

An Overview of Seawater Intake Facilities for Seawater Desalination

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Abstract

Seawater desalination facilities require an intake system capable of providing a reliable quantity of clean seawater with a minimum ecological impact. To meet these objectives, it is essential that a thorough assessment of site conditions be conducted. Physical characteristics, meteorological and oceanographic data, marine biology, and the potential effects of fouling, pollution, and navigation must be evaluated, and an appropriate intake design employed. As the first step in the pretreatment process, the intake will affect a range of feedwater quality parameters and determine the performance of downstream process systems.

Intake designs are highly site specific, possibly more so than any other aspect of the desalination facility. The design, modeling, monitoring, and permitting activities that surround them, may represent as much as 20% of the capital cost of the entire facility, and it is possible that intake-related issues may ultimately determine the feasibility and performance of the desalination plant itself.

Environmental impacts associated with concentrate discharge have historically been considered the greatest single ecological impediment when siting a seawater desalination facility. However, recent analyses have noted that marine life impingement and entrainment associated with intake designs were greater, harder-to-quantify concerns and may represent the most significant direct adverse environmental impact of seawater desalination.

This paper will consider the seawater intake technology options available for desalination plants, including intakes shared with electric power plants, and will review the technologies employed to minimize impingement and entrainment of marine life while meeting the intake's objective of providing a reliable quantity of seawater at the best quality available.

Introduction

Access to a reliable supply of consistent-quality seawater is one of the most fundamental issues to be addressed when evaluating potential desalination plant sites; however, the supply of seawater to a coastal desalination plant often seems to be relatively straightforward consideration. Because of the apparent simplicity, an intake's importance on the location, design, and performance of a desalination plant is often underestimated.

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The ocean is a dynamic entity with a constantly changing shoreline and bottom profile. Powerful waves and changing currents can damage structures, affect water depths, and dramatically alter water quality. Operational problems are compounded by seawater's corrosiveness and the marine organisms that can attack and foul equipment and systems.

The distance of the intake to the desalination plant site affects plant economics, and the available feedwater quality and quantity will directly affect pretreatment process decisions. As the first step in the pretreatment process, an intake's operation can have far-reaching effects on the overall plant operation and its impact on the marine environment. In fact, the ability to permit a new desalination facility may hinge on the methods used to mitigate environmental concerns associated with the seawater intake. Consideration must also be given to potential loss of recreational uses in the intake area and the visual impact that may result from certain intake arrangements.

Most of the world's experience with seawater intakes is a result of their use in the electric power generation industry where seawater is commonly used for cooling purposes in large surface condensers. (Figure 1) Although thermal desalination processes such as multistage flash evaporation (MSF) and multiple effect distillation (MED) have intake water quality requirements virtually identical to power plant condensers, seawater reverse osmosis (SWRO) systems can benefit greatly from a finer level of screening. Since SWRO is expected to be the predominate desalination technology employed in Texas, this review will focus on its requirements.

Seawater intakes can be broadly categorized as *surface intakes* where water is collected above the seabed, and *subsurface intakes* where water is collected via beach wells, infiltration galleries, or other locations beneath the seabed. The most appropriate location and type of the intake can only be determined after a thorough site assessment and careful environmental evaluation.

A good intake design will not only protect downstream equipment and reduce environmental impact on marine life, it will improve the performance and reduce the operating cost of the pretreatment equipment.

Water Quality and Quantity

Seawater desalination capacities vary based on the desalination process employed. Feedwater volume requirements generally range from approximately two times the plant production capacity for reverse osmosis (RO) systems to more than ten times the distillate production of thermal processes that usually have both process and cooling water requirements. The necessary feedwater must be available whenever a plant is operating if it is to meet productivity goals.

Like most process systems, desalination plants operate most efficiently and predictably when feedwater characteristics remain relatively constant and are not subject to rapid or dramatic water quality fluctuations. Therefore, the water quality review should consider both seasonal and diurnal fluctuations. The assessment should consider all constituents that may impact plant operation and process performance including thorough review of historical water quality data including seawater temperature, total dissolved solids (TDS), total suspended solids (TSS), and total organic carbon (TOC) is crucial.



