WateReuse Association

Sustainable Solutions for a Thirsty Planet®

Overview of Desalination Plant Intake Alternatives

White Paper

June 2011

The WateReuse 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 and share their experience and/or case studies for consideration for inclusion in the next issuance of the white papers.

WATEREUSE ASSOCIATION
DESALINATION COMMITTEE

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INTRODUCTION

Over 75 % of the US population lives along the coast. Currently, many of our coastal communities are supplied by inland fresh water resources or low-salinity coastal aquifers. Because of the limited availability of these resources and their intensive use over the years, traditional sources of water supply are nearing depletion in many parts of the country, and reliance solely on such resources is no longer sustainable in the long run. Along with enhanced water reuse and conservation, seawater and brackish desalination provides a viable alternative for securing reliable and drought-proof water supplies for coastal communities.

The purpose of desalination plant intakes is to collect source seawater of adequate quantity and quality in a reliable and sustainable fashion so as to produce desalinated water cost-effectively and with minimal impact on the environment. Currently, there are two categories of widely used desalination plant source water collection facilities: open intakes and subsurface intakes (wells and infiltration galleries). Open intakes collect seawater directly from the ocean via on-shore or off-shore inlet structure and pipeline interconnecting this structure to the desalination plant. Subsurface intakes, such as vertical beach wells, horizontal wells, slant wells and infiltration galleries, tap into the saline or brackish coastal aquifer and/or the off-shore aquifer under the ocean floor.

This white paper presents an overview of alternative open-ocean and subsurface intake technologies for seawater desalination plants. While subsurface intakes (beach wells, infiltration galleries, slant wells, etc.) are often favored by the environmental community because of their potentially lower impingement and entrainment impacts on aquatic life, they have found limited application to date, especially in medium- and large-scale desalination projects. The white paper describes the main challenges associated with the use of subsurface intakes and discusses the key factors that determine their feasibility for the site specific conditions of a given desalination project.

Potential impingement and entrainment (I&E) impacts associated with the operation of open ocean intakes for seawater desalination plants are discussed in a separate WateReuse Association white paper entitled “Desalination Plant Intakes – Impingement and Entrainment Impacts and Solutions.”

SUBSURFACE INTAKES

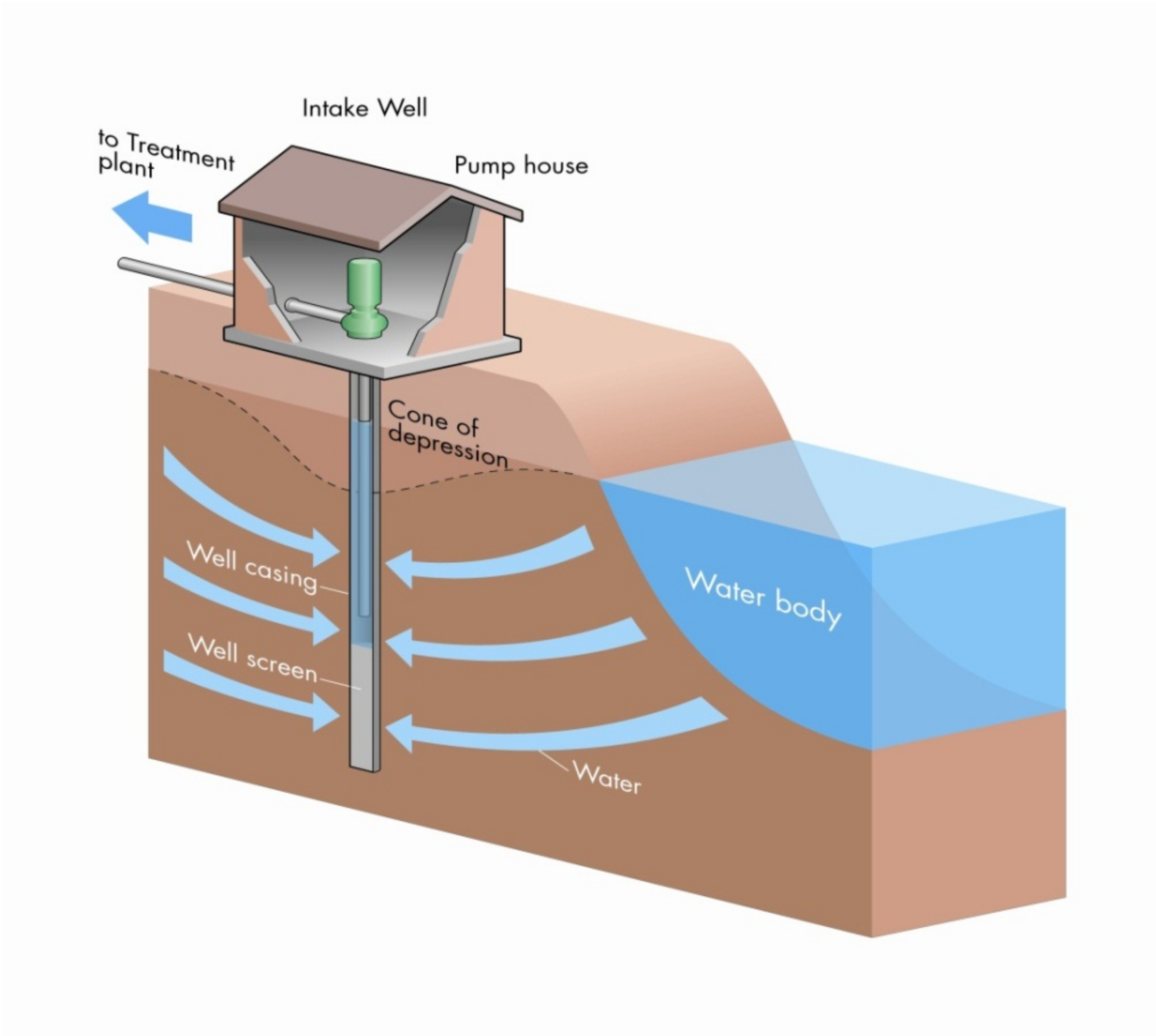
Seawater collected by subsurface intakes is naturally pretreated via slow filtration through the typically sandy ocean floor. As such, the collected flow usually contains low levels of solids, slit, oil & grease, natural organic contaminants, and aquatic organisms. When subsurface intakes collect water from an on-shore coastal aquifer, this water is often of lower salinity than ambient seawater.

