Chapter 1
Overview of Intake Systems for Seawater Reverse Osmosis Facilities

Thomas Pankratz

Abstract The intake is a critical component of every seawater reverse osmosis facility and controls to a great degree the design and operational cost of downstream treatment processes. Two general classes of intake types occur; surface or open-ocean intakes and subsurface intakes. Globally, most large-capacity SWRO plants use open-ocean intake systems with the actual intake located either onshore (commonly shared with a power plant) or offshore. The most common offshore intake type uses a velocity cap at the top of the invert pipe. Inshore or offshore passive screen intakes are used to reduce the impacts of impingement and entrainment. Subsurface intake systems, either wells or galleries, are being used in hundreds of small to medium capacity SWRO facilities. Because of the greater attention being given to the environmental impacts of impingement and entrainment of marine organisms, subsurface intake systems are being specified for a greater number of facilities with higher capacity.

1.1 Introduction

Seawater desalination facilities require an intake that is capable of providing a reliable quantity and relatively consistent quality of seawater to ensure that the plant production targets can be met. While this fundamental objective may appear obvious, it is complicated by the fact that the ocean is a dynamic entity with constantly changing conditions.

Powerful waves and changing currents can damage structures, affect water depths, and dramatically alter water quality and temperature. And, as one moves

---

T. Pankratz (✉)
Water Desalination Report, P. O. Box 75064, Houston, TX 77234, USA
e-mail: PankratzTM@gmail.com

T.M. Missimer et al. (eds.), *Intakes and Outfalls for Seawater Reverse-Osmosis Desalination Facilities*, Environmental Science and Engineering,
DOI 10.1007/978-3-319-13203-7_1

closer to shore, these changes often become more dramatic and occur with increasing frequency. Operational problems are compounded by the corrosiveness of seawater and the marine organisms that can attack and foul equipment and systems.

To meet the design objectives, it is essential that a thorough assessment of the intake site conditions be conducted. Physical characteristics, meteorological and oceanographic data, marine biology and the potential effects of fouling, pollution and navigation must be evaluated. Only then can an appropriate intake design be selected.

As reverse osmosis (RO) has grown to become the predominant seawater desalination process, so have the number and production capacities of the resulting facilities. More and larger capacity plants are being built in locations where none had previously existed, raising concerns over the possible environmental impacts of withdrawing large volumes of seawater. For many seawater desalination projects, the potential for intake-related marine life mortality may represent the most significant direct adverse environmental impact of a project.

Because intake designs are highly site specific—perhaps more so then any other aspect of the desalination plant—the design, modeling, monitoring and permitting activities that surround them may represent a significant portion of a project capital costs. Whereas, seawater intakes formerly represented 4–12 % of an entire facility capital cost, some intake arrangements may now cost 35 % or more of a project capital cost, and it is possible that intake-related issues may ultimately determine the feasibility of the desalination plant itself.

This chapter will consider the seawater intake technology options available for seawater RO plants, including intakes shared with electric power plants, and will review the technologies employed to minimize environmental impacts, while meeting the intake objective of providing a reliable quantity of seawater at the best quality available. A comparison of the intake types is given in Table 1.1. Greater descriptive detail on intakes and diagrams and photographs of various types are contained in Missimer (2009) and in various chapters in this book.

1.2 Water Quality and Quantity

Historically, most large seawater desalination plants have employed the multistage flash evaporation (MSF) or multiple effect distillation (MED) desalination processes and have been co-located at an electric power generating plant with which they share a common shoreline, or nearshore seawater intake. Because a power plant condenser and a MSF or MED facility utilize similar size condenser tubes, both require only a nominal level of treatment, and usually that can be provided by a traveling water screen or rotating drum screen with 6–9.5 mm wire mesh openings.