Figure 1 Typical surface water intake

Environmental Considerations

Environmental impacts associated with concentrate discharge have historically been considered the greatest single ecological impediment when siting a seawater desalination facility. However, an October 2003 study by California's Department of Water Resources noted that "with proper design and location of outfalls, concentrate disposal may not be a major impediment to desalination" and went on to say that marine life impingement and entrainment resulting from intake operation was a greater, harder-to-quantify concern.

Impingement occurs when marine organisms are trapped against intake screens by the velocity and force of water flowing through them. The fate of impinged organisms differs between intake designs and among marine life species, age, and water conditions. Some hardy species may be able to survive impingement and be returned to the sea, but the 24-hour survival rate of less robust species and/or juvenile fish may be less than 15%.

Entrainment occurs when smaller organisms pass through an intake screen and into the process equipment. Organisms entrained into process equipment are generally considered to have a mortality rate of 100%.

The number of affected organisms will, of course, vary considerably with the volume and velocity of feedwater and the use of mitigation measures developed to minimize their impact. If intake velocities are sufficiently low, fish may be able swim away to avoid impingement or entrainment. The swimming performance for different species of fish can predict the types and ages most vulnerable, however, even large fish are frequently caught on intake screens, indicating that swimming ability is not the only factor in impingement. Cold temperatures or seasonal variations in age-selective migrations or growth are also factors.

Since the early 1970s, seawater intakes used for electric power plant cooling water intakes have been required to employ the best available technology to minimize adverse environmental impact under section 316(b) of the US EPA's Clean Water Act. 316(b) requirements for new sources were amended in December 2001 and new rules for existing power plant intakes were proposed in February 2002. California State regulatory agencies have indicated that the siting of a new or existing open water seawater intake for a desalination facility will require a current assessment of impingement and entrainment impacts as part of the environmental review and permitting process.

Surface Water Intakes

Large seawater desalination plants have traditionally employed open sea, surface water intake arrangements. Such arrangements are the type through which most electric power generation plants obtain condenser cooling water where water is pre-screened using traveling water screens, mechanically cleaned bar screens, or passive "well screens." In many instances, the screening chamber is located on or near shore and the intake pipe may extend out hundreds of meters into the sea. Each of these arrangements will be individually considered.

Traveling Water Screens – Traveling Water Screens have been employed on seawater intakes since the 1890's. The screens are equipped with revolving wire mesh panels having 6mm to 9.5mm openings. As the wire mesh panels revolve out of the flow, a high-pressure water spray removes accumulated debris, washing it into a trough for further disposal. The screens can be located onshore, at the end of a channel or forebay that extends out beyond the surf zone, or at the end of a pipe that extends out into the sea, terminating in a vertical "velocity cap" inlet (see following). (Figure 2)