If a subsurface intake collects source water from an alluvial aquifer, however, such water could have very low oxygen concentration and could contain high level of manganese, iron, hydrogen sulfide, and other contaminants that can have an adverse impact on desalination plant reverse osmosis (RO) membrane performance, water production costs, and discharge water quality.

Vertical beach wells (Figure 1) have typically found an application for supplying source water to relatively small seawater desalination plants of capacity of 1 MGD or less. Horizontal wells are more suitable for larger seawater desalination plants and are applied in two configurations: radial Ranney-type collector wells (Figure 2) and horizontal wells with directionally drilled (HDD) collectors (Figure 3). These types of wells have already found full-scale applications worldwide.

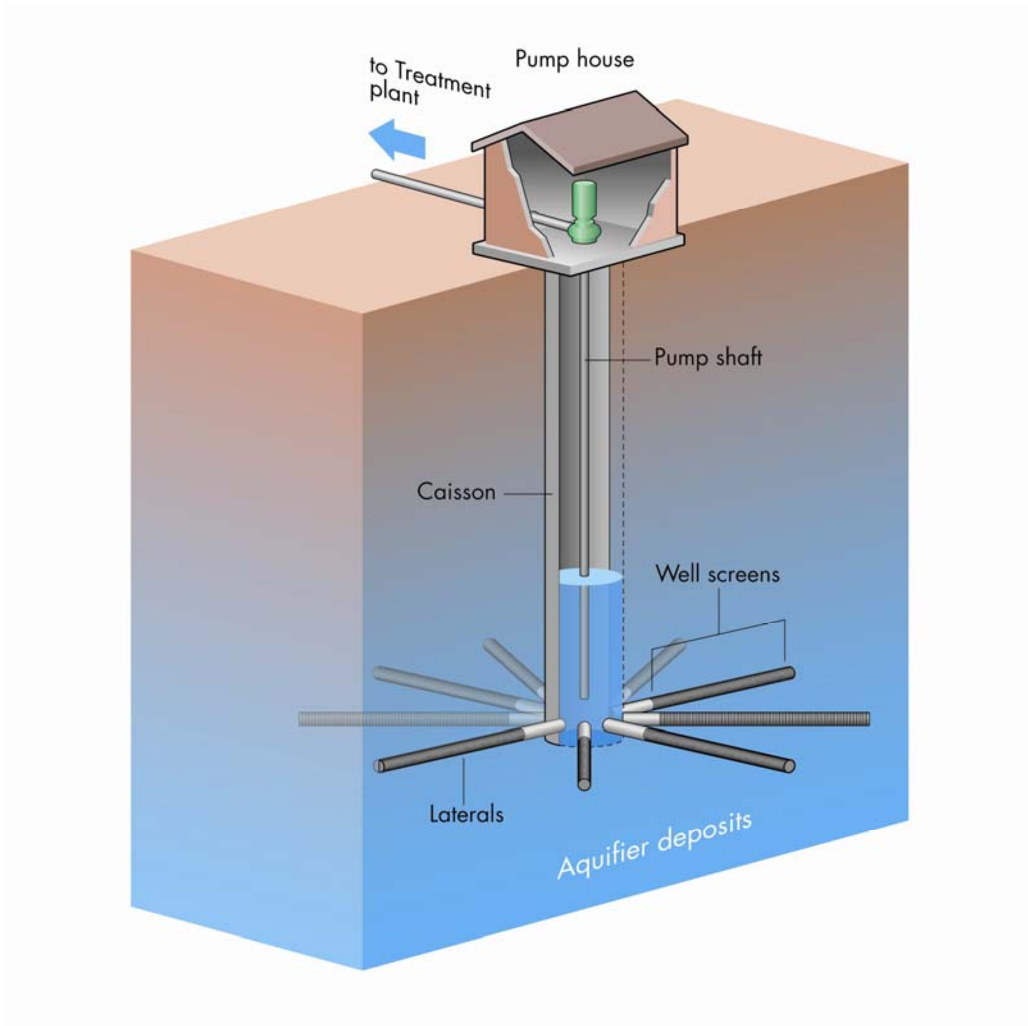
Slant wells are innovative subsurface intakes, which use vertical well drilling technology to install inclined source water collectors under the ocean floor (Figure 4). Such intakes are currently tested by the Municipal Water District of Orange County (MWDOC) at a pilot facility located in Dana Point, California.

Subsurface infiltration gallery intake systems (also known as under-ocean floor seawater intakes or seabed infiltration systems) consist of a series of man-made submerged slow sand media filtration beds located at the bottom of the ocean in the near-shore surf zone (Figure 5). As such, seabed filter beds are sized and configured using the same design criteria as slow sand filters. Currently, such intake system is undergoing long-term testing by the Long Beach Water Department in California.



