A SunCam online continuing education course

Introduction to Planning of Desalination Projects

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1. INTRODUCTION

The purpose of project planning is to define the size, location and scope of the desalination project and chart a roadmap for project implementation. The first step of project planning is to determine the area that the desalination plant must serve, identify the type of water use and assess the water demand and quality requirements of each water customer over the useful life of the desalination project, typically 25 to 30 years.

Once the project size and service area are determined, the next step of the planning process is to define the project. This requires identifying the most viable plant site location, intake and discharge type and configurations, characterization of source water quality and selection of the treatment process.

The selection of the most cost-effective and environmentally sound desalination project location and configuration is based on a thorough evaluation of a number of alternatives for key desalination project components such as saline source water intake, concentrate discharge, pretreatment, RO system, post-treatment and product water delivery system.

Once the project scope and schedule are defined, the project environmental impact assessment must be prepared. Project entitlements such as legal rights to land use, water rights for source water collection; easements for project-related infrastructure; rights-of-way; electric power supply agreement; and environmental permits, licenses and other regulatory, legal and contractual documentation, need to be obtained. This process can take several months to one of more years, depending on the governance environment and project size and complexity.

2. MAIN CONSIDERATIONS

2.1. Service Area

The service area requiring supply of fresh water from the desalination plant is typically determined by the water supply agency (authority) in the area. The area serviced by the desalination plant is selected based on jurisdictional boundaries, demand and location of the main water users in the area, the existing water distribution system in area, and the distance between the water distribution system infrastructure and the potential desalination plant site/s.

The boundary of the desalination plant service area may also be influenced by the ability of the water authority to supply lower cost water to the same area from one or more other sources, or to

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increase the level of water conservation and/or water reuse in this area in order to balance water demand and supply.

Other important factors associated with the size of the service area of the desalination plant are the costs of water production and of water delivery. Usually, a larger desalination project service area will result in a larger size plant, which in turn will yield cost savings from economies of scale. On the other hand, delivering water to a larger service area may require the construction of additional costly fresh water conveyance and distribution infrastructure, which can negate the savings associated with the construction of one or more larger plants.

Due to the variables above, the optimum size and boundaries of the desalination plant service area have to be established based on a life-cycle cost benefit analysis which balances the cost savings associated with building larger desalination plant and expenditures associated with delivering the desalinated water to the final users. .

2.2. Plant Capacity

Typically, project fresh water production capacity is determined based on a comprehensive comparative evaluation of the balance between water demand and the cumulative capacity of all available traditional sources of water supply in the service area, and of alternative new fresh water resources such as reclaimed water or water generated through conservation, that can be used to cover the water demand over the entire planning period.

Usually, desalination is one of the most-costly sources of water supply available for a given service area. Desalination plant capacity is often determined based on the fresh water flow which this water supply alternative can provide during periods of prolonged drought as compared to other water supply resources, and on the incremental costs of new water supplies.

A second factor for the selection of optimum desalination plant size is the economy-of-scale benefit of building one or more large desalination plants supplying fresh water for the entire service area vs. installing a number of smaller facilities located closer to the main water users within the service area.

Supply analysis usually considers annual and daily water supply patterns, water distribution system hydraulic limitations, water quality and quantity requirements of large users in the service area, and future water demand projections. This analysis also includes requirements and costs for conveyance, connection to existing infrastructure and associated capacity limits, hydraulic distribution requirements (i.e. size of piping and equipment, and operating pressure of the water

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distribution system at the point/s of delivery of desalinated water) and system conveyance capacity limitations and potential solutions.

2.3. Plant Site

Desalination plant site selection is most often based on land availability near the main users of water and the configuration of the existing distribution system. The typical land requirements desalination plants of various production capacities are summarized in Table 1. These requirements apply for both seawater and brackish water desalination facilities.

The plant site footprint requirements in Table 1 are based on a comparative review of over 40 desalination projects worldwide. However, sometimes environmental and zoning regulations, physical constraints and/or soil conditions associated with a particular site may yield smaller or larger plant site requirements.

In some cases, when the available site is located in a densely populated area or land costs are at premium, the desalination plant can be located at a fraction of the site footprint shown in Table 1.

Table 1: Desalination Plant Land Requirements

Plant Capacity (m^3/day)	**Typical Plant Site Land Requirements**	
	m^2	**acres**
1,000	800 – 1,600	0.2 to 0.4
5,000	2,500 – 3,200	0.6 to 0.8
10,000	4,500 – 6,100	1.1 to 1.5
20,000	10,100 – 14,200	2.5 to 3.5
40,000	18,200 – 24,300	4.5 to 6.0
100,000	26,300 – 34,400	6.5 to 8.5
200,000	36,400 – 48,600	9.0 to 12.0
300,000	58,700 – 83,000	14.5 to 20.5

Note: Land requirements based on conventional plant layout; compact plants may require less land.

Development of more compact plant layout requires some of the main treatment equipment and systems to be installed below ground or in multi-story buildings, which is usually more costly than housing all plant treatment facilities in single-story buildings at or above site grade.

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The most viable site location for a given project is usually determined through a cost-benefit analysis of several alternative sites within the plant service area. Potential sites must meet the following requirements as a minimum:

- adequate site size, configuration and footprint;
- accessibility from existing main roads, highways, etc.;
- proximity (preferably within 8 km/5 miles) to points of delivery of desalinated water and to source of electrical supply;
- proximity (preferably within 1.0 km/0.6 miles) from to the source of saline water and the location/s of concentrate discharge;
- suitable land planning and zoning requirements;
- minimal soil or ground water contamination, vegetation, debris, and existing surface and underground structures and utilities;
- location of the site outside of environmentally sensitive areas such as wildlife sanctuaries, migratory bird stopover sites, and natural habitats of endangered species;
- location of the plant intake and outfall away from areas of high biological significance and sensitivity such as coral reefs; kelp/seagrass beds; aquatic animal sanctuaries; water habitat restauration zones; and highly productive coastal wetlands.
- reasonable costs for obtaining entitlements associated with the use of and access to the desalination plant site (i.e. less than 0.5 % of the total plant construction costs);
- adequate distance (at least 30 m/100 ft or more) away from residential dwellings, hotels, hospitals, schools, places of worship, and other developments that are sensitive to increased levels of noise and traffic during plant construction and operations.

After potential sites are identified, a number of engineering and environmental review activities are typically completed for each site:

- geological reconnaissance survey;
- land zoning and real estate ownership and cost survey;
- site flooding analysis – the site should be located above the 100-year flood line;
- traffic/access survey;
- survey of existing above and underground utilities and structures (subsurface utility survey);
- biological and archeological surveys;
- evaluation of near- and offshore marine resources with a focus on the type, environmental sensitivity, and location of aquatic species inhabiting the desalination plant intake and discharge areas;

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- review of near and off-shore bathymetry, hydrology, and geology;
- identifying the seasonal location of near and offshore currents that may impact intake water quality and the dissipation and trajectory of concentrate discharge.
- assessment of the plant site risks associated with potential impacts on the plant intake, outfall and facilities of beach erosion/siltation, flooding, severe storms/hurricanes and tornadoes, and earthquakes/tsunamis;
- preliminary analysis of the saline source water quality in terms of mineral and organic content;
- conceptual desalination plant design, layout and implementation schedule; and
- identification of alternative routes for delivery of the desalinated water to the distribution system.

The engineering information collected from the above site studies and investigations is typically compiled into project site alternatives product water delivery routes that are then ranked based on their merits and potential disadvantages. The most viable site is selected on the grounds of a comprehensive site evaluation and cost-benefit analysis of project alternatives.