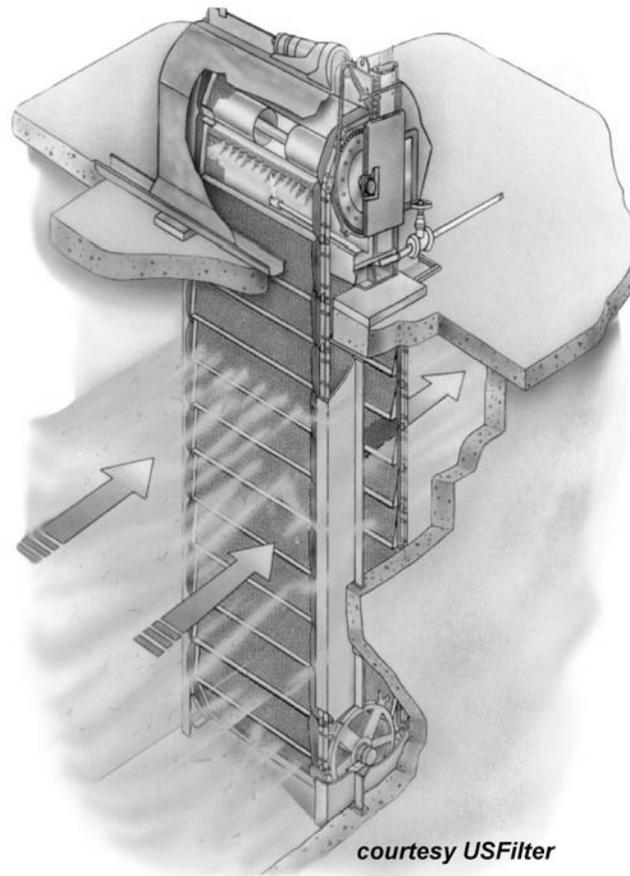


Figure 2 Traveling water screen

Velocity Cap – The cover placed over the vertical terminal of an offshore intake pipe is called a “velocity cap”. The cover converts vertical flow into horizontal flow at the intake entrance to reduce fish entrainment. It has been noted that fish will avoid rapid changes in horizontal flow and velocity cap intakes have been shown to provide 80-90% reduction in fish impingement at two California power stations, and a 50-62% impingement reduction versus a conventional intake at two New England power stations (EPA Efficacy of Cooling Water Intake Structures). (Figure 3)

