Environmental Impacts of Desalination Intakes

Tim Hogan
Alden Research Laboratory, Inc.

INTRODUCTION

Reliance on desalination for drinking water is projected to increase globally. Without careful planning, the associated increase in water withdrawal has the potential to adversely impact aquatic life in the vicinity of these intakes. Therefore, it is important to have both accurate measurements of these impacts and effective mitigation techniques. Consideration of environmental issues is critical because they can also significantly affect facility economics by dictating intake type, size, location and operation requirements as well as the type and magnitude of mitigation required to offset the impacts.

ADVERSE ENVIRONMENTAL IMPACTS: IMPINGEMENT AND ENTRAINMENT

The most significant impacts to aquatic organisms caused by desalination intake structures are broadly categorized into: 1) impingement, and 2) entrainment. Each represents an interaction between the organisms in the source waterbody and the screening technology and each is dependent on organism and screen mesh size. Impingement is the entrapment of larger organisms against the screen mesh by the flow of the withdrawn water (Figure 1). The magnitude of impingement losses for any species from intake operation is a function of the involvement of the species with the intake (number or proportion impinged) and the subsequent mortality of those organisms (referred to as impingement mortality). Entrainment is the passage of smaller organisms through the screening mesh. The magnitude of entrainment losses for any species from intake operation is a function of the involvement of the species with the intake (number or proportion entrained) and the subsequent mortality of those organisms as they pass through the process equipment (referred to as entrainment mortality). Entrainment mortality in desalination treatment processes is 100%.

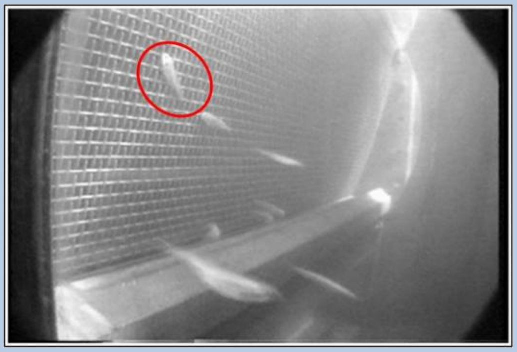

Figure 1 Impingement of juvenile striped bass on a modified traveling water screen (Courtesy of Alden).

A third term, “entrapment” is often used when describing impacts associated with offshore intake structures. These structures are typically comprised of an offshore pipe riser covered with a velocity cap (see Section 0), a long intake tunnel, and an onshore screening facility. Organisms that pass through the offshore velocity cap and are unable to escape the intake velocity in the intake tunnel are often referred to as entrapped. They have technically been entrained into the intake system, but their ultimate fate has not yet been determined. Depending on the mesh size of the screens at the onshore screening facility, these organisms can impinge on or entrain through the final screen mesh. Furthermore, unless the onshore screening facility includes a fish return system to transport impinged fish safely back to the source waterbody, they are considered entrainment mortalities.

Commonly accepted definitions of entrainable and impingeable organisms, as they are used in the United States, are given below:

<u>Impingeable organism</u> – organism large enough to be retained by a 9.5-mm mesh screen. These include larger actively moving juvenile and adult organisms.

<u>Entrainable organism</u> – organism small enough to pass through a 9.5-mm mesh screen. These include small organisms with limited to no swimming ability. Some of these organisms (e.g. fish eggs) lack the ability to avoid the intake flow regardless of velocity.

Intake Regulation in the United States

There exists no federal level directive in the U.S. that regulates the operation of stand-alone desalination intake structures; rather, regulation occurs at the state level. Therefore, the level of environmental protection afforded aquatic organisms can vary nationally. In addition, variations in regulation and permitting requirements can contribute to unpredictable schedules for construction of desalination facilities. State level regulation also typically involves multiple agencies. For example, the agencies involved in the regulation of a California desalination intake may include, among others, the California Coastal Commission, the State Water Resources Control Board, the Regional Water Quality Control Board, the State Lands Commission, the Army Corps of Engineers, the U.S. Fish and Wildlife Service, and the California Department of Fish and Game. The involvement of multiple agencies can make streamlining of the permitting process more difficult than if a single agency oversees the implementation of standards.