3. INTAKE TYPE AND LOCATION

Desalination plant intakes are configured and designed to collect saline source water of adequate quantity and quality reliably and sustainably and to facilitate cost-effective production of desalinated water with minimum impact to the terrestrial and aquatic environments in the vicinity of the project location. Intakes are thus important components of the plant, and their type and location have a measurable impact on the quality, cost, and potential environmental impacts of plant operations.

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 saline source water directly from a surface water body (brackish river or lake, the ocean, etc.) via on-shore or off-shore inlet structure and pipeline interconnecting this structure to the desalination plant. Subsurface intakes, such as vertical and horizontal wells, slant wells, and infiltration galleries are typically used to collect saline water from brackish aquifers for BWRO desalination and from near- or off-shore coastal aquifers for SWRO desalination. Both open and subsurface intakes have functional and capacity constraints and their operation can potentially have environmental impacts.

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3.1. Brackish Water Intake Planning Considerations

Subsurface Intakes. Most brackish water for desalination is collected from groundwater aquifers. The main focus in the initial planning phase of brackish water desalination projects is to find one or more aquifers of adequate size and water quality which can sustainably provide source water over the useful life of the project. Since in many states/and or locations, groundwater ownership is attached to the ownership of the land, securing the rights for groundwater extraction/use and ownership are also of critical importance for the viability of the selected project.

Once the location of an adequate source water aquifer is identified, this aquifer needs to be characterized in terms of transmissivity, thickness, water quality and potential interconnection with other aquifers. The productivity of the target source water aquifer and the projected capacity of the individual extraction wells is determined based on a number of aquifer type, size, water quality and sustainable yield studies including:

- hydrogeological survey which includes the collection of aquifer formation deposits for visual classification and grain-size distribution analysis as well as for groundwater table level determination;
- installation and operation of test and observation (monitoring) wells to determine the safe aquifer water extraction yield;
- collection of samples for groundwater quality/contamination analysis; and
- hydrogeological modeling of well yield, radius of influence and water quality changes over time as well as groundwater movement and interference with existing fresh and brackish water collection fields.

If the target brackish source water aquifer is already in use, water quality information from existing wells can be applied for projecting of the source water quality of the new wells. However, this water quality information alone may not be adequate to predict changes of aquifer water quality as a result of the increased rate of extraction from this aquifer.

Extracting additional volume of water from a given aquifer will always result in the modification of the natural groundwater movement regime in the aquifer. Some brackish groundwater aquifers are density stratified and as lower salinity water is extracted from the top portion of the aquifer, a higher salinity groundwater propagates upwards and increases the desalination plant feed water salinity over time. In addition, for semi-confined aquifers, ground water from an adjacent aquifer can move to the main water extraction aquifer for a given project.

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If the water quality of the adjacent aquifer is very different from that of the main aquifer, the overall plant source water quality may change over time. Therefore, it is of critical importance to complete predictive plant source water quality modeling as a part of the project planning process.

The prime criteria for selecting the most suitable location for the BWRO project source water aquifer are its safe yield capacity and its proximity to the desalination plant site. The presence of potential sources of subsurface or surface contamination which can propagate and contaminate the plant source water (i.e. intake well proximity to unlined sanitary or hazardous waste landfills; leaking fuel oil storage tanks; cemeteries leaking highly toxic preserving solutions such as formaldehyde; industrial or military sites of known ground water or surface water contamination, etc.) means the site is not suitable.

Another issue of importance is the proximity of the desalination plant intake wells to existing fresh water supply wells and the potential for the desalination plant well operation to result in the decrease in the fresh water well production capacity.

Surface Water Intakes. At present, less the 10% of the brackish water desalination plants worldwide have surface water intakes. Such intakes are typically located in the confluence of river and an ocean or sea. One of the largest desalination plants with such intake at present is the Beckton desalination plant near London, United Kingdom (Figure 1). The plant has capacity of 150,000 m^3/day (40 MGD) and is operated by Thames Water. The criteria for selection of location and configuration are similar to these of open seawater intakes.

3.2. Seawater Intake Planning Considerations

Subsurface Intakes. Subsurface intakes, and more specifically vertical beach wells, are the most commonly used type of intakes for *small* size seawater desalination plants. The individual size of such wells can have production capacity of between several hundred and ten thousand cubic meters per day.. Shallow vertical wells are the lowest cost type of intakes thus their popularity. As such intakes filter the source water slowly through the aquifer soils, they usually have low environmental impacts and produce better water quality than open ocean intakes.

If a coastal seawater aquifer of adequate hydrogeological characteristics and yield is available within 10 km/6 miles of the desalination plant site, such intake is often the preferred choice. Typically permeable sand and limestone/dolomite type geological formations of transmissivity of 1,000 m^3/day per meter (0.088 MGD/foot) or higher are the most suitable type of strata for the construction of seawater well intakes.

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Figure 1: Surface Water Intake of Beckton Desalination Plant, London, UK

Productivity of the Coastal Aquifer. The capacity of the coastal aquifer and the quality of water such aquifer can yield are the two most important factors which define the size of the seawater desalination plant and often, its location. Hydrogeological study is a critical component of the SWRO desalination project planning process and aims to determine the aquifer's safe yield and sustainable water quality.

Beaches and shallow bays which have low transmissivity, contain large quantity of silted beach deposits, and are poorly flushed are unsuitable for installation of beach well intakes. Beach wells and near shore open intakes use the same seawater as a source. In desalination plants with open intakes the solids in the source seawater are removed in the plant pretreatment filtration system. With beach well intakes, the same amount of solids is retained on the ocean floor while the filtered water is slowly conveyed through the beach sub-terrain formation until it reaches the well collectors.

The wave action near the ocean floor allows the solids separated from the beach well source water to be dissipated in the ocean. If the bay area is not well flushed, then these solids will

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accumulate on the ocean floor and will ultimately reduce the well capacity and negatively impact the source water quality.

Useful Life of Beach Well Intakes. Depending on the site specific conditions in the vicinity of the subsurface intake collection area, beach wells may have a shorter useful life compared to open ocean intakes. The useful life of open ocean intakes is typically between 30 and 100 years, depending on the quality and type of materials of construction, and configuration.

Without major refurbishment, beach wells will typically operate at design capacity for a period 10 to 20 years. Over time, the beach well yield may diminish due to naturally occurring scaling of the well collectors caused by chemical precipitates or/and bacterial growth. The rate of well yield decrease with time is difficult to predict and requires specialized expertise and detailed studies. Therefore, beach well intakes are usually designed with 20 to 25% reserve/standby well capacity, which adds to their capital costs and the size of the impacted beach shore area.

Beach erosion can also significantly impact the useful life of the intake wells. As seen on Figure 2, if the well intake area is exposed to high rate of beach erosion, wells may loose soil support, productivity and structural integrity. Therefore, beach erosion may shorten the useful life of the beach wells significantly, and may increase the overall life-cycle water production cost.

Due to its significant potential impact on the intake system operation and costs, beach erosion in the vicinity of the intake location has to be thoroughly investigated and considered prior to selection. If the selected beach site has a high potential for erosion, then anti-erosion measures need to be implemented. It is preferable to use deep open intake or install the intake wells inland in an area outside of the zone of active beach erosion.

Beach erosion may also impact the useful life and integrity of open intakes. Therefore, in coastal zones exposed to active beach erosion the first several hundred to one thousand meters of the intake pipeline closest to the shore are typically installed under the ocean floor at depth beyond the zone of active beach erosion.

