A SunCam online continuing education course

Introduction to Desalination Project Design and Delivery

by

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1. PLANT DESIGN

1.1. Introduction

Once the desalination plant service area, location, site, source water quality, product water quality and concentrate water quality are determined, and the intake and discharge type and configuration are selected, the next step of the desalination project planning process is to complete conceptual plant design. The conceptual design includes the type and sequence of the treatment processes and equipment, facility and equipment design criteria and incorporates preliminary plant site layout and hydraulic profile. It also includes project capital and O&M cost estimates and the project implementation schedule.

Furthermore, the conceptual design addresses the type of technology and equipment for energy recovery from the plant concentrate, post-treatment of the plant RO permeate, handling and disposal of the solid and liquid waste streams generated during source water pretreatment and membrane cleaning and finally, plant product water storage and delivery systems.

The conceptual plant design process takes under consideration the physical, operational and environmental constraints imposed on the project, and usually involves initial development of several project alternatives, followed by selection of the most viable alternative based on a set of criteria. This includes capital and O&M costs, size of the overall plant site footprint, environmental impacts, carbon footprint of plant, ease of plant operation and maintenance, overall plant performance in terms of energy and chemical use, plant fresh water production reliability, redundancy and spare capacity, plant expansion and phasing flexibility and ability of the proposed plant design and facility configuration to accommodate future technologies and equipment.

1.2. Selection of Treatment Processes

A typical desalination plant includes processes for removal of debris, suspended and colloidal solids and fine silt from the source water using screens and filters followed by processes for removal of dissolved minerals, organics and pathogens. The combination of these two types of treatment processes (pretreatment and RO membrane separation) produces fresh water (or permeate) of low mineral and pathogen content.

A typical third step of the desalination plant treatment process is re-mineralization of the RO permeate for health and corrosion protection and finally water disinfection (if the water is planned for potable use). If the RO permeate contains dissolved gases which have a negative impact on the taste and odor of the desalinated water (H_2S), such gases are usually removed through an additional post-RO treatment process (typically involving oxidation and/or water degassing). Figure 1 presents a schematic of typical desalination plant and indicates the key treatment processes.

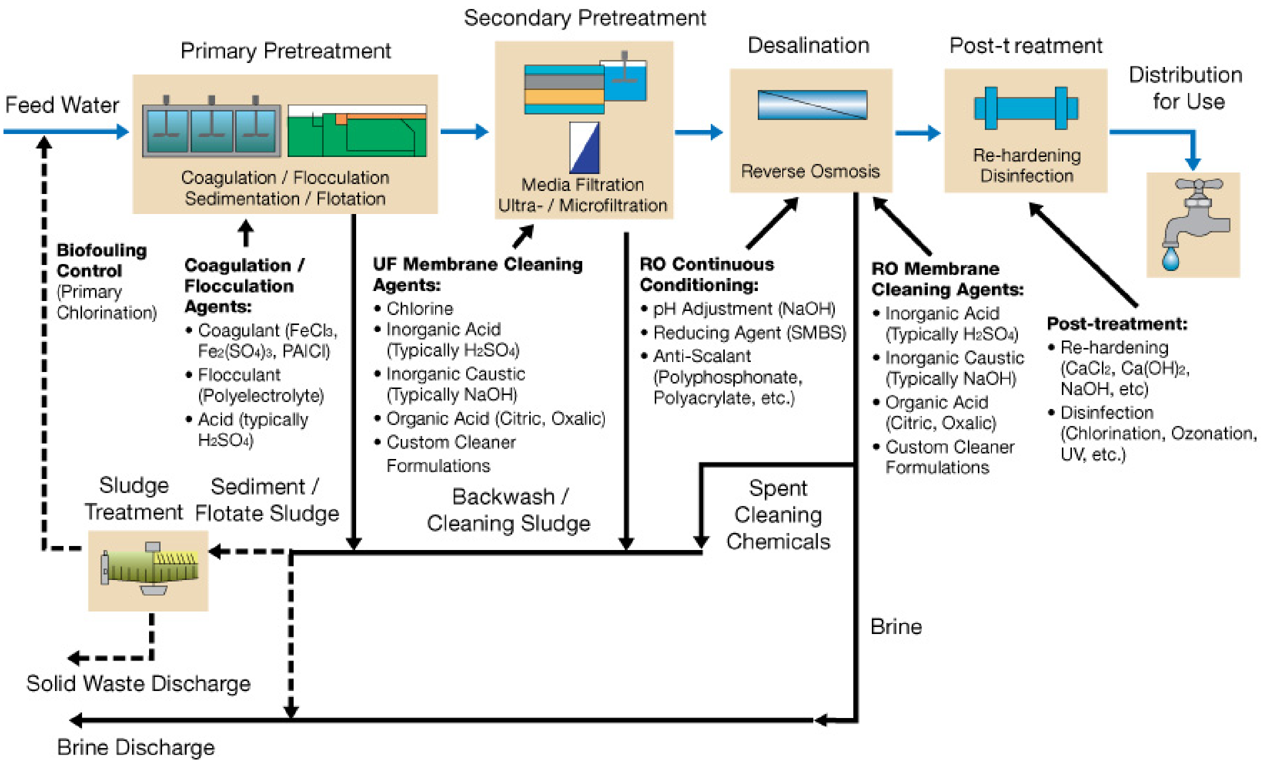

Figure 1: SWRO Desalination Plant Schematic

Note that desalination projects do not always include all of the treatment steps and processes depicted on Figure 1. This figure presents practically all technologies a desalination plant may incorporate (except for degassing) under worst-case scenario of source water quality. The figure is representative of the configuration of a seawater desalination plant with open ocean intake exposed to difficult to treat water of high turbidity, silt, algal and oil content.

Brackish water desalination plants which use intake wells producing low turbidity/low silt source water often do not have elaborate pretreatment systems and instead blend a portion of their source water with desalinated water to add minerals to the finished water and reduce the overall costs of water production. Figure 2 illustrates a typical general schematic of BWRO plant with well intake.

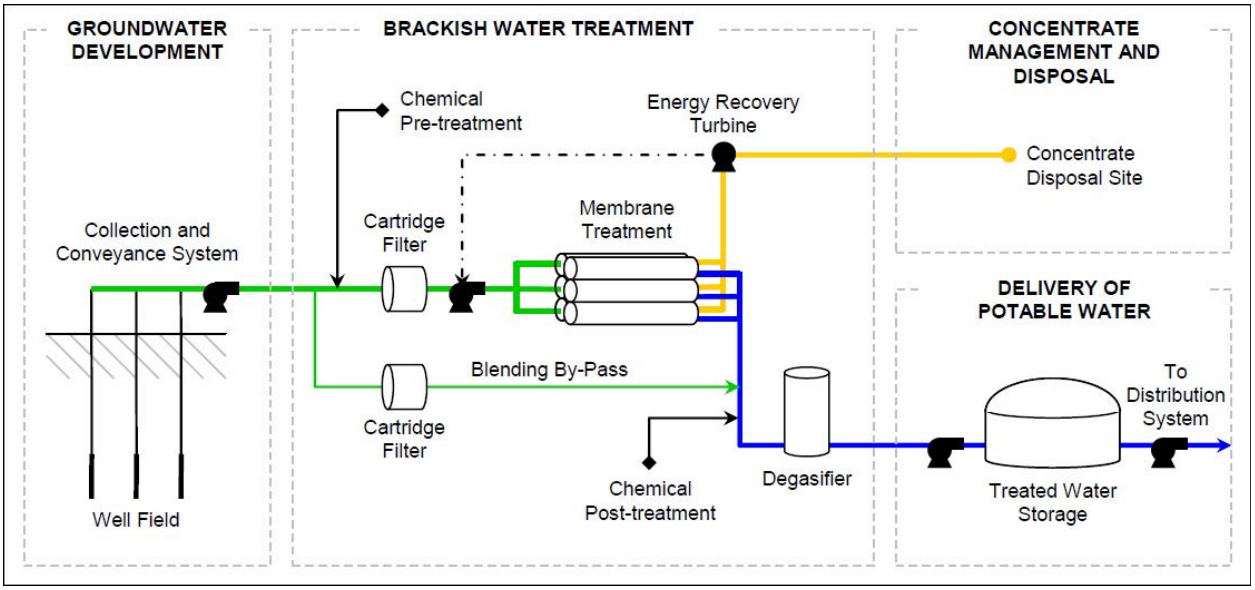

Figure 2: BWRO Plant Schematic

Pretreatment. The main purpose of pretreatment is to reduce suspended solids/silt content in the source water, and this content may vary significantly from one project to another. Some desalination plants (such as plants with well intakes collecting water from pristine saline aquifers which are not impacted by surface water contamination) can have minimal pretreatment which only includes cartridge or bag filtration.