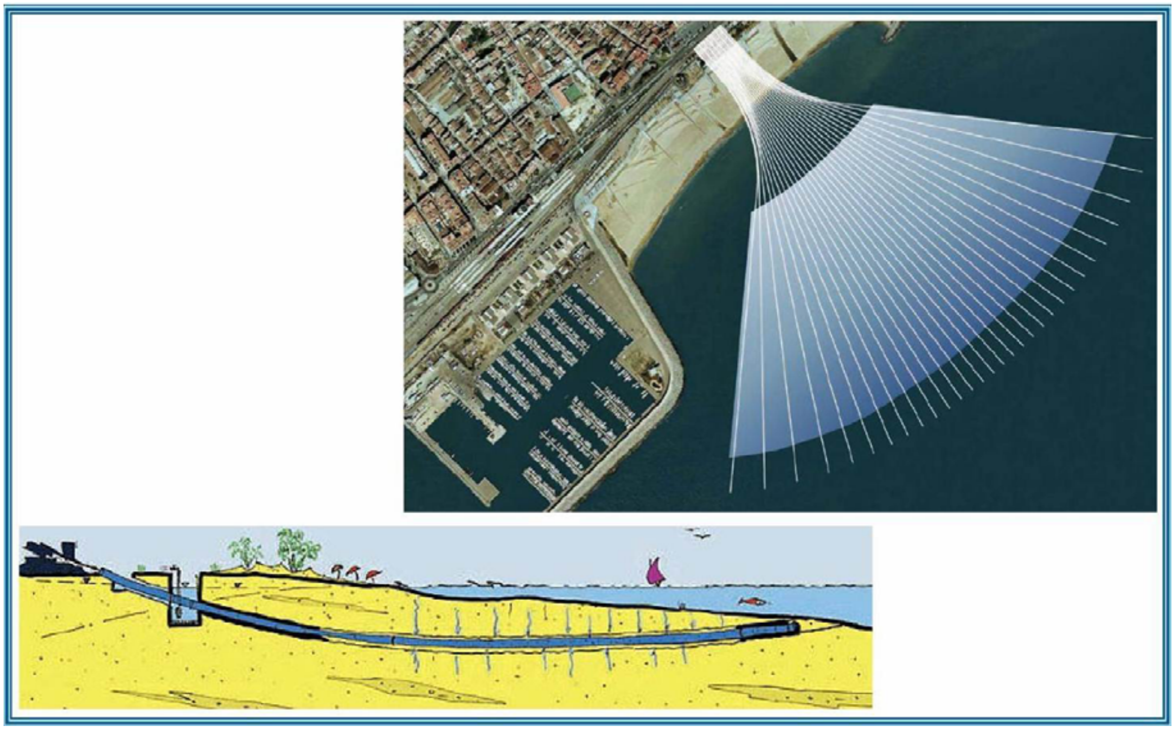
Source: Water Globe Consulting

Figure 1 – Vertical Beach Well



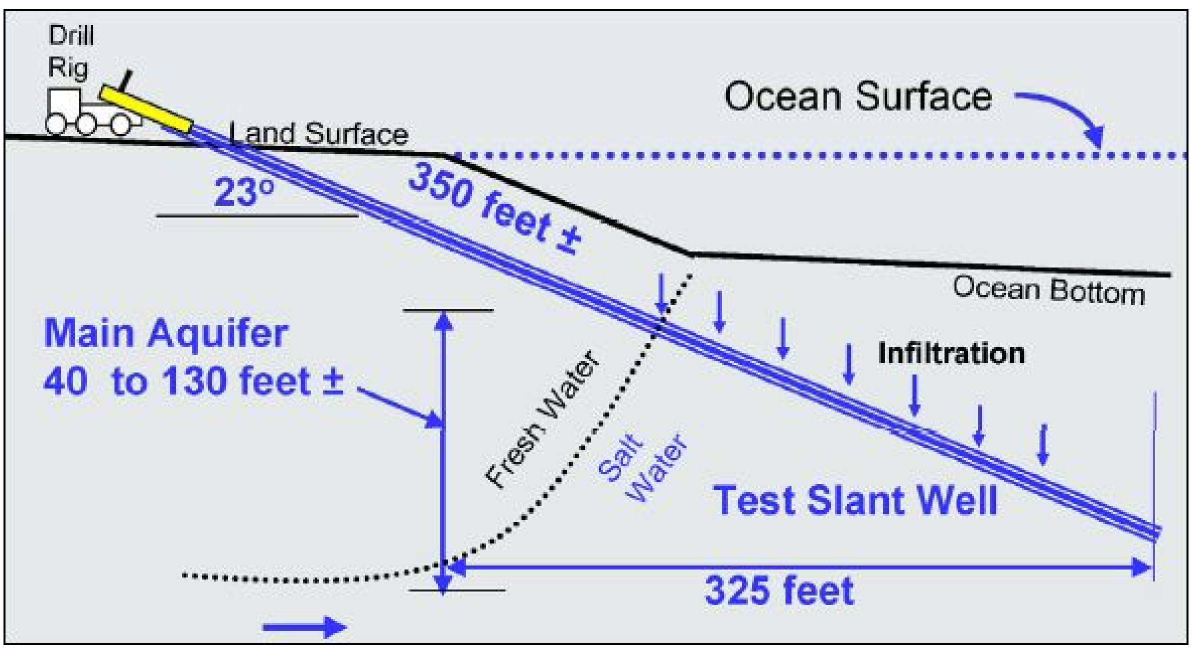
Source: Water Globe Consulting

Figure 2 - Horizontal (Radial) Intake Well



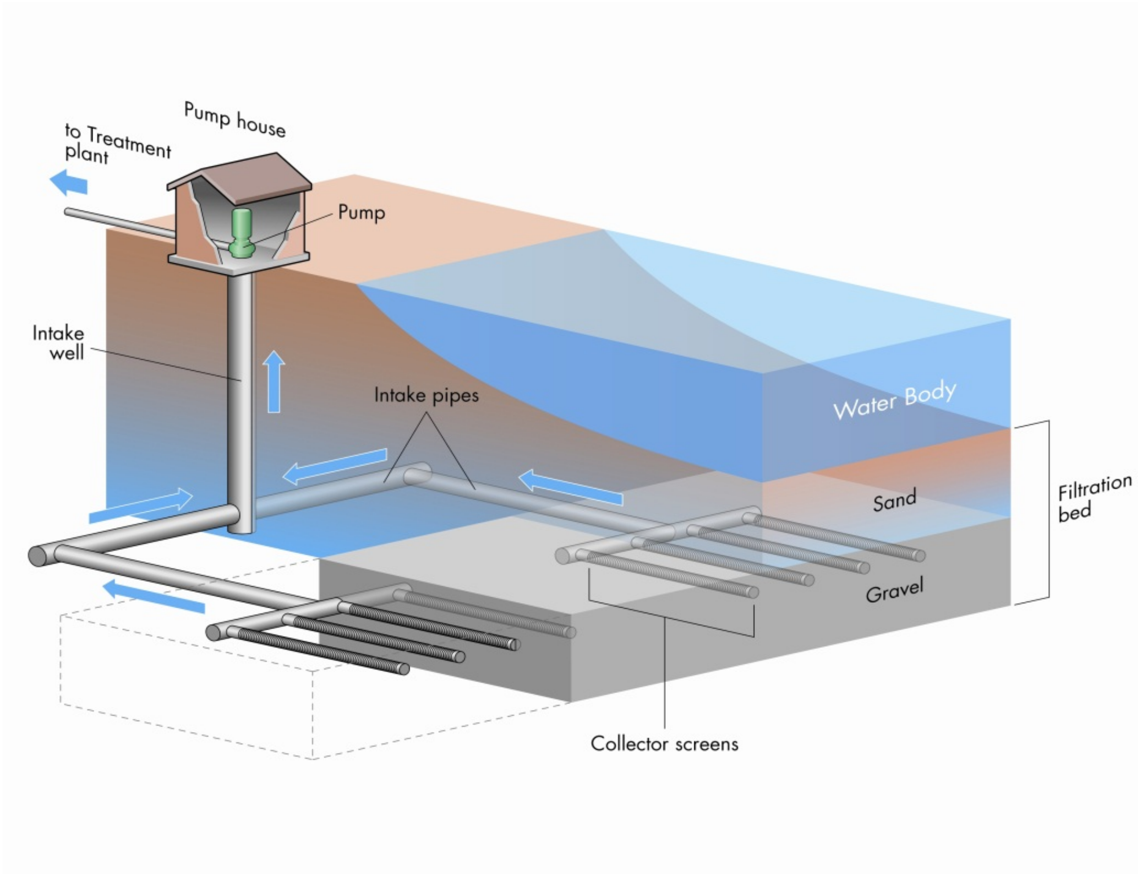
Source: Catalana de Perforacions

Figure 3 – HDD Intake



Source: MWDOC

Figure 4 – Slant Well



Source: Water Globe Consulting

Figure 5 – Infiltration (Seabed) Gallery

Subsurface Well Source Water Quality

While it is typically stipulated that subsurface intakes yield better seawater water quality than open ocean intakes, this assumption only holds true for very site specific conditions: usually when subsurface intakes are located in well flushed ocean bottom or shorelines which are away from surface fresh water influence and are collecting seawater from a coastal aquifer of uniformly porous structure, such as limestone. There are numerous small seawater desalination plants located in the Caribbean and several medium-size plants in Malta which have such subsurface intakes and which require only minimal pretreatment (typically bag filters and/or sand strainers) ahead of the reverse osmosis membrane separation system. However, the majority of the existing seawater desalination plants worldwide using subsurface intakes require an additional filtration pretreatment step prior to membrane salt separation.

At present, the largest seawater desalination plant in the world using infiltration gallery type of subsurface intake is located in Fukuoka, Japan. The plant has capacity of 13.2 MGD, and has been in operation since 2006. This plant pretreats the source seawater collected by the infiltration gallery using ultrafiltration (UF) membranes because its water quality is not adequate for direct application to the RO membranes.

The 34 MGD San Pedro Del Pinatar (Cartagena) plant in Spain is the largest seawater desalination plant in the world today which uses subsurface intakes (HDD wells). While the HDD wells have performed adequately for the initial 17 MGD project phase, site specific hydrogeological constraints have limited their use for the plant expansion to 34 MGD, and a new 17 MGD open water intake system was constructed instead[1]. The source water collected by the plant HDD well intake system also has to be pretreated by granular media filtration in order to make it suitable for seawater desalination by reverse osmosis.

