Fig. 1).

5. SITING WITH RESPECT TO INTAKE DEPTH (Appendices 3 and 6 C)

Install screened stationary intakes at a minimum depth of 25 m below the zero tide level (Fig. 2). This guideline is in addition to not siting marine intakes near sensitive fish larval areas. The depth guideline is designed to locate the intake below the layer where marine organisms are found in greatest numbers. Note that the recommended depth criterion may have practical limitations.

6. INTAKE ELEVATION OFF THE BOTTOM (Appendix 6 D)

Elevate the intake 2.0 m above the seabed, as measured from the seabed to the bottom of the intake screen. This measure will help avoid entrainment of epibenthic plankton living near, and associated with, the seabed substrate. Such organisms may include mysids, late zoea stages of prawns, cod larvae and larvae of other fish species. This requirement should pose no problems since intakes are generally raised on support structures well off the bottom to avoid any siltation or burial of screens. However, care should be taken to ensure that the intake is not secured by means of rip-rap or other material which would act as a fish attractant. Note that a higher intake elevation off the bottom is not recommended since it may result in precarious intake positioning due to unstable or shifting substrate, strong currents, etc. Also, the greater the specified intake elevation off the seabed, the greater the overall depth requirement (i.e. 25 m depth to intake plus elevation depth).

7. INTAKE WATER VELOCITY (Appendix 6 E)

Maximum approach velocities (i.e. velocity near the screen face) of 3 cm/sec for stationary screens and 12 cm/sec for self-cleaning screens are recommended. encouraged for smaller intake screens. This value is based on studies involving the swimming abilities of pink and chum fry (<40mm). While it is recognized that herring larvae will be entrained at these velocities, the losses should be reduced considerably by the correct siting of the intake (see Siting specifications above). Note that the intake water velocity is governed by pumping rate, screen mesh size and percent open area in the screen (see specifications No. 8, 9 and 10).

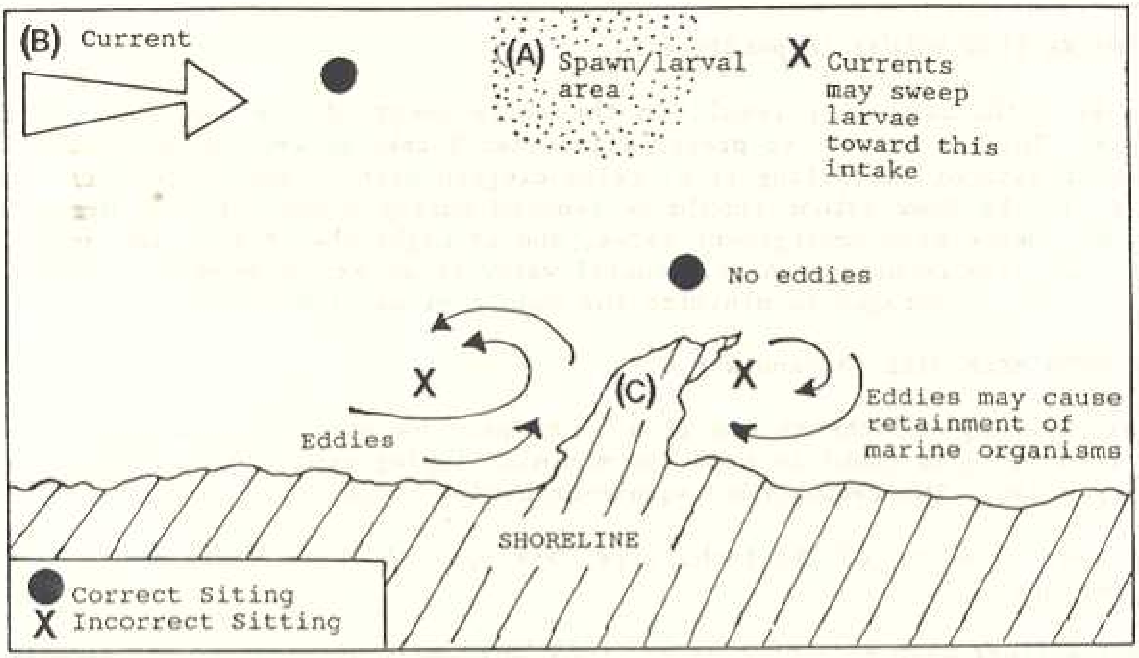


Figure 1. A diagrammatic sketch (bird's eye view) of correct "●" and incorrect "x" siting of a marine intake relative to: (A) spawn/larval area, (B) current direction and (C) land irregularities.

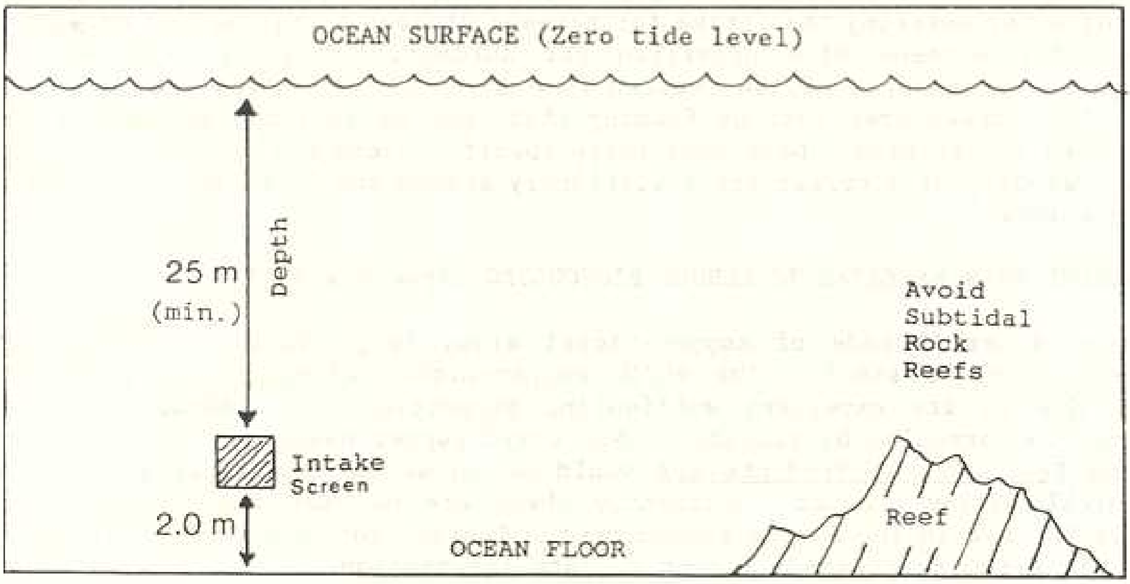


Figure 2. A diagrammatic sketch showing the preferred depth location of a marine intake.

8. INTAKE FLOW VOLUME (Appendix 6 F)

Any intake withdrawal will result in the entrainment of the smallest larval organisms. This is because no practically sized intake screen can avoid larval entrainment without biofouling (i.e. being clogged with organic material). If possible, intake flow volume should be reduced during months of high organism density and hence high impingement rates, and at night when higher impingement rates are usually reported. Also, general water conservation measures, such as recycling, are encouraged to minimize the amount of water withdrawn.

9. SCREEN MESH SIZE (Appendix 6 G)

The clear openings of the screen (i.e. the space between strands) should not exceed 4.75 mm (3/16 inch) in order to minimize impingement and entrainment of small organisms. The recommended square-mesh wire cloth screen is:

> 4 mesh, 1.60 mm (0.063 inch) wire, 56% open, 4.75 mm (3/16 inch) openings.

Note that a finer mesh size of 2.54 mm (1/10 inch) will be required for all mesh intake screens where the intake depth criterion of 25 m cannot be met. Only self-cleaning (i.e. automatic cleaning) screens are recommended for these shallower depths.

10. OPEN AREA IN THE SCREEN (Appendix 6 H)

Provide a minimum 50% open screen area as a percent of total screen area. This feature, together with flow rate, determines the average through-screen velocity. In order to achieve the necessary pressure drop across the screen a minimum unobstructed screen area of 0.93 m^2 (10 ft^2) is required for each 0.0283 m^3/sec (1 cfs) of water entering the intake for screens without provision for automatic cleaning; for screens with provision for automatic cleaning, the minimum unobstructed screen area may be reduced to 0.23 m^2 (2.5 ft^2) for the same flow volume. The screen area lost by framing shall not be included as part of the unobstructed screen area. Note that these specifications will result in a mean approach velocity of 3 cm/sec for a stationary screen and 12 cm/sec for a self-cleaning screen.

11. SCREEN MESH MATERIAL TO REDUCE BIOFOULING (Appendix 6 I)

Use screen material made of copper-nickel alloy (e.g. 90/10 or 70/30), or unpainted stainless steel. The 90/10 copper-nickel alloy is the preferred material due to its excellent antifouling properties, high durability, and resistance to corrosion by seawater. Non toxic copper-based paints registered under the Pest Control Products Act would be an acceptable alternative to a copper-nickle alloy product. Currently there are no such registered paints available for use in the marine environment. Contact the Pest Control Products Officer of Agriculture Canada for up to date information.

Increasing the size of mesh opening is not acceptable practice to reduce biofouling. The proponent may need to increase the screen area in locations where biofouling may be a problem; specifications for this are to be determined on the basis of individual studies.

As part of the preliminary assessment, a year-long site-specific testing of screen performance may be advisable regarding seasonal effects of debris clogging and biofouling. Results must be made available to DFO.

12. INTAKE SCREEN SHAPE AND ORIENTATION (Appendices 6 J and 6 K)

Design the intake structure to allow a uniform flow distribution through the total screen area. For best velocity distribution, as in small-mesh cylindrical screens, the length of screen should not exceed the diameter, i.e., avoid using elongated cylindrical screens so as not to create velocity "hot spots". For effective debris shedding, use spherical or the more practical, cylindrical screen shape. Consider also intake orientation since it can affect current direction at the intake structure and hence the avoidance reaction of organisms.

13. STRUCTURAL STRENGTH, ACCESSIBILITY AND SCREEN PROTECTION (Appendix L)

Support the screen with stiffeners or back-up material to prevent excessive sagging and provide sufficient structural strength. The screen must also be readily accessible for cleaning and inspection. Screen panels or screen assemblies must be removable for cleaning, inspection and repairs. Where necessary, the screen should be equipped with a trash rack or similar device to prevent damage from suspended debris.

14. ADDITIONAL ACCEPTABLE INTAKE DESIGNS (Appendix 6 M)

Use velocity caps over vertical inlets to provide an effective behaviour barrier (Figs. 3 and 4). Perforated pipe inlets may have application for smaller intake withdrawals (Fig. 5). However, a perforated pipe intake does not allow for much open screen area, and velocity "hot spots" may develop due to non-uniform flow distribution.

For shallow, low volume seawater withdrawals, marine infiltration gallery intakes can be acceptable. These can provide low withdrawal rates, generally below 0.028 m^3/sec (1 cfs) of seawater. However, two units would be required, with one gallery as a standby for maintenance periods. For additional operating efficiency, a back-flushing system should also be installed.

ADDRESSES FOR CORRESPONDENCE AND APPROVALS

1. Habitat Management Unit Head
Fraser River, Northern B.C. and Yukon Division
610 Derwent Way, Annacis Island
New Westminster, B.C. V3M 5P8 Phone: 666-6479

2. Habitat Management Unit Head
South Coast Division
3225 Stephenson Point Road
Nanaimo, B.C. V9T 1K3 Phone: 756-7270

3. Habitat Management Unit Head
North Coast Division
716 Fraser Street
Prince Rupert, B.C. V7J 1P9 Phone: 624-0453

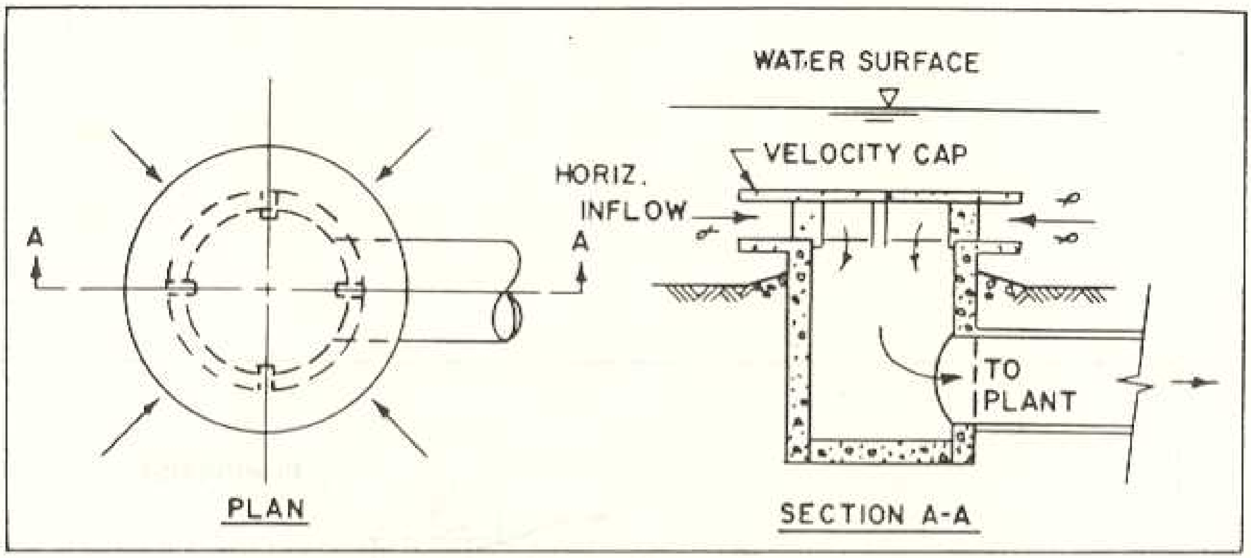


Figure 3. Velocity cap intake. (From: Richards 1977)

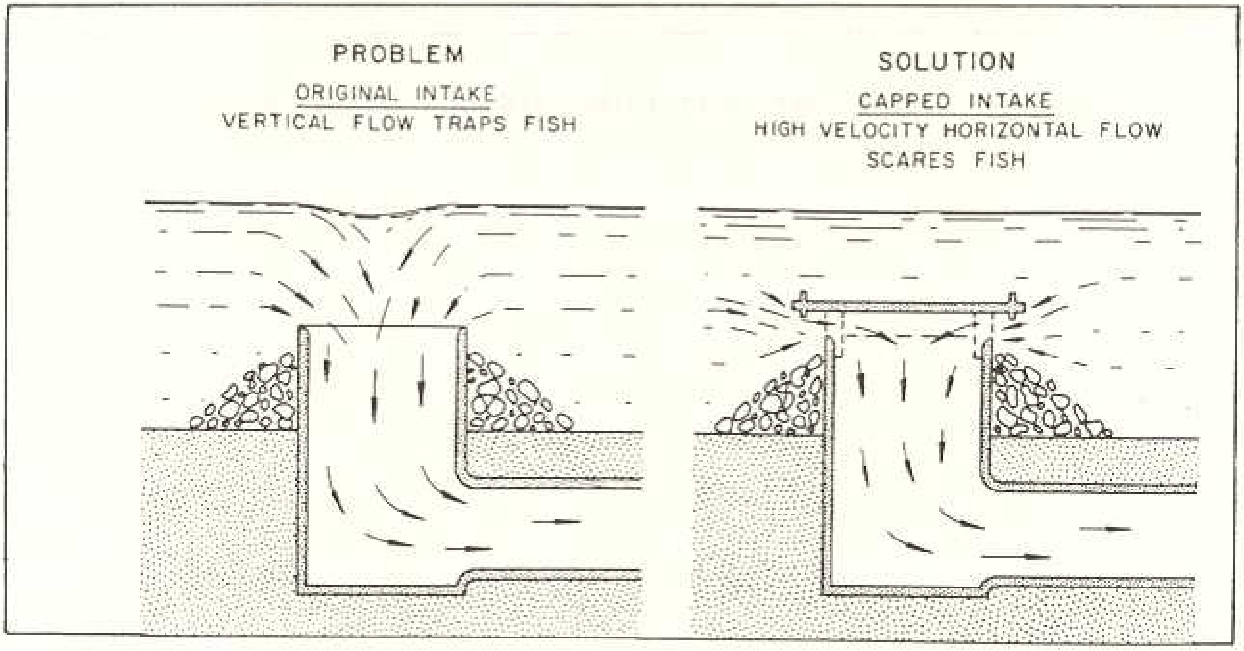


Figure 4. Diagrammatic comparison of an "open intake" and a "velocity capped intake." (From: Coutant 1974). Note that the guidelines for British Columbia suggest to avoid heavily rip-rapped intake structures as they may attract some fish species.

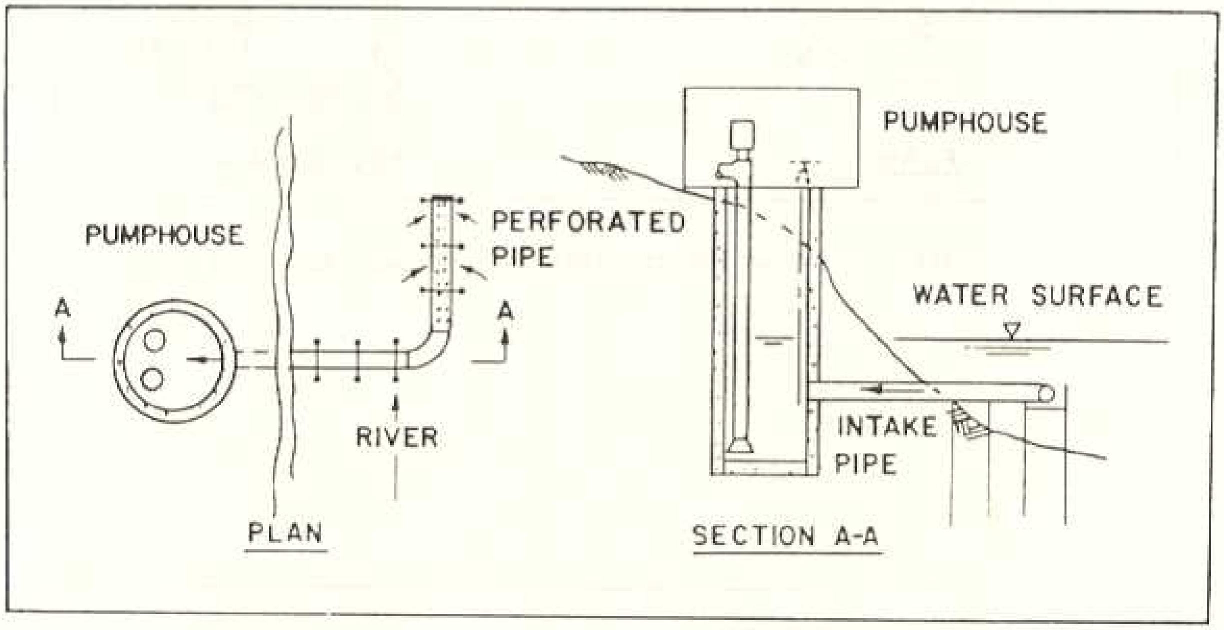


Figure 5. Perforated pipe intake system. (From: Richards 1977)

APPENDICES

The following literature review and personal communications have provided the basis for the guidelines presented in this report.

APPENDIX 1. IMPINGEMENT AND ENTRAINMENT MORTALITY

Source: Marcy (1973)

The percentage of mechanical damage incurred during entrainment varies with the species of fish, their life stages and size. For example, greater mechanical damage would be expected to fish larvae measuring 15 mm compared to 20-40 mm. It may be impossible to effectively screen small fish larvae to avoid entrainment and impingement. Kerr (1953) found that impingement of striped bass eggs and larvae on fine mesh screens for even a short time was fatal.