Table 1.1 Assessment of intake options for SWRO plants

	Intake options summary				
	Vertical wells	Infiltration gallery	Open ocean, with offshore passive screens	Open ocean with velocity cap, onshore mechanical screens	Conventional shoreline, with mechanical screens
Feasibility	Limited by local geology	Limited by local hydrogeology, offshore sea conditions	Moderate-high	High	High
Feedwater quality produced	High	High	Moderate-high	Moderate	Low
Environmental implications	No impingement, entrainment	No impingement, entrainment, but construction impacts	No impingement, low entrainment	Low impingement, moderate entrainment	Impingement and entrainment
Flexibility	Low, space limitations may limit well addition	Low	Production limitations can be overcome by adding screens	Moderate	Moderate
Reliability	Wells can be rehabilitated and/or new ones added	Difficult to predict, cleaning may be marginally effective	Plugging can be monitored and cleaning is effective	Plugging can be monitored and cleaning is effective	Plugging can be monitored and cleaning is effective
Susceptibility to operational anomalies	Low	Low	Moderately vulnerable to jellyfish runs, algal blooms	Moderately vulnerable to algal blooms	Moderate to highly vulnerable to jellyfish runs, algal blooms
Maintenance	Low	When/if required, could be substantial	Pig pipeline 2X per year, clean/inspect screens quarterly	Pig pipeline 2X per year, maintain screens as required	Maintain screens as required
Construction risk	Moderate	High	Low-moderate	Low-moderate	Low
Relative capital cost, typical	Low-moderate	High	Moderate-high	Moderate-high	Moderate

Conversely, the performance of a seawater reverse osmosis (SWRO) plant may benefit greatly from a more consistent quality of water and a finer level of screening. Since most seawater RO plants are standalone facilities with a purpose-built intake, there is a much greater focus on selecting a design/location that will provide a consistent seawater quality possible and the lowest practical suspended solids. As the first step in the SWRO pretreatment process, the intake effectiveness can have far-reaching effects on overall plant operation and performance.

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 a 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.

Most seawater RO facilities convert 40 to 50 % of the intake water to product water, while the remaining water, which includes the salt removed by the RO system, is pumped back to the sea for controlled discharge. It is therefore beneficial to locate the desalination plant as close to the seashore as possible to minimize intake/discharge pumping requirements.

1.3 Environmental Considerations

Potential environmental impacts associated with concentrate discharge are often considered the greatest single ecological impediment when siting a seawater desalination facility. However, it has now been widely demonstrated that a properly modeled, designed and strategically located outfall can effectively mitigate discharge impacts, while marine life impingement and entrainment resulting from intake operation is often 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 (Chap. 4). 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-h 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 (Chap. 4). Entrained organisms 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 employed to minimize their impact. If intake velocities are sufficiently low, usually less than 0.15 m/s, 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 that are 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 for electric power plant cooling water intakes have been required to employ the best technology available to minimize adverse environmental impact under §316(b) of the US. Environmental Protection Agency (USEPA) Clean Water Act (CWA). The section of the CWA has been updated three times and applies to all intakes that withdraw greater than 7570 m^3/d of seawater and use 25 % or more of the water for cooling purposes. Some state regulatory agencies have indicated that the siting of a new or existing seawater intake for a desalination facility will require a §316(b)-type assessment of impingement and entrainment impacts as part of the environmental review and permitting process.

1.4 Intake Categories

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

1.5 Surface Water Intakes

Large seawater desalination plants have traditionally employed open-ocean, surface water intakes that are equipped with mechanically cleaned screens and virtually identical to those installed electric power generating plants use to obtain condenser cooling water.

In most arrangements, a pump station and screening chamber is located onshore and directly connected to the open ocean by means of a concrete channel or jetty, or an intake pipe that may extend out hundreds of meters into the sea.

1.5.1 Traveling Water Screens

Traveling water screens, also referred to as band screens, have been employed on seawater intakes since the 1890s (Fig. 1.1). The screens are equipped with revolving panels fitted with wire mesh panels that usually have 6–9.5 mm openings.