Existing experience with the use of beach wells for seawater desalination in California to date, and at the largest beach-well seawater desalination plant on the Pacific coast in Salina Cruz, Mexico indicate that some desalination plants using subsurface intakes may face a costly challenge – high concentrations of manganese and/or iron in the intake water. Unless removed ahead of the seawater reverse osmosis (SWRO) membrane system, iron and manganese may quickly foul the 5 micron cartridge filters and reverse osmosis membranes, thereby rendering the desalination plant inoperable. The treatment of beach well water which naturally contains high concentrations of iron and/or manganese requires chemical conditioning and installation of conservatively designed “green sand” pretreatment filters or UF membrane pretreatment system ahead of the SWRO membranes. This costly pretreatment requirement may significantly reduce the potential cost benefits of the use of beach wells as compared with an open seawater intake. Open seawater intakes typically do not have iron and manganese source water quality related problems.

An example of a beach well desalination plant which faced an elevated source water iron challenges is the 1.2 MGD Morro Bay SWRO facility in California. The plant source water is supplied by five beach wells with a production capacity of 0.3 to 0.5 MGD each. The beach well intake water has iron concentration of 5 to 17 mg/L. For comparison, open intake seawater typically has several orders of magnitude lower iron concentration. The Morro Bay facility was originally designed without pretreatment filters, which resulted in plugging of the RO cartridge filters within half-an-hour of starting operations during an attempt to run the plant in 1996. The high-iron concentration problem was resolved by the installation of pretreatment filter designed for a loading rate of 2.5 gpm/ft^2. For comparison, a typical open-intake desalination plant is designed for pretreatment loading rates of 4.0 to 5.0 gpm/ft^2 – and, therefore would require less pretreatment filtration capacity.

Usually open ocean intakes are considered a less viable source of water for desalination plants in areas located in close proximity to wastewater discharges or industrial and port activities. Open intake seawater is typically free of endocrine-disruptor or carcinogenic type of compounds such as: Methyl Tertiary Butyl Ether (MTBE); N-nitrosodimethylamine (NDMA); and 1,4-dioxane.