Source: Hanson et al. (1977a)

Fish may be trapped and impinged on intake screens by high debris densities and algal mats. Entrainment and impingement at intakes of juvenile and adult fish may result in immediate mortality due to mechanical abrasion and suffocation, or delayed mortality due to exhaustion, suffocation, or external and internal injury. Such stressed and damaged organisms would be more susceptible to disease and predation. The extent of physical damage is directly related to duration of impingement, techniques of handling impinged fish, and intake water velocities. For example, both increased water velocity and increased impingement time will result in increased degree of oxygen stress and increased mortality in juvenile salmon. The damage incurred by fish at water intakes also depends on the species, the stage of life history and size. For example, juvenile herring, striped bass and alewives appear to be particularly vulnerable to impingement stresses compared to catfish, carp and many salmonids. Mortality resulting from impingement increases with decreasing fish size. Thus, smaller fish are affected more by partial descaling compared to larger fish, with salmon less than 30 cm in length, reported dead 3-18 h after 30-50% scale loss. The entrainment and impingement of larval and juvenile fish poses a particularly serious problem due to the high vulnerability of these early life stages and the long regeneration time of fish populations.

Source: Kelso and Leslie (1979)

Available information indicates that entrainment mortality of fish larvae in power plant intakes is high (40-100%).

Source: Hocutt and Edinger (1980)

Fish impingement mortality at intake screens has been well documented. Once caught against the screens, fish eventually succumb to descaling and other physical damages, or suffocation as water pressure holds the gill chambers closed. Impingement mortality appears to be related to water velocity and duration of impingement. The impingement coefficient, defined as the ratio of number of fishes impinged to amount of water pumped at the power plant intake, depends on:

1. Number, size and orientation of intake screens,
2. Intake volume and velocity, and
3. Age and species structure of the fish community.

Source: Hoss and Blaxter (1981)

Fish with gas-filled organs are most likely to be at risk when subjected to the pressure changes which occur during entrainment or passage through the cooling water system of a thermal power station. Herring larvae below about 40 mm total length and especially those in the 25-30 mm length range are particularly vulnerable to large rapid pressure changes encountered during entrainment. Such larvae have a developed inner ear (bulla) but as yet no adaptation mechanism to changes in hydrostatic pressure. Consequently, larvae less than 40 mm in length may suffer implosion of the inner ear during entrainment.

Source: Schneeberger and Jude (1981)

Impingement mortality of organisms such as fish larvae, is site- and species-specific and must be determined from in situ studies conducted during power plant operations. Some of the most important factors influencing post-impingement survival include impingement duration, fish size, and approach velocity. As fish larval size increases, larvae become less susceptible to entrainment, and may show increased long-term survival after impingement on screens.

Source: Goeman (1984)

Fish impinged on water intake screens at power plants can be killed directly or may suffer delayed mortality due to exhaustion, suffocation or other physical injury. Impingement survival of fish is species-specific. Juveniles may show lower impingement survival than adults of the same species since juveniles may be more easily stressed to a point of mortality.

Source: Huguenin and Huguenin (1984)

Large intake systems such as those required for condensers of a power plant, can over time process immense quantities of water. This may result in potential injury and mortality of large numbers of small marine plants and animals near the base of the food chain, as well as eggs, larvae and juveniles of larger organisms such as herring. Injury can occur through mechanical damage and/or thermal shock. Low suction-side pressure due to screen clogging of intake screens can result in air being drawn into the system, which after going through a pump, results in supersaturated levels of dissolved gases. The exposure to supersaturated gas levels can be fatal to marine organisms entrained in the system but which otherwise may pass through unharmed. Mass mortalities have been reported as a result of "gas bubble" disease.

Source: Helvey (1985)

In general, fish entrapment at intakes is governed by the quantity of water withdrawn at the intake and the behaviour of fish e.g. nocturnal vs. diurnal activity, reef vs. non-reef associated, seasonal vs. year-round presence, etc. Entrapment vulnerability of fish species at marine intakes is usually greater at night than during daytime due to increased nocturnal fish activities associated with feeding, and the loss of visual perception of the water currents at intakes. Vulnerability also increases during storms probably due to reduced water visibilities.

APPENDIX 2. ORGANISMS THAT MAY BE AFFECTED BY MARINE INTAKES LOCATED OFF THE BRITISH COLUMBIA COAST

Sources: J. Marliave and M. St. John (pers. comm.)

Plankton may be greatly impacted by marine intakes located off the British Columbia coast. Plankton consist of a complex assortment of generally microscopic, passively drifting or weakly swimming organisms. These organisms include phytoplankton and zooplankton (plant and animal forms of plankton, respectively). Zooplankton consist of various crustaceans, such as copepods and euphausiids (i.e. krill), jellyfishes, certain protozoans, worms, molluscs, and the eggs and larvae of benthic and pelagic animals (Ingmanson and Wallace 1973). Many shellfish (e.g. shrimp, prawns, crabs and oysters), and fish (e.g. herring, rockfish, flatfish and groundfish, such as hake and cod) have planktonic juvenile stages. Marine intakes may also impact the epibenthic plankton, which live near, and are associated with, the seabed. These organisms generally inhabit the 0-2 m layer above the seabed, and include many fish larvae, and crustaceans.

There is concern that a large seawater intake close to a herring spawning area will entrain large numbers of herring larvae. This concern is magnified by the fact that herring are of major economic importance in British Columbia. To ensure maximum protection of this resource, a good understanding of herring biology is essential. The impact on herring should be considered at all life history stages, and especially the egg and larval stages which are the most vulnerable (D. Hay, pers. comm.). Hay et al. (1989) suggest that it is essential to conserve herring spawning areas that have a history of repetitive spawning over time, and to protect areas immediately adjacent to spawning areas. A brief outline of the biology of herring larvae, relevant to the topic of seawater intakes in British Columbia, is presented in Appendix 3 below.

APPENDIX 3. HERRING BIOLOGY

Sources: Stevenson 1962; J.A. Morrison (MS 1988 DFO Memo); R. Eliasen, J. Marliave and M. St. John (pers. comm.)

Pacific herring generally spawn along the nearshore areas in or just below the intertidal zone (a zone between mean high and mean low water levels). Eggs are deposited on macrophytes, and most hatching occurs during March to April. At this time, greatest concentrations of newly hatched larvae (4-8 mm) are found in inshore surface waters near the spawning grounds. Newly hatched herring larvae are planktonic, i.e. they may drift more or less passively with water movement, and may become dispersed rapidly by offshore and tidal currents. For example, these larvae are commonly found throughout the Strait of Georgia to a depth of about 20 m.

Yolk sac disappears at about 9 mm, but the larvae remain planktonic to a length of about 21-22 mm or until some 20 days after hatching. Sometime later, the larger larvae (26-35 mm) metamorphose into a juvenile form. During this period, larvae become free swimming and start schooling; they also move back to inshore waters. These larger larvae show diurnal vertical migration to the surface at sundown but generally stay in the pycnocline - a narrow water layer defined by a rapid change in temperature and salinity and which is generally found above the 15 m depth. While it is commonly recognized that herring larvae are most concentrated in the upper 10 m of the water column, studies in Barkley Sound suggest that they may migrate vertically down to a depth of 20 m and possibly 30 m.

Herring larvae are relatively passive and vulnerable to currents. Studies suggest that larvae in Barkley Sound may be transported up to 14 km/day in the surface waters where they are densely concentrated at night. Screening for herring larvae at marine intakes would be impossible due to the small size of larvae and inadequate screen technology including problems with biofouling and water passage through fine mesh screens.

Source: Hay et al. (1989)

Spawning areas of British Columbia herring are presented in Volumes I to VI for the Queen Charlotte Islands, North Coast, Upper Central Coast, Lower Central Coast and Johnstone Strait, Strait of Georgia and West Coast Vancouver Island, respectively.

Source: McCarter and Hay (MS 1990)

A survey of herring larval distribution at the 20 m depth was conducted in the Strait of Georgia in April 1989. Larvae were found throughout most of the Strait of Georgia, with densities at the 20 m depth ranging from 0 to 61 larvae/m^3. Mean larval lengths varied from 7.6 mm (newly-hatched larvae) to larvae approaching metamorphosis (21.0 mm). Herring larvae appear to have a complex and variable system of dispersal mechanisms. These include oceanographic influences, such as the counterclockwise surface current gyral in the Strait of Georgia, large freshwater runoffs, and wind and tidal effects. Biological influences such as predation and food availability also affect larval dispersal.

APPENDIX 4. EXAMPLES OF MARINE INTAKES (OPERATIONAL AND PROPOSED) IN BRITISH COLUMBIA

PROJECT: LNG TERMINAL PROPOSED FOR PORT SIMPSON

Source: D. Hay (Pacific Biological Station, pers. comm.)

Proposal

Dome Petroleum Ltd. proposed to build an LNG Terminal at Port Simpson, north of Prince Rupert. The proposal included a large marine intake.

Problems

Proposed site was located within a herring spawn area. DFO required a major environmental impact study for this project, including expensive near-shore surveys, and studies of the potential entrainment of herring larvae. Environmental assessment surveys were conducted in 1983. These data indicated that herring would be entrained at all intake depths considered by the Dome Petroleum Ltd. D. Hay calculated that the total volume of water used in one year would have exceeded the volume of the bay at Port Simpson. Therefore, the probability of larval entrainment was high and the potential loss of larvae was sufficient to pose concerns with respect to management.

Resolution

The project was eventually abandoned for reasons related to the Company's financial prospects.

PROJECT: BURRARD THERMAL PLANT

Source: R. Eliasen (DFO South Coast Division, pers. comm.)

Site

The thermal plant was built in early 1950s in Burrard Inlet opposite Port Moody. Marine intake receives cooling water through 4 to 5 travelling screens made of stainless steel. Screens are shallowly placed and are partially exposed at low tide. However, placement of this intake is not a concern to DFO since no significant populations of herring larvae exist in the area. Marine intakes similar to the above, are very expensive, self-cleaning installations with a large flow capacity of about 25 m^3/sec. The large expense of the screens limits their widespread use.

PROJECT: SALMON FARM PROPOSED IN MACOAH PASS IN BARKLEY SOUND

Sources: D. Hay (pers. comm.), D. Hay (MS 1988 DFO Memo), C.W. Haegele (MS 1988 DFO Memo), J.A. Morrison (MS 1988 DFO Memo), L.A. Webb (MS 1988 DFO Memo).

Proposal

A Norwegian Company proposed to build a major land-based salmon farm (Cedar Fish Farm) in the Macoah Pass area in Barkley Sound. The proposal included placing a large marine intake pump (1.4-2.0 m^3/sec) at a depth of 20-30 m.

Problem

Significant entrainment of herring larvae would be expected in this area since Macoah Pass is one of the major herring spawning areas on the British Columbia coast. This area is also a prime herring larval and juvenile rearing habitat. Eggs are deposited to a depth of 20 m, and larvae and young herring likely inhabit the nearshore waters for a period of several weeks to several months each year.

Other relevant information

Circumstantial evidence suggests that when herring larvae "disappear" from surface waters several weeks after hatching, they may be undergoing offshore migration across the bottom of the seabed; presumably these larvae then rear in offshore waters for a period of time before returning inshore. If so, a seawater intake transporting daily a block of water 10 m x 10 m x 1.7 km could represent a significant entrainment risk to outmigrating larvae.

Resolution

Initially, DFO approved parts of this operation related to the water quality issues. Subsequently, DFO suggested a proper assessment of the environmental risk by conducting a sampling program specific to the site and related to larval herring distribution. The site was eventually relocated to a less sensitive area.

PROJECT: FERROCHROMIUM PLANT PROPOSED FOR NANAIMO AREA

Source: D. Hay (MS 1989 DFO Memo)

Proposal

Proposal to build a smelter for ferrochromium with a marine intake at Northumberland Channel near Nanaimo.

Problems

Northumberland Channel has a very high density of herring larvae (1989 survey, D. Hay, 1989 DFO Memo). Therefore, the proposed intake would likely cause major damage to this resource.

Resolution

The project was abandoned due to other concerns.

PROJECT: NANAIMO MARINE FARMS PROPOSAL

Sources: R. Eliasen (pers. comm.), R. Eliasen (MS 1989a DFO Memo)

Proposal

Proposal for a large land-based salmon tank farm near Nanaimo (Hagensborg Marine Farms Inc.). The project would include a set of seawater intakes at a depth of 15 m below zero tide level, with a maximum withdrawal volume of 3.5-5.0 m^3/sec.

Problem

The proposed site is within one of the primary herring spawning grounds in Southern British Columbia. Consequently, considerable risk to herring larvae in Stuart Channel would be expected.

Resolution

Application was granted despite the presence of herring spawn. Marine Farms will serve as an experimental station to monitor the impact and screening efficiency of the large marine intake over a period of one year. Results from this program may help refine the DFO guidelines for future fish farm marine intakes and other developments in British Columbia.

PROJECT: HOWE SOUND PULP AND PAPER

Source: R. Eliasen (MS 1989b DFO Memo)

Proposal

Proposed pulp mill marine intake at Port Mellon, B.C.

Site

In Howe Sound.

Problem

Some herring may occur in the area.

Resolution:

DFO Habitat Management Unit provided preliminary guidelines on screen intake design to help minimize or alleviate impacts on aquatic marine organisms (see Appendix 7).

APPENDIX 5. EXAMPLES OF INTAKES AND ASSOCIATED PROBLEMS WITH IMPINGEMENT AND ENTRAINMENT IN OTHER AREAS

SUBJECT: VULNERABILITY AND SURVIVAL OF YOUNG FISH ENTRAINED AT THE CONNECTICUT YANKEE NUCLEAR POWER PLANT ON CONNECTICUT RIVER, U.S.

Source: Marcy (1973)

Project description

The intake pumps at peak load approximately 25 m^3/sec of water, and has an intake water velocity of 30-60 cm/sec; 1 cm mesh travelling screen is installed at the intake. Water is returned to the river downstream of the plant via a 1.8 km long discharge canal. Entrained organisms are moved along the discharge canal at an average velocity of 30-60 cm/sec, and are exposed for 50-100 minutes to elevated water temperatures in the canal.

Methods

The study was conducted during June and July 1970-1972. Organisms were sampled using plankton nets.

Results

Of the total entrained fish larvae and juveniles, 98% consisted of alewives and blueback herring. Of these, 98% measured 3-15 mm and were in the post yolk-sac larval stage, while 2% measured 15-40 mm and were early juveniles. The number of young fish entrained at the intake (i.e. fish which passed through the 1 cm mesh travelling screen) averaged about 4% of those passing the plant under conditions of unidirectional net tidal flow.

Most fish larvae and early juveniles that went through the plant were dead by the time they reached the end of the 1.8 km long discharge canal. June and July sampling of larval and juvenile fish showed that 80% of the mortality in the canal was caused by mechanical damage and 20% was attributed to heat shock and prolonged exposure to temperatures elevated above 28°C.

SUBJECT: EFFECTS OF ENTRAINMENT ON MARINE PLANKTON, ESPECIALLY COPEPODS AND PHYTOPLANKTON, AT THE MILLSTONE POINT NUCLEAR POWER STATION LOCATED ON LONG ISLAND SOUND IN EASTERN UNITED STATES

Source: Carpenter et al. (1974)

Project description

The power plant generates 650 MW and entrains 26 m^3/sec of seawater, with only surface waters being entrained. Entrained water is heated 13°C in about 2 minutes.

Results

An estimated 4.25 x 10^{11} copepods are lost annually at this site due to entrainment mortality. This loss may represent about 0.1-0.2% of the secondary productivity over a 333 km^2 area of the Long Island Sound. About 70% of the copepods entrained in the intake die within 5 days of entrainment as a result of mechanical and hydraulic stresses of entrainment, and not due to temperature shock or chlorination.

Because of warming effects due to water entrainment, phytoplankton productivity in discharge waters usually increases in the cooler months by 5-25% over that at the intake, but decreases by about 60-95% in the warmer months when the intake water temperatures exceed 10-15°C. Even very low chlorination decreases primary productivity by about 80%. Therefore, the use of chlorine as a fouling organism biocide will likely result in substantial harm to entrained marine phytoplankton.

SUBJECT: IMPINGEMENT AND ENTRAINMENT OF VARIOUS FISH STAGES ON POWER STATION INTAKE SCREENS IN SOUTHEASTERN UNITED STATES

Source: Coutant et al. (1979)

Results

Steam electric cooling systems move entrained planktonic eggs and larvae to new locations and stun or damage them to a state of high predator vulnerability. At steam electric generating stations in the southeastern United States, several local fish species, such as the threadfish shad, are commonly impinged on intake screens.

SUBJECT: ENTRAINMENT OF LARVAL FISH BY THE DOUGLAS POINT GENERATING STATION ON LAKE HURON IN ONTARIO

Source: Kelso and Leslie (1979)

Project description

The 200-MW generating station with a once-through cooling system has a cooling water flow range of 22-25 m^3/sec. The cooling water intake is located 600 m offshore at a depth of about 15 m, and is provided with an intake screen mesh size of approximately 1 cm.

Methods

Fish larvae were sampled by net in Lake Huron and at the power plant intake and outfall during spring to fall 1975.

Results

Of the 12 species of fish larvae entrained, fourhorn sculpins, rainbow smelt and alewife were the most abundant. The densities of fish larvae in cooling water frequently exceeded up to 10 times the densities in the lake. The calculated entrainment rate for combined species ranged widely from 3,200 to 592,300 fish larvae per day, and was greatly influenced by vertical distribution of larvae and hence their proximity to the submerged intake.

In general, power plants appear to entrain fish larvae with relatively little bias. For example, entrainment of major species of fish larvae paralleled their dominance and abundance pattern in the lake. However, some differences were observed between larval fish species entrained and those occurring naturally. For example, yellow perch, brook stickleback and shiny sculpin caught in the lake in significant numbers, were not entrained; conversely, white sucker was entrained but was not captured in the lake. Entrainment did not appear to be notably size selective since sizes of larval fish entrained (range 4-40 mm) were generally similar to those in the lake (range 3-50 mm). Note that the upper limit of approximately 40 mm for entrained larvae was imposed by the screen size of about 10 mm.

The above findings suggest that thermal generating stations may have serious biological implications because:

1) power plants appear to concentrate larval fish and
2) some selection by species occurs.

SUBJECT: PRE-OPERATIONAL STUDY RELATED TO THE OPERATION OF THE J.H. CAMPBELL POWER PLANT ON LAKE MICHIGAN

Source: Zeitoun et al. (1981)

Project description

The freshwater intake is located 1,067 m offshore at a depth of 11 m and is constructed of cylindrical wedge-wire screens with 9.5 mm (3.8 in) square slot openings. The screens are designed for a flow rate of 0.3 m^3/sec at 15 cm/sec through-slot velocity. The screens provide uniform velocity fields at relatively low approach velocities.

Methods

The study was conducted during summer of 1979 using a scaled down replica of the plant intake (the actual plant began operation the following year). The program was designed to investigate the effectiveness of 2.0 mm and 9.5 mm cylindrical wedge-wire intake screens in reducing entrainment of fish eggs and larvae at the proposed location of the plant intake. Previous laboratory tests indicated that entrainment of fish larvae was reduced with small-mesh flat or cylindrical wedge-wire screens. Reduction was attributed to larval avoidance induced by water velocity through the screens.

