



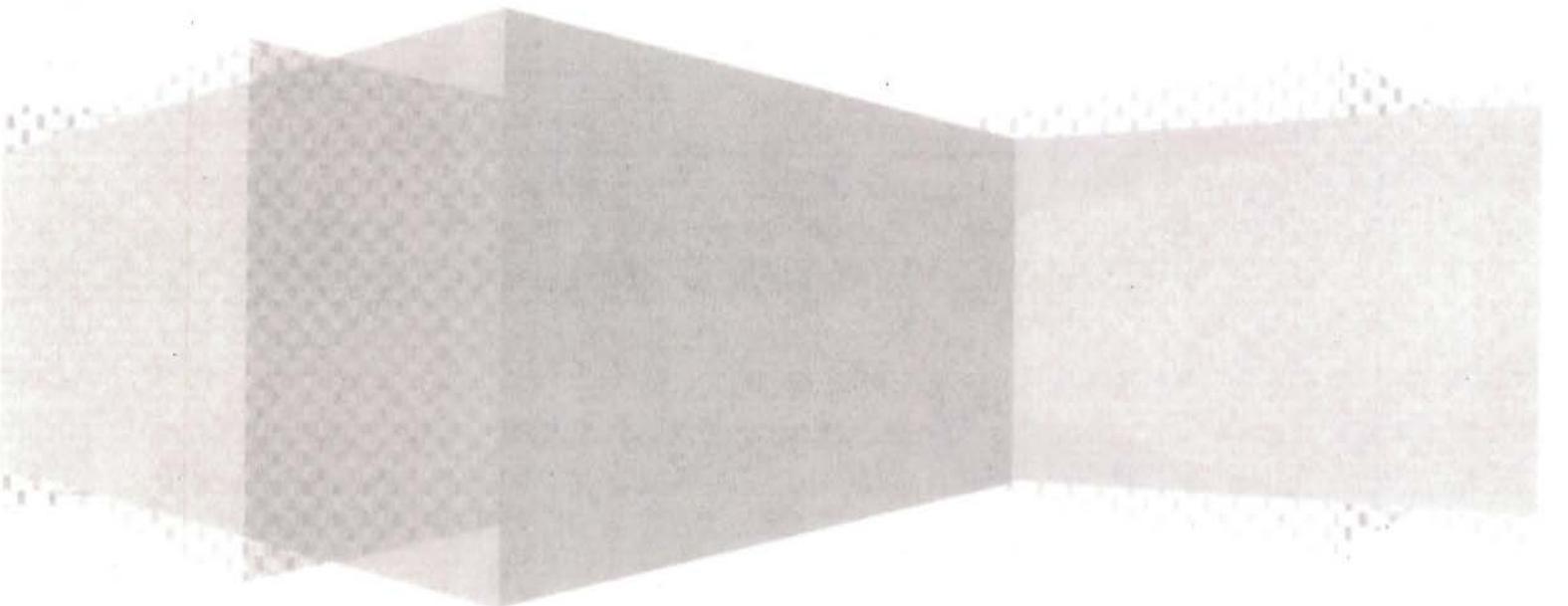
*Sustainable Solutions for a Thirsty Planet®*

# Desalination Plant Intakes

## Impingement and Entrainment Impacts and Solutions

White Paper

March 2011; Revised June 2011



The WaterReuse Desalination Committee's White Papers are living documents. The intent of the Committee is to enhance the content of the papers periodically as new and pertinent information on the topics becomes available. Members of the desalination stakeholder community are encouraged to submit their constructive comments to [white-papers@watereuse.org](mailto:white-papers@watereuse.org) and share their experience and/or case studies for consideration for inclusion in the next issuance of the white papers.

# WATEREUSE ASSOCIATION DESALINATION COMMITTEE

## Desalination Plant Intakes – Impingement and Entrainment Impacts and Solutions

### White Paper

#### INTRODUCTION

Seawater intakes are an integral part of every seawater desalination plant. The purpose of this white paper is to provide an overview of potential impingement and entrainment (I&E) impacts associated with the operation of open ocean intakes for seawater desalination plants and to discuss alternative solutions for efficient and cost effective I&E reduction. For information on alternative intakes for seawater desalination plants, refer to the WaterReuse Association's white paper titled "Overview of Desalination Plant Intake Alternatives."

#### WHAT IS IMPINGEMENT AND ENTRAINMENT?

As with any other natural surface water source currently used for fresh water supply around the globe, seawater contains aquatic organisms (algae, plankton, fish, bacteria, etc.). *Impingement* occurs when organisms sufficiently large to avoid going through the screens are trapped against them by the force of the flowing source water – i.e., algae, plankton and bacteria are not exposed to impingement. On the other hand *entrainment* occurs when marine organisms enter the desalination plant intake, are drawn into the intake system, and pass through to the treatment facilities.

Impingement typically involves adult aquatic organisms (fish, crabs, etc.) that are large enough to actually be retained by the intake screens, while entrainment mainly affects aquatic species small enough to pass through the particular size and shape of intake screen mesh. Impingement and entrainment of aquatic organisms are not unique to open intakes of seawater desalination plants only. Conventional open freshwater intakes from surface water sources (i.e., rivers, lakes, estuaries) may also cause measurable impingement and entrainment.

A third term, "*entrapment*," is then used when describing impacts associated with offshore intake structures connected to an on-shore intake screen and pump station via long conveyance pipeline or tunnel. Organisms that enter the offshore intake and cannot swim back out of it are often referred to as entrapped<sup>1</sup>. Such marine organisms could either be impinged on the intake screens or entrained if they pass through the screens and enter the downstream facilities of the desalination plant.

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<sup>1</sup> [http://www.waterlink-international.com/download/whitepaper\\_uploadfile\\_21.pdf](http://www.waterlink-international.com/download/whitepaper_uploadfile_21.pdf)

Attention to seawater intake impingement and entrainment issues is partially prompted by the Section 316(b) of the 1972 Clean Water Act that regulates cooling water intake of the steam electric industry by the environmental scrutiny associated with the public review process of desalination projects in California.

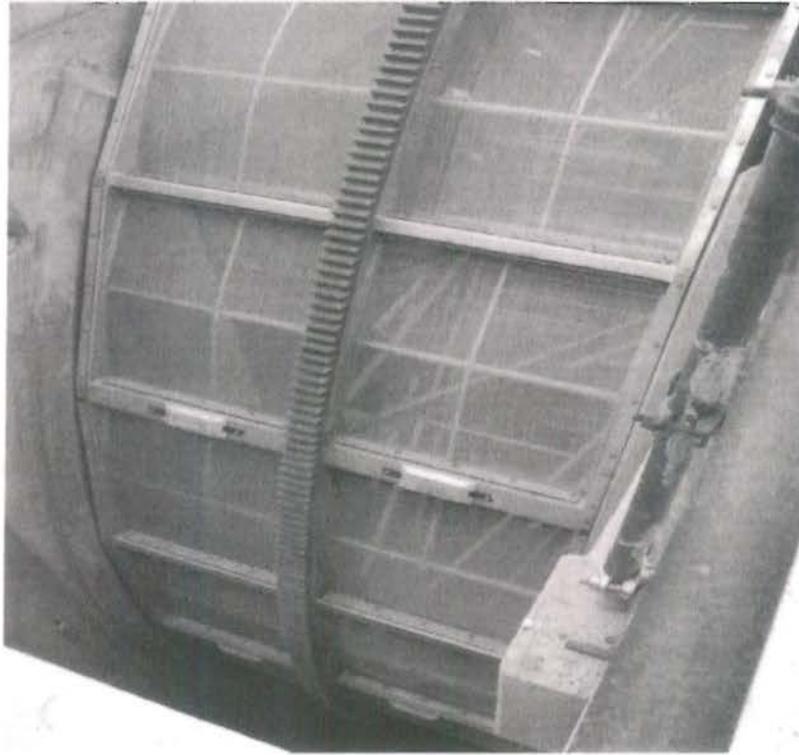
### **MAGNITUDE OF ENVIRONMENTAL IMPACTS**