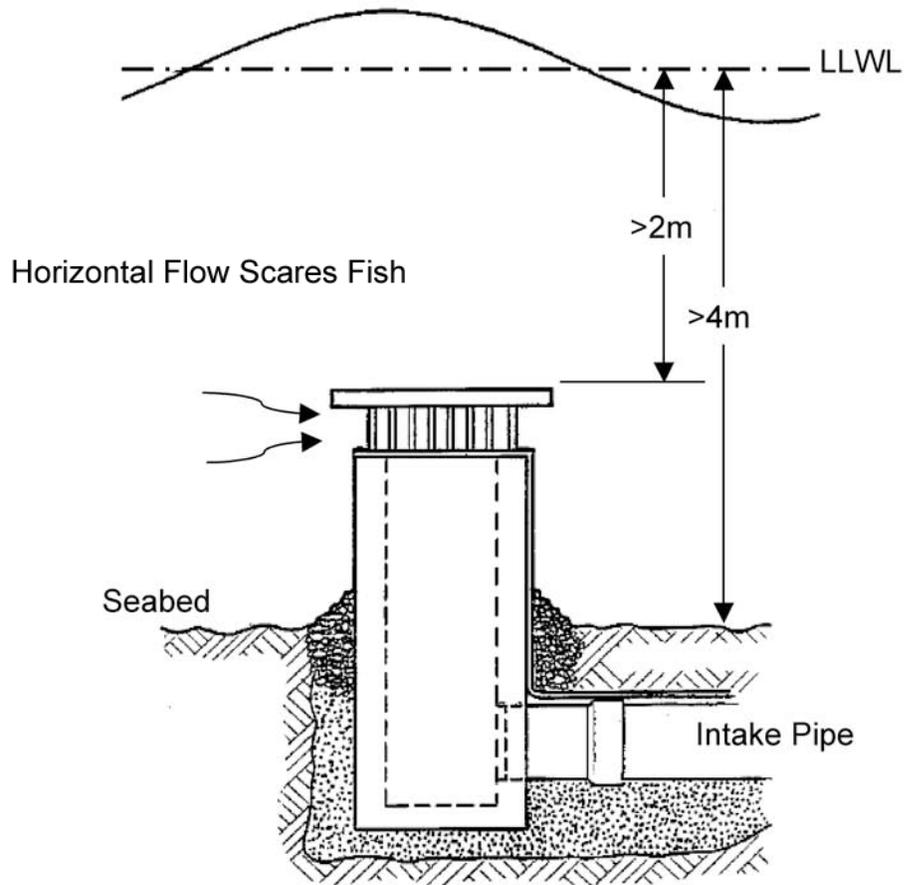
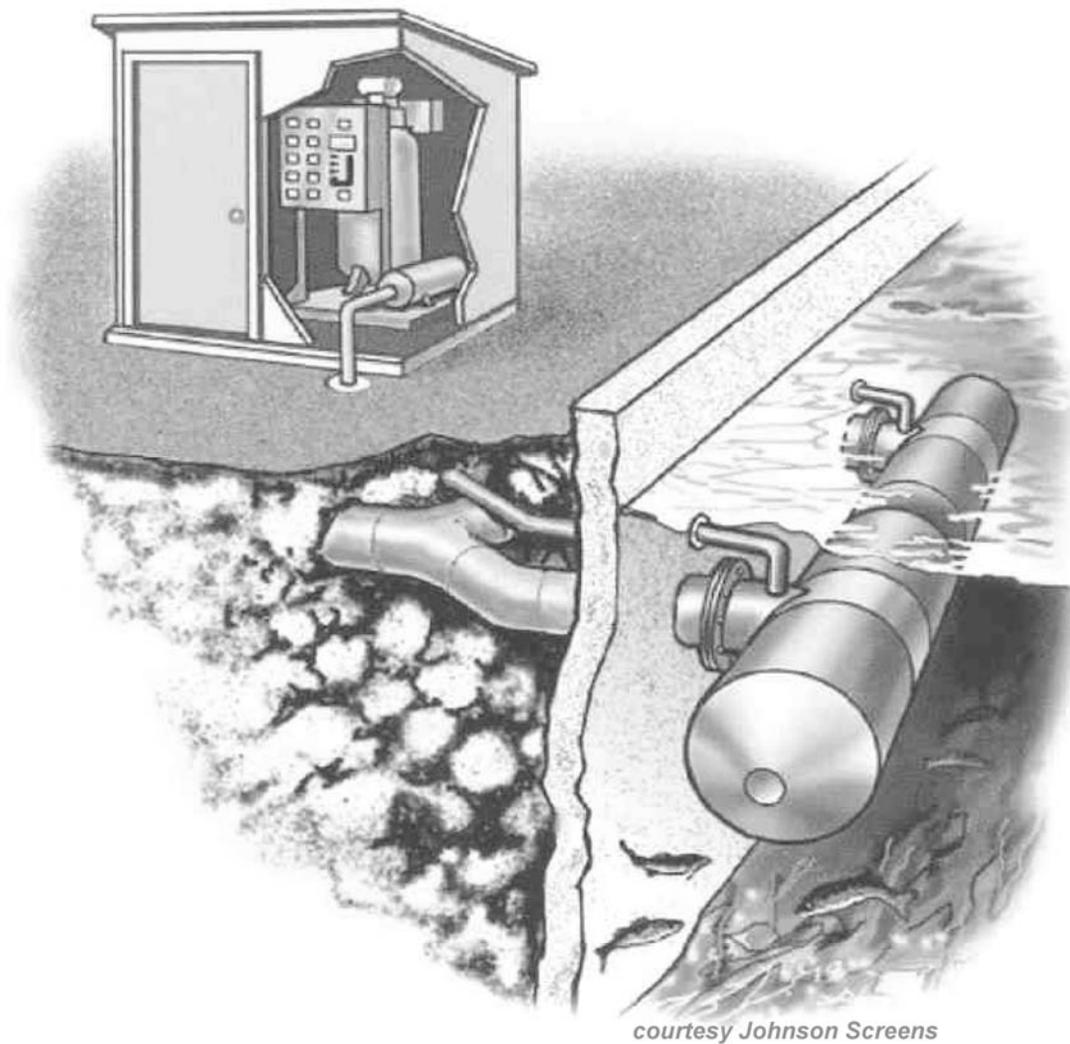


Figure 3 Velocity cap intake terminal

It has been shown that the relationship of the vertical opening (x) to the length of horizontal entrance ($1.5x$) can be optimized to create a uniform flow and improve a fish's ability to react. As with all intake configurations, there are many design issues that must be considered, and the performance of a velocity cap may vary in still water versus areas subject to tidal cross-flows.