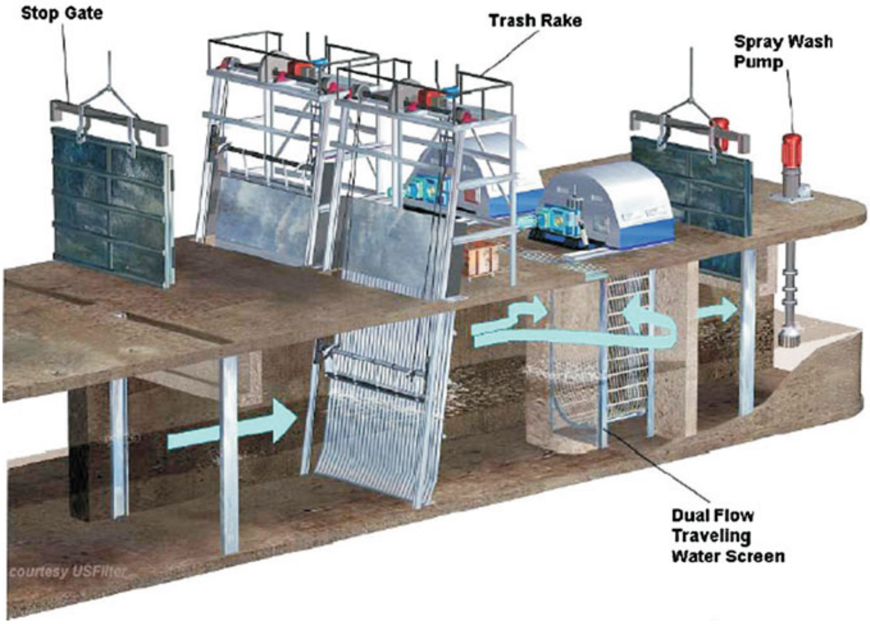

Fig. 1.1 Dual-flow traveling water screen (From Pankratz 2007)

As the wire mesh panels revolve out of the flow, a high-pressure water spray is used to remove accumulated debris, washing it into a trough where it is sluiced away for further disposal.

The screens are almost always located onshore in concrete channels, either at the far end of a forebay or a longer channel that extends out beyond the surf zone. The screens may also be installed in a wet well or pump station that is connected to the sea by a pipe that extends out into the sea and terminates in a coarse-screened inlet or a velocity cap.

The screens are usually designed so that the maximum water velocity through the screen is less than 0.15 m/s.

1.5.1.1 Rotating Drum Screens

Rotating drum screens are an alternative to traveling water screens, and consist of wire mesh panels mounted on the periphery of a large cylinder that slowly rotates on a horizontal axis (Fig. 1.2). They are cleaned with a spray wash system similar to traveling water screens. Drum screens may range up to 15 m in width and 4 m in diameter.

Fig. 1.2 Drum screen (From Pankratz 2007)

1.5.1.2 Fine Mesh Traveling Screens

Fine mesh traveling screens have been used to successfully reduce entrainment of eggs, larvae and juvenile fish at some intake locations where traveling water screens have been outfitted with wire mesh panels having openings ranging from 0.5 to 5 mm, and which may reduce entrainment by up to 80 %.

However, 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.

1.5.1.3 Ristroph Screens

Ristroph screens are a modification of a conventional traveling water screen in which screen panels are fitted with watertight fish buckets that collect fish and lift them out of the water where they are gently washed from the screen with a low-pressure spray, prior to debris removal with a high-pressure spray wash (Fig. 1.3).

Studies at a New York power plant seawater intake, showed the 24-h survival of marine life impinged on conventional screens averaged 15 % compared with 80–90 % survival rates for Ristroph-type traveling water screens. A review of 10

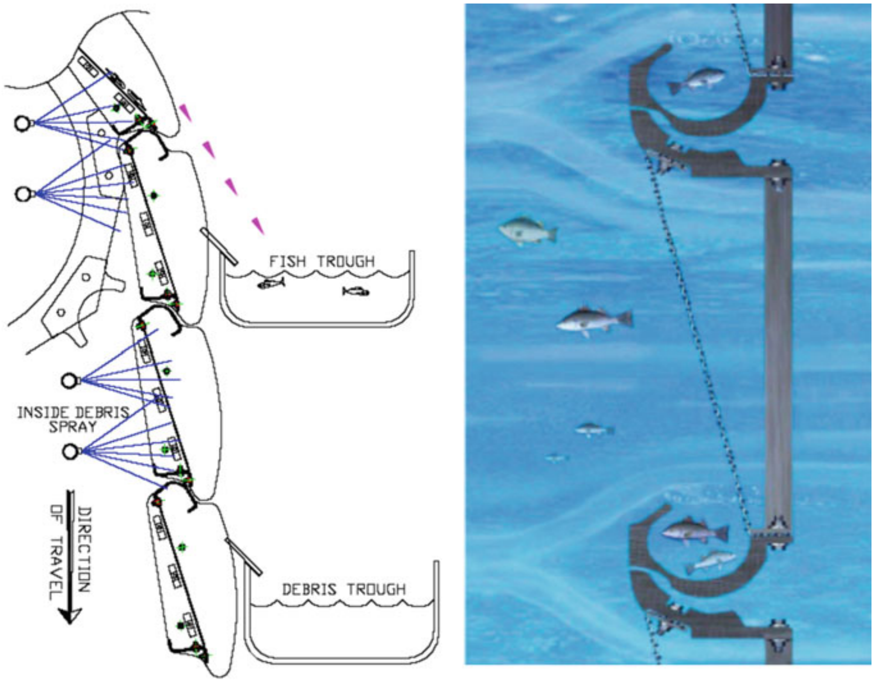

Fig. 1.3 Ristroph screen apparatus

similar sites reported that Ristroph modifications improved impingement survival 70–80 % among various species.