[1] California Coastal Commission CDP application E-06-013 November 15, 2007, hearing transcript pages 170-171.

Beach well water, however, may contain difficult to treat compounds especially when the intake is under influence of contaminated groundwater or surface water runoff. If a saline coastal aquifer used as a desalination plant source water is connected to a fresh/brackish groundwater aquifer contaminated with pollutants (such as fuel oil contaminants, endocrine disruptors, heavy metals, arsenic from a nearby cemetery, etc.) then the desalination plant may need to be provided with additional treatment and/or disposal facilities, which would erode the benefits of well intake use. Potential sources of pollution of the on-shore coastal aquifers include existing landfills, septic tank leachate fields, and industrial & military installations. The compounds of concern could be treated by a number of available technologies, including activated carbon filtration, ultraviolet irradiation, hydrogen peroxide oxidation, ozonation, etc. However, because these treatment systems will need to be constructed in addition to the RO system, the overall desalinated water production cost will increase measurably.

Example of such challenge is the Morro Bay desalination plant, where beach well intake water was contaminated by MTBE, a gasoline additive, caused by contamination from an underground gasoline tank spill. Similar problems were observed at the Santa Catalina Island (California) 0.132 MGD seawater desalination plant that uses beach well intakes.

Site Feasibility Considerations

The feasibility of using subsurface intakes is very dependent on the availability of suitable surface and hydrogeological site conditions. The most favorable hydrogeological condition for constructing subsurface intakes is highly permeable geological formation (sand, limestone, gravel) with hydraulic conductivity which exceeds 1,000 gallons/day/ft^2 and depth of at least 45 feet[2]. The consistency of the hydrogeological conditions along the portion of the shoreline that will be used to develop a subsurface intake is also of critical importance for the feasibility of subsurface intakes. Such favorable aquifer conditions are not always readily available and are especially difficult to find for large desalination projects because of the random nature of the size and consistency of the coastal geological formations. Often the on-shore hydrogeological conditions do not extend significantly off-shore due to beach erosion and deposition of poorly consolidated marine sediments.

One important consideration for well intake feasibility is to establish whether there is a clear separation between the coastal aquifer that will be used for seawater plant supply and the under- and/or overlaying fresh water aquifers, especially if they are already used for potable water supply. Removal of large volumes of water from an on-shore coastal aquifer hydraulically connected to a freshwater aquifer may result in lowering the water levels in the exiting fresh water supply wells in the area and, thereby, reducing their production capacity.

[2] AWWA (2007), Manual of Water Supply Practices, M46, Reverse Osmosis and Nanofiltration, Second Edition.

Special attention has to be given to seawater intake well sites in the vicinity of existing coastal wetlands. The operation of large intake wells located adjacent to coastal wetlands may result in a substantial drawdown of the groundwater table and could ultimately drain or irreversibly impair the wetlands and cause significant environmental damage. Year-round study of the interaction between the coastal aquifer and the nearby wetlands is warranted.

Similarly, beaches contiguous to shallow bays that contain significant amount of mud and alluvial deposits may have limited natural flushing and are not considered favorably for the use of subsurface intakes. High content of fine solids in the bay seawater in combination with low frequency of bay flushing and low transmissivity of the beach deposits may render shallow bay beaches less desirable or unsuitable for construction of desalination plant beach well intakes.

It should be pointed out that both beach wells and open intakes use the same seawater as a source to produce drinking water. If the intake area is not well flushed and the naturally occurring wave movement is inadequate to transport the solids away from the beach well collection area at a rate higher than the rate of solids deposition, then these solids will begin to accumulate on the ocean floor and will ultimately reduce the well capacity and source water quality.

In desalination plants with open intakes, the solids contained in the source seawater are removed in the desalination plant's pretreatment filtration system in a closely monitored and controlled manner. When subsurface intakes are used, the same amount of solids is retained on the ocean floor in the area of the well source water collection, while the filtered water is slowly conveyed through the ocean floor sediments until it reaches the well collectors. The wave action near the ocean floor is the main force that allows the solids separated from the beach well source water to be dissipated in the ocean.

Potential Beach Erosion Impacts

If the intake site is exposed to accelerated beach erosion, such erosion could compromise well performance as a pretreatment filtration device. In order for wells to provide adequate pretreatment, the well collectors will need to have a minimum sustainable ocean bottom sediment layer through which natural filtration is accomplished. As beach erosion may reduce or completely remove the filtration layer over time, long-term well performance may be difficult to predict and rely upon for consistent source seawater pretreatment.

As seen on Figure 6 depicting a 3.8 MGD horizontal beach well for seawater desalination plant located in Salina Cruz, Mexico, beach erosion after only a few years of operation may result in a loss of structural support on the ocean side of the wells and associated service buildings, which in turn could cause the wells to tilt towards the ocean, and ultimately could compromise well structural integrity and performance. Unless controlled by special protection or revetment measures, further tilt of the well structure may result in damage of the well collectors and render the wells inoperable or unpredictably impact their performance.

Therefore, beach erosion may shorten significantly the useful life of the intake wells and increase the overall life-cycle water cost if the well location is not selected appropriately, or the well design does not take into account for this impact on well performance and integrity. Due to its significant impact on the intake system operation and costs, potential for beach erosion in the vicinity of the targeted intake well location has to be thoroughly evaluated and investigated. If the selected beach site has a high potential for erosion, then the beach wells have to be provided with anti-erosion measures.

Source: Water Globe Consulting

Figure 6 – Desalination Plant Intake Beach Well Erosion

Useful Life

Inevitably, some of the solid particles contained in the source seawater may propagate into the natural filtration layer above the beach well's lateral collectors and over time these particles may plug the filtration layer pores and ultimately reduce the intake well productivity or render the wells inoperable. Usually, this process of reduction of well capacity spans over 10 to 20 years. However, particle penetration processes can occur at a much faster rate (six to nine months) if the aquifer contains porous formations which cannot be naturally flushed. In this case, practically nothing can be done to recover well capacity; typically under-performing wells are abandoned, and additional wells are constructed to address such conditions.