The magnitude of environmental impacts on marine organisms caused by impingement and entrainment of seawater intakes is site specific and varies significantly from one project to another. Open ocean intakes are typically equipped with coarse bar screens (Figure 1), which typically have openings between the bars of 20 mm to 150 mm followed by smaller-size (“fine”) screens with openings of 1 mm to 10 mm (Figure 2), which preclude the majority of the adult and juvenile marine organisms (fish, crabs, etc.) from entering the desalination plants. While coarse screens are always stationary, fine screens could be two types – stationary (passive) and periodically moving (i.e., rotating) screens. Figure 2 depicts a 3-mm rotating fine screen. Most marine organisms collected with the source seawater used for production of desalinated water are removed by screening and downstream filtration before this seawater enters the reverse osmosis desalination membranes for salt separation. After screening, the water is typically processed by finer filters for pretreatment of seawater, which typically have sizes of the filtration media openings (pores) between 0.01 microns to 0.2 microns for membrane ultra- and micro-filters and 0.25 to 0.9 mm for granular media filters.



Source: GHD

**Figure 1 – Intake Bar Screen**



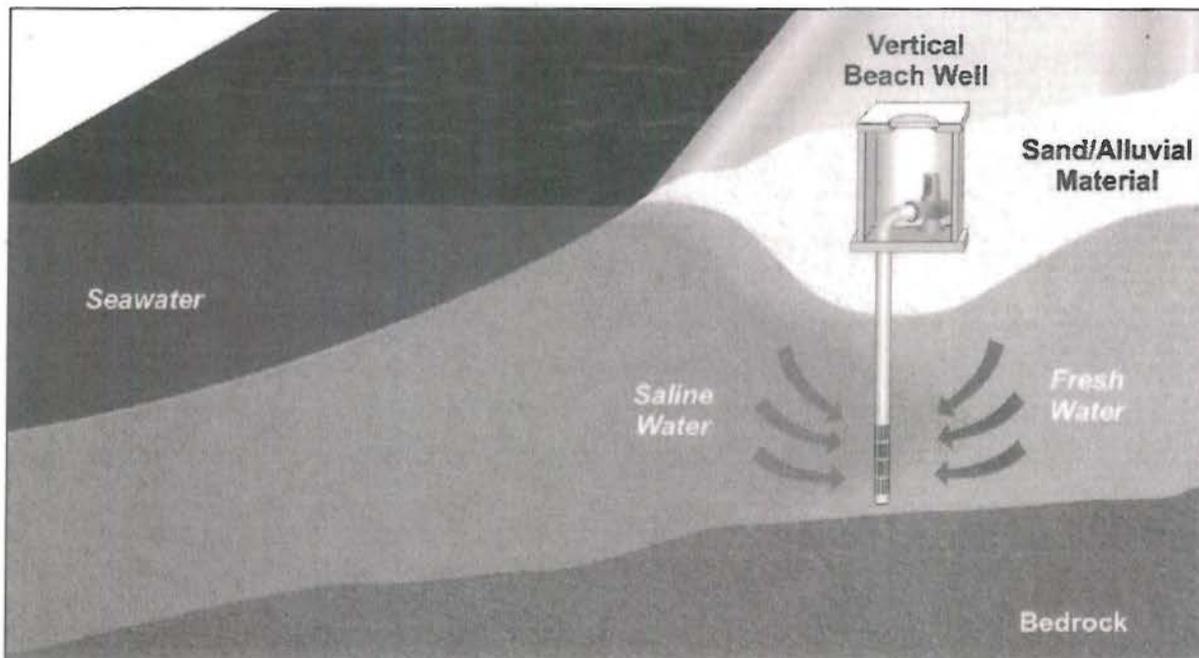
Source: Water Globe Consulting

**Figure 2 – Fine Intake Screen**

By comparison, intake wells and infiltration galleries pre-filter aquatic life through the ocean bottom sediments. In this case, the ocean bottom provides a natural separation barrier for adult and juvenile marine organisms. Since subsurface intakes collect source seawater through the ocean bottom and coastal aquifer sediments (see Figure 3), they are not expected to exert an impingement type of impact on the marine species contained in the source seawater. However, the magnitude of potential entrainment of marine species into the bottom sediments caused by continuous subsurface intake operations is not well known and has not been systematically and scientifically studied to date. An ongoing side-by-side study of the I&E effects of a subsurface intake and an open ocean intake equipped with a passive wedgewire screen at the West Basin Municipal Water District's desalination demonstration plant is expected to provide more detailed information on this topic<sup>2</sup>.

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<sup>2</sup> <http://www.watereuse.org/node/978>



Source: Kennedy/Jenks Consultants

**Figure 3 – Subsurface Intake Schematic**

A comprehensive multi-year impingement and entrainment assessment study of the open ocean intakes of 19 power generation plants using seawater for once-through cooling completed by the California State Water Resources Control Board in 2010 provides important insight into the magnitude of these intake-related environmental impacts<sup>3</sup>. Based on this study, the estimated total average annual impingement of fish caused by the seawater intakes varied between 0.31 pounds (lbs.) per million gallons a day (MGD) of collected seawater (Diablo Canyon Power Plant) and 52.29 lbs./MGD (Harbor Generating Station); and for all 19 plants it averaged 6.63 lbs./MGD. Taking into consideration that this amount is the total annual impact, the average daily impingement rate is estimated to be 0.018 lbs./MGD of intake flow (6.63 lbs./365 days = 0.018 lbs./MGD).

Using the California State Water Resources Control Board impingement and entrainment study results as a baseline, for a large desalination plant of 50 MGD production capacity collecting 110 MGD of intake flow, the daily **impingement impact** is projected to be **2 lbs. per day** (0.018 lbs./MGD x 110 MGD = 2 lbs./day). This impingement impact is less than the daily food intake of **one pelican** – up to 4.0 lbs./day<sup>4</sup>. The comparison illustrates the fact that the impingement impact of seawater desalination plants with open ocean intakes is not significant and would not have measurable impact on natural aquatic resources (Figure 4).

<sup>3</sup> [http://www.watereuse.org/sites/default/files/u8/Quote\\_3.pdf](http://www.watereuse.org/sites/default/files/u8/Quote_3.pdf)

