El-Hammam Desalination Water Project
Sea Water Reverse Osmosis (SWRO) Desalination Plant Concept and Conceptual Design
240,000 cubic meters per day

July, 2019 **PESCO**

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Proposed Concept for Reverse Osmosis (RO) Desalination Plants

1. Introduction

As most countries globally moved forward in its economic reform program to a more market-based economy, Egypt has joined the other countries that are committed to private sector participations in their infrastructure projects. With the increase in electricity demand to support mainly the industrial and domestic use, the Egyptian government has shifted its resources to welfare projects and emphasized on the participation of the private sector in the electric power generation projects.

Accordingly, Egypt has achieved its goal for electric power generation installed capacity. Currently, Egypt possess over than 10,000 MW of excess capacity ready to be utilized for generating the needed fresh water requirements through available and appropriate desalination technologies.

2. Production of Fresh Water Through Desalination

Desalination is a separation process used to reduce the dissolved salt content of saline water to a usable level. The earliest form of desalination was accomplished by boiling the salt water, then cooling and condensing as fresh water. The best-known thermal technologies are the following:

Multi-Stage Flash (MSF), Multi-Effect Distillation (MED), and Vapor Compression (VC).

The newest commercial technology for desalination is based on membrane treatment. Brackish Water Reverse Osmosis (BWRO), or Sea Water Reverse Osmosis (SWRO), is the fastest growing desalination technique with the greatest number of installations around the globe; it is beginning to dominate the current and future desalination markets. Its energy consumption is usually some 70% less than for comparable evaporation technologies.

Advancements have been made in membrane technology, resulting in stable, long-lived membrane elements. Component parts have been improved, as well, reducing maintenance and down time. Additional advancements in pretreatment have been made in recent years, further extending membrane life and improving performance. Reverse osmosis delivers product water or permeate having essentially the same temperature as the raw water source (an increase of 1C may occur due to pumping and friction in the piping). This is more desirable than the hot water produced by evaporation technologies. RO systems can be designed to deliver virtually any required product water quality. For these and other reasons, RO is usually the preferred method of desalination today.

A disadvantage of RO is the need for significant pre-conditioning of the feed water to protect the membranes. The extent of pre-treatment requirements depends on a variety of factors, such as seawater composition and temperature, seawater intake, membrane materials, and recovery ratio.

Typical electricity consumption of SWRO plants is in the range of 3 to 4 kWh/m3, depending on sea water salinity, recovery ratio, required permeate quality, plant configuration, and energy recovery in the brine blow down.

3. Reverse Osmosis (RO) system

Reverse osmosis is a membrane separation process in which pure water passes from the high-pressure seawater side of a semipermeable membrane to the low-pressure permeate side of the membrane. To overcome the natural osmotic process, the seawater side of the system is to be pressurized to create a sufficiently high net driving pressure across the membrane. In practice, the seawater can be pressurized to pressures as high as 70 to 80 bars. The remaining feed water continues through the pressurized side of the unit as brine. No heating or phase change takes place.

3.1 RO System Component

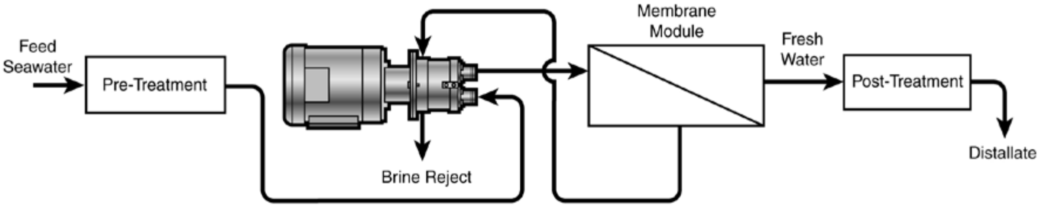
The two most basic individual components in a seawater RO system are the high-pressure feed pump and the RO membranes. These components comprise the heart of any RO system and require careful selection and application for successful operation. In addition to these, other components related to the pretreatment of the inlet water and adjustment of the product water are also included.

Pretreatment. The incoming feed water is pretreated to be compatible with the membranes by removing suspended solids, adjusting the pH, and adding a threshold inhibitor to control scaling caused by constituents such as calcium sulfate.

Pressurization. The pump raises the pressure of the pretreated feed water to an operating pressure appropriate for the membrane and the salinity of the feed water.