The useful life of a well-designed and operated seawater desalination plant is 25 to 30 years. As beach wells often have a shorter useful life span than that of the desalination plant, in the worst-case scenario, two sets of beach wells may be required over the useful life of the SWRO plant. The need for replacement of some or all of the original beach wells after the first 10 to 20 years of operation will also magnify the shoreline impacts of the beach wells and increase the overall cost of water production. Therefore, the potential difference between the useful life of beach

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wells and open intakes has to be reflected in the life-cycle cost comparison associated with intake selection.

Figure 2: Seawater Intake Well Exposed to Beach Erosion

Source Water Pretreatment Requirements. Seawater beach wells typically yield better intake water quality than open intakes in terms of turbidity, algal content and silt density index. These are the key parameters associated with the selection, sizing, complexity and costs of the desalination plant pretreatment system. It should not be assumed that pretreatment will not be required however: as this is only the case for very site specific favorable hydrogeological conditions (i.e., the wells are located in well flushed ocean bottom or shore; are sited away from surface fresh water influence; and are collecting seawater from a coastal aquifer of uniformly porous structure, such as limestone or dolomite).

Long term operational experience at numerous small seawater desalination plants in the Caribbean and several medium-size plants in Malta which have well intakes located in limestone and other favorable rock formations, indicates that such plants can successfully operate with minimal pretreatment (typically bag or cartridge filters and/or sand strainers) ahead of SWRO

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pretreatment. However, most seawater desalination plants using subsurface intakes have to include an additional granular or membrane filtration step prior to RO membrane salt separation to be able to process source water collected by subsurface intakes.

Existing experience with the use of beach wells for seawater desalination in California and at the largest beach-well seawater desalination plant on the West Coast in Salina Cruz, Mexico indicate that some desalination plants using beach wells may face a costly problem – high concentrations of manganese and/or iron in the intake water. Unless removed ahead of the reverse osmosis membrane system, iron and manganese may quickly foul the cartridge filters and SWRO membranes, and render 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 "greensand" pretreatment filters ahead of the SWRO system. This pretreatment requirement may significantly reduce the cost benefits of the use of beach wells as compared to an open intake. Open seawater intakes rarely have iron and manganese source water quality related problems as open ocean water does not contain these compounds in significant quantities that can cause RO membrane fouling.

An example of a beach well desalination plant which faced an elevated source water iron problem is the 4,500 m^3/day (1.2 MGD) Morro Bay SWRO facility located in Northern California, USA. The plant source water is supplied by five beach wells with production capacity of 1,100 m^3/day to 1,900 m^3/day (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 surface loading rate of 6.1 m^3/ m^2.h (2.5 gpm/sq ft). For comparison, a typical open-intake desalination plant is designed for pretreatment loading rates of 10 to 13.5 m^3/ m^2.h (4.0 to 5.5 gpm/sq ft) and therefore, will require less pretreatment filtration capacity.

The largest existing Pacific-coast seawater desalination plant in Salina Cruz, Mexico has also faced iron and manganese challenges, which have been resolved by the installation of pretreatment filters and chemical conditioning of the beach well water. The existing experience

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shows that the costs for pretreatment of seawater with high iron/manganese content collected by a beach well intake are typically comparable or higher than these for pretreatment of seawater collected using an open-ocean intake.

Source Water Quality Variations. Open ocean intakes provide relatively consistent seawater quality in terms of total dissolved solids concentration. The intake source water TDS concentration data collected for the development of the Huntington Beach seawater desalination project in Southern California, USA indicate that the open intake salinity varied within 10% of its average value of 33.5 ppt.

Although in general beach wells produce source water of consistent salinity, they can also yield water of unpredictably variable TDS concentration with swings exceeding over 30% of the average. For example, the TDS concentration of the two operational wells at the Salina Cruz water treatment plant vary in a wide range – for well No. 2 between 16.8 and 21.8 ppt, and for well No. 3 between 17.8 and 19.8 ppt. The wide range of source salinity concentration in this case is explained by fresh groundwater influence.

A similar trend was observed at the Moro Bay SWRO plant in California. During the plant's initial operation in 1992, the well water TDS was approximately 26,000 mg/L. In December 2001, the TDS of the intake water was 6,300 mg/L. The December 2002 data for the same plant indicate intake salinity of 22,000 mg/L.

The wide range of intake salinity in systems using beach wells over time requires the installation of variable frequency drives on the high pressure pump motors for efficient power use control, which ultimately increases the construction cost of such system and complicates its operation.

One important issue to consider when assessing the viability of using beach wells is whether intake well salinity can change unpredictably over time when the well operation is influenced by fresh water inflow to the well source water aquifer. This uncertainty of intake water quality increases the risk of uncontrollable increase in unit cost of water production over time and has to be considered when comparing the overall life-cycle costs of the desalination plant operations.

Therefore, the beach well intake water quality must be characterized by installing a set of test wells and collecting water quality samples under a variety of operational conditions. Thorough year-round water quality characterization is of high importance for beach wells which source water may be influenced by fresh groundwater aquifers with seasonal fluctuation of water quality.

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Emerging Contaminants. Usually open ocean intakes are considered less viable source of water for desalination plants in areas located close to wastewater discharges or industrial and port areas. However, the open intake seawater is typically free of endocrine-disruptor or carcinogenic type of compounds such as: Methyl tert-butyl ether (MTBE), N-Nitrosodimethylamine (NDMA) and 1,4-dioxane. Long-term water quality data collected for the development of the Huntington Beach and Carlsbad SWRO projects in Southern California and a number of other desalination plants worldwide, confirm this observation.

Beach well water may contain difficult to treat compounds especially when they are influenced by contaminated groundwater. Example is the Morro Bay SWRO plant, where beach well intake water was contaminated by MTBE caused by a leak from an underground gasoline tank. MTBE is a gasoline additive. Similar problems were observed at the California's Santa Catalina Island 500 m^3/day (0.132 MGD) seawater desalination plant that uses beach well intake.

The compounds of concern can be treated by a number of available technologies, including activated carbon filtration, UV irradiation, hydrogen peroxide oxidation, ozonation, etc. This additional treatment may increase the overall desalinated water production cost considerably.

Although beach wells have proven to be quite cost-competitive for plants of capacity smaller than 4,000 m^3/day (1 MGD), open surface ocean intakes have found significantly wider application for large SWRO desalination plants. At present, worldwide there are less than a dozen operational SWRO facilities with capacity larger than 20,000 m^3/day (5.3 MGD) using beach well intakes. The largest SWRO facility with beach wells is the 54,000 m^3/day (14.3 MGD) Pembroke plant in Malta. This plant has been in operation since 1991.

The largest SWRO plant in North America which obtains source water from beach wells is the 15,000 m^3/day (3.8 MGD) water supply facility for the Pemex Salina Cruz refinery in Mexico. This plant also has the largest existing seawater intake wells – three Ranney-type radial collectors with capacity of 15,000 m^3/day (3.8 MGD), each.

Surface Water Intakes for SWRO Plants. Open intakes typically include an inlet structure (forebay) with coarse bar screens, a source water conveyance pipeline or channel connecting the inlet structure to an onshore concrete screen chamber and mechanical fine screens in the chamber.