<sup>4</sup> <http://www.sandiegozoo.org/animalbytes/t-pelican.html>



Source: US Fish and Wildlife Service

**Figure 4 – Average Daily Desalination Intake Impingement Impact Is Less than the Daily Fish Intake of One Pelican**

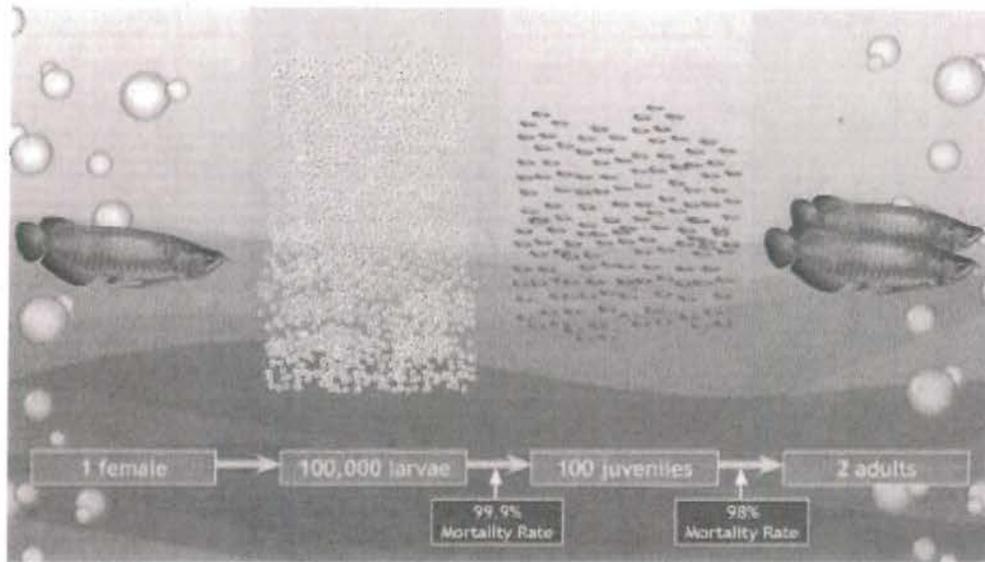
The California State Water Resources Control Board report mentioned earlier also gives a baseline for assessment of the entrainment impact of seawater intakes. The study indicates that the magnitude of such annual impact on larval fish can vary in a wide range – from 0.08 million (MM)/MGD (Contra Costa Power Plant) to 5.8 MM/MGD (Encina Power Plant) and illustrates the fact that the entrainment impact is very site-specific.

As per the same report, the average annual entrainment is estimated at 2.14 million of fish larvae per MGD of intake flow. Prorated for a 110 MGD intake of a 50 MGD seawater desalination plant, this annual entrainment impact is 235.4 MM of larval fish/yr. While this number seems large, based on expert evaluation and research, large entrainment numbers do not necessarily equate to a measurable impact to adult fish populations because of the enormous amount of eggs, fish larvae and other zooplankton in seawater<sup>5</sup>. Due to the large natural attrition of larval fish, very few larval fish actually develop to juvenile and adult stages in the natural environment (see Figure 5)<sup>6</sup>. The majority of larvae are lost to predation, exposure to destructive forces of nature such as wind and wave action, and the inability to find appropriately-sized prey during the

<sup>5</sup>[http://www.swrcb.ca.gov/water\\_issues/programs/ocean/cwa316/docs/workshop\\_oakland2005/pres\\_tenera.pdf](http://www.swrcb.ca.gov/water_issues/programs/ocean/cwa316/docs/workshop_oakland2005/pres_tenera.pdf)

<sup>6</sup>[http://www.scwd2desal.org/documents/Presentations/Nov\\_10\\_2010/02\\_Tenera\\_nov10\\_web.pdf](http://www.scwd2desal.org/documents/Presentations/Nov_10_2010/02_Tenera_nov10_web.pdf)

critical period of their development (i.e., after their yolk sack is empty). All of these forces have several orders of magnitude higher impact on fish populations than seawater intakes.



Source: Tena Environmental

**Figure 5 – Typical Reproduction and Survival of Larval Producing Organisms**

For example, a single female halibut produces as many as 50 million eggs per year for as long as 20 years, or one billion eggs over a lifetime<sup>7</sup>. In simple terms, the annual entrainment impact of one **50 MGD** desalination plant would be comparable to the annual bio-productivity of **five adult female halibut fish** (i.e., the “environmental impact” which five fishermen can cause with their daily halibut catch quota of one fish each).

The environmental impact of desalination plant operations should be assessed in the context of the environmental impacts of water supply alternatives that may be used instead of desalination. Desalination projects are typically driven by the limited availability of alternative lower-cost water supply resources such as groundwater or fresh surface water (rivers, lakes, etc.). However, damaging long-term environmental impacts may also result from continued over-depletion of those conventional water supplies, including inter-basin water transfers. For example, over-pumping of fresh water aquifers over the years in a number of areas worldwide (i.e., the San Francisco Bay Delta in Northern California; wetlands in the Tampa Bay region of Florida; and fresh water aquifers, and rivers and lakes in northern Israel and Spain, which supply water to sustain agricultural and urban centers in the southern regions of these countries), has resulted in substantial environmental impacts to the traditional fresh water resources in these regions. One

<sup>7</sup><http://www.watereuse.org/sites/default/files/u8/Quote%207%20-%20Presentation.pdf>

such specific example of dramatic environmental impact is the reduction of the habitat of delta smelt as a result of over-pumping caused by California State Water Project's intake facilities.<sup>8</sup>

Such long-term fresh water transfers have affected the ecological stability in the fresh water habitats to the extent that the long-term continuation of current water supply practices may result in significant and irreversible damage of the ecosystems of traditional fresh water supply sources and even the intrusion of saline water into the freshwater aquifers, such as the case in Salinas Valley, Monterey County, California. In such instances, the environmental impacts of construction and operation of new seawater desalination projects should be weighed against the environmentally damaging consequences from the continued expansion of the existing fresh-water supply practices.

A responsible approach to water supply management must ensure that sustainable and drought-proof local supplies are available, and long-term reliance on conventional water supply sources (i.e., surface water, groundwater) is reconsidered in favor of a well-balanced and diversified water supply portfolio which combines surface water, groundwater, recycled water, water conservation, and desalination. For example, this type of reliability-driven, balanced water supply program is currently implemented by West Basin Municipal Water District ([www.westbasin.org](http://www.westbasin.org)), the Texas Water Development Board, Tampa Bay Water, and other agencies in the United States.

## IMPINGEMENT AND ENTRAINMENT SOLUTIONS

While impingement and entrainment associated with seawater intake operations are not expected to create biologically significant impacts under most circumstances, best available *site, design, technology*, and when needed, *mitigation measures*, are prudent for minimizing loss of marine life and maintaining the productivity and vitality of the aquatic environment in the vicinity of the intake.

### Prudent Open Intake Design

#### Installation of Intake Inlet Structure Outside of the Littoral Zone

Intakes in the littoral zone (i.e., the near-shore zone encompassed by low and high tide levels) have the greatest potential to cause elevated impingement and entrainment impacts. The US EPA considers extending intakes 125 meters (410 feet) outside of the littoral zone a good engineering practice aimed at reduced impingement and entrainment<sup>9</sup>. According to the Office of Naval Research, the littoral zone extends 600 feet from the shore<sup>10</sup>. Thus, intakes with an inlet structure located at least 1100 feet from the shore could result in reduced environmental impacts. In addition, installing the intake to depths where there is a lower concentration of living organisms

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<sup>8</sup>[http://www.science.calwater.ca.gov/pdf/eco\\_restor\\_delta\\_smelt.pdf](http://www.science.calwater.ca.gov/pdf/eco_restor_delta_smelt.pdf)

<sup>9</sup>[http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/phase1/upload/2009\\_04\\_02\\_316b\\_phase1\\_support\\_contents.pdf](http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/phase1/upload/2009_04_02_316b_phase1_support_contents.pdf)

<sup>10</sup><http://www.onr.navy.mil/focus/ocean/regions/littoralzone1.htm>

(i.e., at least 20 meters) is also expected to decrease environmental impacts associated with intake operations.

#### Low Through-Screen Velocity

Impingement occurs when the intake through-screen velocity is so high that species such as crab or fish cannot swim away and are retained against the screens. The US EPA has determined that if the intake velocity is lower or equal to 0.5 feet per second (fps), the intake facility is deemed to have met impingement mortality performance standards<sup>11</sup>. Therefore, designing intake screening facilities to always operate at or below this velocity would adequately address impingement impacts.

#### Small-Size Bar Screen Openings

Use of bar screens with a distance between the exclusion bars of no greater than 9 inches is recommended for preventing large organisms from entering the seawater intake<sup>12</sup>.