Passive Screens – Another intake arrangement utilizes slotted screens constructed of trapezoidal-shaped “wedgewire”. The cylindrical screens have openings ranging from 0.5 millimeters (mm) to 10 mm are usually oriented on a horizontal axis with screens sized to maintain a velocity of less than 15 centimeter per second (cm/s) (0.5 feet per second, fps) to minimize debris and marine life impingement. Passive screens are best-suited for areas where an ambient cross-flow current is present, and air backwash system is usually recommended to clear screens if debris accumulations do occur. As with all submerged equipment, material selections should reflect the corrosion and biofouling potential of seawater.

Passive screens have a proven ability to reduce impingement and entrainment. Their effectiveness is related to their slot width, and low through-flow velocity. It has been demonstrated that 1 mm openings are highly effective for larval exclusion and reduce entrainment by 80% or more. (Figure 4)



courtesy Johnson Screens

Figure 4 Passive screen seawater intake

Impingement & Entrainment Mitigation Measures – A *Ristroph Screen* is a modification of a conventional traveling water screen in which screen panels are fitted with fish buckets that collect fish and lift them out of the water where they are gently sluiced away prior to debris removal with a high pressure spray. At one New York seawater intake, the 24-hour survival of conventional screens averaged 15% compared with 79-92% survival rates for Ristroph Screens. A review of 10 similar sites reported that Ristroph modifications improved impingement survival 70-80% among various species. Ristroph Screens may be effective for improving the survival of impinged marine life, but they do not affect entrained organisms. (Figure 5)

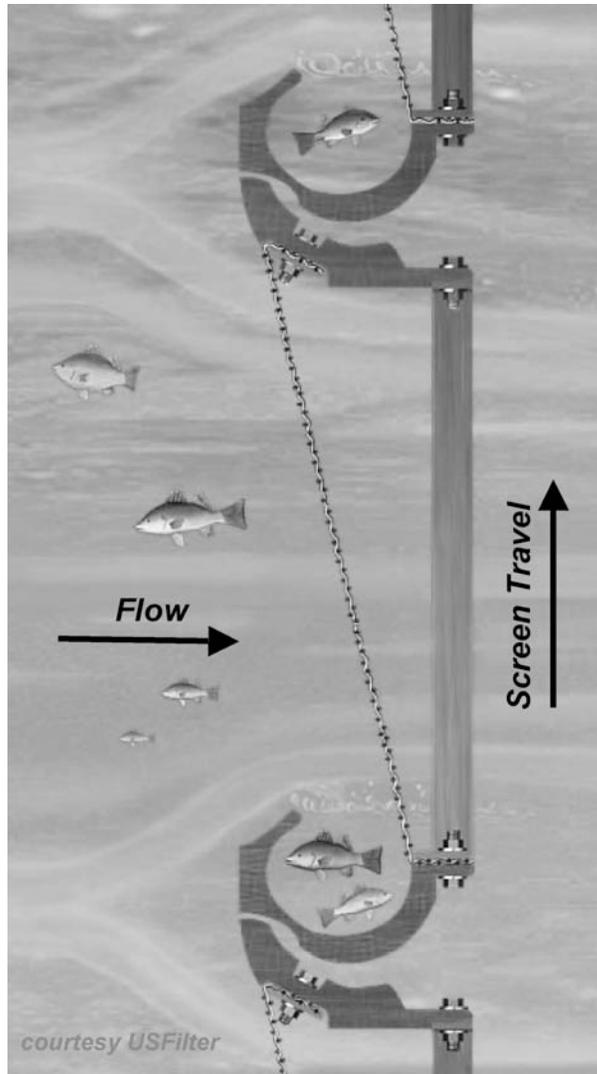


Figure 5 Ristroph screen panel modifications

Fine Mesh Screens have successfully reduced entrainment of eggs, larvae, and juvenile fish at some intake locations where traveling water screens have been outfitted with mesh having openings ranging from 0.5 mm to 5 mm, reducing entrainment by up to 80%. Fine mesh screens may result in operational problems due to the increased amount of debris removed along with the marine life, and in some locations, the fine mesh is only utilized seasonally, during periods of egg and larval abundance.