Desalination facilities co-located with power plants are held to the same standards as the power plant. Cooling water intake structures (CWIS) at electric generation facilities fall under the jurisdiction of the federal Clean Water Act (CWA) which is administered by the U.S. Environmental Protection Agency (EPA). Section 316(b) of the CWA required that the location, design, construction, and capacity of a CWIS reflect the “best technology available” for minimizing adverse environmental impacts. In 2004, rulemaking by the EPA established new guidelines for the implementation of Section 316(b) (the Rule), which required all CWIS to meet national performance standards relative to impingement mortality and in some cases entrainment (EPA 2004). The Rule laid out benchmark performance standards for the reduction of impingement mortality and entrainment.

The Rule was remanded in January 2007 and temporary authority was given to states to use Best Professional Judgment in issuing permits in the absence of a federal level directive. A new Rule is forthcoming from the EPA and it follows that many states may adopt the standards and criteria put forth in the new Rule, but others may not. With some exceptions, desalination intakes designed to future Section 316(b) performance standards should be sufficient to meet state regulatory requirements. The current trend in intake design in the United States’ desalination industry bears this out. However, the global trend in intake design is markedly different. The permitting and regulatory framework is often inversely correlated to potable water needs – when need is great, regulation is less stringent. Globally, need for potable water often trumps environmental concerns. This results in vast global variation in the design of intakes for protection of aquatic organisms.

SOLUTIONS FOR ADDRESSING ADVERSE ENVIRONMENTAL IMPACTS

Selecting the Best Technology Available (BTA)

The selection of the proper intake technology is critical to the protection of aquatic organisms. However, intakes must also be cost-effective to construct, operate, and maintain if potable water is to be produced at reasonable rates. There are a number of intake technologies that are both highly protective of aquatic resources and cost-effective. These technologies have undergone intensive research by the power generation industry to meet impingement and entrainment standards.

An intake technology can be considered to have potential for application when it has proven biological effectiveness, is available and does not require further engineering development, and has engineering and/or biological advantages over other potential technologies. The potential of each technology to entrain early lifestages of aquatic life and impinge later lifestages are critical considerations in the selection of the proper intake technology. The most conservative approach is to select a technology that minimizes entrainment of early lifestages, which will also effectively eliminate impingement of juveniles and adults. Regulators and stakeholders have recently emphasized the importance of selecting intake technologies that minimize the entrainment of early lifestages of organisms (eggs and larvae), less stress has been placed on impingement than in the past.

Two intake technologies that have demonstrated potential to minimize the entrainment of early life stages of aquatic organisms at desalination intakes include: 1) narrow-slot cylindrical wedgewire screens, and 2) fine-mesh traveling water screens.

Narrow-slot Cylindrical Wedgewire Screens

Narrow-slot cylindrical wedgewire screens are designed to reduce impingement mortality and entrainment by physically preventing passage of organisms into the intake. Biological effectiveness is enhanced with the presence of an ambient flow (current) past the screens to transport debris and non-motile early life stages with little or no swimming capabilities away from the intake. Wedgewire screens are typically designed to minimize entrainment through a combination of narrow spaced slot widths and low through-slot intake velocities. The through-slot intake velocity is the rate at which water is drawn into the screen measured perpendicular to the screen surface. A large diameter narrow-slot cylindrical wedgewire screen is shown in Figure 2.

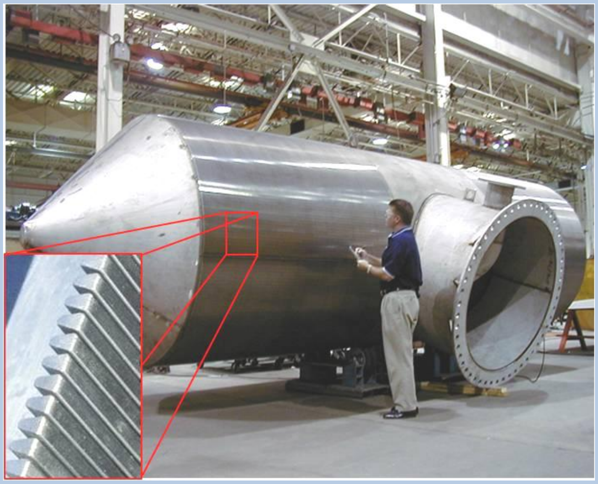

Figure 2 Narrow slot cylindrical wedgewire screen (Courtesy of Johnson Screens)