Separation. The permeable membranes inhibit the passage of dissolved salts while permitting the desalinated product water to pass through. The saline feed is pumped into a closed vessel where it is pressurized against the membrane. As a portion of the water passes through the membrane, the salt content in the remaining brine increases. Portion of this brine is discharged without passing through the membrane.

Stabilization. The product water from the membrane assembly usually requires pH adjustment and degasification before being transferred to the distribution system for use as drinking water. The product passes through an aeration column in which the pH is elevated from a value of about 5 to close to 7.



Schematic diagram of a RO system.

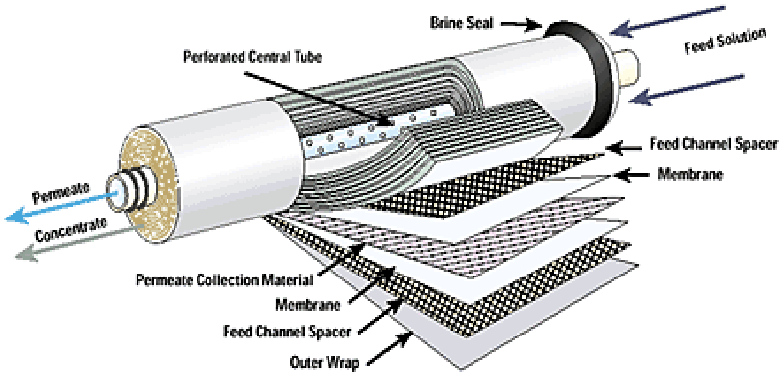
3.2 Membrane Configuration and Material

RO membranes come in a variety of configurations. Two of the commercially successful configurations are the spiral-wound module and hollow-fiber module. In both configurations, module elements are serially connected in pressure vessels (up to seven in spiral-wound modules and up to two in hollow-fiber modules).

Spiral – Wound module

A spiral-wound module element consists of two membrane sheets supported by a grooved or porous support sheet. The support sheet provides the pressure support for the membrane sheets, as well as providing the flow path for the product water. Each sheet is sealed along three of its edges, and the fourth edge is attached to a central product discharge tube.

A plastic spacer sheet is located on each side of the membrane assembly sheets, and the spacer sheets provide the flow channels for the feed flow. The entire assembly is then spirally wrapped around the central discharge tube forming a compact RO module element. The recovery ratio (permeate flow rate divided by the feed flow rate) of spiral-wound module elements is very low, so up to seven elements are arranged in one module to get a higher overall recovery rate.



Spiral-wound RO module element.

Hollow – Fiber Module

Hollow-fiber membranes are made of hair-like fibers, which are united in bundles and arranged in pressure vessels. Typical configurations of hollow-fiber modules are U tube bundles, similar to shell and tube heat exchangers. The feed is introduced along a central tube and flows radially outward on the outside of the fibers. The pure water permeates the fiber membranes and flows axially along the inside of the fibers to a “header” at the end of the bundle.

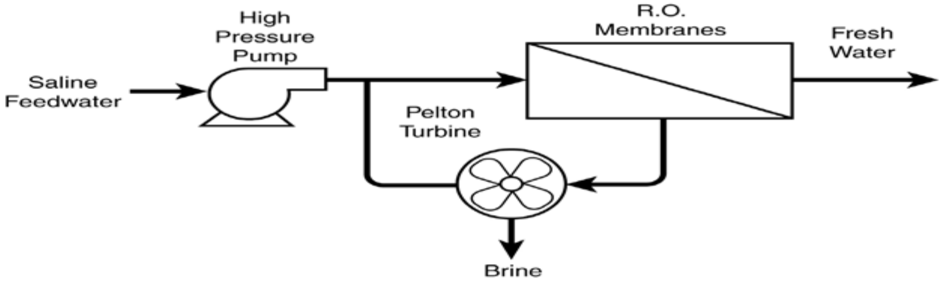
Hollow fiber module

3.3 Energy Recovery in RO System

A key criterion for the RO system is the specific electricity consumption, which should be as low as possible. That means that the recovery ratio must be kept as high as possible and the accompanying feed water pressure as low as possible, fulfilling the drinking water standards as well as the design guidelines of the manufactures. Because the overall recovery ratios of current seawater RO plants are only 30% to 50%, and because the pressure of the discharge brine is only slightly less than the feed stream pressure, all large-scale seawater RO plants, are equipped with energy-recovery turbines that recover a part of the pumping energy.