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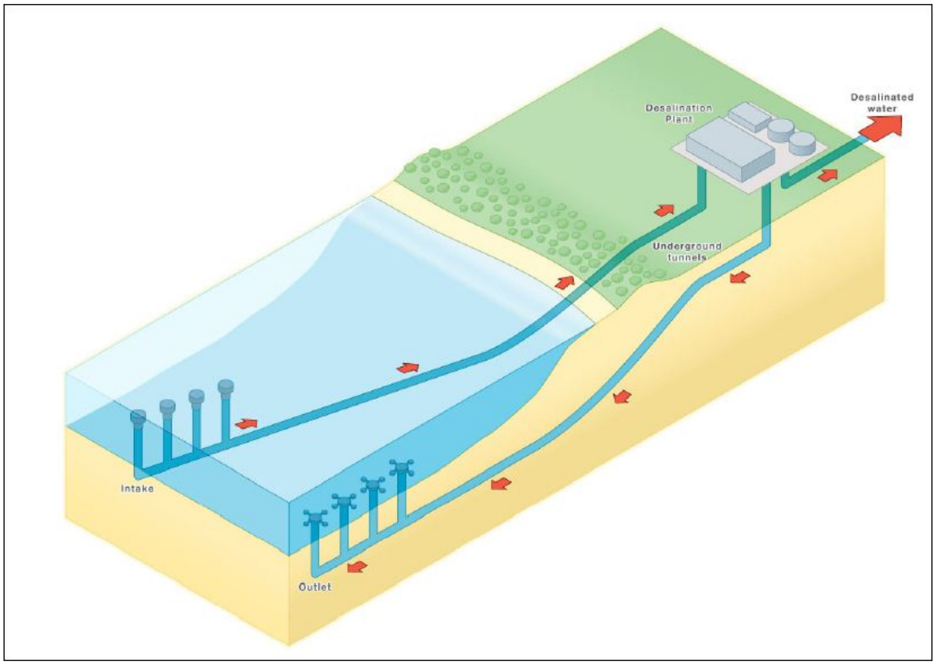

Figure 3: Desalination Plant with Offshore Intake

Depending on the location of the inlet structure, the intakes can be on-shore or off-shore. Offshore 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 3).

The open intake inlet system may include passive wedgewire screens (see Figure 4). The use of such screens eliminates the need for coarse and fine screens on shore. Wedgewire screens are cylindrical metal screens with trapezoidal-shaped "wedgewire" slots with openings of 0.5 to 10 mm (typical size – 3 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 higher than 0.3 m/s (1.0 fps) are naturally available . This high cross-flow velocity allows organisms that will otherwise be impinged on the wedgewire intake, to be carried away from the screens with the flow.

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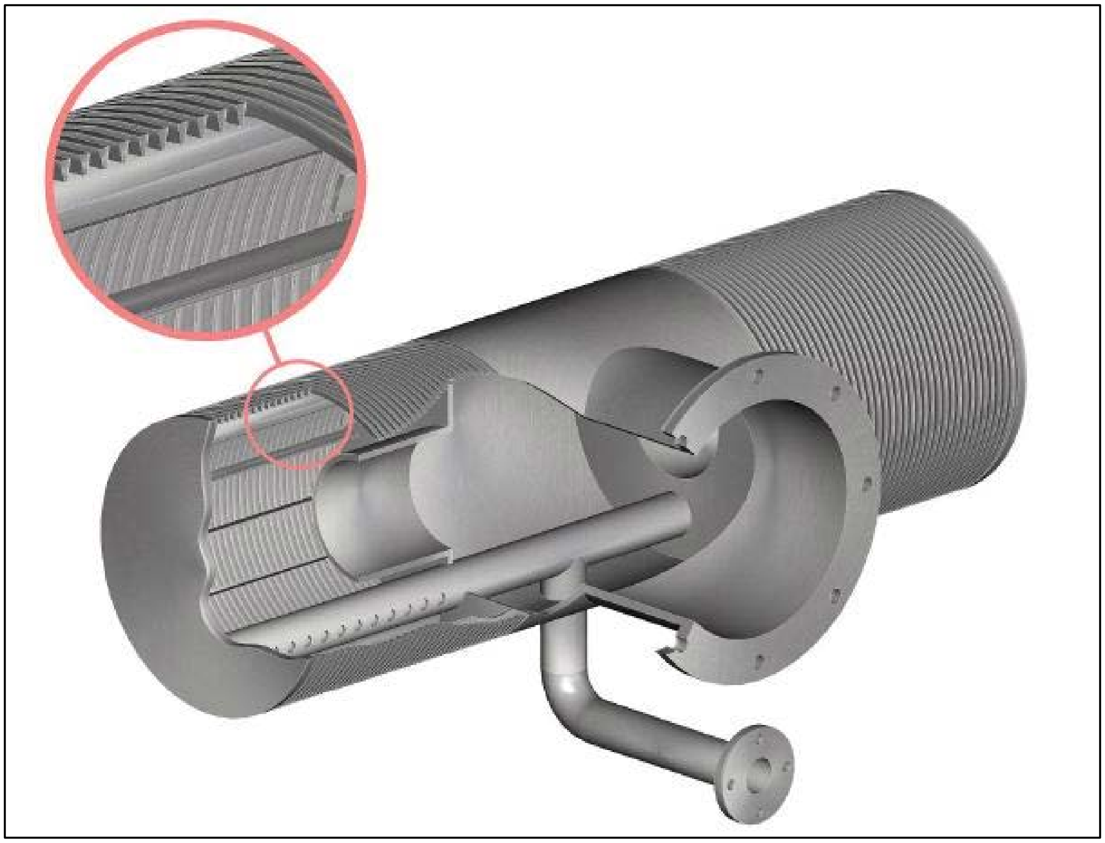

Figure 4: Wedgewire Screen

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.

Collocated intake is a type of open intake for desalination plants co-sited 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. This warmer cooling water discharged by the power plant is less viscous than the ambient ocean water, which reduces the energy needed for desalination by membrane separation. In addition, the use of collocated intakes in most cases eliminates the need for construction of separate intake and outfall for the desalination plant, which reduces the overall project capital expenditures.

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Open intakes have some of the same challenges associated with the siting and construction of beach wells including beach erosion and impacts from high-magnitude earthquakes and storms. In addition, since open intakes collect water directly from the water column, the source water could contain large quantities of debris, algae, silt, hydrocarbons, and other contaminants of anthropogenic or natural origin. Since RO membranes are easily fouled by such contaminants, use of open intakes usually requires elaborate seawater pretreatment as compared to the construction of beach wells.

Considerations for Selection of SWRO Plant Intake Type. At present, open-ocean intakes are the most widely used type of intake technology worldwide, and can be installed in practically any location and built to 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, 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.

Subsurface intakes have found somewhat limited application, and mainly for relatively small plants where only a small number of beach wells is required. This is due in part to the difficulty in finding favorable hydrogeological conditions in the vicinity of the desalination plant site. Land availability is a further constraint often encountered in densely populated coastal areas where large desalination plants are needed.

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

Intake selection should be based on a reasonable balance between the costs and environmental impacts associated with production of water. 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.

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4. SOURCE WATER QUALITY

Selection of saline water source and thorough analysis of its water quality are of critical importance for the successful planning, implementation and long-term operation of desalination projects. Source water quality has impact on all key treatment processes of desalination plants and their construction and operation costs.