Results

The 2.0 mm and 9.5 mm intake screens showed similar entrainment rates of fish larvae. The dominant species entrained included rainbow smelt, alewife, yellow perch and minnow larvae. Smallest larvae ranged in size from less than 5 mm to over 10 mm. About 90% of fish larvae at the intake site avoided entrainment i.e. ambient larval fish densities were about 11 times greater than those found in entrainment collections. Two mechanisms, larval avoidance and, to a lesser extent, larval exclusion by fine screens, were responsible for the low entrainment. Larval avoidance responses to the low velocity currents at the intake screens declined at night when significantly higher rates of entrainment were observed compared to daytime. It is suggested that visual detection of screens was curtailed at night.

Avoidance reaction of fish larvae

Fish larvae avoidance is a function of larval ability to sense structures visually, detect velocity gradients around screens, and then swim away to escape entrainment. Therefore, avoidance is partly a sensory and partly a muscular function and potentially eliminates or substantially reduces both impingement and entrainment. Growing larvae should show progressively stronger avoidance reactions at intake screens due to the organisms' stronger muscular systems and relatively more developed sensory perception. Therefore, while exclusion by fine-mesh intake screens is important for reducing entrainment and impingement of passively moving organisms, avoidance reaction by the larger organisms with swimming ability also plays an important role in reducing mortality at intake screens.

SUBJECT: IMPINGEMENT AND ENTRAINMENT AT THE J.H. CAMPBELL POWER PLANT ON LAKE MICHIGAN

Source: Jude et al. (1982)

Methods

Impingement and entrainment of fish and larvae were monitored at the power plant during 1981. Fish and larval distribution and abundance were compared with pre-operational years (1977-1980).

Project description (see also study by Zeitoun et al. (1981) above)

The submerged intake is located at a depth of 11 m approximately 1,070 m offshore in Lake Michigan. The intake is raised about 2 m off the bottom. Maximum through-slot velocity is only 15 cm/sec through 9.5 mm square slot openings. At this low intake velocity, juvenile and adult fish suffer only minor impingement loss. The cylindrical wedge-wire intake design minimizes potential biological effects and enhances the probability of operational success because of the following features: expanded withdrawal area, low approach velocity, smooth screen surface, cylindrical screen shape, slot width and low profile.

Project guidelines used for fish protection

Campbell Plant Unit 3 exemplified three design approaches to reduce both impingement and entrainment of fish and larvae at the intake:

1) Water withdrawal structures were located in an area where field studies indicated the least probability of entrapping vulnerable life stages of organisms which are ecologically important at that site.

2) The intake velocity was lowered to a point at which even the most vulnerable stages of organisms to be protected could escape. This approach is becoming a widely accepted means of limiting entrainment and impingement of fishes, and is generally accomplished by increasing the surface area over which the required water is withdrawn.

3) Screening was used to exclude even the smallest larval fish forms. This method has been widely used to limit entrainment and impingement of fish.

Results

Fish adults and juveniles: Divers observed no impingement of fish on the intake screens.

Fish larvae: An estimated 10.2 million fish larvae were entrained at Unit 3 intake in 1981, most of them (81%) in June. This represents a minimal impact on larval populations in the vicinity of the plant. Of the 11 larval species entrained, the most common were yellow perch (32%) and alewife (29%), reflecting partly larval abundance and partly larval susceptibility to entrainment.

The 9.5 mm mesh wedge-wire intake screens showed a high level of size-selective entrainment. Most of the entrained larvae of alewives, spottail shiners and perch were newly hatched (about 5 mm) and none were longer than 10 mm, although larval size range in the field samples was 5-25 mm. However, much larger rainbow smelt larvae (11-21 mm), as well as smelt fry (35-42 mm) were also entrained.

Susceptibility of fish larvae to entrainment at the 9.5 mm screen intake with 15 cm/sec through-slot velocity was dependent on the following:

1) Larval size - larger larvae, especially those greater than 10 mm, successfully avoided the wedge-wire screens.

2) Time of day - entrainment of larvae was lowest during daylight periods suggesting that larvae were able to visually detect and avoid the screens.

3) Numbers of fish attracted to the intake rip-rap for spawning. The intake structures and associated rip-rap are known to attract invertebrates and fish by providing cover and food. Several fish species spawned in and around the rip-rap and consequently, their larvae were more susceptible to entrainment. Divers also observed several fish species resting on top of the wedge-wire screens, apparently unaffected by the low through-slot current velocities.

4) Intake location relative to the distribution of a given fish species. For example, spottail shiners were very abundant in the lake but showed relatively low larval entrainment. This species is a bottom-oriented minnow whose larvae are concentrated in the bottom strata and whose spawning and nursery areas are usually confined to nearshore areas. The intake screens on the other hand, were placed over 1,000 m offshore, away from nearshore concentrations of larvae, and about 2 m off the bottom in 11 m deep water.

In conclusion, the above intake design succeeded in only partial reduction of larval entrainment losses, probably because the necessarily extensive rip-rap surrounding the intake area attracted fish and served as a spawning substrate. Therefore, while the 9.5 mm wedge-wire screen effectively eliminated impingement and reduced entrainment of larger larvae (> 9 mm), smaller larvae remained highly vulnerable. Other studies showed that even a 2 mm mesh screen would not successfully reduce entrainment of small (≤ 9 mm) larvae which are numerous during summer months. This is because the fusiform shaped larvae are sufficiently small in cross-section to go through the much smaller screen openings.

SUBJECT: VULNERABILITY OF SAND SMELT (A SMALL INSHORE MARINE FISH) TO IMPINGEMENT ON MARINE INTAKE SCREENS AT FAWLEY POWER STATION IN NEW HAMPSHIRE

Source: Turnpenny and Bamber (1983)

Project description

The power station has an onshore canal-like cooling water intake. The intake velocity ranges from 75 to 150 cm/sec.

Methods

The fraction of sand smelt which might escape capture at the water intake screens was determined using data on fish swimming capabilities in relation to the speed of intake water currents.

Results

Sand smelt in front of the intake grid showed a steady sustained swimming performance, with fish schools maintaining position in front of the intake for long periods. Fish swimming performance increased with body size and water temperature. The fish were most vulnerable to impingement at the low water tidal cycle, i.e., 80% of the fish captured at the intake screens during one 12-h tidal cycle were impinged within about an hour of low water.

Given that the maximum critical swimming speed of a large (137 mm) sand smelt was about 40-70 cm/sec (i.e. less than the intake velocity of 75-150 cm/sec at all times), any sand smelt entering the intake canal would be sooner or later impinged on the screen. Note that the smaller sand smelt (50-70 mm long) had a critical swimming speed of only about 15-40 cm/sec.

SUBJECT: IMPINGEMENT AND ENTRAINMENT OF ORGANISMS AT OYSTER CREEK NUCLEAR GENERATING STATION IN NEW JERSEY ON EASTERN COAST OF THE UNITED STATES

Sources: Tatham et al. (1977) and Kennish et al. (1984)

Project description

The nuclear generating station was constructed during 1964 to 1969 between Forked River and Oyster Creek, 3.5 km inland of Barnegat Bay. Cooling water was drawn from Barnegat Bay, a shallow enclosed estuary (mean depth 1.5 m) with little tidal fluctuation (0.15 m).

The nuclear station utilized a once-through cooling system with four circulating pumps, each with a design capacity of 7 m^3/sec of cooling water for a total capacity of 29 m^3/sec. Intake included six trash racks with 6.5 cm openings between the bars, and six vertical travelling screens of approximately 1 cm mesh. Operating velocity in front of the trash racks with travelling screens averaged 17-22 cm/sec (actual velocity range was 1-67 cm/sec).

Results

Operation of this station caused entrainment of estuarine organisms (e.g. plankton) and impingement of fish and macroinvertebrates on intake screens in front of the circulating pumps. Between September 1975 and September 1977, the most abundant fish and macroinvertebrates impinged on intake screens, in numerical order, included the blue crab, sand shrimp, bay anchovy, grass shrimp, Atlantic menhaden, spot, Atlantic silverside, smallmouth flounder, striped searobin, and blueback herring. The estimated total mortality of these species due to impingement was 30%, with a range of 7% to 90% depending on the species.

Factors affecting survival of impinged organisms included: hardiness of the species (e.g. blue crab and northern pipefish are hardy while Atlantic menhaden and bay anchovy are not), size and physical condition of the organism, volume of intake flow, approach velocity, and continuous vs intermittent rotation of the travelling screens (continuous operation of the vertical travelling screen increased survival).

Population surveys of fish and macroinvertebrates indicated that the standing crop lost through impingement was less than 10% for species in central Barnegat Bay. Numerous assessment studies conducted in the area during 1965 to 1980 indicated that long-term impacts on aquatic communities were generally restricted to the discharge canal and Oyster Creek. Primary entrainment (i.e. organisms pumped through the station) was in part responsible for reductions in abundance of zooplankton in Oyster Creek relative to the nearby Forked River.

Resolution

To mitigate future impingement effects, the conventional vertical travelling screens (about 1 cm mesh) on the intake structure of the station were replaced in 1979 with Ristroph screens composed of a continuously rotating travelling design modified with a low pressure spray wash and fish recovery and return system. The Ristroph screens contain water-tight fish buckets which collect impinged organisms washed from the screens and return them to the discharge canal via a sluiceway. Experimental testing of the Ristroph screens from 15 May to 25 September 1978 indicated that total fish mortality was reduced from 48% to 24%.

SUBJECT: BEHAVIORAL FACTORS INFLUENCING FISH ENTRAPMENT AT OFFSHORE COOLING-WATER INTAKE STRUCTURES IN SOUTHERN CALIFORNIA

Source: Helvey (1985)

Project description

The open-coastal electrical generating stations in southern California have "once-through" cooling systems. These withdraw continually large quantities (about 230 m^3/sec) of seawater through submerged velocity-capped intake structures (Appendix Fig. 1) located several hundred meters offshore.

Methods

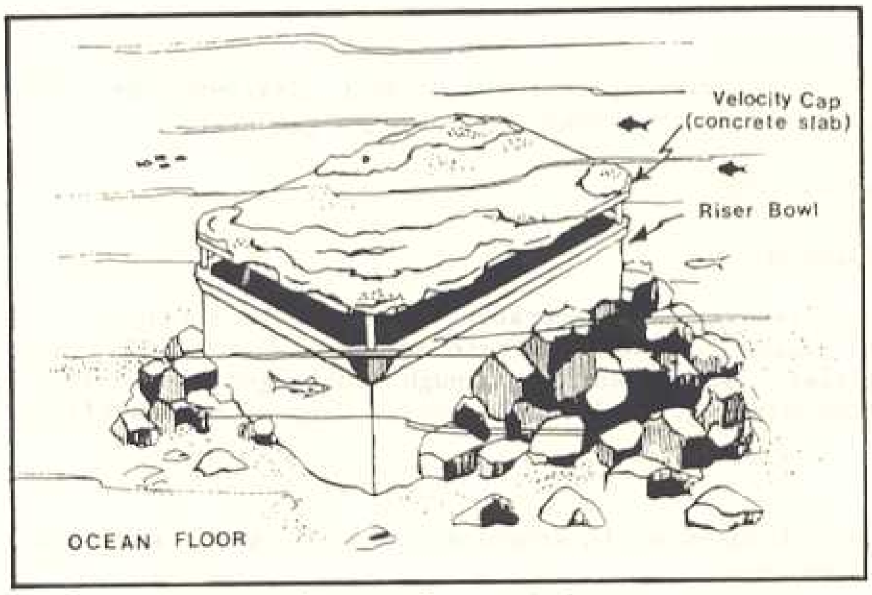
A two-year study focused on interactions of both "reef" and "non-reef" fishes with intake structures.

Results

At the monitored coastal generating stations, 137 fish species were observed to be entrapped. The majority (95%) of the overall fish losses were attributed to only seven species and included mostly transient or non-reef fish (see below). Two types of fish populations were distinguished in this study based on their vulnerability to impingement at marine offshore intakes: 1) Non-reef species and 2) Reef-associated species. These two groups are discussed below.

I. Transient or non-reef species

These species have relatively high entrapment rates and include queenfish, white croaker, walleye surfperch and northern anchovy. Transient fish encounter "reefs" or intake structures incidentally and primarily at night, when their activity (i.e. active dispersal offshore) and associated vertical movement (i.e. dispersal throughout the water column) increase. This nocturnal activity is apparently related largely to feeding behaviour. Since the intake structure may be elevated some 6-8 m off the ocean floor, those transient species which disperse upwards at night are at a greater risk of contacting the intake water current and being entrapped at night than in the daytime. For example, depending on the fish species, entrapment rate may be 5-11 times higher at night than in



Appendix Figure 1. A typical offshore cooling-water intake structure in southern California. Intakes consist of large vertical conduits (riser bowls) extending several meters above the sea floor and capped with a concrete slab (velocity cap). Water is withdrawn through the space between the velocity cap and riser bowl. Rock boulders strewn around the base of the structure curtail sand erosion. (From: Helvey 1985) the daytime when the fish are clustered close to the bottom in the more inshore waters.

II. Reef-associated or intake-associated species

These species are commonly associated with reefs or intake structures for much of their lifetime and have relatively low entrapment rates. The species include black perch, pile perch and kelp bass. Many of these species are attracted to the intake currents and the surrounding intake rip-rap structure for the abundant planktonic and benthic prey available in this area.

Previous studies have shown that intake structures can support diverse fish assemblages with many intake-associated, reef fishes swimming in and out of the intake water current without incident. Such reef species are entrapped less frequently than non-reef species. Since most intake-associated species restrict their feeding activities to the daylight hours when they can use visual cues, they are less likely to be impinged on the intake screens.

The different entrapment rates observed for the reef and non-reef fish groups above, and the results of earlier swimming speed studies, suggest that fish entrapment may be viewed as a function of fish behaviour rather than poor swimming speed. For example, while in the daytime fish are able to detect visually water currents and avoid them, this ability is impaired at night so that nocturnally active fish may drift passively with currents and become more readily impinged on intake screens. Other behavioral factors include diurnal and seasonal fish distribution. For example, the northern anchovy show extensive geographical movements and are therefore, not prone to year-round entrainment at a given intake site.

The above findings indicate that fish entrapment can be realistically reduced by means of intake design, such as uniform approach velocities and proper siting. This means that dynamics of fish movement past potential intakes must be quantified, especially regarding fish densities and their temporal and spatial movements. As well, it should be determined whether intakes provide directional clues and whether unusual intake hydraulics are involved.

SUBJECT: IMPINGEMENT AND ENTRAINMENT AT THE D.C. COOK NUCLEAR POWER PLANT ON LAKE MICHIGAN

Sources: Thurber and Jude (1985) and Jude et al. (1986)

Project description

The 2,200-MW utility has three intakes drawing a total of 104 m^3/sec of cooling water. The intakes are located approximately 690 m offshore at a depth of 7 m. Intake rip-rap and structural frames elevate the intake openings several meters off the bottom so that most cooling water is drawn from the 3-5 m depth of the water column. Water entering the intakes is screened first with 6.6 cm trash bars, then with 9.5 mm bar mesh travelling screens. Maximum water velocity within the intake pipe is 180 cm/sec.

Methods

Impingement losses were determined for all fish species and their life stages (eggs, larvae, juveniles and adults) on a monthly and annual basis between 1975 and 1982.

Results

Fish larvae: During 1975 to 1982, annual losses of fish larvae ranged from 34 to 167 million. In addition, from 1 to 7 billion fish eggs were entrained annually. Variations in annual losses were generally caused by a combination of biological and non-biological factors including fluctuations in year-class strength and differences in plant operation.

During the study, 13 species of fish larvae were found in entrainment samples, with alewives comprising the majority (74%) of the total. Entrained alewife larvae and juveniles ranged from 2 mm to 50 mm, but the vast majority (61% to 94% per year) were the newly hatched planktonic larvae less than ≤ 5 mm in length. Seasonal entrainment of fish larvae peaked in June or July when alewife spawning and hatching peaked, and terminated in October or November as fish larvae and underyearlings migrated to deeper offshore zones. Entrainment rates of larvae were significantly higher at night than in the daytime. This indicated that larvae were actively avoiding the intake structures during the day, and that their possible diel vertical migrations also affected diurnal entrainment rates.

Alewife larvae were extremely susceptible to entrainment as indicated by their predominance in the entrainment samples. Factors responsible were: 1) high abundance of this species, 2) mode of reproduction - these pelagic spawners broadcast randomly large numbers of semi-buoyant eggs, 3) time and location of spawning - throughout summer in the nearshore area within the influence of intakes so that peak concentrations of newly hatched larvae are in the vicinity of the intakes during the peak demand for cooling water, and 4) behaviour, distribution and form of larvae - newly hatched alewife larvae measure only 2.5-5 mm in length, are frail and poorly developed, and are present in the 3-5 m depth from which cooling water is drawn.

Compared to alewife larvae, larvae of spottail shiner showed reduced vulnerability to entrainment due to: 1) lower abundance of this species, 2) mode of reproduction - spawning is concentrated in nearshore waters outside the influence of intake currents, and 3) behaviour and form of larvae - spottail shiner larvae are found near bottom and therefore are less likely to be drawn into intakes than pelagic alewife larvae; spottail shiners are also better developed and more robust at hatching than alewife larvae, and are probably better able to avoid intakes at an earlier stage.

Entrained spottail shiner larvae ranged in length from 3 mm to 14 mm but nearly 75% were the newly hatched (≤ 5 mm) forms. Entrainment of spottail shiner larvae was strongly affected by diel period, with 76% of the annual entrainment occurring during darkness. This may be due to larvae migrating off the bottom at night and becoming exposed to offshore currents and to the influence of intakes during that time.

Adult and juvenile fish: During 1975 to 1982, annual impingement losses of fish ranged from 53,190 to 2,307,654 (or 1,800 kg to 71,200 kg). Fish impingement peaked seasonally each year during June or July, with a secondary peak often observed in spring. Few fish were impinged during winter. Of the overall fish impinged, alewives comprised 68%, and the combined spottail shiners and yellow perch 19%. An average of 1,000 salmonids were impinged each year, and included juvenile chinook, lake trout and adult coho.

Variability among years in impingement losses was a function of 1) abundance of various age groups of fish in the lake and their behaviour during major physical events (thermal bar, storms, strong currents) and 2) pumping rate and whether maximum pumping rates occurred during certain key months when fish were particularly susceptible to impingement.

Susceptibility of individual fish species to impingement was dependent on their biology and behaviour. Different species were brought into the influence of the intakes at different times, based on their seasonal and diel movements related to spawning and feeding, and movements in response to temperature. For example, sculpins were attracted to the rip-rap around the intakes and consequently, were impinged in large numbers. Many fish were impinged during the spring as they moved shoreward seeking warm water.

Impingement of species increased during periods of darkness, storms or high currents, as these factors decrease the avoidance capabilities of fish. For example, fish movement increases during storms and this in turn seems to increase fish vulnerability to entrapment. Water turbidity and wave action may disorient fish, making them less able to avoid entering the intake structure. Summer impingement losses of cold water species, such as lake trout and rainbow smelt, appeared to be directly related to upwelling frequency since these species accompanied cold upwelled waters inshore and into the influence of the intakes.

SUBJECT: FISH IMPINGEMENT ON MARINE INTAKE SCREENS OF POWER PLANTS IN THE SEVERN ESTUARY AND INNER BRISTOL CHANNEL OFF THE COAST OF ENGLAND

Source: Claridge et al. (1986)

Project description

The intakes are located in the main deep water channel and in the shallow inshore areas. Intake screens are of the rotating drum or band design with a mesh size of approximately 13 mm x 19 mm.

Results

Large numbers of estuarine-dependent marine fish which represent a wide range of species (97 in this study) were impinged on the intake screens. Impinged fish contained a large proportion of juveniles and included lampreys, elasmobranches (e.g. sharks and skates) and teleosts (i.e. fish with completely ossified skeletons).