However, surface water intakes collecting water from heavily contaminated areas (industrial ports, shallow bays prone to frequent algal blooms or from locations near a wastewater treatment plant and/or storm drain discharge) can be exposed to significant contamination and often requires a series of primary and secondary treatment facilities such as these shown in Figure 1. This is necessary to produce water of low suspended solids and silt content (TSS < 1.0 mg/L, turbidity of < 0.3 NTU, and SDI < 4) which is suitable for RO separation. The pretreated water should also have low oxidant content in order to preserve the structural integrity of the RO separation layer (residual chlorine < 0.01 mg/L and oxidation-reduction potential (ORP) < 250 mV).

In addition to suspended solids and silt removal, desalination plant pretreatment is intended to minimize membrane scaling. Membrane scaling is the excessive precipitation and accumulation of minerals such as calcium and magnesium salts and silica on the RO membrane surface which over time may foul the membranes and hinder the salt separation process productivity and efficiency. Membrane scaling is typically minimized by source water conditioning with a specific class of chemicals termed antiscalants (or scale inhibitors).

Besides productivity reduction caused by solids and minerals, RO membrane system performance can also be hindered by fouling of organic and microbial contaminants contained in the saline source water. Natural organics and particulate/colloidal fouling are commonly controlled applying coagulants and flocculants to the source water to enlarge the particle size of these contaminants and ultimately, to remove them by sedimentation, dissolved air flotation (DAF), granular media filtration, UF or MF membrane filtration or combination of these processes as shown in Figure 1.

Membrane Salt Separation. At present reverse osmosis is the salt separation process which is most commonly used for desalination. RO elements incorporating thin-film composite polyamide membranes in spiral-wound configuration are applied in over 90% of the municipal desalination projects built worldwide in the past two decades.

RO membrane elements have standard diameters and lengths, and are installed in pressure vessels which house six to eight elements per vessel. The RO elements and pressure vessels are divided into brackish water and seawater types depending on their application. Typically, seawater membrane elements and vessels are used to desalinate source water with TDS concentration of 15,000 mg/L or more. Brackish water RO elements and vessels are applied for source waters of lower salinity or for additional (second pass) treatment of permeate generated by SWRO elements to produce desalinated water of very high quality (typically. TDS, chloride, boron and bromide concentrations lower than: 100 mg/L; 60 mg/L; 0.5 mg/L and 0.4 mg/L, respectively).

RO system type and configuration are selected based on the source water quality of the desalination plant, and the target product water quality. Since desalinated water of very similar quality can be produced from the same source water by a number of different RO system configurations and membrane products, usually the most viable RO system for a given project is determined based on a life-cycle cost-benefit analysis.

Post-treatment. Post treatment of the desalinated water includes two types of processes: re-hardening and disinfection. Re-hardening is the addition of hardness and bicarbonate alkalinity to the RO permeate to provide corrosion protection of the distribution system conveying this water to the final users. The most common compounds used for addition of hardness and alkalinity to the permeate are calcium hydroxide (lime) and carbon dioxide. Recently, use of calcite (limestone) in combination of carbon dioxide or sulfuric acid are becoming more prevalent post-treatment technologies for corrosion protection due to the lower turbidity water they tend to produce.

In addition to alkalinity and hardness, desalinated water produced for human consumption is disinfected by adding chlorine-based chemicals such as chlorine gas, chlorine dioxide, and sodium or calcium hypochlorite. Desalinated water which will be bottled usually is disinfected by ozonation or ultraviolet (UV) irradiation instead of chlorine-based disinfectants to prevent aftertaste that may be generated from the interaction of chlorine and the plastic bottle material.

Ozonation is sometimes used for disinfection of finished water from BWRO desalination plants if this water has a low content of bromide. However, ozone is practically never applied for disinfection of desalinated seawater because this water often has elevated bromide content (i.e. bromide levels higher than 0.4 mg/L) and ozonation may result in excessive generation of bromate, which is a carcinogenic compound and its content has to be limited to less than 10 micrograms/L to comply with USEPA regulations and World Health Organization’s drinking water quality guidelines.

1.3. Equipment Selection

Selection of equipment for a given desalination project is based on the type of the treatment process, materials from which the equipment is fabricated, and equipment efficiency in terms of energy use. Cost, ease of operation and maintenance, size and capacity of the individual equipment units available on the market, and its useful life and track record for similar applications. are also considered in the selection process.

Typically, plastic equipment and piping are preferred for low-pressure applications (for working pressures under 10 bars/140 psi). Except for plastic pressure vessels, RO membrane elements, and plastic or ceramic components of some of the available energy recovery systems and ultrafiltration systems, most of the other equipment used for high-pressure applications is usually made of high grade (duplex or super duplex) stainless steel or is coated for corrosion protection.

Depending on the regulatory requirements for public health protection and the use of the finished water, in many countries (such as US, Australia, Canada, Switzerland, Germany) the quality and type of the materials selected for the desalination plant equipment and piping have to comply with regulatory requirements ensuring that they will not release chemical compounds hazardous to human health into the finished drinking water. In the US, for example such requirements are stipulated in NSF/ANSI Standard 61 and are enforced by state and federal human health protection agencies.

1.4. Treatment Process Validation and Optimization by Pilot Testing

Often, the overall feasibility of the developed conceptual plant design, including type, performance design criteria and configuration of the selected pretreatment filtration technology and RO membrane system as well as chemicals for source water conditioning and membrane cleaning are verified by pilot testing. Pilot plants are facilities of capacity between 1:100 and 1:2,000 of the final capacity of the desalination plant.

One of the main objectives of the pilot plant testing is to collect project specific source and concentrate water quality data needed for project design. The pilot test results are used to evaluate plant performance at both typical operational conditions as well as at extreme events associated with maximum or/and minimum levels of salinity, temperature, turbidity, colloidal contaminants (e.g., iron and manganese), and organic content in the saline source water. Therefore, it is critical to design the pilot testing program in such a manner that it allows capturing events with potentially significant impact on the plant operations such as heavy rain storms and algal blooms, intense ship traffic, intake area dredging, seasonal winds, and periodic waste discharges from nearby industries or wastewater treatment plants.

For desalination plants with subsurface intake (wells, infiltration galleries, etc.) pilot testing will need to encompass period of at least 6 to 12 months, especially for larger projects. Extended pilot testing will allow to determine of the safe and reliable yield of the intake system and to account for water quality changes triggered by seasonal or other events such as heavy rains creating surface runoff of high silt content or reducing the sand cover over the well intake area, well fouling with silt and bio-growth over time, mobilization of contaminants in the source water from adjacent aquifers and/or sources of contamination such as landfills, leaking underground oil tanks and pipelines, and release of embalming liquids from nearby cemeteries.

Pilot testing is the most viable method to generate technical data required for a desalination project's environmental review including plant source water and waste streams (concentrate, spent filter backwash, spent membrane cleaning chemicals and solids residuals) and water quality needed for assessment of the environmental impact of the plant operations. In addition, side-by-side pilot testing is often completed to assess the feasibility of alternative pretreatment technologies and new RO membrane elements and configurations for the site-specific project conditions, to optimize overall plant design.

Pilot testing also creates opportunities for public outreach and education regarding the quality, benefits and advantages of desalinated water as compared to alternative water supply sources. Often public acceptance of the project by the local hosting community, rather than technical and cost feasibility determines the overall viability of project implementation.

1.5. Plant Configuration and Layout

Desalination plant configuration and layout are typically selected to maximize flexibility of plant operations and to minimize the length of piping and electrical conduits between the individual treatment facilities and equipment. Another important consideration for the development of plant layout and for determination of the building configuration and size of interconnecting roads is the accessibility of main plant equipment (including pumps, motors, energy recovery equipment, pretreatment and RO membrane vessels, cartridge filters) for inspection, maintenance and replacement.

The plant layout should be developed to simplify access of large trucks to plant areas designated for storage of chemicals and of sludge (residuals). Roads to these facilities should be designed with turning radius adequate for the largest size delivery and fire-fighting trucks. Such roads should be at least 6 meters (18 feet) wide and should be paved and designed to withstand heavy truck loads.