Usually, the useful life of a well-designed and operated seawater desalination plant is 25 to 30 years. Because intake wells may often have a shorter useful life span than that of the desalination plant, two sets of intake wells could potentially need to be constructed over the useful life of the desalination plant. The need for replacement of some or all of the original intake wells after the first 10 to 20 years of the desalination plant operation would magnify the shoreline impacts of the beach wells and would increase the overall water production cost. Therefore, the potential difference between the useful life of beach wells and open intakes has to be reflected in the life-cycle cost comparison associated with the selection of the most viable type of desalination plant intake.

Operation and Maintenance Considerations

Depending on their type, subsurface intakes may require significant maintenance efforts over their useful lifespan. For example, infiltration galleries operate as slow-sand filters and retain the majority of the particles contained in the source seawater on the surface of the filter bed. While a portion of this layer is removed periodically be the tidal movement of the ocean water, over time the layer of fine particles retained from the filtered source water would accumulate in the upper portion of the bed and would have to be removed offsite by dredging or replacement of the filter bed media in order to maintain intake capacity. Depending on the intake size, periodic dredging of the filtration bed or replacement of the upper portion of the intake filtration media would involve significant cost and time expenditures, and would preclude the use of the seashore in the vicinity of the intake for other activities such as recreation, fishing, boat traffic, etc.

Environmental Impacts Associated with Construction of Infiltration Galleries

It should be noted that infiltration gallery filter beds are sized and configured using the same design criteria as slow sand filters. The design surface loading rate of the filter media is typically between 0.05 to 0.10 gpm/ft^2. For example, for a 10 MGD desalination plant operating at 50 % recovery, the source seawater collected by the intake would have to be at least 20 MGD (13,880 gpm). At a loading rate of 0.075 gpm/ft^2, the active filtration bed area would need to be 185,100 ft^2 (4.3 acres). This would mean that 4.3 acres of the ocean bottom sediments would need to be excavated to a depth of 6 to 8 feet, and would have to be disposed of offsite to a landfill in order to construct the plant intake. The environmental impact of such excavation is significant, because it would involve the destruction of 4.3 acres of bottom marine habitat during the period of intake construction. The actual environmental impact will be higher because infiltration gallery intake construction will also include the installation of intake piping connecting the infiltration gallery to the desalination plant as well as periodic removal of the surface layer of the infiltration gallery filter bed to recover intake capacity.

Discharge Issues

Beach well water typically has a very low dissolved oxygen (DO) concentration. The DO concentration of this water is usually less than 2 mg/l, and it often varies between 0.0 and 1.5

mg/L. The SWRO treatment process does not add appreciable amounts of DO to the intake water. Therefore, the SWRO system product water and concentrate have the same or lower DO concentration. Low DO concentration of the product water will require either product water re-aeration or will result in significant use of chlorine.

If the low DO concentrate from a well intake desalination plant is to be discharged to an open water body, this discharge will not be in compliance with the United States Environmental Protection Agency (US EPA) daily average and minimum DO concentration discharge requirements of 4 mg/L and 5 mg/L, respectively. Because large desalination plants which use intake wells would discharge a significant volume of low-DO concentrate, this discharge could cause oxygen depletion and stress to aquatic life in the vicinity of the discharge. Therefore, this beach well desalination plant concentrate has to be re-aerated before surface water discharge.

For a large desalination plant, the amount of air and energy to increase the DO concentration of the discharge from 1 mg/L to 4 mg/L is significant and would have a measurable effect on the potable water production costs. Discharge of this low DO concentrate to a wastewater treatment plant outfall would also result in a significant additional power use to aerate this concentrate prior to discharge. For comparison, concentrate from SWRO plants with open intakes have DO concentration of 5 to 8 mg/L, which is adequate for disposal to the ocean, without re-aeration. If disposed to a wastewater treatment plant outfall, this concentrate will actually help in terms of the DO of the discharge blend, taking into consideration that wastewater plant effluent usually has lower DO level.

Potential Visual Impacts

If large horizontal intake wells are constructed as above-ground concrete structures, then they will have a visual and aesthetic impact on the shore line on which they are located (see Figure 7). For relatively small-size beach wells, the caisson/vertical well collector can be built water-tight and located below grade to minimize visual impact. However, the size and servicing of the well pumps, piping, electrical, instrumentation and other auxiliary equipment of large-capacity wells usually dictates the location of their pump house to be above grade. In addition, the construction of below-grade wells would require the use of submersible intake pumps, which for large-size applications are not advisable due to their overall lower energy efficiency. Typically, large-size wells use vertical turbine intake pumps rather than submersible pumps to minimize power use and simplify maintenance. Although the above-grade pump house could be designed in virtually any architectural motif, this facility and its service roads with controlled access/fencing provisions would change the visual landscape of the seashore.