Filter Net Barriers are a relatively new method of reducing intake impingement and entrainment. A full-depth, porous filter fabric with openings ranging from 0.4mm to 5mm is placed at the entrance to an intake structure and suspended by a floating boom and anchored to the seabed. The system is sized to provide enough surface area to have a through-flow velocity low enough to avoid impingement of marine life or debris.

Behavioral systems using lights, bubbles, or sound to enhance fish avoidance or attract them to a fish diversion system have generally been ineffective and are used infrequently.

Subsurface Intakes

Subsurface intakes may consist of horizontal or vertical beach wells, infiltration galleries, or seabed filtration systems. In each of these designs, the open seawater is separated from the point of intake by a geologic unit. A subsurface intake can be used where geologic conditions beneath a surface water are relatively impermeable or of sufficient thickness and depth to support water extraction. In addition to providing some natural filtration, this arrangement has the advantage of separating most of the marine organisms from the water intake. In some cases, subsurface intakes may be evaluated and regulated as groundwater sources.

The use of subsurface intakes offers a distinct environmental advantage because the ecological impact associated with impingement and entrainment of marine life is virtually eliminated. However, subsurface designs should consider their potential negative impact on nearby fresh groundwater aquifers.

Vertical Beach Wells – Vertical beach wells are shallow intake wells that make use of beach sand or other geologic structure as a filter medium. Beach wells can be an economical alternative to open sea intakes for desalination plants with capacities less than 20,000 cubic meters per day (m^3/d) (5 million gallons per day, mgd). They have the advantage of delivering “pre-filtered” water that may greatly reduce additional pretreatment requirements.

A vertical beach well consists a non-metallic casing, well screen, and vertical turbine pump. Site suitability is determined by drilling test wells and conducting a detailed hydrogeologic investigation to determine the formation transmissivity and substrate characteristics. It is preferred to locate beach wells as close to the coastline as possible, and the maximum yield from individual wells range from 0.1 to 4000 m^3/d (0.1 to 1.0 mgd). (Figure 6)