Typically, the content of total dissolved solids, as well as the concentration of main ions (sodium, calcium, magnesium, bromide, boron, chlorides, sulfates, carbonates, and bicarbonates) in the source water are of prime importance for planning of both brackish and seawater desalination plants. These parameters, along with water temperature and pH, drive the design and configuration of the reverse osmosis system of most desalination projects since usually, over 60% of plant construction costs and O&M expenditures are associated with the RO facilities. If brackish water of adequate quality and yield is available in the service area, the construction of brackish rather than seawater desalination plant will usually be less costly, and is almost always preferred. Mostly, such choice is limited by the availability of suitable, plentiful brackish water sources especially for larger desalination projects. Compared to the ocean, which is practically "limitless" source of drinking water, confined groundwater aquifers have volume and recharge rate constrains, which limit the safe yield of the wells used for groundwater collection and the associated desalination plant capacity.

Groundwater collected via subsurface intakes can contain high concentrations of dissolved and colloidal iron and manganese in reduced form, colloidal silica, nitrates, ammonia, cyanide and radionuclides and may have a very low level of oxygen. The concentrations of these source water quality constituents must be evaluated in detail as they have significant impact on desalination project planning and design.

Furthermore, some brackish groundwater sources may have an elevated concentration of natural organic matter that causes discoloration of the source water or may contain odorous gases such as hydrogen sulfide. Presence of such contaminants at high levels typically requires additional treatment to produce desalinated water of drinking quality.

On the other hand, surface saline water sources (including brackish lake or river waters, or open ocean seawater) can periodically be exposed to algal blooms or contain floating oil, grease and hydrocarbons as well as man-made pollutants originating from surface wastewater discharges. In addition surface source waters can have high levels of suspended solids and nutrients which

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typically originate from surface water runoff and/or anthropogenic contamination. Such source water quality contaminants must be taken into consideration in project planning and can impact on plant design and costs.

Since water quality can vary significantly over time, source water characterization should encompass both typical conditions and events which result in extremely low of high values of the water quality parameters discussed above. These include heavy storms and ship traffic, dredging of the intake area, algal blooms, seasonal changes in the direction of underwater currents and near-shore winds, and periodic industrial and municipal wastewater discharges which fluctuate in volume and quality daily and seasonally.

Source water quality has a measurable impact on the cost of production of desalinated water. In general, both construction and O&M costs increase with the increase in the total dissolved solids concentration of the source water and decrease in water temperature. Source seawater TDS concentration is directly related to the SWRO system design feed pressure, the overall plant design recovery and configuration. The use of lower salinity source water typically allows reducing the costs associated with construction and operation of the RO system and at the same time to increase plant recovery.

The consistency of the desalination source water quality is often equally important for a successful desalination plant design and operation, as is the level of TDS in the source water. For example, construction of a plant intake near the confluence of river into the ocean can reduce the overall source water salinity and therefore, can decrease the plant's total energy use. However, if the river water carries heavy loads of turbidity, organics, nutrients, and man-made pollutants the removal of the contaminants contributed by the river water may require a more elaborate desalination pretreatment, which in turn may negate the cost savings from use of lower salinity water.

5. PRODUCT WATER QUALITY

5.1. Water Quality of SWRO Desalination Plants

Mineral Content. Content of minerals in the permeate produced by RO membrane desalination plants may vary depending on the ion composition and temperature of the saline source water, the RO system configuration and the salt rejection of the membranes.

Concentrations of TDS (300 to 500 mg/L), chlorides (150 to 240 mg/L) and sodium (90 to 180 mg/L) in the permeate generated by single-pass SWRO systems are typically within US EPA

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regulatory requirements and WHO drinking water quality guidelines. However, if such water is intended to be used for irrigation of crops sensitive to salinity (i.e. avocados, strawberries) and/or ornamental plants (some species of palm trees, flowers or grasses), the introduction of this desalinated water into the distribution system may pose potential challenges unless the desalinated water is diluted by other water sources in the distribution system to below 250 mg/L of TDS, 120 mg/L of chlorides and 80 mg/L of sodium, respectively.

Alternatively, seawater treatment by two-pass RO system can produce water quality suitable for all municipal, agricultural and horticultural uses. Similarly, treatment of brackish water with typical brackish RO membranes in single-pass RO systems can meet the product water quality targets for TDS, sodium and chloride listed above.

In addition, the ratio of sodium (Na^{+}), calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in irrigation water, referred to as Sodium Adsorption Ratio (SAR), can also impact on some crops. Excessively high SAR value (i.e. high level of sodium and low content of calcium and magnesium) contributes to soil dispersion and structural breakdown, which in turn results in filling up of the soil pores with finer soil particles, and ultimately in reduced water and nutrient infiltration rates, and reduced crop yield.

The permeate produced from seawater by single-pass RO systems is relatively high in sodium and very low in calcium and magnesium as compared to traditional water supply sources. As a result, the SAR value of this permeate is usually unacceptably high (8 to 12 meq/L) for direct agricultural irrigation of most crops. However, RO permeate post-treatment including calcium addition and as needed second RO pass treatment, allows reducing the SAR of the desalinated water to acceptable levels of 4 to 6 meq/L or less which makes it suitable for agricultural irrigation

Typically, reverse osmosis permeate has significantly lower concentrations of potassium – K (<1.0 mg/L), calcium – Ca (0.3 to 0.5 mg/L), and magnesium – Mg (0.4 to 4.0 mg/L) as compared to water produced from conventional fresh surface water sources (1 to 3 mg/L of K; 4 to 30 mg/L of Ca; and 10 to 40 mg/L of Mg, respectively). At these low mineral levels the desalinated water is of inferior taste, and has higher corrosivity than conventional water sources. Usually, these water quality challenges are addressed by the addition of calcium hardness and alkalinity to RO permeate at concentration of 60 to 120 mg/L as $CaCO_3$.

While still under debate, there are recommendations from the World Health Organization and the agricultural community to establish a minimum limit for magnesium in public water supply

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based on its benefits to human health and agriculture. Typically, desalinated water contains magnesium levels of less than 2 mg/L while mineral supplementation to enhance human health protection and nutrient value for agricultural application is recommended at levels of 5 to 10 mg/L and 15 to 20 mg/L, respectively.

The levels of boron and bromide in desalinated water are usually an order of magnitude higher than these in conventional fresh water sources. For example, typical river water has boron concentration of 0.05 to 0.20 mg/L, while source seawater boron levels are usually between 4.0 and 6.0 mg/L, and the boron content of desalinated water treated by a single-pass SWRO system is usually between 0.7 and 1.5 mg/L. Two-pass SWRO systems typically produce water of boron levels between 0.3 and 0.5 mg/L. Both of these ranges are well within the boron limit of 2.4 mg/L recommended in the 2011 WHO drinking water guidelines.

The US EPA and all other states except California have not established drinking water regulatory requirements for boron. The California Department of Public Health has a boron action level of 1 mg/L. Some countries such as Israel, Cyprus, Qatar, Bahrain, and UAE have boron limits in the drinking water of 0.5 mg/L or less. The low boron limits in these countries are driven by the use of a large portion of the desalinated water for irrigation of citrus fruits (oranges, lemons, lime, etc.) and by the need to improve the quality of traditional water sources which have naturally high boron levels. Boron concentrations above 0.5 mg/L are known to have a negative impact on citrus fruit yield, size and color.

Bromide levels in fresh water sources are usually between 0.05 and 0.30 mg/L, while source seawater has bromide concentration of 55 to 85 mg/L. The content of bromide in permeate produced by single pass SWRO systems is typically between 0.6 and 0.9 mg/L. Two-pass SWRO systems can produce bromide levels in a range of 0.2 to 0.4 mg/L.

Drinking water can exhibit unpleasant taste and odor changes if desalinated water with bromide concentration of 0.4 mg/L or more is blended with other water sources that contain phenols. Bromide concentration of desalinated seawater may also have a significant effect on the finished water quality if this water is disinfected using chloramines rather than chlorine, or if it is ozonated.