Although Ristroph screens may be effective at improving the survival of impinged marine life, they do not affect entrained organisms.

1.6 Offshore Intakes

Submerged, offshore intakes have long been a preferred seawater intake arrangement, particularly for shallow coastlines. Power plants and desalination plants often employ them in a desire to obtain a ‘better’, more consistent quality of water that is less susceptible to operational upsets from storm events, algal blooms and jellyfish. An offshore intake may also mitigate environmental impacts if it is designed and located in an area so as to reduce marine life impingement and entrainment.

In most offshore intake arrangements, the intake structure is usually located well beyond the surf zone, so it is less vulnerable to wave action. In some locations, this may be as little as 200 m offshore, but for larger plants, or locations with gently sloping sea bottoms, the intake could be located more than 1000 m offshore.

The offshore intake terminal is usually equipped with a coarse screen having 50–225 mm openings, or a velocity cap (see Sect. 1.7). Water enters the intake structure and is conveyed to an onshore pump station through a connecting pipe or tunnel (see Chaps. 2 and 3).

For most SWRO applications, especially those locations with a sandy seabed, a high-density polyethylene (HDPE) pipe can be fitted with concrete collars/anchors and laid directly on the seabed, although the portion of the pipeline that extends through the surf zone and onshore to the pump station is usually laid in a dredged trench and backfilled (Chap. 5).

Where intake lines must pass through environmentally sensitive areas or extend far offshore to reach deeper water, trenchless installation methods including tunneling, pipe jacking (microtunnelling) or horizontal directional drilling (HDD) may be used for all, or a portion of the line (Chaps. 2 and 3).

Unless the intake terminal of an offshore intake is fitted with a passive screen system, the onshore pump station must be equipped with traveling water screens or rotating drum screens to protect downstream pumps and pretreatment equipment.

1.7 Velocity Caps

The vertical riser of an offshore intake pipe may be fitted with a velocity cap that acts as a behavioral barrier to guide aquatic organisms away from the intake structure. The velocity cap is a horizontal, flat cover located slightly above the terminus of the vertical riser to convert a vertical flow into a horizontal flow at the intake's entrance (Fig. 1.4).

The cover converts vertical flow into horizontal flow at the intake entrance, and works on the premise that fish will avoid rapid changes in horizontal flow. Fish do not exhibit this same avoidance behavior to the vertical flow that occurs without the use of such a device. Velocity caps have been implemented at many offshore intakes and have been successful in decreasing the marine life impingement.

The design is based on the premise that a change in flow pattern created by a velocity cap, and operating at an entrance velocity of about 0.30 m/s, and as high as 0.9 m/s, triggers an avoidance response mechanism in fish, which aids in escaping impingement. This avoidance behavior was not exhibited in response to a vertical flow that would occur with an uncapped riser. It was also found that extending the cap and riser lip by 1.5 times the height of the opening would result in a more uniform entrance velocity, increasing the reaction time of a fish.

In recent years, the definition of a velocity cap has strayed well beyond its original definition, and many now incorrectly refer to any offshore covered intake head—regardless of its entrance velocity and the height of its opening—as a velocity cap.

This was noted in a 2012 USEPA review of proposed rule changes for the Section 316(b) of the Clean Water Act:

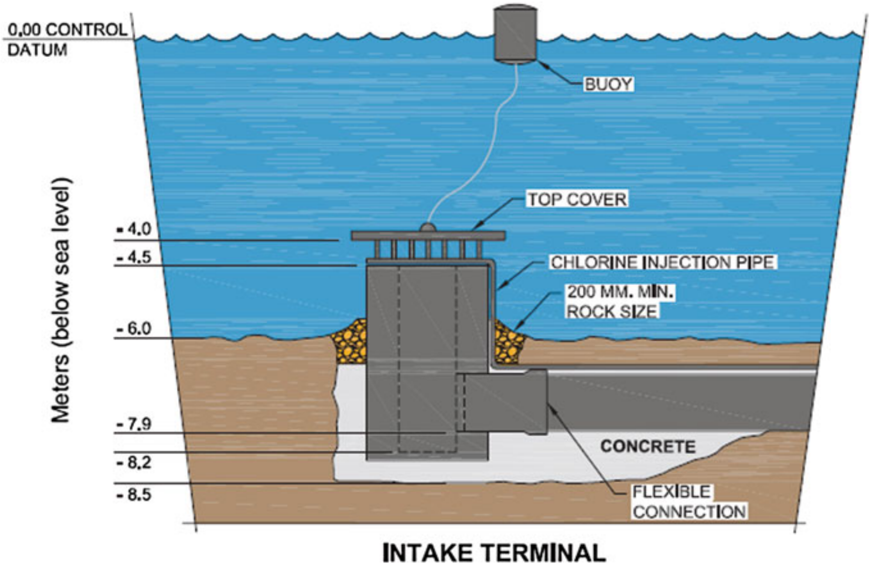

Fig. 1.4 Velocity cap intake structure (From Missimer 2009)

> "EPA is aware that low intake velocity is sometimes confused with velocity cap technologies, and EPA would like to clarify that these concepts are not the same. Most velocity caps do not operate as a fish diversion technology at low velocities, and in fact are often designed for an intake velocity exceeding one foot per second."

In its final rule on cooling water intake structures issued on 15 August 2014, the USEPA noted that it had reviewed studies documenting performance from 11 offshore intakes equipped with a velocity cap. The data shows that by solely locating an intake over 240 m offshore, even without a velocity cap, it is possible to achieve a 60–73 % impingement reduction. Similarly, it also shows that the use of an EPA-defined velocity cap alone can achieve a 50–97 % reduction in impingement.

Based on this record of performance, the final rule designated offshore intakes fitted with a properly designed velocity cap as one of the "pre-approved" best technologies available for impingement.

To qualify as a pathway for impingement compliance, a velocity cap must usually be located more than 240 m offshore.

Virtually all velocity cap intakes require some on-shore screening system, usually a traveling water screen or rotating drum screen to protect downstream pumps and pretreatment equipment. The screens may be equipped with a Ristroph-type marine life handling system to further reduce impingement mortality and/or fine screens to reduce entrainment of entrapped organisms.

1.8 Passive Screens

Another intake arrangement utilizes fixed cylindrical screens constructed of trapezoidal- or triangular-shaped “wedgewire” bars arranged to provide 0.5–3.0 mm wide slotted openings (Chap. 5). The screens are usually oriented on a horizontal axis with the total screening area sized to maintain a velocity of less than 0.15 m/s to minimize debris and marine life impingement.

Passive screens are best suited for areas with an ambient cross-flow current that acts to ‘self-clean’ the screen face. Systems may also be equipped with an air backwash system 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—due to their low through-flow velocities—and entrainment—through exclusion resulting from the narrow slot openings. Tests have shown that 1 mm openings are highly effective for larval exclusion and may reduce entrainment by 80 % or more.

1.9 Subsurface Intakes

Subsurface intakes are those in which seawater is withdrawn below the surface of the seabed and 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 (Missimer 2009; Missimer et al. 2013). A subsurface intake can be used where geologic conditions beneath the seabed can support water extraction while providing some level of natural filtration.

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 must consider their potential impact on nearby fresh groundwater aquifers.

1.9.1 Vertical Wells

Vertical onshore wells that are hydraulically connected to the sea, or draw water from saline aquifers or deep regional aquifer systems that contain seawater may be used to feed seawater desalination plants (see Chap. 8). The site geology must be adequate to allow individual well yields to be high enough so that the number of production wells needed to meet an RO plants raw water supply is reasonable or cost-competitive with other supply options.

Often, the term ‘beach well’ is used to describe any vertical well, but this is incorrect if it applies to wells that are not directly recharged by seawater and located on or very near to the beach.

Many vertical wells make use of beach sand, coral or other geologic structures as a filter medium, and are often economical alternative to open sea intakes for desalination plants, especially those with production capacities less than 20,000 m^3/d, although one 80,200 m^3/d seawater RO plant has successfully employed vertical wells.

A vertical beach well usually consists a non-metallic well casing, well screen, and a vertical turbine or submersible 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 may range up to 4000 m^3/day or more.

1.9.2 Horizontal Directional Drilling

Horizontal directional drilling (HDD) techniques can be used to position a horizontal well within porous strata 2–4 m under the seabed. Drilling can be accomplished by sonic, rotary, percussion, or jetting techniques. The advantages offered by HDD technology versus conventional trench installation techniques include minimized surface disturbance/impacts, reduction in the quantity of excavated material, accuracy of conduit placement, and backfill and compaction of open trenches is eliminated.