Source: Water Globe Consulting

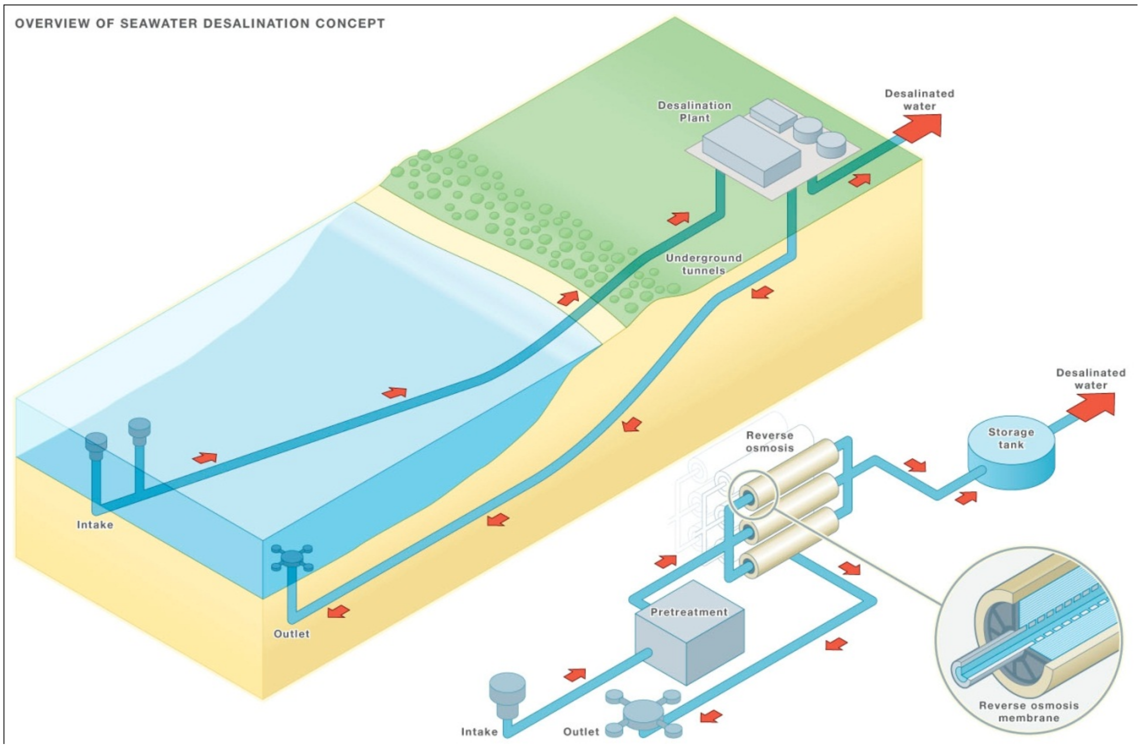
Figure 7 – 3.8 MGD Intake Beach Well of Large Seawater Desalination Plant

Taking into consideration that the desalination plant source water has to be protected from acts of vandalism and terrorism, the individual beach wells may need to be fenced-off or otherwise protected from unauthorized access. The tall fenced-off beach well concrete structures would have a limited visual and aesthetic appeal. Since beaches are visually sensitive areas, the installation of large beach wells may affect the recreational and tourism use and value of the seashore, and may change the beach appearance and character.

For comparison, open coastal intakes are typically lower-profile structures that may blend better with the coastal environment and its surroundings. If the desalination plant is collocated with an existing power plant, construction of new on-shore structures or facilities is typically not required and is more favorable in terms of additional negative visual and aesthetic impact on the coastal environment and landscape.

OPEN OCEAN INTAKES

Open intakes typically include the following key components: inlet structure (forebay) with coarse bar screens; source water conveyance pipeline or channel connecting the inlet structure to an onshore concrete screen chamber; and mechanical fine screens in the chamber. Depending on the location of the inlet structure, the intakes could be on-shore or off-shore type. Off-shore intakes with vertical inlet structures are the most commonly used for seawater desalination projects. The off-shore inlet structure is usually a vertical concrete or steel well (vault) or pipe located at or above the ocean floor and submerged below the water surface (see Figure 8).

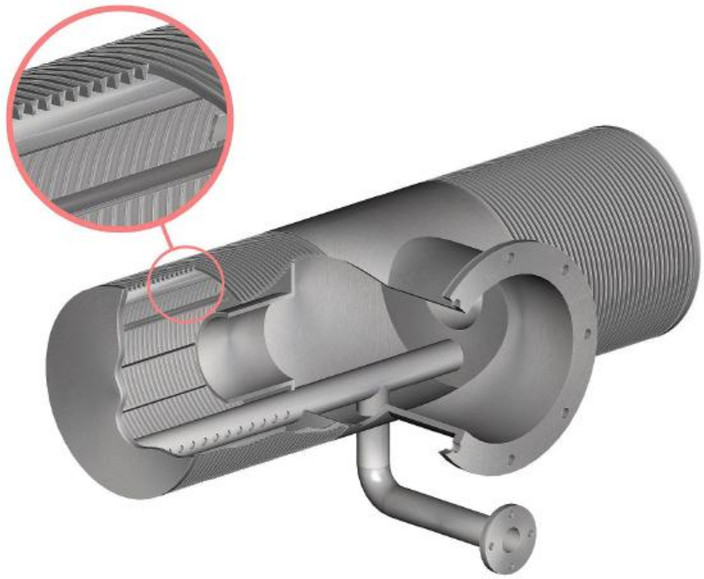


Source: Sydney Water

Figure 8 – Desalination Plant with Off-Shore Intake

The open intake inlet system may include passive wedge-wire screens (see Figure 9). The use of such screens eliminates the need for coarse and fine screens on shore. Wedge-wire 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. These screens are designed to be placed in a water body where significant prevailing ambient cross flow current velocities (≥ 1 fps) exist. This high cross-flow velocity allows organisms that would otherwise be impinged on the wedge-wire intake, to be carried away with the flow.

An integral part of a typical wedge-wire 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.