#### Suitable Fine Screen Mesh Size

After entering the bar screen, the seawater has to pass through fine screens to prevent debris from interfering with the downstream desalination plant treatment processes. The fine screen mesh size is a very important design parameter and should be selected such that it is fitted to the size of a majority of the larval organisms it is targeting to protect. Typically, the openings of most fine screens are 3/8 inch (9.5 mm) or smaller because most adult and juvenile fish are larger than 10 mm in head size.

#### Design Enhancements for Collection of Minimum Intake Flow

Membrane reverse osmosis desalination plants typically collect seawater for one or more of the following three purposes: (1) to use it as a source water for fresh water production; (2) to apply it as a backwash water for the source water pretreatment system; and (3) to pre-dilute concentrate generated during the salt separation process down to environmentally safe salinity levels before it is discharged to the ocean.

The percent of source seawater converted to fresh water during the desalination process is known as plant recovery. Typically, seawater desalination plants are designed to recover 45 to 55% of the seawater collected by the intake. Designing the desalination plant to operate closer to the upper limits of recovery (i.e., 50 to 55%) would require collecting less water and therefore, would reduce impingement and entrainment associated with seawater intake operations. Long-term testing completed by the Affordable Desalination Collaboration, aimed to identify the most suitable operational conditions for low-energy SWRO desalination, indicates that optimum

<sup>11</sup> [http://edocket.access.gpo.gov/cfr\\_2008/julqtr/pdf/40cfr125.94.pdf](http://edocket.access.gpo.gov/cfr_2008/julqtr/pdf/40cfr125.94.pdf)

<sup>12</sup> <http://www.watereuse.org/sites/default/files/u8/Quote%2012%20-%20Policy.pdf>

energy consumption is achieved at a membrane flux of 9.0 gallons per square feet per day (gfd) and RO system recovery of 48%<sup>13</sup>.

Most desalination plants collect 4 to 10% of additional water to wash their pretreatment filtration systems and discharge the spent filter backwash water back to the ocean. A design approach which may allow reducing this water use significantly is treatment and reuse of the backwash water. Such a backwash treatment and reuse approach has cost implications but is a prudent design practice aimed at reducing overall plant seawater intake flow and associated impingement and entrainment.

Collecting additional seawater for concentrate pre-dilution may be needed when existing wastewater intake or power plant outfalls are used for concentrate discharge and the existing outfall volume is not sufficient to produce adequate dilution of the saline discharge. This additional flow intake could be eliminated by designing facilities for storing concentrate during periods of low outfall flows when adequate dilution is not available, or by installing a discharge diffuser system which allows enhancing concentrate dissipation into the ambient marine environment without additional dilution.

If the desalination plant production capacity has to vary diurnally, the design and installation of variable frequency drives on the intake pumps could also allow decreasing impingement and entrainment of the plant intake by closely matching collected source seawater volume to the plant production needs.

#### **Use of Low-Impact Intake Technologies**

Impingement and entrainment of marine organisms could be minimized by using various subsurface and open intake technologies. Currently, there are no federal and state regulations which specifically define requirements for reduction of impingement and entrainment caused by desalination plant intakes. However, the US EPA Section 316(b) of the Clean Water Act federal regulations have stipulated national performance standards for intake impacts from power generation plants which require 80 to 95% reduction of impingement and 60 to 90% reduction of entrainment as compared to those caused by uncontrolled intake conditions<sup>14</sup>. Technologies that can meet these impingement and entrainment performance standards are defined by US EPA as Best Technology Available (BTA).

#### Subsurface Intakes

Subsurface intakes (vertical and horizontal directionally drilled wells, slant wells and infiltration galleries) are considered a low-impact technology in terms of impingement and entrainment. However, to date there are no studies that document the actual level of entrainment reduction that

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<sup>13</sup> <http://www.affordabledesal.com/home/news/ADC%20Completes%20Profile%20of%20SWRO%203-28-08.pdf>

<sup>14</sup> [http://edocket.access.gpo.gov/cfr\\_2008/julqtr/pdf/40cfr125.94.pdf](http://edocket.access.gpo.gov/cfr_2008/julqtr/pdf/40cfr125.94.pdf)

can be achieved by these types of intakes. In addition, the potential application of a subsurface intake is very site specific and highly dependent on the project size; the coastal aquifer geology (aquifer soils, depth, transmissivity, water quality, capacity, etc.); the intensity of the natural beach erosion in the vicinity of the intake site; and on many other environmental and socio-economic factors.

Because optimal conditions for subsurface intakes are often impossible to find in the vicinity of the desalination plant site, the application of this type of intake technology to date worldwide has been limited to plants of relatively small capacity. As indicated in WateReuse Association's White Paper titled "Overview of Desalination Plant Intake Alternatives,"<sup>15</sup> the largest seawater desalination facility with a subsurface intake in operation at present is the first 17 MGD phase of the 34 MGD San Pedro Del Pinatar (Cartagena) desalination plant in Spain. For this project, site-specific hydrogeological constraints made it impossible to use intake wells for plant expansion, and the second 17 MGD phase of this project was constructed with an open intake.

Ongoing long-term studies of innovative subsurface intakes in Long Beach and Dana Point, California are expected to provide comprehensive data that would allow completing a scientifically-based analysis of the viability and performance benefits of subsurface intakes for larger-size applications. The tested subsurface intake technologies are currently under evaluation and do not yet have established performance, reliability, and environmental track records.

#### Wedgewire Screen Intakes

Wedgewire screens are cylindrical metal screens with trapezoidal-shaped "wedgewire" slots with openings of 0.5 to 10 mm. They combine very low flow-through velocities, small slot size, and naturally occurring high screen surface sweeping velocities to minimize impingement and entrainment. This is the only open intake technology approved by US EPA as Best Technology Available. Such approval, however, is granted provided that sufficient ambient conditions exist to promote cleaning of the screen face; the through screen design intake velocity is 0.5 feet/sec or less; and the slot size is appropriate for the size of eggs, larvae, and juveniles of any fish and shellfish to be protected at the plant intake site<sup>16</sup>.

Wedgewire screens are designed to be placed in a water body where significant prevailing ambient cross flow current velocities ( $\geq 1$  fps) exist. This high cross-flow velocity allows organisms that would otherwise be impinged on the wedgewire screen intake to be carried away with the flow.

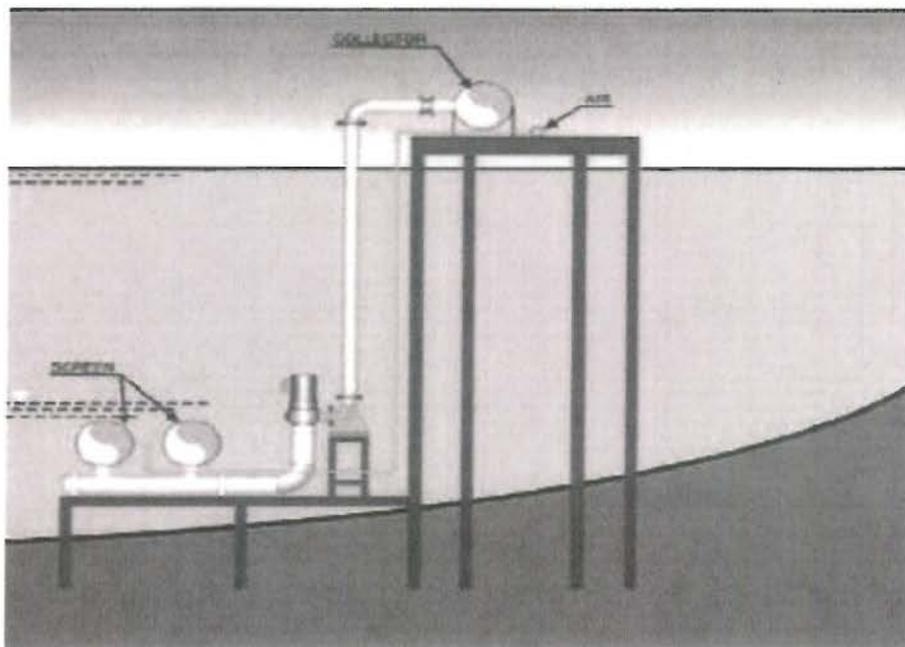
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<sup>15</sup> <http://www.watereuse.org/node/1340>

<sup>16</sup> [http://edocket.access.gpo.gov/cfr\\_2006/julqtr/pdf/40cfr125.99.pdf](http://edocket.access.gpo.gov/cfr_2006/julqtr/pdf/40cfr125.99.pdf)

An integral part of a typical wedgewire screen system is an air burst back-flush system, which directs a charge of compressed air to each screen unit to blow-off debris back into the water body, where they are carried away from the screen unit by the ambient cross-flow currents.