Disinfection of desalinated water with chlorine only (in the form of chlorine gas or sodium hypochlorite) creates very stable chlorine residual that shows minimal decay over long periods of time (60 days or more). Therefore, when desalinated water is used as the main source of water

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supply in a given service area, chlorination (rather than chloramination) is the most commonly applied disinfection method.

However, applying a combination of chlorine and ammonia to desalinated water to create chloramines (a practice widely used in the US), may yield unstable total chlorine residual that decays rapidly (within several hours) to unacceptably low levels of 0.3 mg/L or less. This de-stabilizing effect of bromides on chloramine residual is very pronounced for desalinated water which contains bromide levels higher than 0.4 mg/L. The destabilizing chloramine residual impact of desalinated water with high bromide can be mitigated either by producing desalinated water of lower content of bromide (higher quality) or by super-chlorination (i.e. applying initial chlorine at doses of 3.5 to 4.0 mg/L).

Ozonation of desalinated water with bromide concentration of 0.4 mg/L or more may result in the formation of an unacceptably high concentration of bromate which exceeds most drinking water regulations worldwide, which stipulate maximum bromate limit of 10 µg/L.

Organics. Desalinated seawater produced by SWRO systems usually contains an order of magnitude lower level of organics than most traditional fresh water sources (rivers, lakes and groundwater). When disinfected with chlorine, the content of disinfection byproducts (DBPs) in desalinated water is very low.

Specific class of organic compounds that are of concern for the quality of desalinated water originating from surface water sources are low-molecular weight toxins such as domoic acid and saxitoxin, often referred to as algal toxins. Such toxins are generated during algal blooms when the concentration of algae in the seawater increases several hundred times.

Algal bloom events are accompanied with an overall deterioration of source seawater quality, including water discoloration, oxygen depletion and elevated content of organics released from algal cell decay. Certain algae, such as *Pseudo-nitzshia serata* have red pigmentation and their excessive growth during algal blooms results in reddish discoloration of the seawater - red tide - as illustrated in Figure 5.

While a number of other organic toxins such as yessotoxin, okadaic acid, brevetoxin, microcystin and nodularin, are generated during algal blooms, domoic acid and saxitoxin are two algal toxins of specific interest as their molecular weight and size are comparable with the average molecule rejection size (molecular cut-off) of the SWRO membranes and theoretically some of them might pass through the membranes. Domoic acid is of particular concern because it concentrates up to

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several hundred times in shellfish and when ingested with the contaminated shellfish it can cause amnesic shellfish poisoning.

Figure 5: Red Tide near Carlsbad, California

A common practice of health departments of coastal United States, Australia, and other countries worldwide is to monitor concentration of domoic acid in shellfish tissue and to issue advisories for temporary discontinuation of shellfish harvesting when the concentration of domoic acid in the tissue exceeds 80 µg/L.

Despite the small molecular weight of some of the algal toxins, reverse osmosis membranes can completely reject such organic compounds and thereby can produce safe drinking water even when the source seawater is exposed to heavy algal blooms. Rejection of domoic acid and saxitoxin by SWRO membranes have been studied at the West Basin Municipal Water District and Carlsbad pilot SWRO plants in Southern California, US in 2005 during a 50-year red-tide algal bloom. The test results at both facilities indicate that the two algal toxins are completely

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rejected by the SWRO membranes and permeate produced by these membranes is safe for human consumption.

Pathogens. While SWRO membranes are not an absolute barrier for microbial contaminants, they are typically expected to achieve 4 to 6-logs of pathogen removal or more. Pretreatment filtration system upstream of the RO desalination membranes typically provides an additional 2 to 4-logs of pathogen removal.

A virus-challenge study completed by the US Bureau of Reclamation using state-of-the-art pretreatment systems and SWRO membranes clearly indicates that membrane seawater desalination plants can consistently achieve 6 to 12-log removal of microbial contaminants (see Figure 6).This figure shows log removal of conventional media filtration (CMF) pretreatment, (i.e. single-stage sand/anthracite media filters); ultrafiltration (UF) membrane seawater pretreatment; seawater reverse osmosis membranes (SWRO); and a combination of conventional media filtration and SWRO treatment of seawater (CMF-SWRO) and ultrafiltration pretreatment and SWRO separation (UF-SWRO). Challenge testing in this study was completed using MS-2, PRD1 and Fr viruses.US EPA regulations require drinking water production plants, including desalination facilities, to incorporate in their treatment process multiple barriers for removal or inactivation of pathogens.

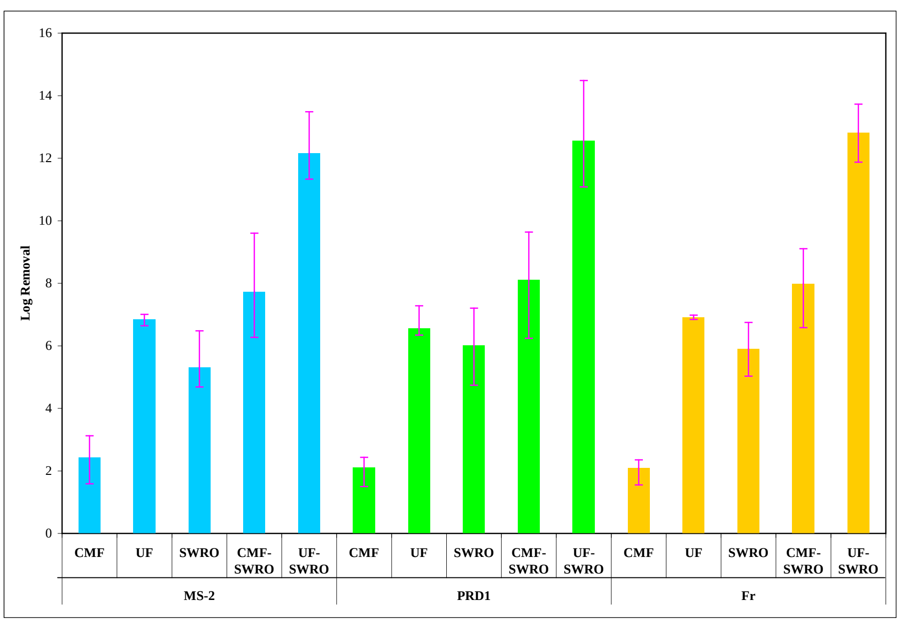

Figure 6: Pathogen Log Removal of Seawater Pretreatment and RO Systems

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Table 2 summarizes the minimum and maximum reduction requirements and the credits given to typical treatment processes employed in seawater and brackish water desalination. Analysis of Table 2 indicates that a typical SWRO desalination plant including conventional pretreatment, followed by RO membrane system and chlorine disinfection can be assigned a total of 6-log virus removal credit, 5-log giardia removal credit, and 4-log Cryptosporidium removal credit, which matches closely the maximum log reduction requirements that may be imposed on a desalination project even under worst-case scenario source water quality.