For additional comprehensive literature review on entrainment and impingement at water intakes, the reader is referred to papers by Carrier (1978) and Uziel et al. (1979).

APPENDIX 6. CONCERNS IN INTAKE DESIGN, AND GUIDELINES PROPOSED OR USED ELSEWHERE (i.e. OUTSIDE BRITISH COLUMBIA) FOR REDUCING ENTRAINMENT AND IMPINGEMENT AT INTAKES

The following concerns and/or guidelines dealing with intake design and construction are discussed individually below (note that many of these guidelines were developed originally for freshwater power plant intakes rather than for marine intakes):

A. Preliminary studies
B. Siting
C. Intake depth
D. Intake elevation off the bottom
E. Intake water velocity
F. Intake flow volume
G. Screen mesh type and size
H. Open area in the screen
I. Screen mesh material and other techniques to reduce biofouling
J. Intake screen shape
K. Intake orientation
L. Structural strength and accessibility
M. Various intake designs and exclusion barrier techniques
N. Freshwater intake design
O. Centralized database for intake design
P. Implementation of guidelines

APPENDIX 6 A. PRELIMINARY STUDIES - biological and physical

Source: Sharma (1977)

Determine the density and distribution of organisms in the general vicinity of the proposed intake site. Where possible, calculate the potential losses as a fraction of the standing crop or as annual losses to fishermen's catch. Where applicable, focus on the "rare" important species.

Determine salinity fluctuations in estuarine locations since salinity changes will likely affect density and distribution of species near the intake. Monitor seasonal temperature fluctuations as these may be correlated with seasonal inshore movements of several fish species.

Source: Hanson et al. (1977a)

At the proposed site, define the temporal and spatial distribution of important species at critical life stages to estimate the vulnerability of a species to entrainment, entrapment and subsequent impingement. Based on this information, select an appropriate intake site to minimize the impact.

Source: ASCE (1982)

Conduct preliminary biological site assessment studies to obtain baseline biological data at the proposed intake site for assessing the impact on aquatic biota. Use this information, together with plant design criteria, to determine specific measures which must be taken to reasonably ensure that aquatic communities will not be adversely affected by plant operation. The biological assessment data should be obtained very early in the planning stage since environmental constraints may well dictate intake placement, design and location of plant components. The baseline data should include information on life histories of aquatic organisms, such as fish and crustaceans, in the source water; seasonal, diurnal and spatial distributions of organisms; their migration patterns; location of spawning areas; food sources and other relevant data.

Source: C.W. Haegele (1988 MS DFO Memo)

Prior to approval of a power plant with a marine intake, conduct a study to determine the occurrence of marine life that could be impacted by the proposed plant.

Source: J.A. Morrison (1988 MS DFO Memo)

Assess properly environmental risk to herring larvae at the proposed marine intake site, and conduct a site-specific sampling program of herring larval distribution. DFO had previously suggested this approach for the Macoah Passage proposal.

APPENDIX 6 B. SITING - with respect to estuaries and currents, and siting guidelines elsewhere

Source: Hanson et al. (1977a) - related to power plant cooling-water intakes.

Impacts from entrainment and entrapment at intakes situated in estuaries may be particularly serious since estuaries serve as nursery areas for anadromous and marine species.

Avoid areas of high fish population density. Avoid critical spawning and nursery areas or migratory pathways by conducting thorough site-specific studies on the temporal and spatial distribution of motile organisms, diel and annual migration patterns, and cyclic reproduction. During site evaluation, be alert for the probability of organisms being re-entrained or recirculated as a result of basic geographic or hydraulic characteristics. Site evaluation should also determine potential maintenance problems resulting from biofouling and deterioration of cooling system components.

Source: Richards (1977)

Locate the intake in an area of low concentration of aquatic life. Place an intake in such a manner that fish are not attracted to the intake area. For example, screen structures aligned flush with the natural shoreline attract fewer fish than those placed at the end of a channel cut into the shoreline. Another example is a deep offshore intake location which will not attract fish concentrating near shallow banks.

Source: Sharma (1977) - based on operating experience at existing intakes and especially at power plant cooling water intakes in the United States.

Site water intakes to withdraw water from areas and depths known to have relatively low concentrations of fish, shellfish, and planktonic organisms for most of the year e.g. avoid areas with high densities of free swimming larval stages of commercially important shellfish. Avoid recessed locations such as embayments or blind channels along the shoreline since fish tend to concentrate in such recessed areas and, if unable to escape the intake flow, will get impinged on the intake screens. Avoid areas with topographical features that promote eddies (e.g. upstream of a peninsula). Avoid man-made submerged structures (e.g. wharfs, bulkheads, piling arrays) as these are known to attract fish. Avoid construction of intake canals as these tend to concentrate and entrap fish. Alternatively, install satisfactory screening devices at the entrances to the intake canals so that fish cannot enter them. Where the depth of biotic abundance changes significantly with season, consider installing variable depth intake openings to effectively reduce the annual impingement and entrainment.

In siting an intake, study primarily those factors that influence the density and distribution of organisms in the vicinity of the proposed site because these factors greatly affect the number of organisms impinged or entrained at the intake. Note that lowering intake velocity by itself will not effectively lower impingement and entrainment rates if the density of vulnerable organisms in the vicinity of the intake remains high.

Source: Zeitoun et al. (1981) - based on studies at a power plant on Lake Michigan.

To minimize entrainment of fish eggs and larvae, locate intakes as follows: 1) offshore or away from spawning beds, 2) in areas of low ichthyoplankton abundance and 3) where larvae are old enough to possess a strong muscular system and relatively developed sensory perception to successfully avoid the intake screens.

Source: ASCE (1982)

Consider the following site factors in developing the engineering design of an intake:

1. Water depths at extreme low water.
2. Water level variation from extreme low to extreme high water.
3. Direction and strength of water currents in the water source since these may influence the uniformity of inflow to the screening facility.
4. Suspended sediment concentrations since sediment may settle out in the intake facility.
5. Potential periodic migration of bottom material at the proposed intake site.
6. Potential for scouring of waterway banks and bottom as a result of placing the intake structure in a rapidly moving current.
7. Navigation restrictions, such as minimum channel depth limits.
8. Debris loading characteristics of the waterway e.g. leaf mats, seaweed and general detritus.
9. Potential biofouling.
10. Fish concentrations at screens. The intake should be so located that it does not attract fish and does not tend to modify water current patterns in a manner to trap fish.
11. Access to the site for installation and maintenance of the intake.

Source: Huguenin and Huguenin (1984)

Locate the intake in a flow field away from pockets that tend to collect debris and away from concentrations of marine organisms.

Source: Marliave (1986)

Planktonic fish larvae of certain shoreline species (cottid, stichaeid, pholid and gobiesocid), sampled in the protected waters off the coast of British Columbia (Howe Sound, Vancouver Harbour), do not disperse but rather remain in the extreme nearshore waters throughout the larval stage. The type of protected rocky shoreline habitat sampled in this study is very common on the British Columbia coast, e.g. 65% of the Strait of Georgia shoreline is rocky (Levings et al. 1983). Marliave's findings suggest that larval populations of rocky intertidal fishes could be severely impacted by improperly positioned marine intakes. This is because poorly dispersed planktonic larvae would have a low recovery potential, compared to well dispersed larvae where only a portion of the population would be impacted.

Source: J. Marliave (pers. comm.)

Avoid subtidal rock reefs (defined here as a mass or ridge of rock in a marine waterway) with the growths of Agarum and other macrophytes. These reefs serve as significant nurseries for juvenile stages of prawns and rockfish.

Sources: M. St. John, R. Eliasen and J. Marliave (pers. comm.); Stevenson (1962)

A safe distance between a given herring spawn area and a marine intake will vary with currents in the region. This is because the distribution of herring larvae and other planktonic organisms is affected by water movement (i.e. both tidal currents and the steady unidirectional net transport current). Tidal currents may transport passive larval populations, possibly toward the intake, depending on its location. Therefore, due to the relatively nearshore location of marine intakes, tidal currents may be of concern in siting intakes.

The extent of horizontal transport of newly hatched herring larvae is site-specific, and will vary with the magnitude of the net current transport (i.e. sum of currents), which in turn is highly dependent on the prevailing wind conditions. Several studies have demonstrated that each area is unique in the velocity of currents it experiences. For example, Stevenson (1962) reported mean seasonal flows of 1.5 km and 7.4 km/25 h tidal cycle at two sites in Barkley Sound, and a potential seaward net transport of about 14 km/day in surface waters of the Sound. Since herring larvae aggregate at night in surface waters, such extensive transport will disperse the larvae far out to sea from the main spawning grounds. Stevenson (1962) also noted that within Barkley Sound, newly hatched herring larvae may be transported some 13 km in under 11 days. In contrast, his study at Queen Cove (the upper WCVI) indicated relatively little dispersal from that bay in the first two weeks after hatching. M. St. John (pers. comm.) observed in another study, in Lambert Channel, British Columbia, a mean current velocity of 1.2 km/day.

It would be cumbersome and time consuming to obtain the data required to determine the net daily transport at a given site. Such data would include: 1) current readings at the selected site for a period of one month using two current velocity meters set at different depths, 2) current depth profiles from serial measurements, and 3) wind velocity for that period (e.g. using records from the nearest airport).

The recommended safe buffer zone between the intake site and the spawn area must accommodate a potential horizontal net transport of larvae. In a situation where the placement of an intake may endanger the local herring spawn, despite adherence to the guidelines, the intake should be positioned upstream of the spawning area. This measure will reduce considerably the potential net transport of herring larvae toward an intake site. Note, however, that in most siting cases, the net transport current (unlike the tidal current), may not be a major concern since net transport is much lower in nearshore waters where intakes would be sited, compared to the much deeper offshore waters.

APPENDIX 6 C. INTAKE DEPTH

<u>Source</u>: Kelso and Leslie (1979)

Position the intake below the deepest range of vertical distribution of the organisms of concern. For example, studies at a Lake Huron power plant intake located at a depth of about 15 m indicated that entrainment rate of fish larvae was greatly influenced by larval vertical distribution.

<u>Source</u>: Jude et al. (1986) - based on studies at the D.C. Cook nuclear power plant on Lake Michigan.

Locate intakes at a greater depth to avoid nearshore nursery and spawning areas and thereby reduce entrainment losses of fish larvae. For example, densities of alewife larvae generally decline with increasing depth and distance offshore. Note however, that offshore deeper intakes will be more detrimental to local zooplankton populations which are concentrated at greater depths and serve as fish food organisms.

<u>Sources</u>: D. Hay and M. St. John (pers. comm.)

A minimum depth of 25 m below the zero tide level was suggested for marine intakes off the coast of British Columbia. The following advantages would be gained by adopting this intake depth:

1) Reduced entrainment of herring larvae and most other marine organisms since they are found in greatest numbers at or above the pycnocline (a layer with a sharp gradation in water density due to temperature and salinity changes). Note that a pycnocline can be found as deep as 20 m in extreme cases; many planktonic forms, such as euphausiids and larval stages of shrimp and prawns, also can be found down to a depth of 20 m.

2) Elimination from intake water of phytoplankton species which could be toxic or harmful to juvenile salmonids. This is of special concern at fish farm intakes. For example, many diatom species have spines which could pierce fish gills causing fungal infections. Also, some forms of dinoflagellates which are toxic to salmonids, migrate vertically to depths below the pycnocline i.e. below 10-15 m depth.

3) Greatly reduced biofouling and clogging of intake mesh screens due to very low incidence of small organisms at that depth.

Unless an intake is located at a "safe" depth of at least 25 m where few if any herring larvae are present, its positioning even 10 km away from a major herring spawn area may not assure complete safety to herring larvae because they may be transported laterally for considerable distances by strong offshore and tidal currents. The extent of this horizontal transport is difficult to predict since the movement (i.e. strength and direction) of the water is affected by various factors such as tidal currents, freshwater discharge, winds and salinity gradients, and many of these variables may change dramatically with time.

Source: R. Eliasen (pers. comm.)

Marine intakes should be below the zone of light penetration to reduce biofouling and the incidence of small organisms. Since fewer small organisms may be expected at greater depths, larger mesh-size screens may be used without significantly increasing entrainment mortality, thereby further reducing biofouling.

APPENDIX 6 D. INTAKE ELEVATION OFF THE BOTTOM

Sources: Hocutt and Edinger (1980) and R. Eliasen (pers. comm.)

Offshore intakes are often elevated off the bottom thereby preventing benthic organisms, such as crabs and lobsters from entering the cooling water system. Siltation or burial of screens is also avoided by elevating the intakes.

Source: Jude et al. (1986) - based on studies at the D.C. Cook nuclear power plant on Lake Michigan.

When elevating intakes, avoid heavily rip-rapped intake structures as they may show increased entrainment. For example, some rip-rapped intake screenfields can form effective artificial reefs which attract some fish species providing them with a spawning substrate and additional habitat. These structures also provide shelter for potential fish-food organisms.

Source: J. Marliave (pers. comm.)

A marine intake should be elevated about 2 m above the seabed to reduce entrainment of epibenthic plankton living near and associated with the seabed substrate, e.g. mysids, late zoea stages of prawns, cod larvae and larvae of other fish species.

APPENDIX 6 E. INTAKE WATER VELOCITY

<u>Source</u>: Anon. (1955)

Experiments with coho and chinook juveniles averaging 70 mm in length showed an impingement rate of 15% at an approach velocity of 16 cm/sec but no impingement at velocities of 13 cm/sec or less. It appears that these juveniles were able to swim freely in front of the intake screen when the approach velocity was below about 15 cm/sec. It may be argued that since sustained swimming speeds decrease with a decrease in body size, a lower "safe" approach velocity will likely be required for smaller fry (<40 mm) such as the pink and chum fry which migrate to sea soon after emergence (I. Williams, PBS, pers. comm.).

<u>Source</u>: Hanson et al. (1977a)

Low intake velocities at power plant intakes do not guarantee low fish losses. This is because the development of intake design criteria should consider not only the swimming capability of fish but also their behavioral response. With increasing water velocity at an intake, juvenile salmon showed increased oxygen stress. For example, oxygen stress and loss of equilibrium were evident in fish impinged for 15 minutes at a water velocity of 61 cm/sec. The minimal intake velocity at which haemorrhaging occurred in impinged salmonids was approximately 46 cm/sec.

<u>Source</u>: Richards (1977)

The selected approach velocity (i.e. water velocity in front of the screen) is an important factor in design since the size of the screen (and hence the size of the intake) affects greatly the approach velocity. A commonly recommended approach velocity is 15 cm/sec but this may vary depending on the organisms to be protected. Note that an "average" approach velocity may show a considerable range of point values in screen approach channels and at the screen itself. Therefore, the uniformity of flow distribution must also be considered.

<u>Source</u>: Sharma (1977) - especially applicable to power plant cooling water intakes.

Provide appropriate intake velocity to accommodate the swimming capabilities and performance of the organisms most likely to be impinged and entrained at the intake. Reduction in intake velocity is known to reduce impingement rate of fishes at intake structures.

Avoid skimmer walls in intake designs. A skimmer wall results in higher intake velocity because of reduced cross-sectional area under the wall. Where appropriate, design water intakes with fresh escape ports.

Source: Leithiser et al. (1979)

At many power plants in the United States, intake flow rates through the travelling screens are only 15-30 cm/sec.

Source: Hocutt and Edinger (1980)

At power plants in the United States, approach velocities before intake screens are almost always less than 46 cm/sec and often less than 30 cm/sec. Direction and velocity of the intake flow likely serve as physical stimuli inducing rheotaxis (i.e. movement toward or away from a water current) and schooling responses of fish in the vicinity of intake structures. Young fish swim more slowly than do adults since a direct correlation exists between body length and absolute swimming speed. For example, striped bass larvae have difficulty swimming against a current of 15 cm/sec, but one year old fish can swim against a 30 cm/sec current.

Source: Sazaki et al. (unpubl. report, California, cited in Tomljanovich et al. 1980).

Swimming abilities of larval and juvenile chinook salmon, steelhead trout and striped bass were investigated. Of the fish tested, 90% of the 10-12 mm striped bass were able to maintain themselves in a current of 6.1 cm/sec for six minutes, while 90% of the 50 mm fish were able to maintain themselves in a current of 18.3 cm/sec for six minutes.

Source: Tomljanovich et al. (1980).

Approach velocity is the calculated or measured velocity of water in the flume upstream of the test screen through which water is withdrawn. Tests conducted on 12 species of freshwater fish larvae indicated that an intake slot velocity no greater than 7.5 cm/sec and a screen slot width of 0.5 mm may be required for optimum protection of very small larvae (<6.0 mm total length).

Source: ASCE (1982) - regarding approach velocity

Approach velocity is defined here as the average water velocity through the most restricted area of the intake waterway, e.g. near the screen face, over an entrance sill, or through a gate restriction upstream of the screens. Optimum water velocities entering and within the intake structure will depend on the swimming characteristics of the fish and on the type of the screening device to be used. Factors affecting fish swimming and screen avoidance abilities include fish species and size, water temperatures and water quality.

Criteria for optimum approach velocities differ for different devices because a different response is expected from the fish in each case. Examples of different devices include a flat screen placed at right angles to the waterway as in a standard through-flow travelling screen, velocity cap intakes, angled screens, angled louvers and fish bypass systems.

Recommended approach velocities for the conventional travelling screen or any flat faced screen at the end of a confined channel, range from 15 to 30 cm/sec. Recommended approach velocities for a velocity cap intake range from 15 cm/sec to 46 cm/sec. For this velocity range, entrapment of several freshwater species tested did not change markedly. For a cylindrical pipe inlet, a typical velocity through the open area of perforations is 15 cm/sec. Site specific testing on selected species may be required to develop velocity criteria for a major water intake.

Source: Huguenin and Huguenin (1984) - regarding through-screen velocity

The accumulation of debris and impingement of marine organisms on the screen face is determined primarily by the through-screen velocity. The higher the through-screen velocity, the greater the probability of attracting passing debris and marine life to the screen face and holding it against the screen. Through-screen velocity depends on cleanliness of the mesh, flow rate through the screen, screen shape and position of the screen with respect to the flow field around it. Through-screen velocity and other factors affecting the accumulation of debris (excluding site location and season) are all manipulable design variables.

Smaller intake screens are easier and cheaper to build and commonly have high through-screen velocities of about 30.5 cm/sec (1 ft/sec) based on the open area of the screen. At such velocity, many small fish and large quantities of marine organisms with even lower swimming abilities, may be entrapped. In the presence of seaweeds, seagrasses or other debris, such an intake may require very frequent cleaning (every few minutes), and may accumulate debris even in apparently debris-free areas.

The through-screen velocity should be less than the water current in the area of the screen in order to minimize problems with impingement of marine life and drifting debris. Under these conditions, the natural currents tend to cleanse the screen and prevent debris and most marine life from being impinged. Reducing the through-screen velocity to about 3 cm/sec (0.1 ft/sec) will minimize impingement of both debris and marine life. Such low velocities are often quite practical for small intakes with low flow volume rates of about 0.005-0.35 m^3/sec. However, for high-flow rates the resulting size and cost are often prohibitive.

Source: R. Eliasen (MS 1988 DFO Memo) - regarding approach velocity

Approach velocity is a function of intake flow volume and the minimum unobstructed gross screen area. For example:

1) A large intake volume and a large screen area = low approach velocity.

2) A similarly large intake volume but a small screen area = high approach velocity.