Figure 6 presents a schematic of the wedgewire screen intake used at the 40 MGD Beckton desalination plant in London, England. The Beckton desalination plant is equipped with seven (7) 3-mm wedgewire screens installed on the suction pipe of each of the plant intake pumps. Total screen length is 11.55 ft. (3500 mm) and the screen diameter is 3.6 ft. (1100 mm). The plant intake is under significant influence of tidal exchange of river water and seawater. To capture the ebb tide and minimize entrainment, the intake adjusts as it also targets lower salinity waters.



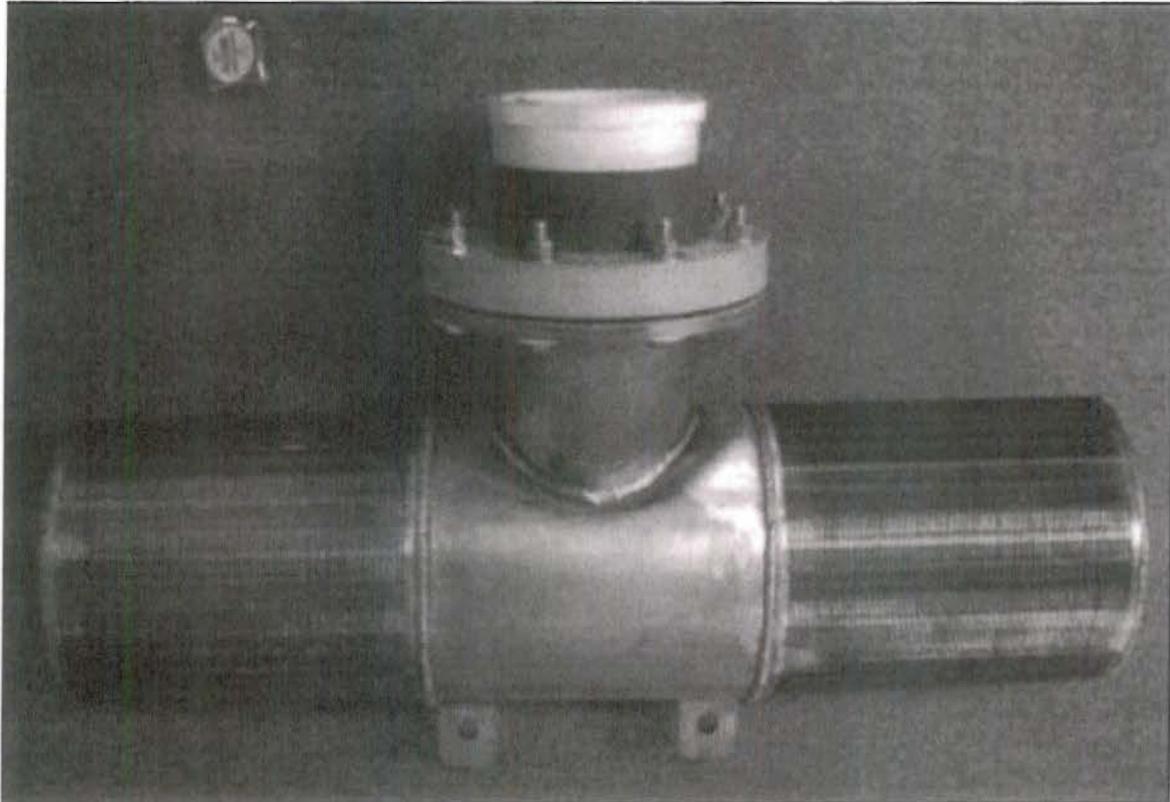
Source: Acciona Agua

**Figure 6 – Wedgewire Screen Intake of Beckton Desalination Plant**

An I&E study of a cylindrical wedgewire screen (Figure 7) was conducted over a 13-month period from April 2009 through May 2010 by Tenera Environmental for a seawater desalination project currently under development by the City of Santa Cruz Water Department and Soquel Creek Water District in California<sup>17</sup>. The intake for the full-scale desalination project would be designed to collect of up to 7.0 MGD of source seawater in order to produce an average of 2.5 MGD of fresh drinking water.

<sup>17</sup>[http://www.scwd2desal.org/documents/Reports/Open\\_Ocean\\_Intake\\_Effects/Open%20Ocean%20Intake%20Effects%20Study%20Final%20Dec%202010.pdf](http://www.scwd2desal.org/documents/Reports/Open_Ocean_Intake_Effects/Open%20Ocean%20Intake%20Effects%20Study%20Final%20Dec%202010.pdf)

The tested wedgewire screen had 2.0 mm of slot openings and was constructed of copper-nickel alloy. The diameter of the screen was 8-5/8 inches; the overall screen length was 35 inches; and the outer flange was 6-5/8 inches. Seawater was pumped from a depth of 15 to 20 feet beneath the sea surface.



Source: Tenera Environmental

**Figure 7 – Wedgewire Screen Used in Santa Cruz I&E Study**

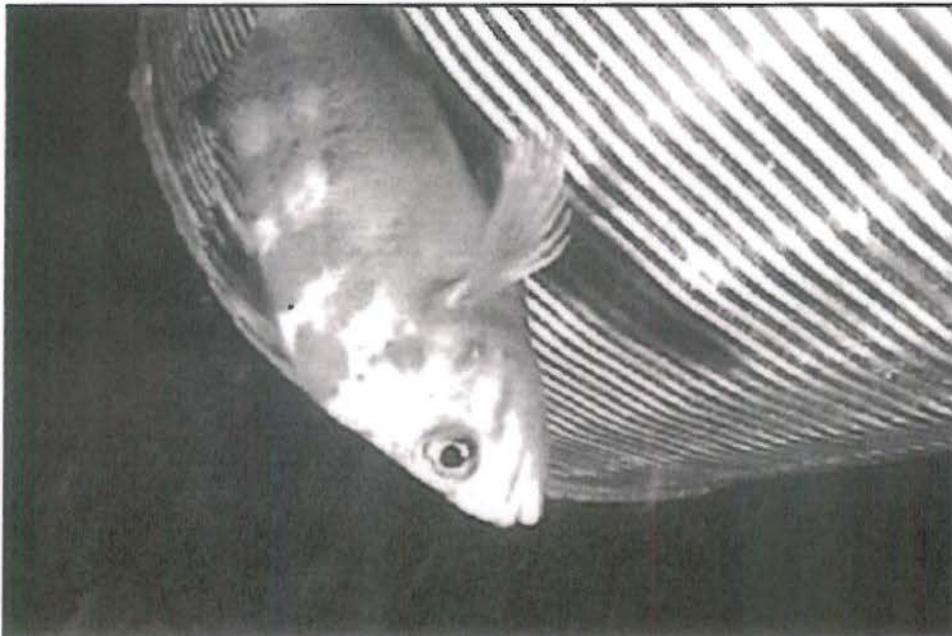
The results of this comprehensive I&E study indicate that:

- No endangered, threatened, or listed species were entrained.
- At an average intake velocity of 0.33 fps, the screen was successful in completely eliminating impingement.
- The wedgewire prevented entrainment of adult and juvenile fish species.
- The greatest projected proportional mortality that could be attributed to the screen operation for the top 80% of the fish larvae in the source water area at 7.0 MGD intake flow was 0.06%.
- The greatest projected proportional mortality for the caridean shrimp and cancrid crab larvae in the source water area for 7.0 MGD intake flow was 0.02%.
- The extremely low proportional losses of fish, shrimp and crab populations indicate that the full-scale wedgewire intake screen operation at 7.0 MGD will not cause significant

environmental impact considering that the natural mortality rates of these species are over 99.9%.