Table 2: Pathogen Log Reduction Credits Assigned to Typical Treatment Processes

Pathogen	Log Reduction Requirement(1)(2)		Log Reduction Credits Allocated for Treatment Processes by State Regulatory Agencies						
	Min	**Max**	**Slow Sand Filtration**	**Conventional Pre-treatment**	**MF**	**UF**	**RO(5)**	**UV**	**Chemical Dis-infection(3)**
Viruses	4	6	1	2	0.5 - 1(4)	1 - 4(4)	2	0	2
Giardia	3	5.5	2	2.5	4	4	2	2	0.5
Crypto-sporidium	2	4	2	2	4	4	2	2	0

1) Maximum reduction requirements based on impaired water sources as determined by Watershed Sanitary Survey monitoring of total coliforms and Cryptosporidium monitoring.
2) States may require a minimum 0.5 log of *Giardia* or 2 log of virus disinfection beyond filtration to provide a multi-barrier treatment approach.
3) Chemical disinfection refers to the use of free chlorine following the RO process.
4) The virus removal credit for MF and UF will depend on the specific system used and the state in which the system is permitted.
5) Credits for RO are based on California Department of Public Health guidelines and may differ as more states adopt policies on desalination.

While SWRO membranes can consistently provide over 4 logs (99.99%) of pathogen rejection, due to the lack of standard procedures for RO membrane integrity testing at present, often SWRO membrane systems are typically credited with only 2-log pathogen removal by the regulatory agencies involved in public health protection. The two-log removal credit of SWRO

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systems is assigned based on the continuous monitoring of the actual membrane TDS log removal (measured as conductivity log removal).

Since SWRO membrane systems typically remove at least two logs (99%) of the source water salinity, TDS removal in this case is used as a conservative surrogate measure of pathogen removal. As the desalination industry evolves, it is anticipated that alternative membrane integrity test procedures will be developed in the future, which will allow assignment of significantly higher pathogen removal credit to SWRO membranes, reflective of their actual ability to provide very high levels of pathogen removal.

5.2. Water Quality of BWRO Desalination Plants

Mineral Content. Wide variability in brackish source waters requires site-specific analysis of the ability of product water to meet drinking water standards for various constituents. As compared to desalinated seawater, the product water from inland BWRO facilities typically has relatively lower levels of sodium and chloride and relatively higher content of other ions (typically calcium and/or magnesium cations and sulfate and/or bicarbonate anions).

Organics. Similar to SWRO membranes, brackish water RO membranes are also capable of removing over 90% of most organics contained in the source water. Due to their higher molecular weight cutoff, brackish RO membranes typically have lower rejection of organic compounds characterized by small molecular weight.

Pathogens. Brackish water RO membranes can provide over 4 logs of pathogen rejection. However, similar to SWRO membranes they are often credited with only one or two logs of pathogen removal due to the lack of standard on-line testing method that allows continuous monitoring of their actual pathogen removal and integrity.

5.3. Disinfection Byproducts in Desalinated Water

Disinfection byproducts (DBPs) include a range of compounds, such as trihalomethanes, bromine, iodine, bromates, and haloacetic acids which are formed through the interaction of chlorine (and to a lesser degree, chloramines) with organic matter and bromides in the source water or in the distribution system. Organic content of saline source water is typically high in inland surface water and variable in seawater and groundwater.

Organic content of desalinated water is usually an order-of-magnitude lower than that of most fresh surface water sources, and thus has a significantly lower organics-related DBP formation potential than traditional fresh water supplies. While RO membranes reject most organics in the source water, the process is not as efficient in removing a DBPs, which are formed when chlorine is used for source water pretreatment.

Brackish water membranes are less efficient in terms of DBP removal than seawater RO membranes. In addition, because the BWRO permeate is more often blended with source water, this blend may require enhanced post-treatment to reduce DBPs.

5.4. Blending of Desalinated Water in the Distribution System

In projects where desalinated water is not the main water supply source, blending it with other source waters of inferior quality (such as surface water or groundwater of elevated salinity) usually has a very positive effect on the quality of the water blend and therefore, it is highly desirable.

Blending of low-DBP desalinated seawater with surface water of high DBP content can reduce the overall DBP concentration of the drinking water. However, as indicated previously, when desalinated water has a high content of some unwanted minerals, such as bromide, boron, sodium, and chlorides, mixing this water with drinking water originating from other sources may have a negative impact on the blended water quality. The compatibility of the blended water sources must be taken into consideration.

Potential differences in bromide and TOC levels in the blended waters may have an effect on the DBP concentration of the blend. The type of disinfection used for the various water sources may impact DBP formation and chlorine residual stability.

Before blending, desalinated water usually has significantly lower levels of calcium and magnesium ions as well as low alkalinity concentration as compared with fresh surface water sources. Blending of desalinated water with drinking water of high hardness and high alkalinity may be sufficient to provide the needed chemical stability if the blended water meets target water quality requirements for corrosion control.

5.5. Wastewater Treatment and Water Reuse Considerations

Impact of High Boron Concentration on Reclaimed Water Quality. As previously indicated, elevated boron concentrations (above 1 mg/L), while safe for human consumption may have an impact on water use for agricultural and horticultural irrigation. As municipal activities and household detergents add approximately 0.2 to 0.3 mg/L of boron to drinking water during its conversion to wastewater, desalination treatment operations should consider the impact this addition has on water reuse applications. Additional treatment during desalination to further

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reduce boron concentrations may be necessary to achieve suitable levels if reclaimed water of elevated boron content is to be used for irrigation of sensitive plants and crops.

Low Alkalinity Impact on WWTP Nitrification. Often, desalinated water has lower alkalinity compared to other water sources. In such cases, introduction of desalinated water to the distribution system will lower the alkalinity of the influent of the wastewater treatment system processing such water. Wastewater alkalinity concentration is very important if the treatment plant has biological nitrification system, which consumes 7.14 mg of alkalinity (as $CaCO_3$) for every milligram of nitrified ammonia (as N) contained in the wastewater.

While alkalinity is added to the desalinated product water at a dosage of 40 to 100 mg/L for corrosion protection, such dosage is often inadequate to sustain the WWTP nitrification process, even though wastewater alkalinity is typically 100 to 150 mg/L higher than that of the drinking water. Possible solutions include increasing the desalinated product water alkalinity, employing biological denitrification in the activated sludge system of the wastewater plant, and directly increasing alkalinity of the wastewater treatment plant influent by feeding strongly basic conditioning chemical, such as sodium or calcium hydroxide.

5.6. Selection of Target Product Water Quality

At present, reverse osmosis desalination technology, combined with other commercially available pre-and post-RO water treatment processes, allows production of practically any water quality. The target product water quality for a given desalination project is determined based on the requirements regulating the finished product water and the specific water quality needs of the largest water users in the plant service area. If such needs are predominantly industrial or agricultural/horticultural in nature, in some cases the required desalinated water quality may be higher than that of drinking water quality.

As discussed previously, two other key factors that influence the selection of the target desalination plant product water quality are: (1) the content of specific minerals (i.e., sodium, chloride, boron and bromides) in the water, and (2) the overall water production costs. These two factors are inter-related – production of higher quality desalinated water is possible at incrementally (15 to 50 %) higher cost.

In most municipal applications, desalination plants are designed to produce water of quality compliant with drinking water regulations, especially if this water is the main source of supply for the service area. However, many utilities and municipalities worldwide use desalinated water

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as a supplemental source of water supply only and this water is blended in the distribution system with other existing water supplies.

The quality of the desalinated water can be adjusted to a target level more easily than the quality of other traditional water sources, and desalinated water is often produced at quality higher than that of the other sources and subsequently blended to improve the final product water. While this water quality improvement approach results in higher production cost of desalinated water, it is often the most cost effective overall strategy for improvement of water quality in the entire distribution system.

Another approach to determine the target desalination project product water quality is to try to match it as close as possible with the quality of the other water resources delivered to the same service area. This approach, while usually more costly, simplifies the decision making-process in terms of potential modifications which will have to be made to the existing distribution system operations and water quality.