Therefore, to maintain a low approach velocity as intake volume is increased, the unobstructed gross screen area should also be increased. Otherwise, an approach velocity higher than the "critical safe value", will result in increased entrainment and impingement at the intake, and hence increased mortality of organisms. Based on the available information, a maximum approach velocity of 12 cm/sec is recommended for marine intakes. However, lower velocities should be encouraged for smaller intake screens. It is assumed that given the criterion for a critical safe approach velocity, the project engineers will design an appropriate intake structure which will have the required unobstructed gross screen area.

APPENDIX 6 F. INTAKE FLOW VOLUME

Sources: Hanson et al. (1977a), Sharma (1977) and Zeitoun et al. (1981) - regarding power plant cooling-water intakes

Reduce water intake requirements to minimize entrainment of organisms at power plant intakes. For example, implement a closed-cycle (recirculating) cooling system at power plants, thus reducing the required cooling-water volume to about 3-14% of the volume needed for once-through cooling, and decreasing the intake approach velocity. The reduced intake volume will result in reduced entrainment of plankton, while the reduced approach velocity will result in reduced magnitude and severity of fish entrapment and impingement. However, a closed-cycle cooling system is an expensive alternative and may not represent the most efficient design for a particular site.

Source: Huguenin and Huguenin (1984)

Small seawater screen systems (flow volume range 0.005-0.35 m^3/sec) may differ considerably from large ones (3-35 m^3/sec) in their design, operation and maintenance problems. These problems include biofouling, drifting debris and entrainment of organisms.

Source: Jude et al. (1986) - based on studies at the D.C. Cook nuclear power plant on Lake Michigan

Change plant operation to reduce intake flow rates seasonally, i.e. during high impingement periods (June-August for fish larvae), and at night when higher impingement rates are reported.

Source: R. Eliasen (pers. comm.)

The majority of pulp mills in British Columbia utilize fresh water which is withdrawn at a rate of approximately 0.57-0.71 m^3/sec (20-25 cfs). The intakes are equipped with travelling screens.

APPENDIX 6 G. SCREEN MESH TYPE AND SIZE

Source: Sazaki et al. (1972)

Study background

Concerns over the anadromous fishery resources at the 623 m^3/sec (22,000 cfs) Peripheral Canal water diversion in California, led to studies on impingement.

Study purpose

The study focused on the retention and impingement tolerance of larval and juvenile fish.

Methods

The species tested included chinook, steelhead trout and striped bass.

Results

A screen with openings of 0.4 mm or less was needed to retain all striped bass larvae which were the smallest fish tested. Screening was not feasible for individual striped bass larvae less than 40 mm in length at velocities exceeding 18.3 cm/sec.

Source: Prentice and Ossiander (1974)

Obtained 100% retention and survival of 26 mm chinook juveniles on a screen with 2.5 mm openings at approach velocities up to 30.5 cm/sec and impingement durations up to 30 minutes.

Source: Tomljanovich et al. (1980).

Tests conducted on 12 species of freshwater fish larvae indicated that an intake screen with 2.0 mm slots could be used to effectively protect most species of fish larvae which exceed 10 mm length. However, for optimum avoidance of entrapment, this slot size should be combined with low slot velocity (7.5 cm/sec) and a perpendicular orientation of slots to the direction of flow.

Source: Schneeberger and Jude (1981) - use of small mesh screens to limit entrainment

Study background

Small-mesh screening (0.5-2.0 mm) used at cooling water intakes was studied extensively in the 1970s as a fish larva exclusion system. Effectiveness of this method depends partly on larval body dimensions in relation to screen size, as well as on larval avoidance behaviour, impingement and entrainment mortality, and approach velocity of intake water.

Study purpose

To test the use of fish larval morphometry (total length and body depth) for predicting the effectiveness of small-mesh screens in limiting entrainment of larvae at cooling-water intakes.

Methods

Eight species of fish larvae common to Lake Michigan near the J.H. Campbell Power Plant were tested. Length of larvae tested ranged from about 3 mm to 25 mm.

Results

The number of larvae entrained decreases with decreasing mesh size. Calculations showed that depending on the species, 35-100% of the fish larvae that had been entrained in the power plant in 1978 would have been excluded if 0.5 mm mesh screening was used in the plant's cooling water intake system instead of the 9.5 mm bar mesh vertical travelling screens.

Source: ASCE (1982) - regarding fine-mesh screens used at power plants

Mesh type characteristics that influence organism retention and survival at intake screens include material smoothness, mesh opening, mesh shape and percent open area. The screen mesh opening for general screening at power plants is usually 9.5-12.7 mm. However, a mesh opening as small as 0.5 mm can be used to prevent entrainment of fish eggs and larvae. Since such very fine mesh screens will clog much faster, the clogging problem can be minimized by setting additional trash racks (with 12-38 mm clear openings) upstream of the fine screens.

Studies have shown that striped bass eggs (1.8-3.2 mm) were not entrained when using a 0.5 mm mesh opening, while the larvae (5.2-9.2 mm) were entrained when using a mesh opening of 1.0 mm. In another study, the use of 1 mm and 2 mm mesh intake screens showed a similar reduction (by over 60%) in the entrainment of fish larvae.

Cylindrical, profile-wire screens can effectively prevent entrainment of fish eggs and most larvae at power plants provided that:

1) Screen slot size is small (0.5-1.0 mm),
2) Through-slot velocity is low (15 cm/sec), and
3) Relatively high cross-flow velocity (≥ 30 cm/sec) exists to carry organisms around and away from the screen i.e. an ambient current could help prevent larval entrainment at an intake screen since some early larvae exhibit positive rheotaxis (i.e. they move toward the stronger current).

Several laboratory and field studies demonstrate the potential for high survival of fish eggs and larvae following impingement on fine-mesh screens (Appendix Table 1). Survival of impinged ichthyoplankton declined with increasing duration of impingement and increasing approach velocity (see Study No. 3 in Appendix Table 1).

Source: Huguenin and Huguenin (1984)

To reduce the ecological impact of large utility intake systems, a definite shift has occurred in the later 1970s and early 1980s toward reducing total water requirements and toward using fine mesh-screen openings in the order of 1 mm (0.04 in).

Mesh openings of about 1.0-3.8 cm (3/8 - 1½ in) for the largest hole dimension are generally used for small general purpose seawater intake screens. Fine-mesh screens in offshore submerged marine intakes may require daily or even more frequent cleaning, rendering them impractical. In contrast, mesh-hole sizes of 2.5 cm (1 in) may require only a yearly cleaning in some coastal situations, particularly in intakes set in deeper water.

Mesh size is one of the major factors governing biofouling rates (other important factors include site, season, screen material and geographical area). The largest practical mesh hole size is recommended to reduce biofouling, but with considerations for potential impingement and entrainment of marine organisms. One of the considerations is that fish with lengths of four to five times the largest mesh opening dimension can sometimes get through the screens. Selectivity data on the passage of fish through mesh is available from both engineering sources and marine fisheries research.

Source: R. Eliasen (pers. comm.)

In the marine waters; of British Columbia, a screen mesh size of 4.75 mm is showing promising results in a biofouling study currently (since 1990) being conducted at the Nanaimo Marine Farms.

Source: D. Hay (pers. comm.)

Plankton nets with mesh size as small as 0.5 mm will pass some small larvae due to their fusiform shape.

Appendix Table 1. Ichthyoplankton impingement studies involving fine-mesh screening systems for use in power plants (extracted from ASCE (1982), pp. 117-119).

Study	Screen			Organism		Survival following impingement
	Mesh size	Approach velocity	Other features	Species	Size	
1. Operational data for a power plant in Corpus Christi, Texas	0.5 mm	-	-	Bay anchovy and gulf menhaden	15-30 mm	High immediate survival.
2. Evaluation of a fine-mesh, through-flow travelling screen at a power plant on Hudson River	2.5 mm	27 cm/sec	Fish buckets, low pressure spray header and a collection trough	Striped bass (12& 14d old post-yolk - sac stage)	7-9 mm	Larvae not effectively retained; minimum size for retention must be 10-18 mm.
				Striped bass (late post-yolk-sac stage)	15 mm	68% initial survival; 47% latent (96h) survival.
				Striped bass (yearly juvenile)	19 mm	100% initial survival; 88% latent survival.
3. Study by the Tennessee Valley Authority	0.5 mm	Lowest 15 cm/sec	-	Fish larvae	5.1-7.5 mm	90% screening efficiency.
				Smallmouth bass larvae	-	Over 95% survival after 48h of impingement.
	0.5 mm	15 cm/sec	-	Largemouth bass larvae	-	92% latent survival.
	0.5 mm	30 cm/sec	-		-	66% latent survival.
	0.5 mm	46 cm/sec	-		-	49% latent survival.

Appendix Table 1 (cont'd.)

Study	Screen			Organism		Survival following impingement
	Mesh size	Approach velocity	Other features	Species	Size	
4. Evaluation for a power plant on Mississippi River	0.5 mm	15 cm/sec	-	Walleye larvae	8-12 mm	30-40% survival after 16 min of impingement.
	0.5 mm	15-91 cm/sec	-	Catfish larvae	11-26 mm	Over 90% survival* after 16 min of impingement.
	0.5 mm	15-91 cm/sec	-	Bluegill larvae	15-21 mm	Over 90% survival* after 16 min of impingement.
5. Laboratory studies	-	Below 24 cm/sec	-	Striped bass eggs	-	Over 80% survival after 6 min of impingement.
	-	Below 24 cm/sec	-	Striped bass larvae	-	~100% survival after 4 min of impingement.
	-	46 cm/sec	-	Steelhead trout	22-36 mm	Over 90% survival after 50 min of impingement.
	-	76 cm/sec	-	Steelhead trout	22-36 mm	Greatly reduced survival after 10 min of impingement.
	-	76 cm/sec	-	Chinook	36-56 mm	As above.
6. Studies in Maryland	0.7 mm	up to 46 cm/sec	-	Chinook fry	26-170 mm	Impinged for up to 15 min.
	0.7 mm	up to 46 cm/sec	-	Chinook fry	26 mm	100% survival after 60 min of impingement.
7. Studies in Florida	0.5 mm	-	Lower pressure spraywash	Fish eggs & invertebrates	-	High impingement survival.
	0.5 mm	-	Lower pressure spraywash	Fish larvae eg. bay anchovy	-	Low impingement survival.

* Except for extreme combinations of high approach velocity and long impingement duration.

APPENDIX 6 H. OPEN AREA IN THE SCREEN

Source: ASCE (1982)

The percent open area in a fine mesh screen (e.g. 0.5 mm opening) should be above 50% to provide adequate hydraulic efficiency.

Source: Huguenin and Huguenin (1984)

Provide a high percentage of open area in the screen. Open area in the screen is defined as: [Number of holes in the total screen] x [Hole area]. Flow rate divided by the open area in the screen determines the average through-screen velocity. An adequate open area in the screen is necessary to allow water passage at the required flow rate with an acceptable pressure drop across the screen.

The open area in the screen may decrease dramatically as a result of mesh-blockage through biofouling and accumulation of drifting debris. This will result in increased through-screen velocity which will cause increased entrainment and impingement, as well as increased pressure drop or head loss. Since biofouling requires an attachment surface before it can block screen openings, the thinner the mesh strands and the smaller the distance between mesh holes, the better.

APPENDIX 6 I. SCREEN MESH MATERIAL AND OTHER TECHNIQUES TO REDUCE BIOFOULING

Source: Powell (1976)

The 90/10 copper-nickel expanded metal, an alloy containing 90% copper and 10% nickel, has excellent antifouling qualities, durability, resistance to corrosion by seawater, and longevity. This material is used successfully in mariculture cages and is recommended for construction of intake screens for seawater supplies to mariculture facilities.

Source: Hanson et al. (1977b)

Biofouling on screens is a major operational problem at brackish and marine intake sites. To minimize this problem, metals with antifouling properties should be used for screen construction.

Source: Moreton and Glover (1980)

A 90/10 copper-nickel alloy showed considerable resistance to seawater corrosion and biofouling. Copper-nickel used in the form of expanded metal for seawater intake screens, showed both practical and economic advantages.

Source: Browne et al. (1981)

Biofouling rates were compared for test screens set at a depth of 3 - 4 m in an estuarine site in New Jersey. Biofouling rates (expressed as mg wet weight/100 cm^2/day) were very high for unpainted stainless steel screens (443 - 629 mg), but were much lower (108 - 121 mg) for screens of carbon steel and stainless steel painted with copper-based antifouling paint. These low biofouling rates were similar to the low rates (165 mg) observed for the 70/30 copper-nickel screens.

Source: Huguenin and Ansuini (1981)

The 90/10 Cu-Ni expanded metal mesh showed considerable biofouling resistance compared to other mesh types.

Source: McGroddy et al. (1981a)

From an engineering perspective, the factors commonly cited as affecting intake feasibility and performance include hydraulic response to clogging and fouling, required frequency of cleaning and maintenance, cleaning method, and interaction of multiple screen units in a large installation. Note that while clogging of offshore marine screens by debris can be highly variable at a given site, biofouling may require several weeks or months before substantial mass accumulates. Due to the wide variation in debris clogging and biofouling conditions within and among sites, site-specific testing of screen performance is required. The variability in biofouling and clogging limits the extrapolation of test results between sites.

Testing of screen performance for offshore marine intakes showed a better hydraulic performance for the larger mesh screens (about 2 mm x 70 mm) compared to the smaller mesh screens (about 1 mm x 15 mm). This was attributed to reduced ability of the dominant amphipods to bridge the larger openings and restrict flow in the larger mesh screens. Based on the identified need for frequent cleaning of offshore marine screens, from a few hours to weeks depending on ambient conditions, and the lack of reliable cleaning methods at this time, it is concluded that fine-mesh (from 1 x 15 mm to 2 x 70 mm) cylindrical screens on offshore marine intakes are not feasible at this time.

Source: ASCE (1982)

Tests in salt water showed significant but manageable (with regular cleaning) biological growth on fine-mesh intake screens. To reduce screen biofouling use materials such as 70/30 and 90/10 copper-nickel alloys.

Source: Huguenin and Huguenin (1984)

Use copper-nickel alloys (especially the 90/10 Cu-Ni expanded metal mesh) for long-term biofouling resistance. Such screens are practical for offshore submersible intakes since they do not require frequent cleaning in low biofouling conditions. In addition, Cu-Ni alloys show no dangerous leaching of toxicants and are therefore acceptable for marine aquaculture purposes. For example, cages made entirely of Cu-Ni mesh are used to grow marine fish commercially in Japan and Canada. (Note that presently steel is the most commonly used material for screens due to its low cost and ease of manufacturing).

In general, reduce biofouling by providing:

1) Biofouling resistant mesh materials
2) Mesh biofouling allowance
3) High percentage open area for mesh
4) Largest practical mesh hole size
5) Periodic cleaning

Note that reduction of biofouling will help maintain low through-screen velocity and therefore, low impingement and entrainment.

The following are examples of seawater intake screens used successfully in providing long-term biofouling resistance (note that intake flow volumes were not available):

1) LaQue Center for Corrosion Technology in North Carolina

Intake screen description

- small seawater intake screen
- 90/10 Cu-Ni expanded-metal diamond mesh
- 1.3 x 3.8 cm (½ x 1½ in) mesh size with 1.2 cm^2 (0.19 in^2) opening
- 2800 openings/m^2 (260/ft^2)
- 35% open area

2) Alabama Department of Conservation and Natural Resources Gulf Shores Laboratory

Intake screen description

- small cylindrical seawater intake screen (0.9 m diameter x 1.2 m high)
- 90/10 Cu-Ni expanded, 1.6 mm thick diamond mesh
- 65% open area

This screen was used originally for fish cages in a mariculture operation, and later as an intake screen for over two years in a high-biofouling environment without requiring maintenance.

3) Carolina Power & Light Co. nuclear power plant

Intake screen description

- large power plant screen system
- 557 m^2 (6,000 sq. ft.) marine diversion screen at the entrance of the intake canal of its two-unit 1642-MW nuclear electric generating station
- 90/10 Cu-Ni screen mesh
- about 1.0 cm (3/8 in) mesh openings
- approximately 70% open area
- this screen system is followed downstream at the plant by a conventional very fine-mesh travelling screen

4) Several submerged industrial and utility seawater intake screens in the United States and overseas

Intake screen description

- 70/30 Cu-Ni screen mesh
- 2-3.2 mm mesh openings (very fine)
- profile wire (ie. wire with a triangular-shaped cross section)

Source: Weisberg et al. (1986)

Fine mesh wedge-wire screens with small slot width (1-3 mm) and about 15 cm/sec intake velocity, effectively reduce entrainment of ichthyoplankton in freshwater areas where biofouling is low. However, such screens are not practical in a marine environment where biofouling potential is high. Several options, each with specific drawbacks, are available for effective control of marine biofouling on fine mesh screens.

1) Use of Cu-Ni alloy screens. The effectiveness of these screens may vary with the types of biota present at a given site. For example, these alloys are effective where algae or hard-bodied organisms, such as barnacles, are the principal fouling biota since these organisms make direct contact with the toxic copper alloy screen. Organisms that do not make a direct contact with the alloy screen, e.g. tube-building species, may not be affected. Consequently, these organisms may become well established on Cu-Ni screens.

2) Use of antifouling paints such as organotin. Many of these paints are not advisable due to their toxicity to non-target species. Organotin, in particular, is very toxic to fish and not acceptable to the DFO (R. Eliasen, pers. comm.).

3) Hourly backflushing of marine Cu-Ni screens with bursts of air. Less frequent backflushing may not be an effective measure as it will not prevent initial attachment of marine organisms which may have a settling time of less than one day. Note that backflushing is an expensive control measure and not practical for use with small screens.

Source: Elien (1990).

Chlorine is used in once-through seawater cooling systems for biofouling control. The residual chlorine in the effluent is toxic to aquatic life and is difficult to measure because of inherent interferences in seawater. Consequently, alternatives to chlorination are being investigated. These included chlorine minimization, use of substitute chemicals, chlorination/dechlorination, mechanical cleaning methods and antifouling coatings. [DFO Comment: A closed cooling system may be on option.]

APPENDIX 6 J. INTAKE SCREEN SHAPE

Source: ASCE (1982)

For best velocity distribution, as in small-mesh cylindrical screens, the length of screen should not exceed the diameter.

Source: Huguenin and Huguenin (1984)

Use spherical or cylindrical screen shape for effective debris shedding. Spherical shape is best, but cylindrical is more practical and can also be successful if properly oriented in the prevailing current. A length to diameter ratio of approximately one indicates relatively uniform velocity distributions inside the cylindrical screen.

APPENDIX 6 K. INTAKE ORIENTATION

Source: Hocutt and Edinger (1980)

Intake orientation can be effective in reducing impingement since changes in current direction may affect the avoidance reaction of organisms. Therefore, intake design criteria should consider changes in current direction at the intake structure. In addition, site-specific data are required to determine how local velocity gradients or the spatial change in velocity at a proposed intake structure affects fish orientation and behaviour. This step is recommended since designing for average velocities is not sufficient to limit impingement effects at a given site.

Source: ASCE (1982)

Place the screens at an angle to the incoming flow to take advantage of fish guidance principles. This has proved to be a successful approach to fish protection. Consider the direction and velocity of ambient currents at the point of water intake as they will affect screen performance.

APPENDIX 6 L. STRUCTURAL STRENGTH AND ACCESSIBILITY

Source: Huguenin and Huguenin (1984)

Provide sufficient structural strength to withstand impacts from boat anchors and fishing gear. Ensure accessibility to the screen for cleaning and maintenance.