In addition to water treatment, chemical storage and solids handling facilities, the electrical building, the plant motor control centers, the maintenance shop, and other operations, storage and administrative areas, the desalination plant layout should also incorporate adequate parking area for employees and visitors, as well as landscaping that enhances the aesthetics or the plant appearance.

In most urbanized coastal centers, land available for the construction of desalination plants is very limited and comes at a high cost premium. Therefore, often plants in such areas are designed with compact layouts where some of the desalination equipment and facilities are installed in multi-story buildings. If land is readily available, then the least costly plant configuration includes facility location in single-story above ground structures.

Often the shape of the available site determines the plant layout. For example, the site of the 274,000 m^3/day (72 MGD) Hadera seawater desalination plant in Israel is of very elongated shape (see Figure 3) which dictated locating all treatment facilities in one line following the plant treatment process sequence (intake, pretreatment, RO system, product water storage tanks, etc.).

Figure 3: Layout of the Hadera SWRO Plant, Israel

The plant intake pump station and dual media gravity pretreatment filters are located closest to the ocean and are followed by the RO building, the post-treatment limestone contactors, the circular product water storage tank and the product water delivery pump station.

All structures are built at grade. The main access load is located in parallel with the plant buildings and provides access to all facilities, buildings and storage areas. Chemical storage facilities are housed in the middle of the plant at approximately the same distance from the main plant areas where chemicals are used continuously – the pretreatment filters and post-treatment facilities. This plant layout is compact and functional.

Figure 4 depicts the layout of the 95,000 m^3/day (25 MGD) Tampa Bay SWRO desalination plant. The plant site size is approximately 3.4 ha (8.5 aces) and the layout of this plant is more rectangular. The rectangular building located in the center of the figure houses the plant filter effluent transfer pumps, cartridge filters, energy recovery equipment, and the RO trains.

The plant two-stage filtration system (sand filters followed by diatomaceous filters) is located to the left of the RO building, while the plant post-treatment facilities for lime and carbon dioxide addition, the sodium hypochlorite disinfection system, the rectangular product water storage tank and the pump station are shown in the right corner of the picture.

Chemical storage and feed facilities as well as the plant solids handling system are located in the center of the plant near the pretreatment filters. The empty area between the RO building and the post-treatment facilities is planned to be used for plant expansion to up to 132,000 m^3/day (35 MGD).

Figure 4: Layout of the Tampa Bay SWRO Desalination Plant, Florida

Figure 5 presents the layout of the 28,000 m^3/day (7.5 MGD) Southmost Desalination Plant in Brownsville, Texas. This is a typical BWRO desalination facility using groundwater with total dissolved solids (TDS) concentration in a range of 1,800 to 2,000 mg/L collected from 20 supply wells (18 duty and 2 standby) with depth varying between 85 and 100 m (280 and 300 ft) and located approximately 25 km (15 miles) away from the desalination plant site.

Figure 5: Southmost BWRO Plant, Brownsville, Texas

The brackish source water is of very low particulate, organic and silt content. Approximately 5,700 m^3/day (1.5 MGD) of the 34,000 m^3/day (9 MGD) of source water collected by the plant wells is bypassed and blended with 22,700 m^3/day (6.0 MGD) of permeate which is produced form the rest of the source water by BWRO desalination.

The desalination plant incorporates product water tank that can store up to one day of plant production capacity. The plant pretreatment includes source water cartridge filtration and antiscalant addition only. The total plant site shown on Figure 5 is 5.7 ha (17 acres). The plant layout is intentionally developed with additional room for a significant plant expansion.

1.6. Energy Use

Desalination requires a significant amount of energy to overcome the naturally occurring osmotic pressure exerted on the reverse osmosis membranes. This in turns makes reverse osmosis desalination several times more energy intensive than conventional treatment of freshwater resources. Table 3 presents the energy use associated with various water supply alternatives.

Table 3: Energy Use of Various Water Supply Alternatives

WATER SUPPLY ALTERNATIVE	ENERGY USE (kWh/m^3)
Conventional Treatment of Surface Water	0.2 to 0.4
Water Reclamation	0.5 – 1.0
Indirect Potable Reuse	1.5 – 2.0
Brackish Water Desalination	0.3 – 2.6
Desalination of Pacific Ocean Water	2.5 – 4.0

Note: 1 kWh/m^3 = 3.785 kWh/1,000 gallons

Analysis of this table indicates that the energy needed for seawater desalination is eight to ten times higher than that for production of fresh water from conventional sources such as rivers, lakes, and freshwater aquifers. Brackish water desalination typically requires significantly less energy, but sources of low salinity brackish water often are not readily available near urban centres.

Table 4 presents typical ranges for energy use of medium and large size seawater and brackish water desalination plants (plants with freshwater production capacity of 20,000 m^3/day, or more). This table is based on actual data from over 40 SWRO and BWRO plants constructed between 2010 and 2019.

As seen from Table 4, the SWRO systems of best-in-class seawater desalination plants use between 2.5 and 2.8 kWh of electricity to produce 1 cubic meter of fresh water (9.5 to 10.5 kWh/1,000 gallons), while the industry average energy use is approximately 3.1 kWh/m^3 (11.7 kWh/1,000 gallons). The industry-wide medium range energy use for production of fresh drinking water from brackish water varies in a significantly wider bracket – 0.6 to 2.1 kWh/m^3 (2.3 to 8.0 kWh/1,000 gallons) and averages 0.8 kWh/m^3 (3.0 kWh/1,000 gallons) for low-salinity BWRO desalination plants and 1.4 kWh/m^3 (5.3 kWh/1,000 gallons) for high salinity desalination plants, respectively.

Table 4: Typical Energy Use for Medium and Large Size SWRO and BWRO Systems

Classification	Low Salinity BWRO System Energy Use (kWh/m^3)	High Salinity BWRO System Energy Use (kWh/m^3)	SWRO System Energy Use (kWh/m^3)
Low-end Bracket	0.3 - 0.5	0.6 – 0.8	2.5 – 2.8
Medium Range	0.6 – 1.2	1.0 – 2.1	2.9 – 3.2
High-end Bracket	1.5 – 2.0	2.2 – 2.6	3.3 – 4.5
Average	**0.8**	**1.4**	**3.1**

Note: 1 kWh/m^3 = 3.785 kWh/1,000 gallons

1.7. Chemicals Used in Desalination Plants

Desalination plant chemical consumption is highly variable from one project to another and is greatly influenced by the source water quality. In general, the more contaminated the saline source water is with particulate, organic, microbial and mineral foulants, the greater the amount of chemicals needed to produce the same volume of fresh water.

The costliest chemicals in desalination plants are these used for intermittent cleaning of the reverse osmosis membranes and antiscalants to prevent formation of mineral deposits (scale) on the surface of the membrane elements.

Table 5 lists the most common chemicals used in seawater and brackish water desalination plants and their typical dosage and points of application. The table does not include chemicals for periodic membrane cleaning. Polymers are not widely used for pretreatment of saline source water, except for the cases where this water is influenced by high turbidity sources such as heavy rains, sand storms, heavy ship traffic, dredging of the intake area and wastewater discharges. Aluminum based salts are not used for pretreatment because they tend to accumulate on the membrane surface and cause fouling and associated membrane productivity reduction.

Table 5: Chemicals Commonly Used in Desalination Plants

Chemical	**Dosage (mg/L)**	**Point/s of Addition and Purpose**
Ferric Chloride or Ferric Sulfate	0.5 - 30	• Upstream of pretreatment systems for enhanced solids and silt removal.
Sulfuric acid	30 - 100	• To Intake forebay for shellfish growth control in open intakes. • Upstream of pretreatment systems for enhanced solids & silt removal. • Upstream of RO system for scale inhibition. • To permeate for pH reduction/ enhanced dissolution of calcite in post-treatment contactors. • To permeate for final product water pH adjustment.
Polymer (Flocculant)	0 – 2.0	• Upstream of pretreatment systems for enhanced solids and silt removal.
Sodium Hypochlorite	0 - 15	• At Intake forebay (for open intakes) or well heads (for well intakes) and in intake pump station wet well for bio-growth control. • Upstream of secondary pretreatment for biofouling control.
Sodium Bisulfite	0 - 50	• Upstream of RO system when oxidant such as sodium hypochlorite is added to the water - to remove its residual.
Antiscalant	0.5 – 2.0	• Downstream of the points of sodium bisulfite addition and upstream of the RO system for scale inhibition.
Sodium Hydroxide	10 - 40	• Feed water to first or second RO passes for enhanced boron removal. • pH adjustment of the finished water.
Lime	50 to 100	• To RO permeate for addition of hardness and alkalinity.
Carbon Dioxide	30 to 80	• To RO permeate for addition of alkalinity/enhanced dissolution of lime and calcite.