One HDD wellfield system uses a relatively new type of porous polyethylene well pipe that acts as both a well screen and packing in one, and does not require additional external media packing for long-term operation. Pre-packed well screens and filter mesh well screens that can be pulled over a slotted pipe are other options offered by several manufacturers.

When designing a seabed filtration system the well screen and packing system should be sized so that the entrance velocity through the packing and screen does not exceed the prescribed maximum flow velocity for the adjacent formation materials.

Multiple horizontal wells can be installed from the same origin within a caisson in a similar manner to collector wells to supply higher production requirements.

1.9.3 Slant (Angled) Well

A slant well or angled well is similar to both vertical and horizontal directionally drilled (HDD) wells. This is because a slant well is nearly horizontal, yet constructed like a vertical well. The shallow-entry drill rig is angled approximately

15–25° from the horizontal, and then drilled straight, unlike a HDD drill rig that gradually turns as it drills to achieve a horizontal well (see Chap. 13).

1.9.4 Radial Collector Wells

Radial collector wells are a variation of the beach well in which multiple horizontal collector wells are connected to a central caisson that 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 2.75–6 m in diameter and 9–45 m deep, with 200–300 mm diameter radial arms. The caisson can be completed with a flush-grade top slab or in a buried concrete vault and backfilled with beach sand to reduce visual impact. The laterals can extend up to 150 m away from the central caisson.

1.9.5 Infiltration Galleries

An infiltration gallery type intake is a variation of the slow sand granular media filter that has been used in the water treatment industry for two centuries. The systems rely on the slow movement of seawater through the sand to remove particulate matter and biologically degrade bacteria and other organic compounds.

Galleries are designed similarly, whether located close to shore and beneath a beach, or hundreds of meters offshore (see Chaps. 10–12). A typical system consists of a header/lateral underdrain system buried in trenches 2–4 m below the seabed and backfilled with graded sand and/or gravel. The underdrain is used to collect seawater that filters through the seabed at a rate that usually ranges from 2–8 m/day, and conveys it to shore via a pipeline.

Large-scale galleries can be difficult to construct and may require expensive and time-consuming construction methods for their installation. However, they generally produce higher quality water than surface intakes, and their use may reduce the cost and chemical requirements of RO pretreatment systems.

1.9.6 Onshore Karst Pit

In some locations the onshore geology may be hydraulically connected to the sea by underground fissures typical of karst topography formed by the dissolution of soluble limestone or dolomite rocks. These underground networks may serve to

Fig. 1.5 Onshore karst pit intake in Curaçao

feed a below grade basin constructed onshore, and from which seawater may be pumped to a desalination plant.

One such intake was employed for a 26,000 m^3/d SWRO plant in Curaçao, in which a 6 m deep intake basin was located 100 m inland from the shoreline (Fig. 1.5). The basin walls were constructed of prefabricated, perforated concrete slabs and large, limestone rocks were installed around the basin's periphery to ensure a continuous infiltration of seawater.

1.10 Conclusions

The intake system is a critical component of all SWRO plants. The production of feed water to a SWRO plant must be reliable and consistently meet the operational capacity of the plant and should be of a consistent quality.

The intake water quality is critical to the downstream process operations within a SWRO plant. Pretreatment processes must be used to remove debris, suspended solids and organic compounds that adversely impact the primary membrane process. Therefore, the design and location of the intake play an important role in the full plant design and in the overall operational cost of a facility.

A key issue impacting the choice of which intake type to use is the operational reliability of the intake under all operating conditions that could occur at a site. While lower environmental impacts and reduced cost of operation are very important issues, reliability of a facility allows it to be financed and built. Therefore, there is a general bias toward the use of existing and proven intake types, particularly for large capacity SWRO facilities.

References

Missimer, T. M. (2009). *Water supply development, aquifer storage, and concentrate disposal for membrane water treatment facilities* (2nd ed.). Methods in Water Resources Evaluation Series No. 1. Sugar Land, TX: Schlumberger Water Services.

Missimer, T. M., Ghaffour, N., Dehwah, A. H. A., Rachman, R., Maliva, R. G., & Amy, G. (2013). Subsurface intakes for seawater reverse osmosis facilities: Capacity limitation, water quality improvement, and economics. *Desalination, 322*, 37–51. doi:10.1016/j.desal.2013.04.021.

Pankratz, T. (2007). Desalination: Intake and pretreatment options. In *Presentation at Conference on Middle East Electricity, Dubai, UAE*, February 12, 2007.