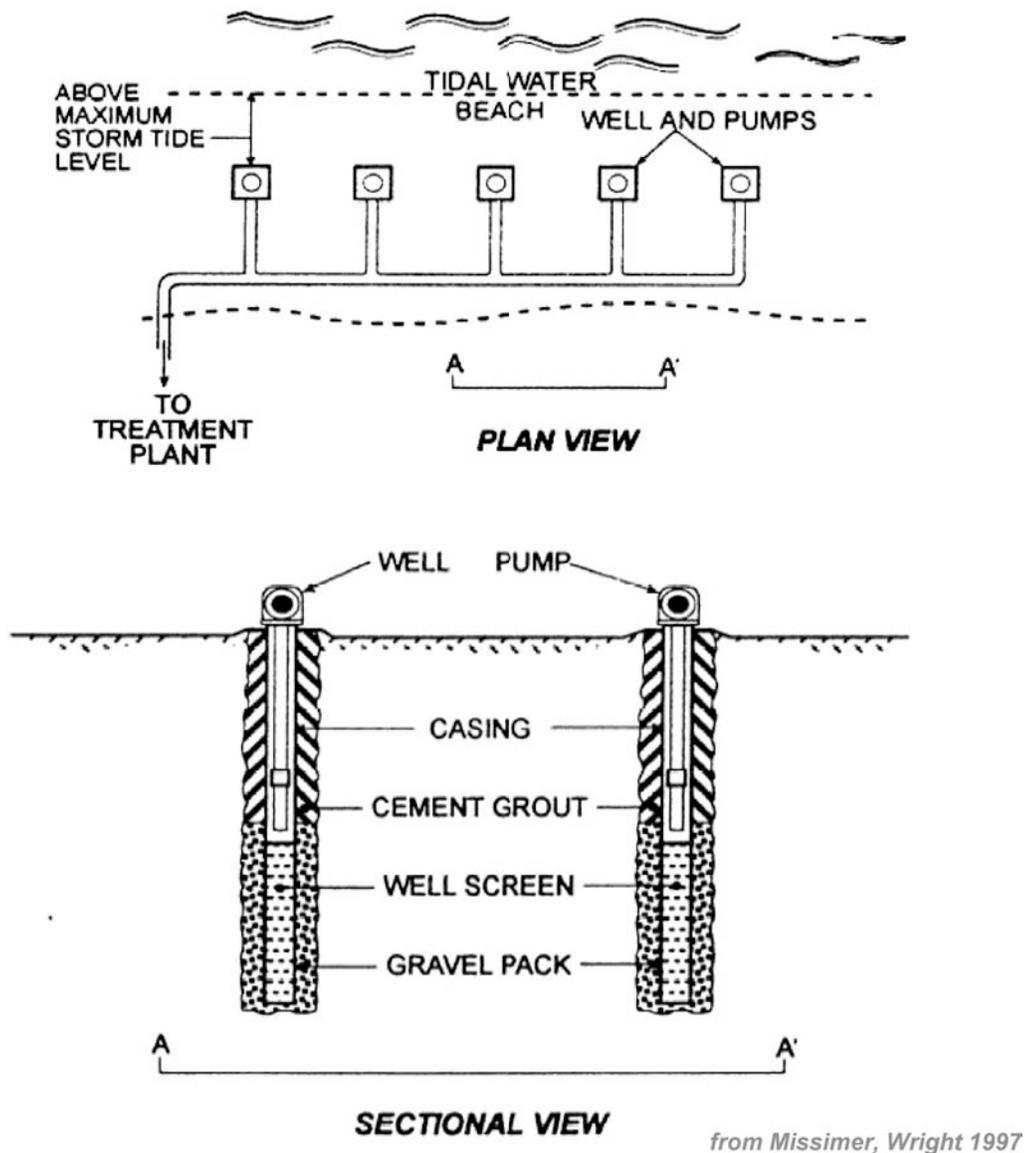


Figure 6 Beach well intake

Radial Well – Radial collector wells are a variation of the beach well where multiple horizontal collector wells are connected to a central caisson which acts a wet well or pumping station from which water is pumped to the desalination plant. The use of multiple horizontal wells means that the production of each radial well can be significantly greater than a single vertical well.

Individual horizontal wells can be drilled or well screens can be hydraulically jacked out from the bottom of the caisson using a direct-jack or pull-back process. Caissons may be 2.75 meters (m) to 6 m (9-20 feet, ft) in diameter and 9 m to 45 m (30-150 ft) deep, and radial arms are usually 200 mm to 300 mm (8-12 inches) in diameter.

The caisson can be completed with a flush-grade top slab or in a buried concrete vault and backfilled with 2-3 ft of beach sand to reduce visual impact. (Figure 7)