2. PROJECT IMPLEMENTATION SCHEDULE AND PHASING

2.1. Project Duration

A detailed project implementation schedule has to be developed during the design phase of the project. The plant construction schedule should as a minimum include the total duration of the project implementation as well as the following durations and start dates:

- contractor mobilization and site preparation;
- project engineering and design;
- procurement and installation of high pressure RO pumps and energy recovery equipment, pressure vessels and high-pressure stainless steel piping; RO membrane elements and any other significant long lead time items, which procurement, installation or start up requires over three months;
- construction of intake facilities, intake and discharge interconnecting piping, pretreatment system, RO system and post-treatment facilities;
- plant commissioning and startup, and
- desalination plant acceptance testing.

Table 6 presents a typical length of desalination project design and construction as a function of the plant size.

Table 6: Typical Length of Desalination Project Implementation

Plant Size (m^3/day)[1]	**Design Period (Months)**	**Construction Period (Months)**	**Start-up and Commissioning (Months)**	**Total[2] (Months)**
Less than 1,000	1 - 2	2 - 3	1 - 2	4 - 7
5,000	2 - 3	4 - 6	1 - 2	7 - 11
10,000	2 - 4	6 - 8	1 - 2	9 – 14
20,000	3 - 5	8 -10	2 - 3	13 - 18
40,000	3 - 6	14 - 16	2 - 3	19 - 25
100,000	5 - 8	18 - 20	3 - 4	26 - 32
200,000	6 -10	20 - 24	3 - 4	29 - 38

Notes: (1) 1 MGD = 3,785 m^3/day; (2) Accelerated implementation of some of the activities is possible but is likely to result in cost increase.

The total length of the desalination plant project design and construction may vary considerably from the indicative periods indicated in Table 6 depending on country-specific legislation, and site specific project scope and conditions. Environmental and procurement regulations may add years to the duration of large projects. Some construction activities may also take longer than the duration indicated in the table, especially if most of the construction has to be completed in adverse weather conditions, compact site layout, limited staging area and limits to construction hours.

A number of construction activities may be accelerated by working in multiple shifts where possible and pre-purchasing some of the long-lead equipment and piping. However, such project acceleration activities usually result in an increase in the overall plant construction costs because of the increase in labor and equipment costs.

2.2. Project Phasing

Desalination projects with the highest and lowest costs have a very distinctive difference in terms of project phasing strategy. The large high-cost projects incorporate single intake and discharge tunnel structures built for ultimate desalination plant capacity (which is often twice the capacity of the first phase). Desalination projects on the low-end of the cost spectrum use multiple-pipe intake systems constructed mainly from high density polyethylene (HDPE) or glass reinforced plastic (GRP) that have capacity commensurate with the production capacity of the desalination plant. Additional multiple intake pipes and structures are installed as needed at the time of plant expansion for these facilities.

While the single-phase construction of desalination plant intake and outfall structures dramatically reduces the environmental and public controversy associated with the plant capacity expansion at a later date, this "ease-of-implementation" benefit typically comes with an overall cost penalty. The larger costs associated with building complex intake and outfall concrete tunnels in one phase tends not to yield the expected overall project cost savings. The main reason being that the cost of 100 meters (300 linear feet) of deep concrete intake or discharge tunnel is over four times higher than the cost of the same capacity intake or discharge constructed from multiple HDPE or GRP pipes located on the ocean bottom, while the economy of scale from one-stage construction is usually less than 30 %.

3. PROJECT ECONOMICS

Project capital, O&M, and overall water production costs depend on a number of factors, most of which are site specific to desalination project location, size, technical and socio-economic circumstances. In general, there are factors controlled by the decisions of the facility owner, but there are also many subjective factors beyond the control of the facility owner, including those which result from regulatory requirements and market forces of free economy. Figure 6 shows the indicative capital cost breakdown for SWRO desalination plants.

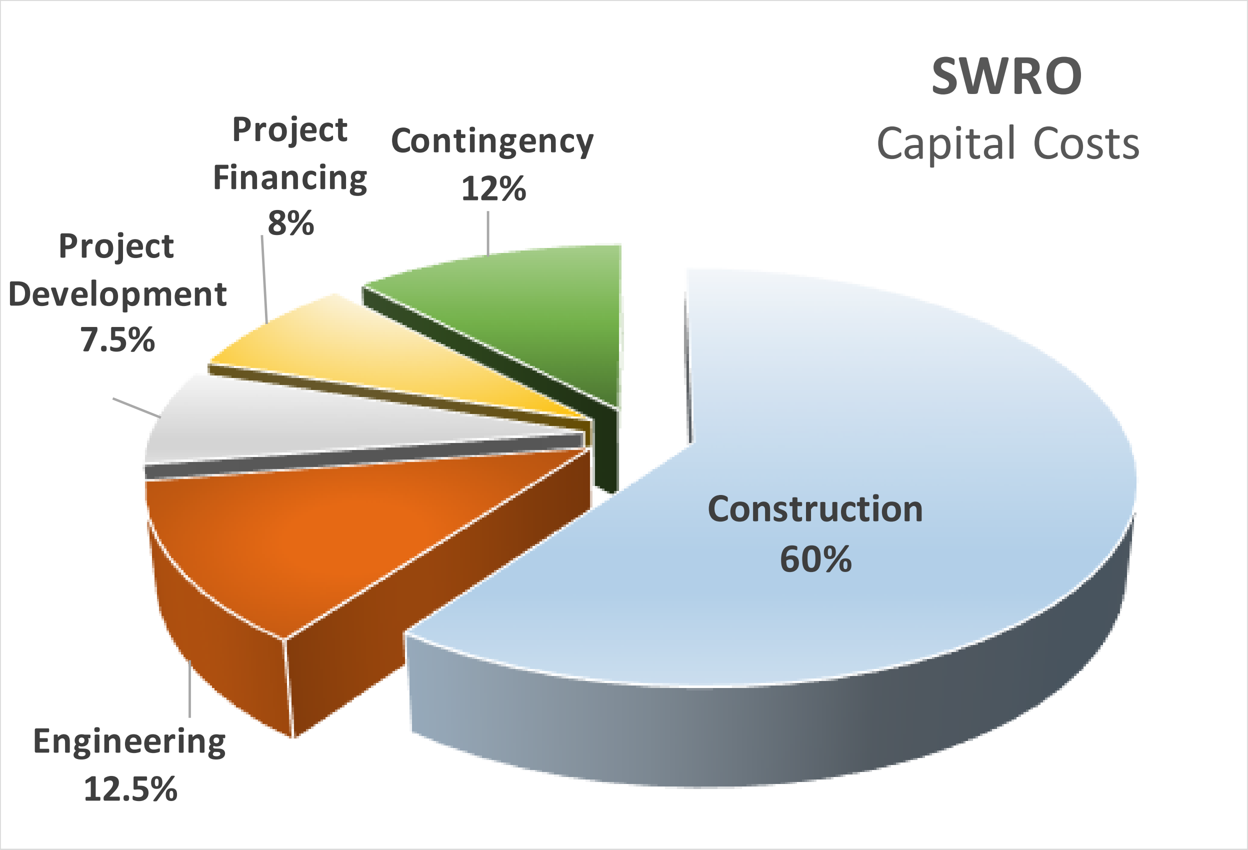

Figure 6: Indicative Capital Cost Breakdown for SWRO Desalination Plants

As seen from Figure 6, the main capital cost component is the cost of plant construction (60%), followed by engineering expenditures (12.5%). Depending on the country and project complexity, approximately 65% of the construction costs are equipment expenditures and 35% - labor costs.

Figure 7 shows the typical operation and maintenance cost breakdown for SWRO desalination plants. These costs are indicative as they will vary from site to site, depending on a number of variables such as source water salinity and temperature, unit labor costs, content of particulates in the source water, biofouling propensity of this water, frequency and magnitude of algal blooms in the vicinity of the intake, etc. Electrical energy is usually the largest component of the desalination plant annual O&M expenditures. Usually, over 70% of the entire desalination plant energy is consumed by the high pressure pumps of the reverse osmosis system.