Fine Mesh Traveling Water Screens

Fine-mesh traveling water screens (Figure 3) utilize mesh as small as 0.5 mm and can be designed to operate at through-slot velocities of 0.5 foot per second (ft/s). Traveling water screens are typically housed in an onshore screening house. This screening house receives water from either an onshore or offshore channel or pipeline. If the intake is located offshore, a velocity cap would likely be used at its terminus in order to minimize potential for organism impingement. Figure 4 depicts a typical velocity cap. Such a device changes an intake flow that would otherwise be vertical to horizontal. It has been shown that fish can more easily detect a horizontal velocity gradient than a vertical one (Weight 1958).

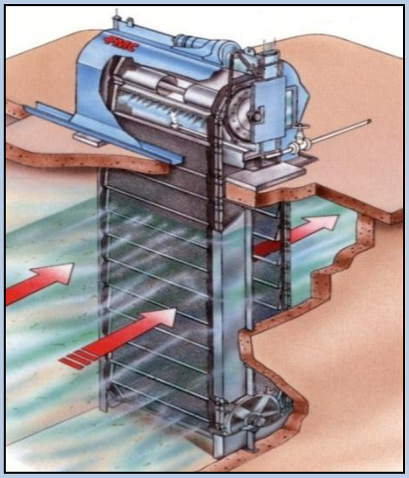

Figure 3 Fine-mesh traveling water screen (Courtesy of U.S. Filter)

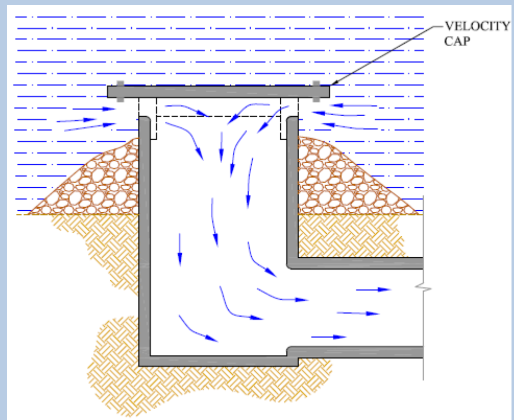

Figure 4 Velocity cap at the terminus of an intake pipe.

Other available screening technologies, such as coarse-mesh screens (traveling water screens, wide-slot cylindrical wedgewire screens, and barrier nets), diversion systems (angled bar racks, louvers, and inclined plane screens), and behavioral barriers (sound, light, and air bubbles) are limited in their potential for use at desalination intakes because they are designed to prevent impingement mortality only, not entrainment.

Entrainment Study

An entrainment sampling study is an important tool for determining the potential impacts of the selected intake on the aquatic resources in the source waterbody. Data from an entrainment study will reveal the species and life stages that are susceptible to entrainment and can be used to estimate the number of organisms that may be entrained by a proposed full-scale facility.

Ichthyoplankton entrainment sampling can be conducted either on a pilot-scale prior to full-scale intake design or at an existing full-scale intake. If conducted on a pilot-scale, samples are typically collected through a pilot-scale screen positioned near the proposed intake location. If conducted at an existing full-scale intake, samples are collected from the water withdrawn through the existing screens using submersible pumps and some type of collection system.

In each case, water is withdrawn downstream of the screen being evaluated and is discharged through a fine-mesh plankton net. Though a 335-micron mesh is typical, net mesh size may vary based on the size of the target species. An in-line flow meter is used to record the volume of water sampled. Entrained organisms are rinsed from the plankton net in the discharge stream with filtered seawater, collected, and preserved. Samples are then transported to a laboratory where they are sorted, identified to the lowest taxonomic level practicable, and enumerated. A subset of all the organisms collected is measured for length and head capsule depth. Entrainment densities are then calculated based on organism abundance and sample volume (e.g., number of organisms per cubic meter).

Ideally, sampling is conducted over multiple years in order to account for inter-annual variability in organism abundance. Typically, samples are collected once per week or once every two weeks over a 12-month period in order to capture any seasonal variations in organism abundance. Sampling may be less frequent during time periods when ichthyoplankton are not present or only occur in very low abundances (e.g., winter months). Daytime and nighttime sampling is also conducted to capture diel variations in organism abundance. Diel sampling also provides data on variations in organism abundance related to tidal cycle. Samples can also be composites comprised of multiple depths in order to determine whether there is any vertical stratification of the entrained organisms. It is also important to monitor ambient current velocities near the intake so that any relationships between organism abundance and ambient hydraulic conditions can be determined.