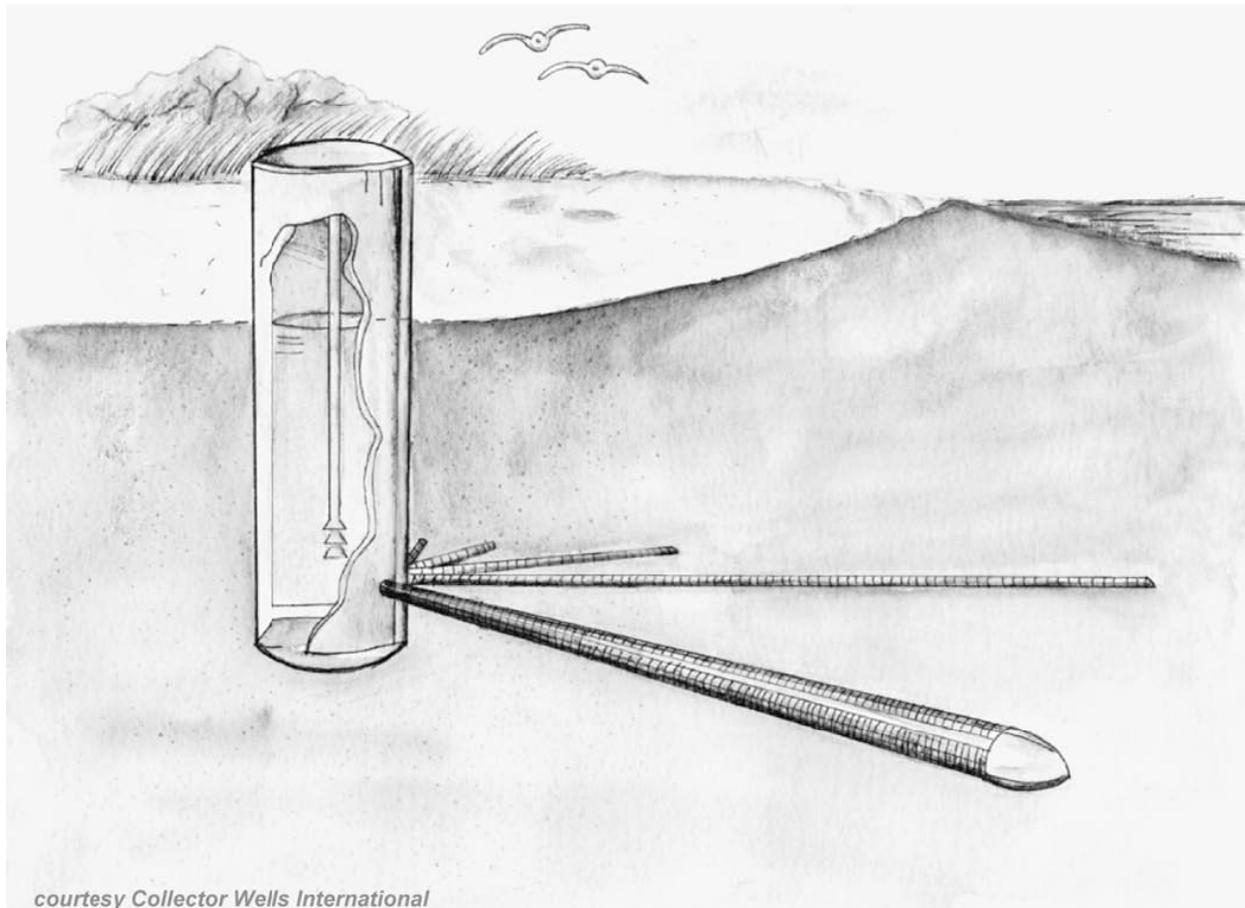


Figure 7 Radial well infiltration

Infiltration Galleries – An infiltration gallery intake is a variation of the radial collector well arrangement and is used where geologic conditions are relatively impermeable or of insufficient thickness and depth to support groundwater extraction. In these locations, it is necessary to install the radial arms and screens in trench that is then backfilled with a gravel pack and/or selected filter materials after the screens are installed.

Electric Power Plant Co-siting

Electric power generating plants with once-through cooling systems require large volumes of cooling water to condense power-cycle steam back to high-purity water for producing new steam. Many seawater desalination plants are now co-located with a power plant with whom they share a common seawater intake. The avoided cost of constructing and permitting a new intake may reduce the capital cost of a large desalination facility by several million dollars.

Some operational benefits may be realized in terms of improved membrane performance if the desalination facility uses warmer, condenser discharge water as feedwater for the seawater desalination system.

Further synergy between a power plant and a desalination facility can be realized by combining the power plant cooling water discharge with the SWRO plant concentrate. This may have environmental benefits to both processes by reducing the thermal footprint of the power plant discharge while diluting the salinity of the RO concentrate.

The co-location of power and seawater desalination facilities is being considered for most of the large desalination projects currently proposed in the United States. However, environmental concerns with once-through cooling systems employed by many of these power plants may actually prove to be detrimental in the ability to permit some proposed co-located desalination facilities. There is some concern that co-locating a desalination facility with a coastal power plant could serve to justify the continued use of an aging, once-through cooling system.

Electric power plants and desalination facilities that may consider sharing seawater intakes or concentrate outfall infrastructure must identify how the operation of both the power plant and desalination plant will be coordinated. In the planning process, the desalination facility should also be evaluated as if it were a stand-alone facility.

Conclusion

When considering environmental, pretreatment, and process advantages of an intake designed specifically for the desalination plant should not be underestimated.