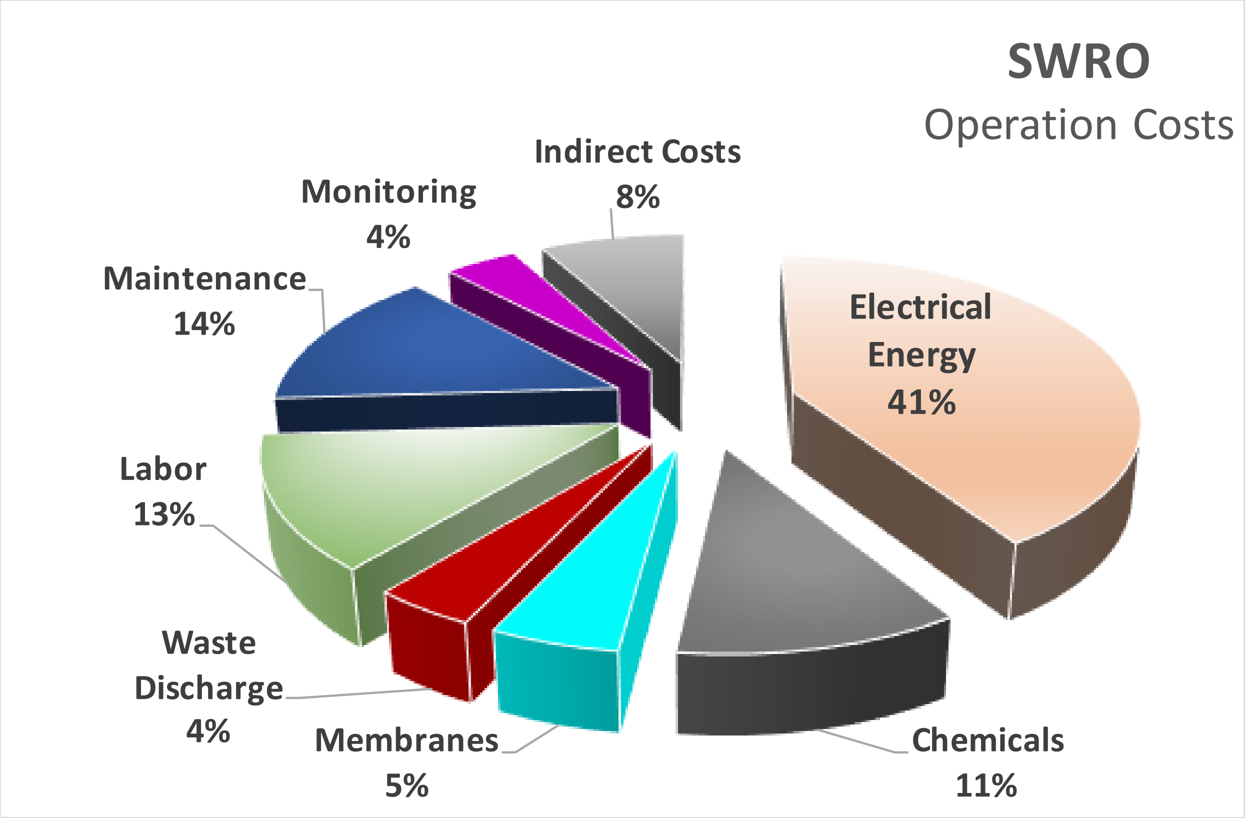

Figure 7: O&M Cost Breakdown for SWRO Desalination Plants

3.1. Effect of Plant Size on Project Costs

Project size has a significant influence on the overall production cost of desalinated water. As illustrated on Figure 8, the cost of water production by desalination can be reduced significantly by building fewer large-scale desalination plants rather than a large number of small facilities. For example, analysis of Figure 8 indicates that the water production costs can be reduced by approximately 50 % when plant capacity is increased from 5,000 to 200,000 m³/day (1.3 MGD to 53 MGD).

This economy of scale is mainly driven by the size of the individual treatment and pumping units, especially the reverse osmosis trains. Currently, the largest size RO train that can be built using off-the shelf standard equipment (high-pressure pumps, energy recovery devices and 8-inch RO membranes) has production capacity of approximately 30,000 m³/day (8 MGD). Construction of larger individual trains is possible, but usually is not as cost effective given the use of custom-made RO system equipment, which is significantly more costly than the off-the-shelf standard equipment units. The gains, and as a result, some of the economy-of-scale savings are negated by the additional equipment costs.

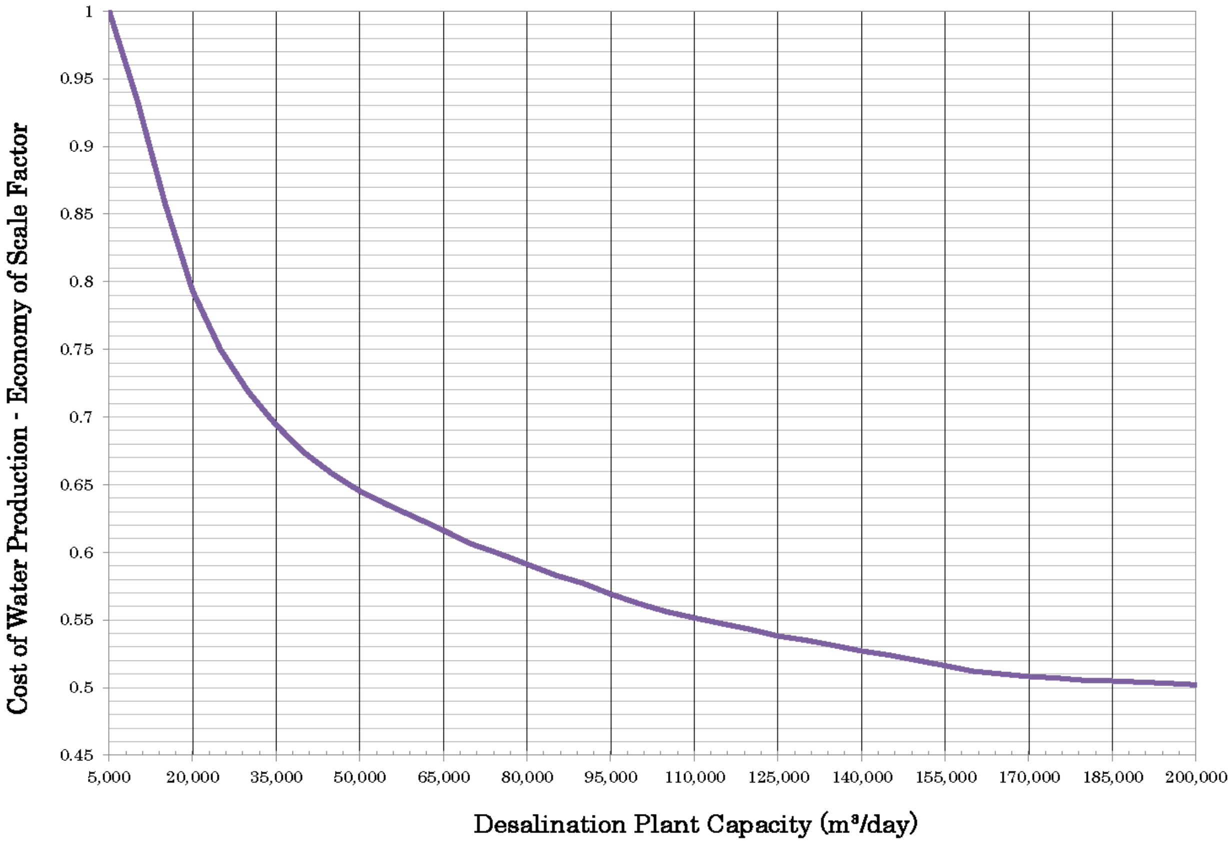

Figure 8: Effect of Plant Size on Water Production Cost

For plants with capacity larger than 200,000 m³/day (53 MGD) the economy-of-scale benefits are very limited mainly due to the added complexity of flow distribution, treatment and operations. In fact, at present most plants with capacity larger than 200,000 m^3/day (53 MGD) are built as multiple identical parallel desalination systems of 100,000 to 200,000 m^3/day (26.5 to 53.0 MGD) which share a common intake and outfall.

As the maximum unit size of commercially available desalination plant equipment increases in the future it is likely that the breakpoint plant capacity at which economy of scale will not yield measurable savings can shift to 400,000 m³/day (106 MGD) or higher. A step in this direction is the introduction of SWRO desalination elements of diameter of 16 inches and larger.