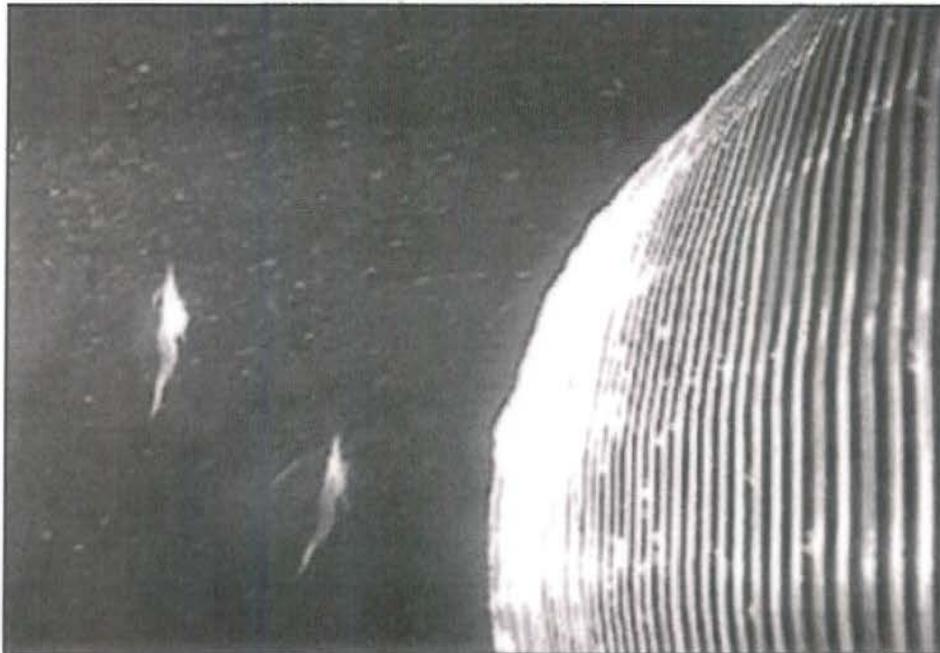
- The absolute numbers of larvae projected to be entrained annually due to the collection of 7.0 MGD of source seawater for desalination plant operation are a very small fraction of the reproductive output of the source populations of marine organisms inhabiting the intake area. For example, for the white croaker – a fish frequently encountered in the intake area – the potential larval losses (fecundity losses) are 3.6 million larvae, which are comparable to the total lifetime fecundity (reproductive yield) of a single female fish.

To study the behavioral responses of different species swimming near or contacting the wedgewire screens, two underwater video cameras were installed to view the surface of the screens during operation. One camera was oriented to provide a lengthwise view of the screen's surface while a second camera videotaped a top view of the screen's surface. Videos were displayed and recorded to a digital video recorder (DVR) when the intake pump was operated. Figures 8, 9 and 10 present still photographs from the impingement video. The video footage shows that all fish, amphipods, and shrimps that encountered the screen were able to free themselves after contacting the screen. The video observations allow the conclusion that operating the wedgewire screen intake at a through-screen velocity of 0.33 fps eliminates impingement.



Source: Tenera Environmental

**Figure 8 – Rockfish Sitting on Screen**



Source: Tenera Environmental

**Figure 9 – Shrimps Swimming Near Screen**



Source: Tenera Environmental

**Figure 10 – School of Juvenile Rockfish Swimming Near Screen**

A wedgewire screen intake I&E study has also been completed at the Marin Municipal Water District SWRO pilot plant near San Francisco, CA<sup>18</sup>. The results of this study indicated that no impingement was observed and the larval entrainment losses were found to be less than 0.2% of the total larval population in the intake area of the desalination plant. The use of cylindrical wedgewire screens is also currently being tested at the West Basin Municipal Water District seawater desalination demonstration plant in California.

#### Offshore Intake Velocity Cap

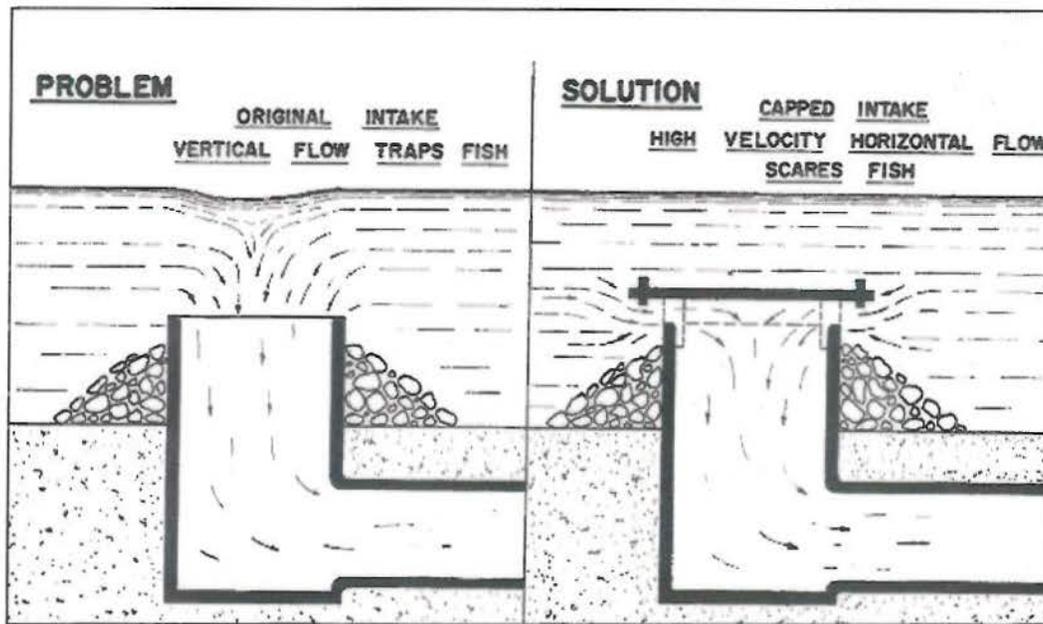
A velocity cap is a configuration of the open intake structure that is designed to change the main direction of water withdrawal from vertical to horizontal (see Figure 11). This configuration is beneficial for two main reasons: (1) it eliminates vertical vortices and avoids withdrawal from the more productive aquatic habitat which usually is located closer to the surface of the water body; and (2) it creates a horizontal velocity pattern which gives juvenile and adult fish an indication for danger – most fish have receptors along the length of their bodies that sense horizontal movement because in nature such movement is associated with unusual conditions. This natural indication combined with maintaining low through-screen velocity (0.5 fps or less) provides fish in the area of the intake ample warning and opportunity to swim away from the intake.

The velocity cap intake configuration has a long track record and is widely used worldwide. This is the original configuration of many power plant intakes in Southern California and of all new large seawater desalination plants in Australia, Spain, and Israel constructed over the last five years. Based on a US EPA technology efficacy assessment, velocity caps could provide over 50% impingement reduction and can minimize entrainment and entrapment of marine species between the inlet structure and the fine plant screens<sup>19</sup>.