In addition to the municipal uses discussed above, the target desalinated water quality may be driven to even higher levels of salt removal by the needs of some industrial applications, especially these where ultrapure water quality is necessary. Such applications may need the enhanced removal of sodium, silica, specific ions, oxygen, and other water quality constituents which will require RO permeate treatment through one or more additional water quality polishing processes such as ion exchange, activated carbon adsorption, advanced oxidation, etc. Such water quality polishing steps can sometimes double desalinated water costs as compared to expenditures associated with producing drinking water for potable use.

6. PLANT DISCHARGE

Typically, both brackish and seawater RO desalination plants generate three key waste streams:

- concentrate (brine) which usually has 1.5 to 5 times higher salinity than the saline source water;
- spent filter backwash water from the plant pretreatment facilities which has the same salinity as the source water; and
- spent chemicals and flush water from periodic RO membrane cleaning which usually are of lower salinity than the source water.

Of these three streams concentrate is by far the largest in volume with potential negative environmental impacts. Therefore, engineering practitioners sometimes refer to desalination plant discharge as concentrate discharge, although they are not truly synonymous.

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Management of concentrate and other waste streams associated with production of desalinated water is one of the important project planning factors that determine plant location, size and treatment processes. For a potential desalination plant site to be feasible, it has to be located within a reasonable distance (typically 0.5 to 10.0 km/0.3 to 6.1 miles) away from a suitable site/s for concentrate disposal. For a plant discharge disposal site to be suitable, it will have to have physical configuration and receiving capacity that allow for the concentrate and, if possible, other plant waste streams to be continuously disposed in an environmentally safe manner for the entire duration of the useful life of the project.

The most common method for disposal of concentrate from seawater desalination plants is surface water discharge via ocean outfall. Common concentrate discharge alternatives for BWRO desalination plants are: discharge to sanitary sewer, deep well injection and evaporation ponds. Other concentrate management methods which are not as widely practiced include spray irrigation, zero-liquid discharge (ZLD) by concentrate evaporation and salt crystallization, and beneficial use of concentrate/ocean brine mining. Such methods are either very costly (e.g., ZLD) or seasonal in nature (spray irrigation and some methods for beneficial reuse). Depending on the size of the project, especially for larger inland brackish water desalination projects, it may not be possible to apply a single method for concentrate disposal, and often such projects rely on multiple disposal alternatives.

Desalination project planning activities associated with concentrate disposal include water quality characterization of concentrate and other waste streams generated by the desalination plant, development of feasible alternatives for management of the desalination plant waste streams and selection of the most viable desalination plant discharge management alternative based on environmental impact and life-cycle cost analyses.

6.1. Concentrate

Concentrate is the largest waste discharge stream in desalination plants. The volume of concentrate generated by seawater desalination plants is significant as a typical SWRO separation process converts only 40 to 55% of the source water into desalinated freshwater. The remaining source water is rejected as concentrate. Seawater concentrate contains over 99% of all source seawater salts and dissolved constituents and its mineral content is between 1.5 and 2.0 times higher than that of the source seawater.

BWRO plants usually convert 70 to 90% of the source water into fresh water and generate relatively smaller volumes of concentrate compared to SWRO plants of the same production

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capacity. However, the mineral content of brackish water concentrate per unit volume is typically 2.5 to 6.5 times higher than that of the source water.

Concentrate water quality is largely determined by the quality of source water and the design of the desalination plant and therefore can be projected based on characterization of the source water quality. Open ocean seawater quality is usually very consistent and over 98% of seawater concentrate salinity is attributed to five dissolved minerals: sodium, chloride, sulfate, magnesium and calcium. The characterization of seawater concentrate focuses on the measurement of the concentration of these minerals, the total content of dissolved solids, conductivity, pH, temperature, turbidity, silt density index, total suspended solids and oxygen content, and concentration of organic and inorganic contaminants defined by the regulatory requirements pertinent to the discharge area.

Water quality of the concentrate generated by SWRO desalination plants with subsurface (e.g.., well) intakes is dependent on whether the coastal source water aquifer is influenced by contaminants present in surrounding aquifers. For example, alluvial aquifers often contain elevated concentrations of colloidal iron and manganese and have very low levels of oxygen, which may have a dramatic impact on the source and product water quality and on the plant concentrate. Therefore, such aquifers should also be characterized thoroughly during the planning phase of the desalination project.

Water quality of brackish water desalination processes may vary significantly between locations and may contain additional constituents, such as colloidal iron, manganese, silica, nitrates, phosphates, arsenic, cyanide, ammonia, and organics. BWRO concentrate may be dominated by sodium or calcium cations and chloride, sulfate, or bicarbonate anions. Groundwater based concentrate frequently has high levels of carbon dioxide (CO_2) and hydrogen sulfide (H_2S), which require degasification prior to discharge. Low oxygen levels in concentrate resulting from desalination of groundwater sources may also require aeration or other means to increase dissolved oxygen prior to discharge. Therefore, these water quality parameters will have to be included in the source water quality characterization.

In addition to the above water quality parameters, desalination plant concentrate should also be analyzed for acute and chronic whole effluent toxicity (WET). This determines the potential synergistic environmental impacts of various contaminants contained in the concentrate. Whole effluent toxicity of the concentrate is difficult to predict based on chemical characterization of the saline source water only. While acute and chronic WET thresholds of the concentrate can typically be correlated with the level of salinity in the source water, some aquatic species can

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also be impacted by the ion makeup of the concentrate (i.e. the relative ratios of ions such as calcium, magnesium, sodium, etc.). Therefore, the most reliable and thorough characterization of the concentrate water quality is achieved by pilot testing of desalination systems with configuration, design and operational conditions similar to these planned for the full scale desalination plant. The concentrate generated from this pilot plant is then analyzed for all government regulated discharge water quality parameters, including WET.

6.2. Spent Filter Backwash Water

Spent filter backwash water is a waste stream produced by the pretreatment filtration system, which serves to remove solid particulates and other compounds before the water stream can be treated by RO membranes. All SWRO processes require a pretreatment step, and thus produce backwash water. Pretreatment is less frequently required for BWRO systems, unless the source water contains high levels of iron and/or manganese.

The amount of solids contained in the spent filter backwash water are dependent on the source water quality and type of pretreatment system employed (granular or membrane filters). Typically, membrane-based pretreatment systems produce larger volumes of backwash water (1.5 to 2 times), but require less, if any, coagulant compared to granular filters, which tend to generate waste streams with a higher proportion of solid constituents. Depending on the pretreatment system, the waste stream may contain iron salts used as coagulants, in addition to suspended solids (for example debris, silt, shell particles) naturally occurring in the source water.

Often spent pretreatment filter backwash water (with or without treatment) is blended and discharged along with the concentrate. The blended plant discharge may contain elevated turbidity, total suspended solids, color, organic content, iron and manganese, and biochemical oxygen demand. The concentration of each contaminant of concern in the blend can be calculated as a flow-weighted average of the concentrations of the same contaminant in the individual waste streams. Alternatively, if a desalination pilot plant is available, the water quality of the mixed plant discharge can be determined by direct sampling and laboratory analysis.

6.3. Spent Membrane Cleaning Chemicals

Waste streams generated from the chemical cleaning of UF and MF pretreatment membranes usually contribute less than 1% of total plant discharge volume, while spent RO membrane cleaning solutions are typically less than 0.5% of the plant discharge. Spent membrane cleaning chemicals should be characterized for the same water quality parameters as the desalination plant's concentrate and spent filter backwash water.

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