3.2. Concentrate Disposal and Plant Costs

Depending on the site-specific conditions of a given project, concentrate disposal expenditures may have a measurable contribution to the total plant construction and O&M costs and to the overall cost of water. For small desalination plants with low-cost access to existing wastewater collection system, concentrate disposal to this system is often the most cost-attractive disposal option. On the other hand, construction of series of deep groundwater injection wells, although widely practiced for small desalination plants, is often costly and site-prohibitive for large projects. The majority of large desalination plants worldwide use on-shore or off-shore discharges for disposal of their concentrate or collocate their discharges with cooling water discharges from power plants or wastewater treatment facilities.

Some large high-cost projects incorporate single discharge tunnel structures built for ultimate desalination plant capacity (which is often twice the capacity of the first phase). Desalination projects on the low-end of the cost spectrum use multiple-pipe outfall systems constructed mainly from high density polyethylene (HDPE) or glass reinforced plastic (GRP) that have capacity commensurate with the production capacity of the desalination plant. The last third of the offshore ocean outfall piping is equipped with diffusers ejecting brine upwards for accelerated mixing of the plant concentrate with the ambient seawater.

3.3. Energy Use and Project Costs

For seawater desalination plants, the cost of power is typically 35 to 50 % of the total expenditure for production of desalinated water. Therefore, both unit power cost and desalination plant power use have a profound effect on project water production costs. For brackish water desalination plants the cost of power is usually a much smaller percentage of the overall fresh water production costs.

3.4. Project Risks and Costs

Costs associated with project financing, development and environmental review can constitute between 10 to 20 % of the overall fresh water production costs. These costs are closely related to the potential risks associated with project implementation and operation.

Financial institutions establish the interest rates of the funds they lend to the project and the acceptable project financial structure based on a thorough evaluation of the project risk profile. To provide low-interest rate funding for a given desalination project, financial institutions demand strong assurances that the project will be permitted and built in a timely and cost-effective manner. Furthermore, the power supply contract and tariff for the project must be reasonable, the operation and maintenance of the desalination plant must be professionally handled by an operator that has prior experience and the environmental impact related project risks and costs must be minimal and manageable.

In the case of build-own-operate-and-transfer (BOOT) projects, financial institutions which are lending funds will require a legally binding water purchase agreement (WPA) between the final user of the desalinated water (public agency or private industrial end-user of the water) and the BOOT contractor. The agreement must be fair and balanced, and apportion risks equitably between the two parties based on their practical ability to manage it.

The entity providing funding for a given project can have a combination of private sector commercial lenders, banks and multilateral agencies, and international financial institutions. Increasingly, funding for desalination projects is sourced from capital markets and project bonds. Public sector bond underwriters/lenders and private sector lenders often have different approaches and requirements for evaluation and mitigation of project risks.

As a general rule, desalination project lenders will only be willing and able to take risks that are quantifiable and manageable at reasonable costs. Typically, lenders are not involved with the construction, operation, or insurance activities related to project implementation. Therefore, they will not take risks associated with these activities and especially risks they are not familiar with or that can be more appropriately managed by other parties involved in the project.

To mitigate risks at early stages, lenders may be involved in the milestones of project development and implementation. This may include negotiation of project contracts, review of key project design and construction activities as well as review and approval of certification of project completion and project acceptance testing for continuous commercial operation. Lenders will generally exercise their review rights over the project implementation with the assistance of an independent engineer.

The main project risks considered by the lending institutions when determining their interest and conditions for funding desalination projects are permitting (licensing) risks, entitlement risks, power supply risks, construction risks, source water risks, technology risks, regulatory risks, operational risks, desalinated water demand risks and financial risks.

Permitting (Licensing) Risks. Permitting risks are risks associated with obtaining and maintaining all permits or licenses required for all phases of project implementation and for long-term plant operation. This includes environmental permits (such as the concentrate discharge permit and drinking water permit), construction permits and operations permits.

As desalination projects are relatively new to most permitting agencies, and given the lack of precedents, and experience in permitting of this type of projects, the time and efforts required for permitting of desalination projects are still more extensive than for conventional water and wastewater treatment plants.

Often permitting of large desalination projects requires long and costly environmental and engineering studies and is influenced by environmental opposition, which in some cases may pose significant political and legal pressures to delay and ultimately to derail the project. As a result, permitting risk is considered by lending institutions and public agencies alike as one of the most significant and costliest risk-related exposures associated with desalination project implementation.

For example, initial difficulties encountered with permitting of the Tampa Bay seawater desalination project in Florida was one of the key reasons why the public utility that initiated this project (Tampa Bay Water) decided to proceed with project implementation under a BOOT method of delivery, which allows this risk and the associated permitting costs to be transferred to the private BOOT contractor.

Experience with environmental review and permitting of the Carlsbad and Huntington Beach SWRO projects in California, which has spanned over a period of more than 10 years, is also indicative of the permitting challenges and risks large desalination projects can face and the complexity of the environmental review of desalination projects. For these projects, permitting costs exceeded 10% of the overall project capital costs.

Entitlement Risks. Entitlement risks are associated with control and cost of use of the site and infrastructure on which the desalination plant and facilities will be located. Where the desalination plant shares existing intake and discharge infrastructure with other facilities, such as power plants or wastewater treatment plants, entitlement risks are associated with potential changes of the existing host facilities in future that may require additional investment in the desalination plant to build its own infrastructure or significantly modify the plant.

For example, if a desalination plant uses an existing wastewater plant outfall, and the wastewater treatment plant owner decides to expand its capacity to occupy a larger portion of the outfall capacity, the desalination plant will be affected. The allowable volume of concentrate discharge through the outfall will be reduced unless it is contractually entitled to use a pre-determined portion of the discharge capacity of the existing outfall throughout the useful life of the desalination plant.

If this desalination plant does not have a contractual entitlement to use of the wastewater plant outfall over the period for which a lending institution funds the project, the lending institution will consider this condition an entitlement risk. Typically, a penalty on project financing costs will be charged to provide adequate protection of the investment against this risk. The size of the interest rate penalty will be commensurate with the additional expenditures needed to address this risk, if loss of entitlement occurs in future.

Power Supply Risks. Power supply risks are risks associated with the availability of power and the magnitude of the unit power cost change over the useful life of the desalination project. Since the cost of power, especially for seawater desalination projects, can be over 30 % of the total water production cost, the financial institution funding the project will require the plant operation costs to be secured with a long-term power supply contract that will allow prediction of power tariff and energy expenditures over the project funding term.

Financial institutions will typically expect the power tariff adjustments allotted in the power supply agreement to be reflected in and matched with the water tariff adjustments in the water purchase agreement. Some projects have adopted self-generation of power using natural gas procured under long-term contracts to mitigate the long-term volatility of electrical power supply tariffs. While firm-price electrical power supply contracts are usually available for a short span of 3 to 5 years, natural gas supply contracts could be executed at predictable firm prices for periods of 20 years or more.

Construction Risks: Construction risks stem from the potential increase in construction costs during the project implementation period which can be due to unusual site subsurface conditions, delay of delivery and installation of equipment, construction cost overruns, designer and construction contractor errors and omissions and performance and reliability risks related to plant startup, commissioning and acceptance testing.

Well-recognized construction companies with a proven track record of successful construction of desalination projects in similar settings and of similar size will greatly increase the confidence level of lenders involved with project financing.

Usually, construction companies which are new to the desalination industry will be considered to have a higher construction risk profile. Similarly, companies with significant cost and schedule overruns and/or ongoing litigation on projects of similar size and complexity will be accepted less favorably by project lenders.

Typically, turnkey fixed price/fixed schedule contracts which allow the owner to hold contractors fiscally accountable for their performance obligations are favored by project lenders. Construction contract completion guarantees with clauses which require performance and payment bonds of 10 to 30 % of the turnkey construction price to be available to the lenders to rectify construction problems are preferred by the financial community as a proven mechanism to mitigate construction risks.

Typically, the size of the performance and payment bond is commensurate with the probability of the contractor's default. This in turn is related to the track record of the contractor with similar projects and contractor experience with technologies and equipment proposed to be used for the desalination project.

Source Water Quality Related Risks. Source water related risks are associated with the potential impacts of the source seawater quality on the desalination plant operation and performance. Such variation in water quality over the useful life of the desalination project impacts on the water production cost.

For example, an increase in source water turbidity, organics or other compounds that may result in accelerated fouling of the membrane elements or in the need for more elaborate pretreatment, are typically of concern. These water quality related risks can be addressed by selecting the location of the desalination plant intake distant to existing wastewater treatment plant discharges, industrial outfalls or in large industrial or commercial ports and shipping channels.