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<sup>18</sup> <http://www.marinwater.org/controller?action=menuclick&id=446>

<sup>19</sup> <http://www.epa.gov/waterscience/316b/phase1/technical/ch5.pdf>



Source: US EPA

**Figure 11 – Velocity Cap for Entrainment Reduction**

As indicated previously, open intakes may also exhibit an *entrainment* effect – fish and other marine organisms that are drawn into the offshore conduit cannot return back to the open ocean because they are stranded between the intake inlet structure and the downstream fine screens. The use of velocity caps and low velocity through both the coarse screen of the intake structure and the downstream fine screens could reduce this entrainment effect.

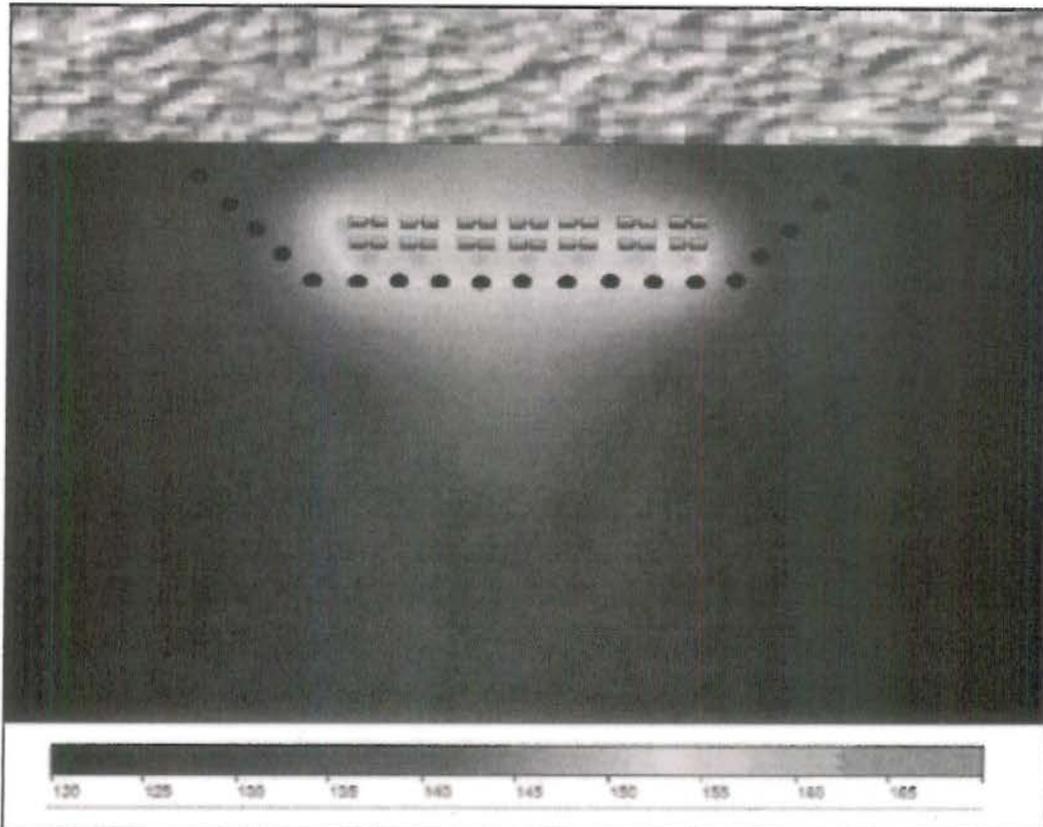
#### Other Impingement and Entrainment Reduction Technologies

In addition to the intake technologies described above, there are a number of other technologies which have been demonstrated to reduce the impingement and entrainment of open intake operations, mainly based on testing at existing power plant intakes. Table 1 below provides a summary of such technologies. Not all of the technologies listed in the table can meet the US EPA performance targets under all conditions and circumstances or deliver both impingement and entrainment benefits. However, if needed, these technologies could be used in synergistic combination to achieve project-specific environmental impact reduction targets. Some of the technologies listed in Table 1 (such as velocity caps, acoustic barriers, wedgewire screens and fine mesh travelling screens) have found full-scale applications for recently implemented seawater desalination projects. In mid-2011, the WateReuse Research Foundation initiated a research study to document and evaluate the impingement and entrainment reduction efficiency of these and other technologies (WateReuse-10-04).

**Table 1 – Potential Open Intake Impingement and Entrainment Reduction Technologies**

Type of I&E Reduction Measures	How Do They Work?	Technologies	Impact Reduction Potential	
			Impingement	Entrainment
<b>Physical Barriers</b>	By Blocking Fish Passage and Reducing Intake Velocity	<ul style="list-style-type: none"> <li>• Wedgewire Screens</li> <li>• Fine Mesh Screens</li> <li>• Microscreening Systems</li> <li>• Barrier Nets</li> <li>• Aquatic Filter Barriers</li> </ul>	Yes	Yes
<b>Collection &amp; Return Systems</b>	Equipment is Installed on Fine Screens for Fish Collection and Return to the Ocean	<ul style="list-style-type: none"> <li>• Ristroph Travelling Screens</li> <li>• Fine Mesh Travelling Screens</li> </ul>	Yes	No
<b>Diversion Systems</b>	Devices Which Divert Fish from the Screens and Direct Back to the Ocean	<ul style="list-style-type: none"> <li>• Angled Screens with Louvers</li> <li>• Inclined Screens</li> </ul>	Yes	Yes
<b>Behavioral Deterrent Devices</b>	Repulsing Organisms from the Intake by Introducing Changes that Alert Them	<ul style="list-style-type: none"> <li>• Velocity Caps</li> <li>• Acoustic Barriers</li> <li>• Strobe Lights</li> <li>• Air Bubble Curtains</li> </ul>	Yes	No

An example of the synergistic use of I&E reduction technologies is the previously referenced 40 MGD Beckton desalination plant in London. Besides wedgewire screens, the intake structure of this plant is equipped with an acoustic fish deflection system. This system includes eight low frequency sound generation units that deflect fish movement away from the wedgewire intake structure (Figure 12). The scale at the bottom of this figure indicates the sound level of the acoustic fish deflection system in decibels (dB). The low frequency (25 – 400 Hz) sound level is maintained at a level of 150 dB or more, which gives a clear cue for danger to fish entering the area of the intake. This acoustic system is only operated for short periods, twice daily, during pump startup. At this time, no published data are available regarding the I&E reduction efficiency of this technology.