In addition to sampling downstream of the intake screen, ambient biological samples should also be collected in the source waterbody near the intake location. These ambient samples serve to establish a baseline to which densities of entrained organisms can be compared, allowing estimation of the biological efficacy of the screen. Additionally, ambient samples can serve as the basis for assessing the impacts of entrainment on local populations of organisms.

Raw entrainment numbers are used to determine the species composition and abundance (density) of organisms in each sample. Data are then analyzed statistically to detect differences in organism densities between entrainment and ambient samples, among years, among seasons, and between daytime and nighttime conditions.

Entrainment Impact Assessment

Total annual entrainment can be estimated for a full-scale facility under actual and maximum design withdrawal. Total annual entrainment losses are used to assess the impacts of entrainment on local populations. Impact assessment models include both demographic models (Adult Equivalent Loss [AEL], Fecundity Hindcast [FH], and Production Foregone [PF]) and a conditional mortality model (Empirical Transport Model [ETM]).

AEL, FH, and PF are demographic models which are often used in cost-benefit analyses. Demographic models are based on relating a number of small organisms to a comparable number of adults. AEL uses entrainment data to convert larval entrainment losses into equivalent numbers of adult fish. . For example, when taking into account natural mortality rates experienced by a particular species, it may take 100,000 larvae to produce one adult. Adults are easier to assign a value to, thus more valuable in an economic analysis designed to determine the value of the organisms lost to entrainment and impingement. FH uses entrainment data to calculate the number of fecund females that would be required to make up for the number of eggs and larvae lost to entrainment. PF calculates the area of estuarine habitat required to compensate for entrainment losses; this type of model is often relied upon when restoration will likely be required to offset entrainment impacts.

ETM is a conditional mortality model. This model incorporates both biological and hydrodynamic data to determine the probability of a larva being entrained into the withdrawn water. The model assumes 100% mortality of entrained larvae. In the ETM model, the risk of entrainment for a larva is dependent on the length of time it is susceptible to entrainment (based on larval length and growth rate), its geographic distribution (determined from ambient sampling of source waterbody), and the probability of entrainment into the withdrawn flow (based on ambient currents/hydrodynamics).

Regardless of the model used, the resulting impact assessments can then be put in the context of their effect on local populations. Such impact assessments can provide clear communication of the extent of the impacts to the stakeholders and can often allay concerns by converting unclear entrainment data into easily understood numbers or concepts.

Mitigation of Entrainment and Impingement

Although entrainment and impingement impacts can be minimized, they cannot be eliminated. It is necessary, therefore, to mitigate for the impacts that cannot be prevented. Mitigation takes a number of different forms, though the most common is wetland restoration. Since wetlands are often the nursery areas for many of the species impacted by desalination intakes, increasing the area of wetlands has the potential to increase the production of the species affected. The number of acres required to mitigate for the number of organisms lost to entrainment and impingement can be calculated using trophic level conversion efficiencies.

CASE STUDY – TAUNTON RIVER DESALINATION PLANT

Laboratory studies are typically the first step in determining the ability of an intake technology to reduce entrainment and impingement of ichthyoplankton effectively at a water intake. The fate of eggs and larvae exposed to a technology can be closely monitored under controlled conditions and multiple parameters can be tested, if needed, with little effort.

Figure 3 Filtrex filter candles used in Alden laboratory evaluation.

Inima/Aquaria is constructing a desalination plant on the Taunton River in Dighton, Massachusetts and needed to ensure that the intake technology selected would provide adequate protection to the early life stages of important fish species in the river. Alden was contracted to conduct a controlled laboratory study to determine the potential impingement and survival rates of impinged organisms exposed to the Taunton River Desalination Plant (TRDP) intake, which used a Filtrex Filter System. The Filtrex Filter System is comprised of racks of "candles" through which river water is withdrawn (Figure 5). The pore size (40 μ) of the Filtrex candles is sufficiently small to prevent entrainment of all ichthyoplankton and other small organisms. The low through-pore velocity (0.2 ft/s) will prevent impingement of juvenile fish and should minimize impingement of fish eggs and larvae. However, until now, there were no data available to assess the actual risk of impingement for ichthyoplankton that may encounter the intake filter system at the TRDP. The laboratory study was therefore designed to determine impingement rates and survival of impinged organisms exposed to a sub-set of Filtrex candles operated as they would be in the field (i.e., same operational cycle and withdrawal flow rate). The species used in the laboratory evaluation included early life stages of river herring (blueback herring and alewife) and American shad.