In BOOT projects the source water quality related risks are contractually addressed by including a source water quality specification in the water purchase agreement with the entities purchasing the water, and in the agreements for turnkey engineering, construction and procurement (EPC) and O&M services. These agreements should also contain provisions for cost of water adjustments when the actual source water quality is outside of the contractual specifications and when unpredictable deviations from the source water quality specifications have material impacts on plant performance and costs.

Technology Risks. Technology risks are related to the potential downsides of using new and unproven technologies with limited or no track record on large-scale desalination plants. Although the use of new technologies typically has performance benefits such as reduced construction costs, power and/or chemical consumption and expenditures, there are potential downsides. These vary from inability to meet contractual product water quantity and/or quality obligations and increased plant downtime due to process under-performance, to equipment failure or malfunction of key system components.

While project engineers tend to focus on the cost and performance advantages, project lenders always take under consideration both potential upsides and downsides on a life-cycle cost basis when evaluating the risks and benefits associated with using new technology. If potential project downsides outweigh cost savings over the useful life of the project or the lending period, then the technology is considered higher risk and financing terms will typically penalize rather than reward the use of new technology. Usually, the project lender will turn this risk into a cost overrun amortized over the term of lender investment and then into an incremental increase in the interest rate of the funds which the lender commits to the project.

The use of new technology may be attractive from an engineering point of view, but is not always beneficial for reduction of the overall project costs, and in reality it may penalize the cost of water production through the increased cost of financing. Such cost penalty is often applied when the new technology lacks full-scale track record of actual availability (downtime). An assumption of 5 to 10 % of downtime of the new equipment is commonly used by the financial community to evaluate technology risks. This corresponds to new technology used for the first time on a project usually requiring two to three generations of improvements before it reaches a reliability of well proven and mature technology (i.e., technology with downtime of less than 1 % and full-scale track record of 5 years).

Regulatory Risks. Regulatory risks are associated with the effect which changes in environmental, engineering, construction or other government regulations may have on the desalination plant construction and/or O&M costs. Regulatory changes may occur during the period of construction (for example, changes in electrical or building codes) and/or during the period of plant operations.

The financial community typically looks for flexibility features in desalination plant design that allows accommodating future regulation-driven technology changes, and for contractual provisions that permit regulatory risks to be mitigated through cost-of-water tariff adjustments.

Operational Risks. Operational risks are associated with desalination plant operation and maintenance over the useful life of the facility/term of lender investment. Consistent and reliable plant operation and maintenance is the key to generating steady revenue streams required to meet financial obligations.

If the project owner does not have in-house experience with operating desalination plants of similar size, contracting of the desalination plant O&M services to an experienced and well established specialized private contractor with proven experience typically results in lower financing costs. As the desalination market matures, O&M challenges and risks associated with shortage of local skilled labor are resolved over time and the importance of this risk diminishes.

Desalinated Water Demand Risk: Desalinated water demand risk is closely related to the need for high-quality water in the service area of the desalination plant and the affordability of this water as compared to available existing water supply sources. Typically, in a public-private partnership, the project lender will look for a “take-or-pay” provision in the BOOT contract which ascertains that a pre-determined minimum volume of desalinated water is purchased by the final user under all circumstances or alternatively the final user pays for this minimum amount of desalinated water independently of its use.

The lending community considers the water demand risk of desalination projects relatively high for conditions where the costs of alternative fresh water supplies are significantly lower than these of desalinated water, and where the need for water is driven by temporary drought or seasonal shortage of fresh water.

Financing community concerns associated with desalinated water demand may be mitigated by putting in place a water cost structure that provides a temporary subsidy for the use of desalinated water, which subsidy is of size equal to the difference between the cost of desalinated water and the cost of water of other existing sources. Examples of such subsidies are the US$0.32/m^3 (US$1.20/1,000 gallons) credit given to the Tampa Bay Water by the South West Municipal Water District for the potable water produced at the Tampa Bay Water seawater desalination plant, and the US$0.20/m^3 (US$0.80/1,000 gallons/ US$250/acre-foot) credit given the Municipal Water

District of Southern California, US has committed to provide to its customers for the use of desalinated seawater.

Similar direct or indirect mechanisms of reducing the water demand risk are used at state or local government levels throughout the world. In many countries, the desalination cost subsidy is implicitly provided at governmental level, often by the state or local government taking upon a number of the risks presented above by providing payment guarantees, and thereby indirectly subsidizing desalinated water costs.

Financial Risks. These risks are directly related to the financial strength of the entity which will be the final user or the desalinated water, who will be responsible for all payment obligations associated with project financing as well as of the parties involved in the project construction and operation. Project lenders favor financial agreements with entities that have proven track record in servicing and repayment of debt and equity obligations on similar projects and which do not carry excessive amount of previous fiscal obligations.

Other financial risks are the risks associated with the political stability of the country in which the desalination project is planned and the country’s currency stability (currency risk). Many of the project financial risks can be addressed cost-effectively by involvement of the private sector in project financing.

Before financial institutions commit to fund a given project they carefully quantify the risks described above and typically address the outstanding risks that are not already adequately mitigated by contractual and technical means, through the incremental increase in the interest rate of the funds they lend. In addition, project lenders may require the project proponent to use only technologies and equipment of proven track record and to incorporate additional equipment and piping standby provisions to mitigate risks associated with downtime and inability of the plant to produce fresh water or contractually defined quantity and quality. It is customary that the desalination plant design and configuration provide for at least 96% of desalination plant operational availability – e.g., at least 350 out of 365 days per year, the plant is producing fresh water of flowrate equal to or higher than its contractually guaranteed capacity.

Project delivery and financing method has a significant effect on the cost of desalinated cost of water. Although desalination projects worldwide have been delivered under a number of different methods and financial arrangements, the most cost-of-water reduction breakthroughs to date have been achieved under a BOOT method of project delivery.

4. CONTRACTOR PROCUREMENT FOR PROJECT IMPLEMENTATION

Desalination projects can be implemented using a number of contracting methods, which can be summarized into three categories: design-bid-build (DBB); design-build-operate (DBO); and build-own-operate-transfer (BOOT). Most of the brackish desalination projects in the US and elsewhere are delivered as DBB projects as a result of a mature market and longer experience.

The DBB method has also been commonly used for procurement of small and medium size seawater desalination plants in Europe, the US and Israel, and for large-scale desalination projects in the Middle East. For comparison, large seawater desalination projects in Europe, Israel, Asia, the Caribbean, and the US are typically implemented using the BOOT method of delivery.

The type of the selected contracting method mainly depends on the type of owner (public agency or private entity), the project risk profile and owner's experience with similar projects and the source of project funding – loans, grants, bonds, equity or a mixture of these funding sources. The project delivery method often has a significant influence on project costs and therefore, it deserves considerable attention.

4.1. Design-Bid-Build

Under this traditional method of project delivery, the desalination plant owner is typically a public entity (municipality or utility), which is responsible for the overall project implementation as well as for the project financing and long-term plant operation and maintenance. In most cases, the owner employs a consulting engineer to prepare detailed technical specifications which are used to procure a construction contractor to build the project. The construction contractors complete their work under the supervision of the owner and the consulting engineer, and their main responsibility is to implement the requirements indicated in the specifications.

The main advantage for the owner is that the owner retains complete control over the plant ownership, design and implementation. In this method, the owner most often operates the desalination plant with in-house staff and takes advantage of cost-savings that membrane technology advancements can yield in a long term.

The owner also takes practically all risks associated with project development as per Section 9.4. If the owner decides to operate the desalination plant with its own staff, it practically takes all risks associated with the long-term project operations and performance. This includes the risk that the desalination plant may not be capable of producing desalinated water at design capacity, operating at or below the projected power, cartridge filter, membrane and chemical use and of meeting all applicable product water quality and concentrate discharge regulations. Since the owner is responsible for the project financing, it also carries the financial risk associated with the project, including reduction of the owner's available bonding capacity for implementation of future projects.

The DBB project delivery method is most suitable for owners that have prior experience with the permitting and implementation of desalination projects and operation of desalination plants. For owners lacking such experience, the use of the design-bid-method of delivery is advisable for the implementation of small desalination projects with low-risk profile, which will allow them to gain the necessary experience and develop in-house desalination plant O&M capabilities.

4.2. Design-Build-Operate

Similar to the DBB method of project delivery, the DBO approach also involves asset ownership by a public entity but the difference is that a DBO contractor is procured for the final process design, detailed design, construction, startup and commissioning, as well as for the long-term operation of the desalination plant. Under this method of delivery the owner remains responsible for project development, permitting and financing as well.