APPENDIX 6 M. VARIOUS INTAKE DESIGNS AND EXCLUSION BARRIER TECHNIQUES

This appendix deals with the following topics: use of fine mesh screens, louver diversion systems and profile wire screens; fish deterrence devices and behavioral barriers; velocity caps for offshore water withdrawals and perforated pipe inlets/cylindrical pipe intakes.

USE OF FINE MESH SCREENS AS AN IMPINGEMENT-RELEASE SYSTEM FOR FISH LARVAE

Source: Tomljanovich et al. (1980) - studied freshwater fish larvae

Study Purpose

The Tennesse Valley Authority conducted laboratory studies on several species of freshwater fish larvae to evaluate two screening concepts for protecting larval fish at water intakes:

1) Impingement-release concept at small-opening continuous travelling screens and

2) Fish avoidance of screens.

Methods

Studies conducted in 1976, used 11 species of freshwater fish larvae ranging in mean length from 6 mm to 40 mm. Studies conducted in 1977-1979, used 16 species of freshwater fish larvae ranging in age from 3 to 19 days, in mean length from 5 mm to 15 mm and in hardiness from very hardy to very fragile.

Results

It is feasible to retain larval fish with fine-mesh screens. The most important experimental variable with respect to percent retention is mesh size. Another variable is larval body depth and length. A 0.5 mm screen opening retained 98% of the smallest larval fish tested (5.0 mm body length). Impingement duration up to four minutes resulted in 80 - 100% survival. Low current velocities of 30 cm/sec or less through the screen provided the highest survival. The tests indicated that to provide optimum protection for very small larvae (< 6.0 mm total length) a screen slot width of 0.5 mm and a slot velocity of 7.5 cm/sec or less may be required.

Source: Edwards et al. (1981) - studied marine fish larvae

Study Background

Studies conducted in the early 1970s indicated that many of the fish and invertebrates impinged on the travelling screens could be returned to the source water body with only minimal mortality.

Study Purpose

To examine the retention and survival of marine fish larvae when exposed to an impingement-release system. To evaluate larval survival following the combined effects of impingement, air exposure and spray wash.

Methods

Impingement testing was conducted on six larval marine species: topsmelt, grunion, northern anchovy, giant kelpfish, white croaker and shadow goby. Mean larval length ranged from 7 mm to 37 mm. Engineering and biological studies were conducted to examine the ability of vertical travelling screens retrofitted with fine-mesh screens to remove larval fish from cooling water flows.

Six meshes were tested: square synthetic (Nytex) 0.5 mm, 1.0 mm, 1.8 mm, and 3.3 mm and metal slot (smooth-tex) 0.5 mm and 1.0 mm. Three approach velocities (15, 30 and 45 cm/sec), and two impingement durations (one and four minutes), were evaluated. Testing was conducted in a test tank in a Southern California laboratory.

Results

Larval retention on screens increased rapidly as the larvae attained a critical length which was dependent on mesh size and type. Note, however, that mesh size and type had no significant effect on survival of retained larvae. Retention was greatly affected by larval body characteristics (depth and width) and by larval behaviour upon impingement. Thus white croaker showed the highest retention, attributed to their shorter and fatter body shape compared to the long and thin bodies of the other species tested. On the other hand, the behaviour of both anchovy and kelpfish helped reduce their retention. The extremely flexible bodies of these two species were capable of wiggling through the mesh, while the rigid-bodied species - grunion, topsmelt and croaker - once lying across a mesh, could not pass through without active swimming.

Impingement survival depended primarily upon species and their age (length) and secondarily upon impingement duration and approach velocity.

The six species tested fell into one of three groups based on survival:

1) Hardy group with a high survival independent of the test variables. For example, both the goby and white croaker were extremely hardy and demonstrated long-term survivals in excess of 95% across all test conditions of velocity, duration of impingement and mesh type. These two species represent a category of larvae likely to survive an impingement-release system.

2) Variable group with a survival dependent upon experimental conditions, for example, grunion and topsmelt.

3) Fragile group with a low survival regardless of impingement conditions. For example, northern anchovy and giant kelpfish were extremely fragile and showed low impingement survivals (mean 10%, range 0 - 33%).

The above study indicates that application of impingement-release concept to intake screens would be limited to hardy species of fish larvae and to the older life stages of some less hardy species. Survival of fragile species would be minimal .

Survival of larvae was considerably reduced following the combined effects of impingement, air exposure and spray washes.

Species	Survival	
	Impingement Only	Impingement, air exposure and spray wash
Grunion	80%	47%
Anchovy	40%	0%

USE OF LOUVER DIVERSION SYSTEMS WITH AND WITHOUT FINE MESH OVERLAYS

Source: McGroddy et al. (1981b)

Study background

Louver diversion systems are used to divert adult marine fish from cooling water intakes at several coastal nuclear generating stations in southern California.

Study purpose

To evaluate the use of angled louvers with or without fine mesh overlays, for reducing entrainment of fish larvae in marine intakes. To examine the effects of larval size on the diversion and survival rates.

Methods

Vertical louvers were placed at a 20° angle to the intake flow. Louver slats were spread 2.5 cm apart and louvers could be covered with wire mesh panels with 1.2 x 14 mm mesh openings. Two approach velocities (30 cm/sec and 61 cm/sec) and five species of fish larvae (grunion, topsmelt, anchovy, white croaker and giant kelpfish) were tested. Size of tested larvae generally ranged from about 13 mm to 30 mm.

Results

For all species of fish larvae tested, guidance along louvers (i.e. away from intake) increased with increasing length of larva. Diversion was improved considerably when fine-mesh overlays were added to louvers, as much smaller larvae could also be guided. Survival of diverted fish larvae varied with species and with size within species. This trend indicates species-specific sensitivity to stress, and improved swimming ability with increased larval length i.e. larger larvae of hardy species, such as topsmelt, grunion and croaker, showed better diversion and survival than did smaller larvae or the more sensitive larval species, such as kelpfish and anchovy.

Diversion efficiency (% of Fish diverted x % Surviving) using louvers with fine-mesh overlay, was 64% to 95% for grunion, topsmelt and croaker larvae over 20 mm in length. Diversion efficiency for the more sensitive kelpfish and anchovy larvae was only 43% and 21% respectively, due to the high diversion mortality. Fish larvae smaller than 20 mm generally showed low diversion and low survival. The study concludes that larvae of marine fish greater than 20 mm in length can be guided in a flow of 60 cm/sec by fine-mesh screens placed over louvers.

Diversion and diversion efficiency (ie. diversion corrected for survival) generally will increase with reduced approach velocity and reduced mesh size. This applies to grunion, topsmelt and croaker fish larvae. However, for kelpfish and anchovy larvae which are highly sensitive to minimal stress, survival of diverted larvae is expected to remain low even at reduced approach velocities and smaller mesh sizes (Appendix Table 2).

USE OF PROFILE WIRE SCREENS TO SUBSTANTIALLY REDUCE ENTRAINMENT AND IMPINGEMENT OF EARLY LIFE STAGES OF FISH

Source: Hanson et al. (1977b)

General

Profile wire screens (Appendix Fig. 2) have great potential for use at surface water intakes because:

1) They are compatible with power plant operation, and

2) They are capable of protecting the early life stages of fishes.

At such screens, entrainment and impingement of organisms are reduced due to:

1) Infinite number of escape routes available,
2) Flow dynamics which enable a fish to easily determine the direction of escape,
3) Rapid decline in approach velocity as the fish leave the screen,
4) Small slot size, and
5) Ambient washing currents which assist escape and avoidance.

Impinged fish can escape with less difficulty because of the low intake velocities and self-cleaning features of the screen. Planktonic organisms are better protected because of the small slot size and boundary currents. Detrital

Appendix Table 2. Ability of different species of fish larvae to avoid impingement and avoid contact with louver/screen diversion barrier, based on larval swimming ability (related to larval size) and approach velocity.*

Larval species	Larval size	Approach velocity	Ability of fish to avoid impingement or contact with diversion barrier mesh
All species tested	to 25 mm	61 cm/sec	Contacted barrier mesh
All species tested	to 25 mm	45 cm/sec	Contacted barrier mesh
Topsmelt	less than 18 mm	15 cm/sec	Impinged
Topsmelt	18-20 mm	15 cm/sec	Not impinged
Grunion	less than 18 mm	15 cm/sec	Impinged
Grunion	18-20 mm	15 cm/sec	Not impinged
Anchovy	less than 30 mm	15 cm/sec	Impinged
Anchovy	30-35 mm	15 cm/sec	Not impinged
Kelpfish	to 19 mm	15 cm/sec	Impinged
Croaker	to 25 mm	15 cm/sec	Impinged

* Data from McGroddy et al. (1981b) and Lawler, Matusky and Skelly (1981).

fouling is greatly reduced and the screen can be quickly and easily cleaned. Profile wire screens are highly versatile. Specialized installations can be engineered for most locations and conditions.

Specific Results

At a 15 cm/sec intake velocity, 1 mm slot cylindrical well screen virtually eliminated impingement of juvenile fish longer than 15 mm fork length. Impingement remained low at velocities as high as 53 cm/sec. At a 15 cm/sec intake velocity, young fish less than 30 mm long held near the intake for up to 3 hours, showed no impingement or stress. At over 30 cm/sec intake velocity, striped bass larvae (8-17 mm long) could resist the intake for over 30 minutes. Larger fish larvae (12-17 mm) escaped readily when impinged. The 1 mm slot screen effectively removed virtually all striped bass eggs (2-3 mm diameter) from the cooling water. Survival of impinged eggs at a 15 cm/sec intake velocity and impingement duration of up to two minutes, was over 95%. The major factors that influenced impingement of small fish were intake velocity, fish size and behaviour. For example, some fish species occasionally rested on the screen surface and left at will regardless of intake velocity, while others exhibited feeding behaviour on and around the screen.

FISH DETERRENCE DEVICES AND BEHAVIORAL BARRIERS

Source: Hanson et al. (1977) - applicable to power plant cooling water intakes.

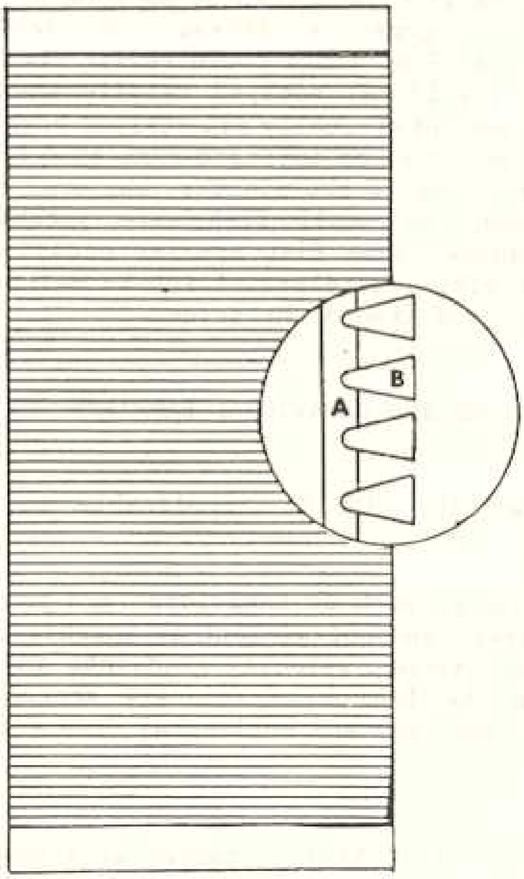
Fish protection devices, such as behavioral and physical barriers, may be used to minimize impingement and entrainment at intakes. Behavioral barriers may be in the form of light, sound, velocity gradients and electric shocks. Physical barriers may be in the form of stationary screens, vertical and horizontal travelling screens, vertical and horizontal drum screens, perforated plates and rapid sand filter.

Source: Zeitoun et al. (1981) - studies at a power plant on Lake Michigan.

Design an intake to utilize avoidance behaviour and/or exclude entrainable ichthyoplankton regardless of the screen-mesh size. Note that entrainment occurs even at a small screen-mesh size of 2.0 mm to 9.5 mm.

Source: ASCE (1982)

Behavioral barriers result in fish avoidance of an intake flow, and include velocity caps, electrical screens, air bubble curtains, hanging chain curtains, light, sound, water jet curtains, magnetic fields and chemicals. Of these devices, only the velocity cap has shown considerable value in deterring fish from entering an intake. Note, however, that fish eggs and larvae are not affected by deterrence devices since these organisms have little or no swimming ability.



Appendix Figure 2. Schematic diagram of a cylindrical Johnson screen with detailed enlargement showing profile shape of wire. The screen is constructed with a single continuous wrap of wire (A=internal support rod, B=wire). (From: Hanson et al. 1977 b)

VELOCITY CAPS FOR OFFSHORE WATER WITHDRAWALS (See Figures 3 and 4 above)

Sources: Richards (1977) and Sharma (1977)

A velocity cap on offshore intakes can effectively reduce fish entrapment. Placement of a velocity cap over the vertical inlet provides a horizontal rather than vertical inflow. This is an effective fish protective measure since fish tend to avoid horizontal but not vertical flow. Velocity caps result in over 90% reduction in the number of fish drawn into inlet structures, and are a standard provision for most offshore sea intakes.

Source: Hocutt and Edinger (1980)

An intake behaviour barrier in the form of a "velocity cap" has been effective in reducing entrainment of fishes in offshore intakes in California. The "velocity cap" design is based on the principle that fish are generally less able to avoid or swim against vertical currents compared to horizontal currents. A velocity cap introduces a horizontal flow which fish can better perceive and avoid.

Schuler and Larson (1975) in Hocutt and Edinger (1980) observed the behaviour of northern anchovy in relation to capped and uncapped intake structures. At an uncapped intake, anchovy were drawn in with their bodies in a horizontal position and showed little effort to escape. At such an uncapped intake, entrainment rate was 85% to 95% higher than at a capped intake, demonstrating the different influences of horizontal and vertical flows on this species' behaviour.

Entrapment at a capped intake was related to flow uniformity and velocity. Fish mortality decreased 60% to 70% after flows below the caps were made uniform. Other studies indicated that a 45 cm/sec velocity at the capped intake structure is optimum, and that lower velocities had little advantage. Nevertheless, while velocity caps at intakes may reduce entrapment, many power plants using this barrier still entrap millions of fish each year.

Source: ASCE (1982)

The velocity cap is virtually a standard provision for offshore intakes in both salt and fresh water. A horizontal velocity cap placed over a vertical inlet effectively reduces the number of fish drawn into this type of structure. This is because fish tend to avoid horizontal but not the vertical flow. Using this method, reductions in fish entrapment in west coast offshore intakes have exceeded 90%.

PERFORATED PIPE INLETS/CYLINDRICAL PIPE INTAKES (See Figure 5 above)

Source: Richards (1977)

For withdrawal of relatively small quantities of water, the perforated pipe inlet with an internal perforated sleeve offers substantial protection to fish. The perforated pipe inlet takes the place of conventional screens and trash bars. River or tidal currents will assist small fish away from the face of the pipe. At a velocity of 15 cm/sec through the pipe perforations, the screen approach velocity a few centimetres away will be negligible.

Source: ASCE (1982)

Cylindrical pipe intakes provide a passive system for physical exclusion of fish. Such intakes draw water through perforations or slots in a cylindrical section placed in the waterway. Cylindrical pipe inlets have been used successfully for many years for water withdrawals up to about 6.7 m^3/sec. Cylindrical screens with very small openings of 1 mm or less can be effective and practical in reducing entrainment of small organisms and reducing impingement of large organisms. However, frequent manual cleaning of the screen units will likely be necessary.

An intake of this type has several fish protection advantages:

1) The absence of a confined channel in which fish can be trapped,

2) The achievement of low velocities through the perforations at a relatively modest screen unit size,

3) Very rapid drop in approach velocity near the screen face, and

4) The ability to position the intake well away from the shore and thus away from fish concentrations.

Note that at this time the perforated cylindrical pipe inlets are not recommended by the Department of Fisheries and Oceans (R. Eliasen, pers. comm.) because a uniform velocity distribution may be difficult to achieve without internal pipe modifications. Without such modifications, velocity "hot spots" may develop. In addition, a minimum 50% open screen area may be impossible to obtain with a perforated screen, although the more expensive profile wire screen can provide over 70% open screen area (ASCE 1982).

APPENDIX 6 N. DEPARTMENT OF FISHERIES AND OCEANS GUIDELINES FOR FRESHWATER INTAKE FISH PROTECTION FACILITIES IN BRITISH COLUMBIA AND THE YUKON TERRITORY

Source: Anon. (MS 1986)

For comparative purposes, this appendix provides guidelines for design and installation of freshwater intakes and fish screening in British Columbia and the Yukon Territory to avoid conflicts with anadromous fish. Note that for marine intakes, additional precautions must be taken due to the intrinsically different biological and physical features of the marine compared to the freshwater habitat, and the much greater potential for biofouling in seawater.

Specifications outlined in this appendix include screen material, mesh size and area; screen support, protection and accessibility; allowable openings; design and location; and fish bypass.

FISH SCREENING DIRECTIVE

Government of Canada
Department of Fisheries and Oceans

WATER INTAKE FISH PROTECTION FACILITIES

The Department of Fisheries and Oceans has prepared this document as a guide to assist in the design and installation of water intakes and fish screening in British Columbia and the Yukon Territory to avoid conflicts with anadromous fish. Additional precautions must be taken at marine intake locations where entrainment of fish larvae, such as eulachon and herring larvae, is a possibility. The screening criteria constitutes the Department's policy regarding the design and construction requirements pursuant to Section 30 of the Fisheries Act.

PROVISIONS OF THE FISHERIES ACT - SECTION 30

Every water intake, ditch, channel or canal in Canada constructed or adapted for conducting water from any Canadian fisheries waters for irrigating, manufacturing,, power generation, domestic or other purposes, shall, if the Minister deems it necessary in the public interest, be provided at its entrance or intake with a fish guard or a screen, covering or netting, so fixed as to prevent the passage of fish from any Canadian fisheries waters into such water intake, ditch, channel or canal.

The fish guard, screen, covering or netting shall have meshes or holes of such dimensions as the Minister may prescribe, and shall be built and maintained by the owner or occupier of the water intake, ditch, channel or canal subject to the approval of the Minister or such officer as the Minister may appoint to examine it.

The owner or occupier of the water intake, ditch, channel or canal shall maintain the fish guard, screen, covering or netting in a good and efficient state of repair and shall not permit its removal except for renewal or repair, and during the time such renewal or repair is being effected, the sluice or gate at the intake or entrance of the water intake, ditch, channel or canal shall be closed in order to prevent the passage of fish into the water intake, ditch, channel or canal.

PROCEDURES FOR INSPECTION AND APPROVAL OF INTAKE STRUCTURES

Diversions less than 0.0283 cms (one cubic foot per second): The intake structure shall be constructed in accordance with specifications indicated herein. Upon completion of construction and prior to operation the owner shall contact a local representative of the Department of Fisheries and Oceans to arrange for on-site inspection and approval of the installation. Permanently submerged screens must be inspected prior to installation.

Diversions greater than 0.0283 cms (one cubic foot per second): The owner shall submit to the Department of Fisheries and Oceans 2 sets of detailed plans of the proposed installation for review and approval prior to fabrication. Design drawings are required whenever the diversion quantity exceeds 0.0283 cms (1.0 cfs) or 817,200 L/day (180,000 Igpd) for industrial diversions (calculated on the basis of 8 hours/day) or 123,350 cmy (100 ac. - ft./year) for irrigation diversions (calculated on the basis of 100 days/year and 12 hours/day). The plans shall contain the following information:

1. Intake structure location and dimensions.
2. Maximum discharge capacity of diversion.
3. Screen dimensions.
4. Mesh size.
5. Screen material.
6. Fabrication details.
7. Minimum and maximum water levels at the intake site.
8. Provision for bypassing fish.