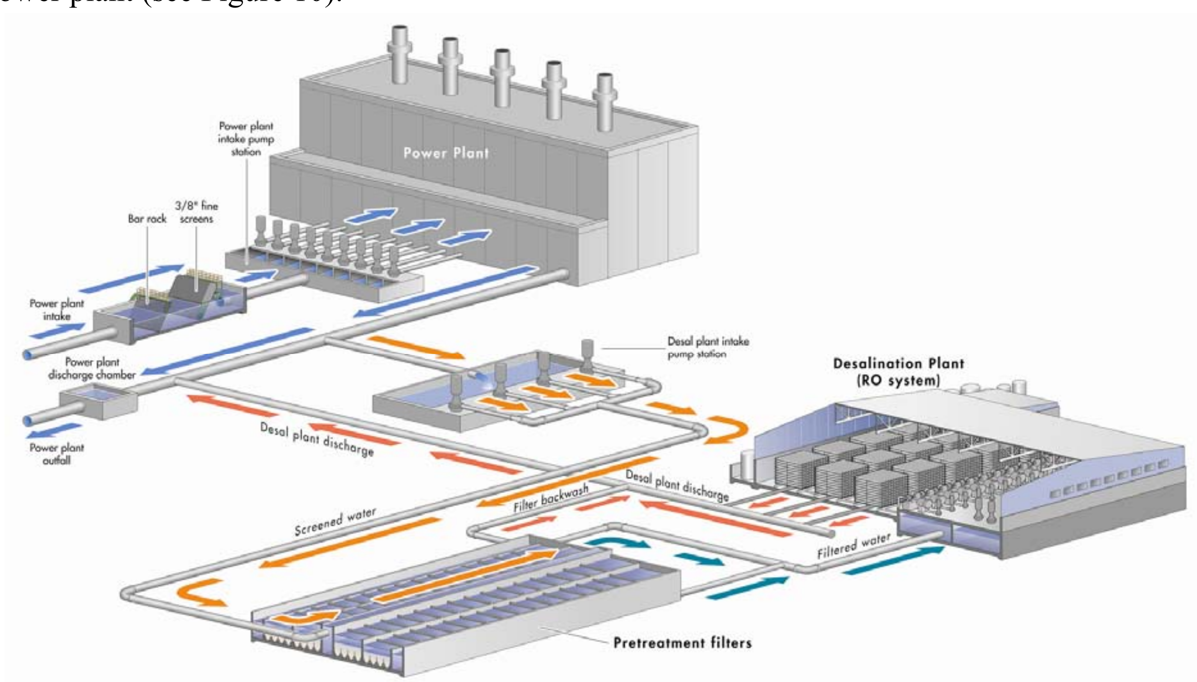


Source: Acciona Agua

Figure 9 – Wedgewire Screen

Collocated Intakes

This is a type of open intake for desalination plants co-sited (collocated) with existing power generation stations using seawater for once-through cooling purposes. Intake and/or discharge of collocated desalination plants are typically directly connected to the discharge outfall of a coastal power plant (see Figure 10).



Source: Water Globe Consulting

Figure 10 – Collocated Desalination Plant

In once-through cooled power plants, seawater enters the power plant intake facilities and, after screening, is pumped through the power plant condensers to cool the steam turbines, thereby removing the waste heat produced during the electricity generation process. The cooling water discharged from the condensers is typically 5 to 15 ^{0}F warmer than the source ocean water. The desalination plant uses a portion of this post-condenser cooling water to produce drinking water. This warmer cooling water is less viscous than the ambient ocean water, which reduces the energy needed for desalination by membrane separation. The main reason for the increased interest in collocated desalination plants over the past decade is the fact that they avoid the need to permit and construct new desalination plant intakes and outfalls, while also improving on the desalination plant membrane performance due to the readily available warmer water.

CONSIDERATIONS FOR SELECTION OF INTAKE TYPE

At present, open-ocean intakes are the most widely used type of intake technology worldwide, because they can be installed in practically any location and built in any size. While open intakes are suitable for all sizes of desalination plants, their cost effectiveness depends on a number of location-related factors such as: plant size; depth and geology of the ocean floor; impact of sources of water quality contamination on their performance (i.e., wastewater and storm water outfalls; ship channel traffic; and large industrial port activities); and ease of installation.

Mainly due to the fact that favorable hydrogeological 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 has been limited to plants of relatively small capacity. In addition, densely populated coastal areas, where large desalination plants are needed, have very limited land availability for installation of numerous beach wells, which often is an important factor and potentially a fatal flaw in certain coastal communities.

Both open and subsurface intakes offer different advantages and usually have different disadvantages in terms of capital, operation, & maintenance costs; construction complexity; environmental impacts; operational considerations; and subsequent source water pretreatment and concentrate disposal needs. Therefore, the selection of the most suitable intake system for the site-specific conditions of a given desalination project should be completed based on life-cycle cost-benefit analysis and environmental impact assessment including all key project components - intake, pretreatment, membrane salt separation, and concentrate disposal.

Intake selection should be based on reasonable balance between the cost expenditures and environmental impacts associated with production of desalinated water. Project proponents should not be burdened with the use of the most costly intake alternative if the environmental impacts associated with the construction and operation of a less expensive type of intake are minimal and can be reasonably mitigated.

While thorough feasibility evaluation of intake alternatives is warranted, this evaluation should be initiated with pre-screening for fatal flaws based on site specific studies for the selected intake location. If the pre-screening shows that certain intake alternatives have one or more fatal flaws that preclude their use, such intake systems should be removed from the evaluation process because their detailed feasibility assessment will be unproductive and would only cause unwarranted project delays and expenditures.

While the desalination project proponent has the burden to complete feasibility evaluation of alternative intakes for a given project, the permitting agencies involved with project review should facilitate the engineering and environmental studies needed to establish their viability. For example, if subsurface intake appears to be possible for a given project, permitting agencies should provide the necessary allowance for test well drilling and installation while not creating hurdles that make the intake feasibility investigations overly complicated.

CONCLUDING REMARKS

At present, open intakes are by far the most widely used type of source water collection facilities worldwide because they are suitable for all sizes of desalination plants; they are more predictable and reliable in terms of productivity and performance; they are easier and more cost-effective to operate and maintain; and they usually offer better economy of scale for desalination systems of capacity greater than 5 million gallons per day (MGD).

The feasibility of subsurface intakes 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 discussed in the previous sections of this white paper.

Both open ocean intakes and wells may have advantages and pose environmental and socio-economic challenges for the site-specific conditions of a given desalination project. Therefore, the selection of most viable intake alternative should be based on balanced life-cycle cost-benefit analysis and environmental assessment.