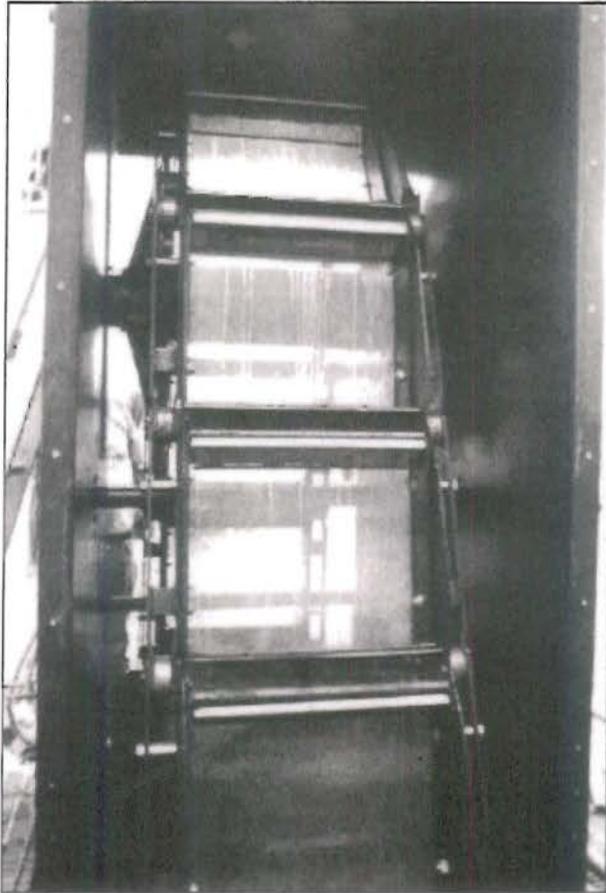
Source: Acciona Agua

**Figure 12 – Beckton Desalination Plant Intake Acoustic Fish Deflection System**

Fine mesh screens are one of the technologies equally popular for both seawater desalination and power plant intakes. One type of fine mesh screen associated with the operations of the 25 MGD Tampa Bay seawater desalination plant is shown on Figure 13. This desalination plant is collocated with the 1200 MW Big Bend Power Plant and uses cooling water from this plant as source seawater for desalination. The Tampa Bay desalination plant does not have a separate seawater intake. However, the intake of the power plant is equipped with 0.5-mm Ristroph fine-mesh screens, which have been proven to reduce impingement and entrainment of fish eggs and larvae through the downstream conventional bar and fine screens of the power plant intake by over 80%<sup>20</sup>.

Unfortunately for the desalination plant, these screens are periodically bypassed (as allowed by permit) and/or screenings are conveyed to the power plant discharge outfall from where the desalination plant collects source seawater. As a result, the screenings can find their way to the desalination plant intake and impact desalination plant pretreatment system performance. This challenge necessitated the need for the remediated desalination plant to be equipped in 2005 with another set of fine screens located just upstream of the pretreatment facilities.

<sup>20</sup> <http://www.epa.gov/waterscience/316b/phase1/technical/ch5.pdf>



Source: Water Globe Consulting

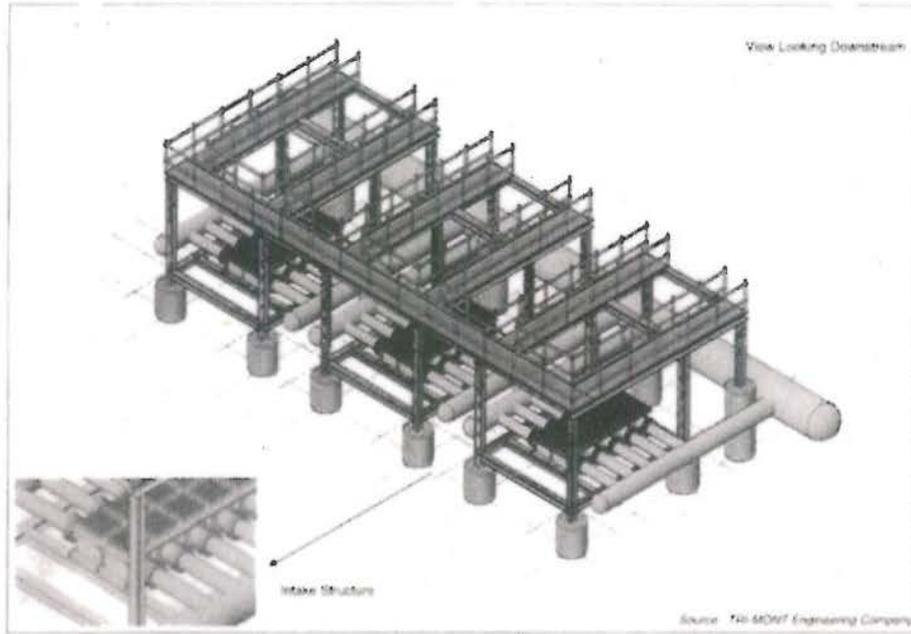
### **Figure 13 – 0.5 mm Fine Mesh Screens of the Tampa Bay Power Plant Intake**

Another example of a full-scale implementation of an intake with advanced impingement and entrainment reduction features is the Filtrex Filter Intake System of the 10 MGD Taunton River Desalination Plant in Dighton, Massachusetts (Figure 14). This plant is planned to be constructed in two 5 MGD phases. The 30 MGD intake system for this plant is comprised of 30 racks with 96, 4.6-inch long individual plastic filtration modules (candles) per rack, through which saline water is withdrawn.

The candles have a pore size of 0.04 mm (40 microns) and very low (0.2 feet/sec) through-pore velocity. These intake features allow complete avoidance of the impingement of adult fish; a reduction of impingement of fish eggs down to less than 15%; and a minimization of entrainment of larval organisms and fish eggs to less than 3% of the species in the intake area<sup>21</sup>. It should be pointed out that this type of screen has a limited track record because the plant began operation in November 2008 and has not been operating at its full 5 MGD production capacity as of yet.

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<sup>21</sup> <http://www.watereuse.org/sites/default/files/u8/Quote%2021.pdf>



Source: TRI-MONT Engineering Company

**Figure 14 – Taunton River Desalination Plant Intake**

#### **Environmental Impact Mitigation Measures**

Environmental impact mitigation is typically applied if the site, design, and technology measures described above do not provide adequate impingement and entrainment reduction to sustain the biological balance of the marine habitat in the area of the intake. Examples of types of activities that may be implemented by desalination facilities to provide environmental impact mitigation include:

- Wetland Restoration;
- Coastal Lagoon Restoration;
- Restoration of Historic Sediment Elevations to Promote Reestablishment of Eelgrass Beds;
- Marine Fish Hatchery Enhancement;
- Contribution to a Marine Fish Hatchery Stocking Program;
- Artificial Reef Development; and
- Kelp Bed Enhancement.

The type and size of the mitigation alternative or combination of alternatives most suitable for a given project are typically selected to create a new habitat capable of sustaining types of species

and levels of biological productivity comparable to those lost as a result of the intake operations.

Coastal wetlands are the nursery areas for many of the species impacted by desalination intakes. Wetland restoration is, therefore, a common mitigation measure for large seawater intake systems. For example, development of new coastal wetlands is the preferred impingement and entrainment mitigation alternative for the 50 MGD Carlsbad seawater desalination project in California.

The time and cost expenditures involved in the permitting, implementation, maintenance, and monitoring of such mitigation measures are significant, and such habitat restorative measures are typically used when the impingement and entrainment reduction measures described in the previous sections are not readily available or viable for a given project.

Some environmental groups do not consider mitigation as an acceptable I&E management alternative and have challenged the legality of the use of I&E mitigation measures for both power plant and desalination plant intakes. Court resolutions to recent legal challenges associated with the permitting of the 50 MGD Carlsbad and Huntington Beach SWRO projects, however, indicate that mitigation by environmental restoration is a viable method for supplementing the use of best technologies available and operational measures to address the potential environmental impacts associated with collecting seawater for desalination.

#### **CONCLUDING REMARKS**

In summary, appropriately sited, designed, and operated seawater desalination plant intakes can have minimal environmental impacts on the marine environment and resources. In fact, based on recent studies, impingement and entrainment resulting from well-planned and designed open ocean intakes would be minor: the equivalent of the daily food intake of one pelican and the loss of the annual bio-productivity of five adult female halibut, respectively. Ongoing developments in impingement and entrainment reduction technology, combined with the existing wealth of knowledge and experience in this field, both domestically and internationally, pave the way for maintaining sustainable and environmentally safe production of fresh water from the ocean. With over 20 years of successful operational experience at more than 8000 desalination plants worldwide, seawater desalination is currently a well-established drinking water production technology of proven performance which will play an increasingly prominent role in well balanced and sustainable water supply portfolios of coastal communities in the US and abroad.