The intake structure shall then be constructed in accordance with the approved plans. Upon completion of construction and prior to operation, the owner shall contact the local representative of the Department of Fisheries and Oceans to arrange for on-site inspection and approval of the installation. Permanently submerged screens must be inspected prior to installation.

SPECIFICATIONS FOR INTAKE STRUCTURES WITHOUT PROVISION FOR AUTOMATIC CLEANING

1. Screen Material: The screen material shall be either stainless steel, galvanized steel, aluminum, brass, bronze, or monel metal. Stainless steel is preferred since corrosion is greatly reduced.

2. Screen Mesh Size: Clear openings of the screen (the space between strands) shall not exceed 2.54 mm (0.10 inch). The open screen area shall not be less than 50% of the total screen area. The following square-mesh wire cloth screens are recommended:

   - 7 mesh, 1.025 mm (0.041 inch) wire, 51% open, 2.54 mm (0.10 inch) openings; or
   - 8 mesh, 0.875 mm (0.035 inch) wire, 52% open, 2.25 mm (0.09 inch) openings; or
   - 8 mesh, 0.700 mm (0.028 inch) wire, 60% open, 2.54 mm (0.10 inch) openings.

3. Screen Area: A minimum unobstructed screen area (gross area) of 0.93 square metre (10 square feet) shall be provided for each 0.0283 cms (1 cfs) of water entering the intake. The required screen area shall be installed below minimum water level. Screen area lost by framing shall not be included as part of the unobstructed screen area.

4. Screen Support: The screen shall be adequately supported with stiffeners or back-up material to prevent excessive sagging.

5. Screen Protection: The intake structure shall, where necessary, be equipped with a trash rack or similar device to prevent damage to the screen from floating debris, ice, etc.

6. Screen Accessibility: The screen shall be readily accessible for cleaning and inspection. Screen panels or screen assemblies must be removable for cleaning, inspection and repairs.

7. Allowable Openings: The portion of the intake structure which is submerged at maximum water level shall be designed and assembled such that no openings exceed 2.54 mm (0.10 inch) in width.

8. Design and Location: The design and location of the intake structure shall be such that a uniform flow distribution is maintained through the total screen area.

9. Fish Bypass: The intake shall be designed to provide a transverse velocity (the component of the velocity parallel and adjacent to the screen face) to lead fish to a bypass or past the screens before they become fatigued. In no case should the transverse velocity be less than double the velocity through the screen.

SPECIFICATIONS FOR INTAKE STRUCTURES WITH PROVISIONS FOR AUTOMATIC CLEANING

The specifications are identical to those for intake structures without provisions for automatic cleaning except that the minimum unobstructed screen area (gross area) of 0.23 square metre (2.5 square feet) need only be provided for each 0.0283 cms (1 cfs) of water entering the intake. However, a regular cleaning and maintenance schedule is required to ensure seals and screen panels remain in good repair preventing impingement and entrainment of fish and debris.

For these self-cleaning intake structures, the location, design and juvenile fish avoidance system all affect operating characteristics. The final design, therefore, may incorporate modifications reflecting the best current technology available for minimizing adverse impact upon the fisheries resource.

ALTERNATE FISH PROTECTION FACILITIES

Enquiries concerning the Department's requirements for indirect intakes, such as infiltration galleries and wells, for salt water ocean intakes, and for new methods or devices for screening intake structures should be directed to the Department of Fisheries and Oceans, Senior Habitat Management Biologist.

Conversion

1 cubic foot per second (cfs)
= 449 U.S. gallons per minute (U.S. gpm).
= 374 Imperial gallons per minute (Igpm).
= 1.98 acre feet per day (Ac.-Ft./day).

= 28.3 litres per second (L/sec.).
= 0.0283 cubic metres per second (cms).

0.10 inch = 3/32" (approx.) = 2.54 millimetres.

Addresses for Correspondence and Approvals

1. Senior Habitat Management Biologist
Fraser River, Northern B.C. and Yukon Division
Department of Fisheries and Oceans
610 Derwent Way, Annais Island
New Westminster, B.C. V3M 5P8 Phone: 666-6479

2. Senior Habitat Management Biologist
South Coast Division
Department of Fisheries and Oceans
3225 Stephenson Point Road
Nanaimo, B.C. V9T 1K3 Phone: 756-7270

3. Senior Habitat Management Biologist
North Coast Division
Department of Fisheries and Oceans
716 Fraser Street
Prince Rupert, B.C. V7J 1P9 Phone: 624-0453

Other Federal and Provincial agencies having jurisdiction in water withdrawals and construction pertaining to watercourses in British Columbia include:

1. Transport Canada
Canadian Coast Guard

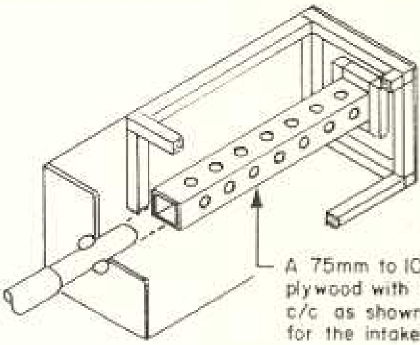
2. B.C. Ministry of Environment
Fish and Wildlife Management

3. B.C. Ministry of Environment
Water Management

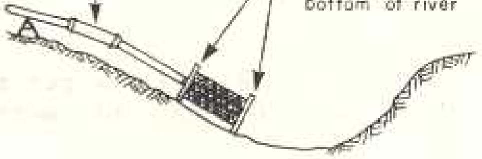
4. B.C. Ministry of Agriculture and Food.

5. B.C. Ministry of Lands, Parks and Housing.

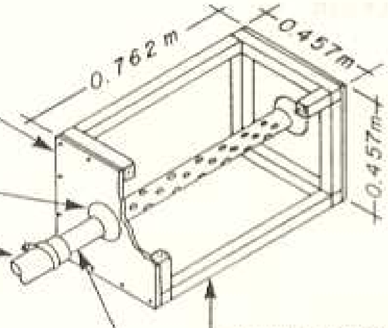
It may be necessary that several or all these agencies also be solicited for approvals prior to the installation of a water intake.



A 75mm to 100mm square box of 19mm plywood with 25mm dia. holes at 75mm c/c as shown, may be substituted for the intake pipe below

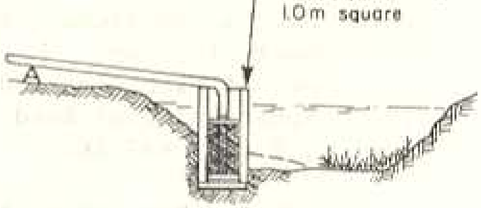


STANDARD INSTALLATION

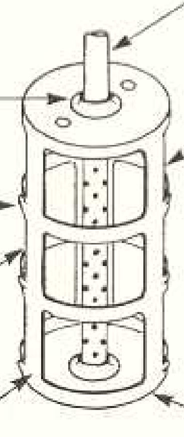


50mm - 100mm std. pipe with the section inside the screen box perforated with 16mm dia. holes at 50mm to 100mm c/c staggered

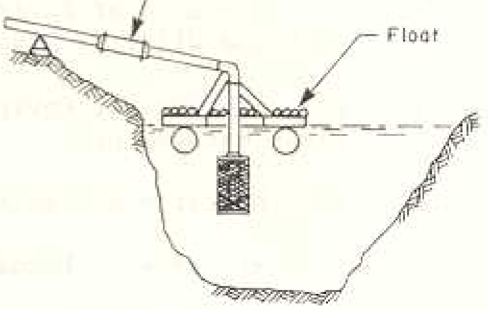
50mm x 50mm painted framing covered on 4 sides with bronze screen (wire cloth) stretched tight and fastened to the framing only. Plywood ends to be removable. Use 8 mesh wire cloth with 0.70mm or 0.64mm dia. wire



INSTALLATION IN SHALLOW WATER
MUDDY OVERGROWN BOTTOM



Wrap bronze screen around drum. A piece 0.914m x 1.880m will cover a std. oil drum. Use 8 mesh wire cloth with 0.70mm or 0.64mm dia. wire



INSTALLATION IN DEEP WATER

NOTE:

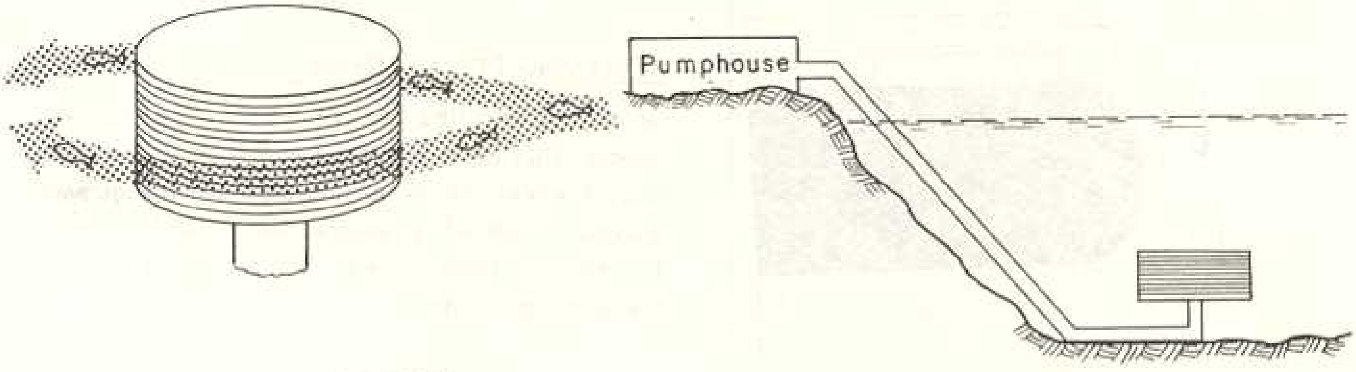
1. Oil drum shall be thoroughly washed out or steam cleaned before cutting openings.
2. All loose rust shall be removed and the drum coated with metal primer. Two coats of machinery enamel or expoxy paint shall be applied before covering with wire cloth.

NOTE:

All screens shall be installed below minimum water level, shall be easily accessible for cleaning, and shall be cleared of debris at regular intervals.

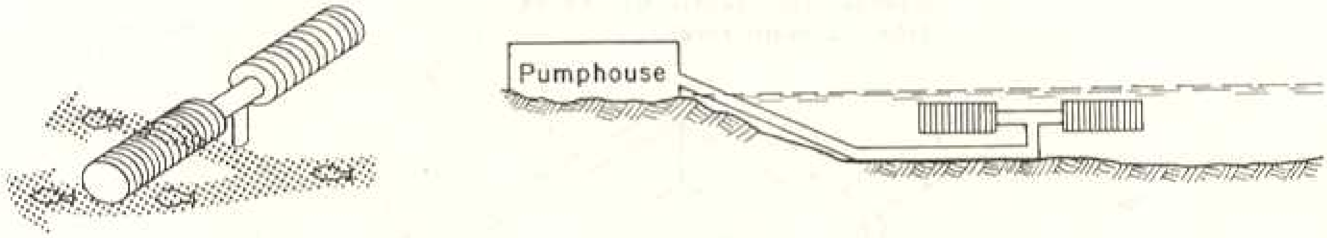
SMALL STATIONARY WATER INTAKE SCREENS

(For pumps of a capacity less than 28.3 L/sec [1cfs, 449 U.S. or 374 Igpm])



DEEP WATER WELL SCREEN

May be installed in lakes and the ocean.



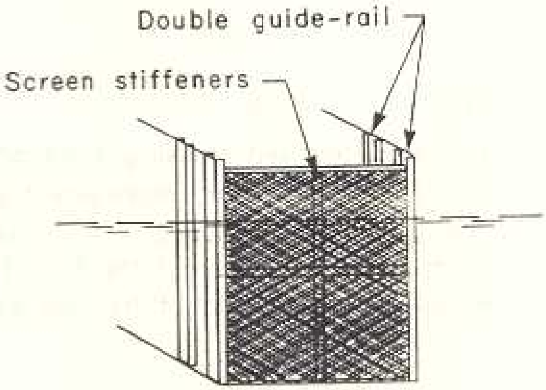
SHALLOW WATER WELL SCREEN

May be installed in lakes, pools, and stable areas in rivers.

Totally submerged cylindrical shaped stainless steel well screens provide for high intake capacity and large percentage of open area permitting water to enter at low velocities. Slot opening shall not exceed 2.54 mm (0.10 inch).

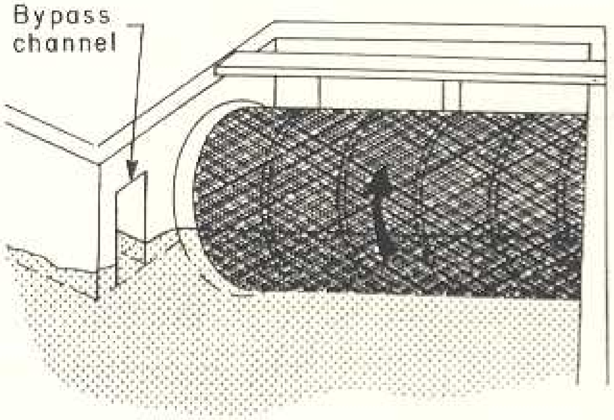
VERTICAL PANEL SCREENS

May be installed in rivers, lakes and the ocean. Generally, requires coarse trashracks, a sluice gate in river installations, double sets of guide-rails, and standby screen panels to allow for cleaning and repairs.



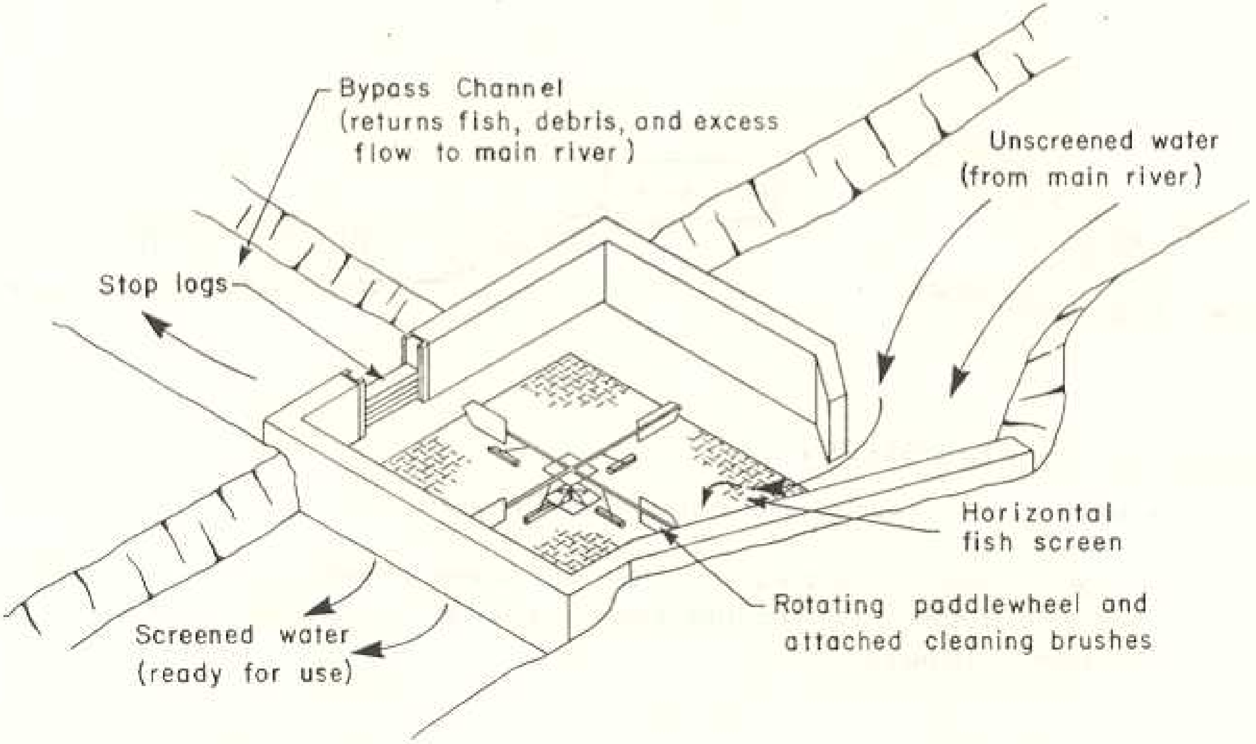
LARGE STATIONARY WATER INTAKE SCREENS

(For pumps of a capacity more than 28.3 L/sec [1 cfs, 449 U.S. or 374 Igpm])



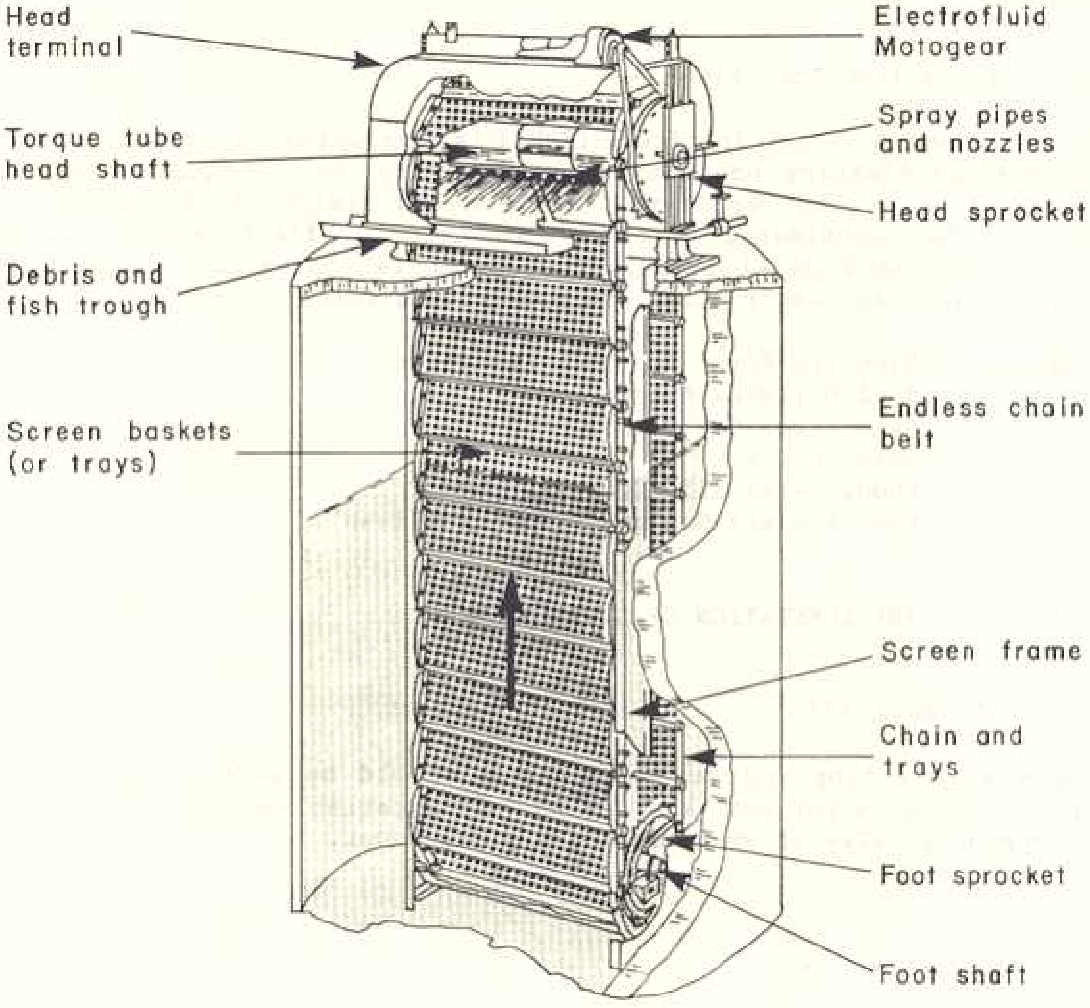
REVOLVING DRUM SCREEN, HORIZONTAL AXIS

Generally, installed to divert fish from irrigation canals. Can be driven by a small motor or by a paddle wheel. To avoid juvenile fish impingement, a bypass channel is required near the front of the screen. Rubber seals are necessary along the base and sides.