The owner's consulting engineer typically develops detailed performance specifications and preliminary project design, which are then used to prepare a tender and retain the DBO contracting team, which usually consists of an Engineer, a Contractor and a private operations company (Operator).

The main advantage of the DBO method of delivery above DBB project implementation is that the early coordination of the facility planning and design with construction activities and plant O&M requirements allows optimizing the plant design, and reducing life-cycle water production costs. Another advantage for the public entity which will use the water is that it retains the ultimate ownership of the desalination plant. In addition, the owner transfers most of the plant O&M risks to the private operator that has the experience and skills to manage these risks more cost effectively.

A modified DBO approach used in Australia is the "alliance" contracting concept. Under this delivery method, the owner and the private DBO contractor share responsibilities, risks and rewards for project delivery and performance. The "alliance" project delivery method gives an opportunity to the public agency to be more actively involved throughout project implementation and to exercise more control over the final product. These benefits are traded for taking up some of the project design and construction risks that are traditionally apportioned to the private DBO or BOOT contractor. The alliance method of project delivery has resulted on some of the costliest desalination projects in the history of desalination of seawater and therefore, its benefits have to be carefully evaluated by the entity that ultimately purchases the desalinated water.

Turnkey engineering, procurement and construction (EPC) of project is a form of BDO contract, with the main exception that after the design and construction of the plant is completed under a turnkey contract by a private contractor, it is then operated by the public agency which funds the project and owns the project assets.

4.3. Build-Own-Operate-Transfer

The main difference between this and the other two methods of delivery is that the public entity purchases water as a commodity rather than a physical asset producing water, the desalination plant. The project ownership is retained by the BOOT contractor.

Under this method the BOOT contractor is responsible for all aspects of project implementation, including environmental and construction permitting, design, equipment procurement, construction, startup, and commissioning, long-term operations and permit compliance and project finance. BOOT projects are usually financed with a combination of equity and debt.

The public (or private) entity that is the final user of the desalinated water procures a turnkey BOOT contractor based on a performance specification developed by the owner's engineer. The BOOT contractor sells product water at a guaranteed price, quality and quantity and point of delivery under a water purchase agreement (WPA).

Once the terms for payment of services are set by the WPA, the BOOT project owner/developer usually retains a turnkey contractor to provide all engineering, procurement and construction (EPC) services needed to build and commission the desalination plant, and a private O&M contractor to operate the plant over the entire term of the WPA. Often, the BOOT project owner/developer may also serve as an EPC and/or O&M contractor and may provide a portion of or the entire amount of equity needed to finance the project.

The WPA guarantees water delivery to the user of the water at pre-determined quantity, quality and availability over the entire term of the agreement. On the other hand this agreement guarantees a pre-determined payment for the delivered water to the BOOT contractor and thereby, secures a revenue stream that the BOOT contractor can pledge to obtain project financing. The provisions incorporated in a well-structured water purchase agreement which minimizes the overall cost of water production are take-or-pay clause, firm water purchase obligations, provisions to assign water contract to lenders, firm and transparent water structure, change-in law-provisions, clearly defined water quality standards and liability for third party-claims.

Water purchase agreements have a number of other provisions which aim to define contractual division of responsibilities and risks between the BOOT contractor and the water purchaser. These provisions may vary from project to project, but in general they have to be such that the project risks are apportioned between the BOOT contractor and the water purchaser commensurate with their ability to control and mitigate the risks and to deliver water to the ultimate consumer at lowest overall cost and competitive market price.

Most of the large seawater desalination facilities built over the past 10 years worldwide, or currently undergoing construction, are delivered under public-private partnership arrangement using the BOOT method of project implementation. Exception is the Kingdom of Saudi Arabia where all of the 30 desalination plants operated by the Saline Water Conversion Corporation are procured using EPC method of delivery.

The BOOT method of project delivery is preferred by municipalities and public utilities worldwide as it allows cost-effective transfer to the private sector of the risks associated with the number of variables affecting the cost of desalinated water. Such risks include intake water quality and its difficult-to-predict effects on plant performance, permitting challenges, startup and commissioning difficulties, fast-changing membrane technology and equipment market and limited public sector experience with the operation of large seawater desalination facilities. A key disadvantage for the water off-taker for projects delivered under the BOOT/BOO contract structure is the ability to share the cost benefits of technological advances in desalination technology over the duration of the contract, especially if such duration exceeds 10 years.

5. PROJECT FUNDING

Desalination projects are capital intensive to construct, and usually produce water at a much higher operational cost than traditional water sources. It is therefore important to optimize the cost of finance. The most common methods of financing desalination projects are government funding, conventional financing through loans or bonds, and private project financing.

Under the government funding scenario a government or public agency directly lends funds (or provides grants, subsidies or guarantees) for repayment of the funds required to build the desalination plant. Government financing of an entire desalination project is not currently very common and is usually only available for construction of small projects under emergency conditions. In many countries the government directly or indirectly subsidizes costs associated with desalination to close the "gap" between the cost of water traditionally available and the cost of desalinated water.

Often, the state government provides sovereign guarantees for payment for water supply services under a BOOT contract with a private company, especially in circumstances where the direct purchaser of desalinated water is a public agency under the fiscal and administrative control of the state government. Sovereign government guarantee is critical for privately financed projects when the contracting public agency does not have fiscal autonomy and/or is not credit risk-rated.

Conventional (bond or construction loan) financing is based on issuing long-term debt in the form of general obligation or revenue bonds or a commercial bank loan for a given project. General obligation bonds are used for financing of publicly owned projects and are secured by the full faith and credit of the issuing entity. To issue this type of bonds, the entity seeking funding has to have taxing powers to support payments of debt obligations.

The advantage of general obligation bonds is that they are backed by the full taxing capacity of the governmental entity, and consequently this credit is considered the strongest security pledge available to a lender, thus comes at the lowest available net interest rate. In addition, issuance of general obligation bonds is usually simpler and less costly than raising other types of debt.

Bonds are typically used to finance medium and large size projects (producing more than 20,000 m^3/day) whereas smaller projects are mainly funded through construction loans issued by commercial banks/lenders specialized in such financing. Fixed-rate commercial loans are widely used for this purpose and these loans have constant interest rate and payment for the full term of the loan. The term of such loans depends on the project size and risk profile, and typically is between 5 and 20 years.

For projects delivered with private project financing one or more private lenders fund the desalination project via a special project company, and rely only on future cash flow from the project for repayment of their investment with no recourse to the project owner/developer and/or product water purchaser. This is widely used for implementation of large BOOT desalination projects - the source of funds are from private lenders, most often the BOOT project developer, private banks, and institutional investors, such as pension and insurance funds. Private project financing is usually a non-recourse financing, where the purchaser and consumer of water (the public or private water supply entity and its customers) does not have any direct liability for repayment of the funds used for project development or construction and therefore, does not need to pledge any of its assets for fulfillment of the project funding related obligations. The desalinated water user only pays for water services and does not carry project payment obligations on their balance sheet.

The sole source of repayment of the funds invested in the project is the revenue generated from the sale of desalinated water. Responsibility for repayment of funds for the development and implementation of the privately financed project lies within the special project company established by the private BOOT contractor, the assets of which are owned by the project investors providing equity for the project. Privately financed projects are usually funded by a combination of debt and equity.

Debt may be in the form of bonds, commercial construction loans, and/or other financial instruments with a long-term or short-term repayment periods. The equity portion of the project funds is typically provided at the request and in accordance with the conditions of the financial institution issuing the project debt, and is usually in a range of 10 to 30 % of the total project capital costs.

Annual interest at a preset rate is charged for the use of the funds which lenders provide under any of the forms of project financing described above. For a given public utility, the cost of funds required to finance a desalination project will depend mainly on the credit rating of the utility and on the restrictions that apply in relation to assuming new debt obligations. Public utilities with relatively low credit rating and/or limited capacity to borrow adequate amount of funds or issue bonds may often be able to obtain more favorable financing terms by using private sources of financing.

In addition to lowering the overall cost of project funding and the project risk profile, involvement of the private sector in project financing also has the benefit of keeping such financing off the balance sheet of the public utility and of sharing project implementation, and performance risks and costs with the private sector.

Many public utilities who are newcomers to the desalination market prefer to minimize their project related risks and fiscal exposure by opting to transfer key project risks and funding responsibilities to private companies and lending institutions specialized in delivering desalination projects. Therefore, most of the recent large seawater desalination projects worldwide are funded applying a BOOT project delivery structure and non-recourse private project financing. The BOOT method of project delivery has resulted in the lowest cost of production of desalinated water to date worldwide.