Laboratory trials were conducted in a Plexiglas flume (Figure 6). Test organisms were released upstream of the Filtrex candles and collected downstream. During the trials, flow was withdrawn through the Filtrex candles at their design flow rate. All test organisms (i.e. those that impinged on the candles and those that bypassed the candles) were collected downstream and held for 48 hours post-test to determine latent mortality.

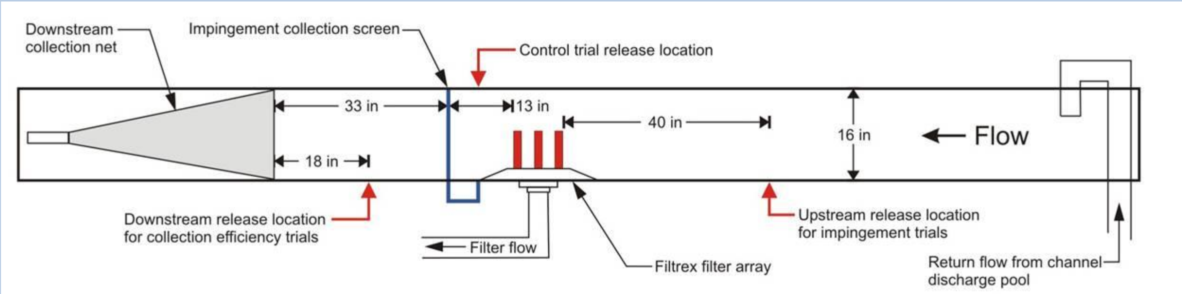

Figure 4 Schematic and photograph of Filtrex test facility with approximate distances between facility components and organism release and collection locations.

The results of the laboratory testing support the conclusion that impingement rates of eggs and larger larvae (> 5 mm) exposed to the Filtrex Filter system will likely be low, that entrainment will not occur for any life stage of ichthyoplankton, and that ichthyoplankton passing by the intake filters without impinging should have high survival rates. The overall impact of impingement mortality in the field should be minimal since only a small portion of the entire population will encounter the intake and an even smaller portion will become impinged.

Because the Filtrex Filter system was considered experimental, the laboratory studies were crucial in demonstrating to the agencies that it would be effective for minimizing potential adverse impacts to the species of concern. Based, in part, on the results of the laboratory evaluation, the Filtrex Filter system was recently permitted by the agencies and currently awaits a final design.

SUMMARY

As desalination becomes a more popular technology for supplying drinking water, the protection of aquatic organisms at salt or brackish water intakes will increasingly gain the attention of local regulators. Detailed laboratory studies have proven effective at evaluating the performance of fish protection systems and communicating this to the relevant agencies.

REFERENCES

United States Environmental Protection Agency (EPA). 2004. National Pollutant Discharge Elimination System - Final Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities. July 9, 2004 Federal Register: Vol. 69, No. 131 Pg 41576-41693

Tim Hogan is a Fisheries Biologist at Alden Research Laboratory. He conducts biological evaluations of intake technologies in both laboratory and field settings. He has provided technical guidance on environmentally-friendly intake design to developers considering desalination as a water supply option. He has been involved in evaluations of water intakes for power plants, desalination facilities, LNG facilities, and drinking water facilities.

About Alden Research Laboratory: Founded in 1894, Alden is the oldest continuously operating hydraulic laboratory in the United States and one of the oldest in the world. Alden has been a recognized leader in the field of fluid dynamics research and development with a focus on the energy and environmental industries. The current Alden organization consists of engineers, scientists, biologists, and support staff in five specialty areas: Hydraulic Modeling and Consulting, Environmental and Engineering Services, Gas Flow Systems Engineering, Flow Meter Calibration, and Field Services. http://www.aldenlab.com/