FINNIGAN SCREEN

The horizontal, self-cleaning Finnigan Screen is another concept, generally installed to divert fish from irrigation or enhancement projects. The stationary horizontal screen is kept clean by a set of brushes attached to a revolving paddle wheel powered by the water current entering the structure. A portion of the flow, the suspended debris, and fish are directed to the bypass channel. The remainder of the flow passes through and below the screen for use as required.



CONVENTIONAL VERTICAL TRAVELLING SCREEN

May be installed in rivers, lakes and the ocean. A common screening method utilized by industry, these self-cleaning mechanical screens with modifications can prevent impact upon fish. Mounted flush to the stream bank (shoreline) or as pier intakes within streams and provided with an opening on the downstream end between the intake screens and trashracks, juvenile fish can generally escape entrapment. Rubber panel, side, and boot seals are required to prevent juvenile fish from gaining entry into the pumpwell. A safe bypass system is essential to return juvenile fish with debris back to the watercourse. Automatic controls are also necessary to ensure operation at a specific minimum head differential.

LARGE INDUSTRIAL AND DOMESTIC WATER INTAKE SCREEN

APPENDIX 6 O. CENTRALIZED DATABASE FOR INTAKE DESIGN

Source: Tetra Tech Inc. (1981)

The Electric Power Research Institute (EPRI) is developing a centralized database and information cleaning house which can provide the information needed for making decisions on the best type, location and design of new intake units. Factors to be considered include biological effectiveness, hydraulic characteristics, mechanical performance, potential operation and maintenance problems, as well as construction and operational costs.

Address: Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California
94304 U.S.A.
Phone (415) 855-2000
EPRI Project Manager - C.W. Sullivan

APPENDIX 6 P. IMPLEMENTATION OF GUIDELINES

Source: Sharma (1977)

Compliance with siting and design criteria should be made mandatory. If a certain criterion is not met, a detailed justification would be required and a plan of measures taken if excessive fish kills occur.

APPENDIX 7. PRELIMINARY GUIDELINES FOR DESIGN OF A PROPOSED PULP MILL MARINE INTAKE AT PORT MELLON IN HOWE SOUND, B.C., TO HELP MINIMIZE OR ALLEVIATE IMPACTS ON AQUATIC MARINE RESOURCE

(Guidelines prepared by R. Eliasen - DFO Eng. Techn., Habitat Management Unit, for Mr. D. Chance - Senior Process Technician in Howe Sound Pulp and Paper (DFO Memo 5903-85-R27, April 4, 1989).

Note that the specifications below are only relevant to the DFO's current information and will be amended as technology develops.

PRELIMINARY GUIDELINES:

1. Screen Material: Stainless steel or copper-nickel screens are recommended since corrosion and bio-fouling are greatly reduced.

2. Screen Mesh Size: The mesh size has not yet been determined but may likely vary with site location. However, we have recently agreed to deploy stainless steel woven wire mesh with 4.75 mm (3/16") openings and an open area of 56% at another marine intake installation. This sizing must be considered strictly experimental and subject to change but is suggested until impact assessment studies on screening efficiency have been completed.

3. Screen Area: Adequate unobstructed screen area (gross area) shall be provided ensuring a maximum approach velocity of 0.12 m/sec (0.40 ft/sec.). Screen area lost by framing shall not be included as part of the unobstructed screen area.

4. Screen Support: The intake shall be adequately supported with stiffeners to prevent excessive sagging.

5. Screen Protection: The intake structure shall, where necessary, be equipped with a trash rack or similar device to prevent damage to the screen(s).

6. Screen Accessibility: The screen shall be accessible for cleaning and inspection. Screen panels or screen assemblies must be removable for cleaning, inspection and repairs. Additional standby screens should be kept on-site in case of the need for repairs.

7. Intake Design and Location: The intake should not be sited at or near herring spawning grounds. If a stationary screen is proposed, the intake depth should be below the light penetration depth, some 15 meters below 0 tide. The design and location of the intake structure shall be such that a uniform flow distribution is maintained through the total screen area.

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Dr. Dave Jude	Center for Great Lakes and Aquatic Sciences, 2200 Bonisteel Boulevard, Univ. Michigan, Ann Arbor, Michigan, 48109-2099 U.S.A. (313-763-3183). Special thanks are extended to Dave Jude who has very kindly and speedily sent over several excellent references.
Dr. Jeff Marliave	Vancouver Public Aquarium (685-3364)
Triva Ricou	Vancouver Public Aquarium Library (685-3364)

Dr. Mike St. John - Univ. British Columbia, Bio-Sciences (228-5124)

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REFERENCES

Anon. 1955. Investigation of salmon losses in irrigation diversions of the Nicola River and the preliminary test results of experimental screening devices. Canada Dept. Fisheries, Pacific Area, Fish Culture and Development Branch: 15 p.

Anon. MS 1975. An inventory of the thermal electric generating plants in the Great Lakes Basin. Int. Joint Comm. MS Rep. Windsor, Ont.

Anon. MS 1986. Fish screening directive. Dept. Fish. Oceans, Pacific Region, Screening Directive: 8 p.

ASCE. 1982. Design of water intake structures for fish protection. Hydraulics Division, American Society of Civil Engineers, New York : 163 p.

Browne, M.E., L.B. Glover, D.W. Moore and D.W. Ballengee. 1981. In-situ biological and engineering evaluation of fine-mesh profile-wire cylinders as powerplant intake screens. pp. 36-46. In: Dorn, P.B. and J.T. Johnson (eds.). Proceedings of the Workshop of Advanced Intake Technology for Power Plant Cooling Water Systems, April 22-24, 1981: 307 p.

Carpenter, E.J., B.P. Bradford and S.J. Anderson. 1974. Summary of entrainment research at the Millstone Point Nuclear Power Station, 1970 to 1972. pp. 31-35. In: Jensen, L.D. (ed.). Proceedings of the Second Workshop on Entrainment and Intake Screening. Rep. No. 15 : 347 p.

Carrier, R.F. 1978. Entrainment. Literature review of 1977. J. Wat. Pollut. Control Fed. 50: 1567-1582.

Claridge, P.N., I.C. Potter and M.W. Hardisty. 1986. Seasonal changes in movements, abundance, size composition and diversity of the fish fauna of the Severn Estuary. J. Mar. Biol. Assoc. U.K. 66: 229-258.

Coutant, C.C. 1974. Opening remarks at entrainment and intake screening workshop: "Evaluation of Entrainment Effect." pp. 1-11. In: Jensen, L.D. (ed.). Proceedings of the Second Workshop on Entrainment and Intake Screening. Rep. No. 15: 347 p.

Coutant, C.C., R.B. McLean and D.L. DeAngelis. 1979. Influences of physical and chemical alterations on predator-prey interactions. In: Clepper, H. Predator - prey systems in fisheries. Int. Symposium on Predator - Prey Systems in Fish Communities and Their Role in Fisheries Management, Atlanta, GA, 14 July 1978.

Edwards, S.J., P.M. McGroddy and D. Lispi. 1981. Fine mesh screens as an impingement-release system for marine fish larvae. pp. 128-137. In: Dorn, P.B. and J.T. Johnson (eds.) Proceedings of the Workshop of Advanced Intake Technology for Power Plant Cooling Water Systems, April 22-24, 1981: 307 p.

Eliasen, R. MS 1988. DFO Memo. Seawater intake guidelines (draft), November 16, 1988 : 1 p.

Eliasen, R. MS 1989 a. DFO Memo to P.E. Anning. Hagensborg Marine Farms Inc. Water intake and effluent discharge facilities conditional approval. January 4, 1989 : 2 p.

Eliasen, R. MS 1989 b. DFO Memo to D. Chance. Proposed pulp mill marine intake, Port Mellon, B.C. File No. 5903-85-R27, April 4, 1989 : 3 p.

Elien, M. 1990. Summary of alternatives to the chlorination of once-through seawater cooling systems and of residual chlorine measurement methods in chlorinated seawater. Prep. for Env. Canada, Conservation and Protection, Pacific and Yukon Region: 26 p.

Goeman, T.J. 1984. Fish survival at a cooling water intake designed to minimize mortality. Fish - Cult. 46: 279-281.

Haegele, C.W. MS 1988. DFO Memo. Salmon farm in Barkley Sound. July 8, 1988: 1 p.

Hanson, L.H., J.R. White and H.W. Li. 1977 a. Entrapment and impingement of fishes by power plant cooling water intakes: an overview. Mar. Fish. Rev. 39: 7-17.

Hanson, B.N., W.H. Bason, B.E. Beitz and K.E. Charles. 1977 b. A practical intake screen which substantially reduces the entrainment and impingement of early life stages of fish. pp. 393-407. <u>In</u> : Jensen, L.D. (ed.). Fourth National Workshop on Entrainment and Impingement, December 5, 1977: 424 p.

Hay, D. MS 1988. DFO Memo. Impacts of tank farms in Barkley Sound. July 5, 1988: 1 p.

Hay, D. MS 1989. DFO Memo to I. Williams. Reply to request on information about ferrochromium effects on herring. November 28, 1989.

Hay, D. and D. Chalmers. MS 1988. DFO Memo to V. Haisst. Preliminary guidelines to seawater intakes. October 24, 1988 : 1 p.

Hay, D.E., P.B. McCarter, R. Kronlund and C. Roy. 1989. Spawning areas of British Columbia herring: a review, geographical analysis and classification. Can. MS Rep. Fish Aquat Sci. 2019.
Volume I. Queen Charlotte Islands. 135 p.
Volume II. North Coast. 99 p.
Volume III. Upper Central Coast. 171 p.
Volume IV. Lower Central Coast and Johnstone Strait. 254 p.
Volume V. Strait of Georgia. 268 p.
Volume VI. West Coast Vancouver Island. 213 p.

Helvey, M. 1985. Behaviourial factors influencing fish entrapment at offshore cooling - water intake structures in southern California. Mar. Fish. Rev. 47: 18-26.

Hocutt, C.H. and J.E. Edinger. 1980. Fish behaviour in flow fields (Chapter VI). pp. 143-181. In: C.H. Hocutt, C.R. Stauffer, J. Edinger, L.W. Hall and R.P. Morgan (eds.). Power Plants: Effects on Fish and Shellfish Behaviour. Academic Press. New York. 346 p.

Hoss, D.E. and J.H.S. Blaxter. 1981. Effects of rapid changes in hydrostatic pressure on the larvae of Atlantic herring (Clupea harengus L.). pp. 328-329. In: R. Lasker and K. Sherman (eds.). The early life history of fish: Recent studies. Rapp. P.-V. Reun. Ciem. 1981.

Huguenin, J.E. and F.J. Ansuini. 1981. Marine biofouling of synthetic and metallic screens. Oceans '81 Proceedings, MTS & IEEE, Boston, MA, Sept. 1981: 545-549.

Huguenin, J.E. and S.S. Huguenin. 1984. Materials and design considerations for small seawater intake screens. Mar. Technol. Soc. J. 18: 35-41.

Ingmanson, D.E. and W.J. Wallace. 1973. Oceanology: An Introduction. Calif. State Univ., San Diego 1973 : 325 p.

Jude, D., C.P. Madenjian, P.J. Schneeberger, H.T. Tin, P.J. Mansfield, T.L. Rutecki, G.E. Noguchi and G.R. Heufelder. 1982. Adult, juvenile and larval fish populations in the vicinity of the J.H. Campbell Power Plant, 1981, with special reference to the effectiveness of wedge-wire intake screens in reducing entrainment and impingement of fish. Special Rep. No. 96 of the Great Lakes Research Division, Univ. Michigan : 516 p.

Jude, D., D. Bimber, N. Thurber, F. Tesar, L. Noguchi, P. Mansfield, H. Tin and P. Rago. 1986. Impact of the Donald D. Cook Nuclear Plant on fish. In : Rossmann, R. (ed.). Southeastern Nearshore Lake Michigan: Impact of the Donald C. Cook Nuclear Plant. Great Lakes Research Div., Publication 22 : 285-351.

Kelso, J.R.M. and J.K. Leslie. 1979. Entrainment of larval fish by the Douglas Generating Station, Lake Huron, in relation to seasonal succession and distribution. J. Fish. Res. Bd. Can. 36 : 37-41.

Kennish, M.J., M.B. Roche and T.R. Tatham. 1984. Anthropogenic effects on aquatic communities. In : Kennish, M.J. and R.A. Lutz (eds.). Ecology of Barnegat Bay, New Jersey., Lect. Notes Coast, Estuar. Stud. 6 : 318-338.

Kerr, J.E. 1953. Studies on fish preservation at Contra Costa steam plant of the Pacific Gas and Electric Company. Calif. Dep. Fish Game Fish Bull. 92 : 66 p.

Lawler, Matusky and Skelly. 1981. Report on larval exclusion project. Prep. for Southern California Company. (Cited in McGroddy et al. 1981b).

Leithiser, R.L., K.F. Ehrlich and A.B. Thum. 1979. Comparison of a high volume pump and conventional plankton nets for collecting fish larvae entrained in power plant cooling systems. J. Fish. Res. Bd. Can. 36 : 81-84.

Levings, C.D., R.E. Foreman and V.J. Tunnicliffe. 1983. Review of the benthos of the Strait of Georgia and contiguous fjords. Can J. Fish. Aquat. Sci. 40: 1120-1141.

Marcy, B.C. Jr. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. J. Fish. Res. Bd. Can. 30 : 1195-1203.

Marliave, J.B. 1986. Lack of planktonic dispersal of rocky intertidal fish larvae. Trans. Am. Fish. Soc. 115 : 149-154.

McCarter, P.B. and D.E. Hay. MS 1990. Distribution of herring larvae in the Strait of Georgia and implications for stock structure, April 10-20, 1989. PSARC Working Paper, 10 p.

McGroddy, P.M., S. Petrich and L.E. Larson. 1981 a. Fouling and clogging evaluation of fine-mesh screens for offshore intakes in the marine environment. pp. 5-21. In: Dorn P.B. and J.T. Johnson (eds.). Proceedings of the Workshop of Advanced Intake Technology for Power Plant Cooling Water Systems, April 22-24, 1981: 307 p.

McGroddy, P.M., S.J. Edwards and P. Dorn. 1981 b. Diversion of marine fish larvae with angled louvers and fish-mesh screens. pp. 225-234. In: Dorn, P.B. and J.T. Johnson (eds.). Proceedings of the Workshop of Advanced Intake Technology for Power Plant Cooling Water Systems, April 22-24, 1981: 307 p.

Moreton, B.B. and T.Y. Glover. 1980. New marine industry applications for corrosion and biofouling resistant copper-nickel alloys. pp. 267-278. In: Proceedings of the 5th International Congress on Marine Corrosion and Foulding. Barcelona, Spain.

Morrison, J.A. MS 1988. DFO Memo to R.H. Higgins. Norwegian Pacific Fish Farms Ltd., Land Based Salmon Tank Farm, Macoah Passage, Maggie River, Barkley Sound. July 14, 1988 : 6 p.

Powell, M.R. 1976. Resistance of cooper-nickel expanded metal to fouling and corrosion in mariculture operations. The Progressive Fish - Culturist 38 : 58-59.

Prentice, E.F. and F. J. Ossiander. 1974. Fish diversion systems and biological investigation of horizontal travelling screen Model VII. Proc. 2nd workshop on entrainemnt and intake screening. EPRI Report No. 15: 205-213.

Richards, R.T. 1977. Present engineering limitations to the protection of fish at water intakes. pp. 415-424. In: Jensen, L.D. (ed.). Fourth National Workshop on Entrainment and Impingement, December 5, 1977 : 424 p.

Sazaki, M., W. Heubach and J.E. Skinner. 1972. Some preliminary results on the swimming ability and impingement tolerance of young-of-the-year steelhead trout, king salmon, and striped bass. Final Report for Anad. Fish. Act Proj. Calif. AFS - 13: 30 p.

Schneeberger, P.J. and D.J. Jude. 1981. Use of fish larva morphometry to predict exclusion capabilities of small-mesh screens at cooling-water intakes. Trans. Am. Fish. Soc. 110 : 246-252.

Schuler, V.J. and L.L. Larson. 1975. Improved fish protection at intake systems. J. Environ. Eng. Div., Proc. Am. Soc. Civil Eng., 101: 897-910.

Sharma, R.K. 1977. Perspectives on fish impingement. pp. 351-356. In : Jensen, L.D. (ed.). Fourth National Workshop on Entrainment and Impingement, December 5, 1977 : 424 p.

Spight, T.M. R.W. Firth, K.E. Tarbox, H. Chin, A. Niedoroda, G.A. Robilliard and M. Busdosh. 1979. Prudhoe Bay waterflood project : biological effects of impingement and entrainment from operation of the proposed intake : summer 1978. Prep. for Prudhoe Bay Unit.

Stevenson, J.C. 1962. Distribution and survival of herring larvae (Clupea pallasi Valenciennes) in British Columbia waters. J. Fish. Res. Bd. Can. 19 : 735-810.

Tatham, T.R., D.L. Thomas and G.J. Miller. 1977. Survival of fishes and macroinvertebrates impinged at Oyster Creek Generating Station. pp. 235-243. In : Jensen, L.D. (ed.). Fourth National Workshop on Entrainment and Impingement, December 5, 1977 : 424 p.

Tetra Tech Inc. 1981. Power Plant Intake Systems Data Base. Prep. for Electric Power Research Institute, California.

Thurber, N.J. and D.J. Jude. 1985. Impingement losses at the D.C. Cook Nuclear Power Plant during 1975-1982 with a discussion of factors responsible and possible impact on local populations. Special Rep. No. 115 of the Great Lakes Research Division, Univ. Michigan : 70 p. + Appendices.

Tomljanovich, D.A., J.H. Heuer, M.Smith, P. Smith, S. Vigander and R. Whittaker. 1980. Evaluation of two concepts for protection of fish larvae at cooling water intakes. EPA - 600/7-80-094: 102 p.

Turnpenny, A.W.H. and R.N. Bamber. 1983. The critical swimming speed of the sand smelt (Atherina presbyter Cuvier) in relation to capture at a power station cooling water intake. J. Fish. Biol. 23 : 65-73.

Uziel, M.S., R.F. Carrier and R.B. McLean. 1979. Entrainment and impingement. Literature review of 1978. J. Wat. Pollut. Control Fed. 51: 1554-1573.

Webb, L.A. MS 1988. DFO Memo to G. Jaltema. Herring habitat protection. July 18, 1988 : 1 p.

Weisberg, S.B., C.F. Stroup and A.F. Holland. 1986. Tests of biofouling control technologies for use with fine-mesh screens in an estuarine environment. Mar. Technol. Soc. J. 20: 37-43.

Zeitoun, I.H., J.A. Gulvas and D.B. Roarabaugh. 1981. Effectiveness of fine mesh cylindrical wedge-wire screens in reducing entrainment of Lake Michigan ichthyoplankton. Can. J. Fish. Aquat. Sci. 38 : 120-125.