Recent advances in energy-recovery device technology, together with improved membrane technology and process operations, have reduced the energy required by SWRO to a level comparable to the energy required to pump and treat surface water in many locations.

Number of turbine-based centrifugal energy recovery devices such as the Pelton wheel, Francis, and Reversal pump have been employed since the 1980s to recover pressure energy from the membrane reject stream and return it to the feed of the RO process.



RO unit with a Pelton turbine energy recovery device

3.4 Operation and Maintenance of RO system

Assuming a properly designed and constructed RO unit is installed, the major operational elements associated with the use of this technology will be the day-to-day monitoring of the system and a systematic program of preventive maintenance. Operation, maintenance, and monitoring of RO plants require trained engineering staff. Staffing levels are about one person for a 200 m^3/day plant, increasing to three persons for a 4,000 m^3/day plant.

Preventive maintenance includes instrument calibration, pump adjustment, chemical-feed inspection and adjustment, leak detection and repair, and structural repair of the system on a planned schedule. The main operational concern related to the use of RO units is fouling, caused when membrane pores are clogged by salts or obstructed by suspended particulates. It limits the amount of water that can be treated before cleaning is required. Membrane fouling can be corrected by backwashing or cleaning, and by replacement of the cartridge filter elements.

4. RO Desalination Economic Evaluation

4.1 System configuration

The selection of process components of RO system is affected to the great extent by the type of water the membrane plant will process. In general a RO plant will consist of the following system components and treatment steps:

A. Raw water source
- Sea Water Intake

B. Pretreatment
- Screening Settling
- Coagulation
- Filtration (conventional or membranes – media filtration)
- Chemical conditioning (acid and/or scale inhibitor)
- Cartridge filtration

C. High pressure pumping unit
- High pressure pumps
- Power recovery equipment

D. RO trains
- Permeate treatment, conditioning and storage.
- Instrumentation and control
- Electric system including motor control center
- Membrane cleaning unit.

4.2 Water Cost

In the last decade there was a significant decrease of capital and operating cost. desalted water cost, supplied to customer. The drivers behind the economical improvements are competition and improvement of process and membrane technology.

Majority of large RO systems are built to provide water to municipalities, usually in the framework of build, own and operate (BOO) arrangements. The desalination projects are awarded as result of a very competitive bidding process. Competitive bidding process affected prices of every equipment component of RO systems (including membrane elements) and resulted in a broad price decline. Better performance of equipment and optimization of process design resulted in lower operating cost.

The water cost is composed of capital cost, power consumption, maintenance and parts, membrane replacement, consumables and labor. The major cost components in seawater RO systems are power and capital cost.

4.3 Seawater RO System Cost

The RO system cost is calculated through cost contribution of major system components:

- Site preparation and building
- Intake and outfall
- Pretreatment
- RO trains
- RO membrane elements
- Piping
- High pressure pumps and power recovery turbines
- Electrical
- Permeate post-treatment and storage
- Membrane cleaning system
- Instrumentation and control system
- Contingency
- Engineering
- Owners cost
- Interest during construction

The construction cost of large capacity RO seawater desalination plants is currently reported to be approximately $900 /m^3-day. The following are the major assumptions used to calculate the net water cost for large RO plant based on BOO concept:

Plant Size	240,000 m^3/day
Capital Cost	$900/m^3-day
Discount Rate	8%
Plant life	25 years

It should be noted that, the plant construction cost is a location specific, depending among other issues on the length of the project preparation process and process requirements in respect of raw water quality and product water quality specifications.
The summary of individual cost components for large RO plant (240,000 m^3/day) is as follows:

Production Water Cost Component	**$/m^3**
a. Capital cost (Capital Recovery, 12 years @8% Discount Rate)	0.327
b. Electric Power ($0.08/kwh)	0.240
c. RO membrane replacement (6 years member life)	0.072
d. Media Filter membrane replacement (7 years membrane life)	0.049
e. Chemicals	0.050
f. Maintenance and spare parts	0.056
g. Labor	0.048
Total cost	**0.842**

Note:

It should be noted that the cost associated to the connection to water distribution system should be added to the above water production cost. This will be subject to the project site and the target distribution zone. Also, an appropriate Egyptian Taxes, if applicable, will be added in the final water production cost.

4.4 Electric Price Impact on Water Cost

Because the high-pressure pump represents the heart of the RO unit, the cost of electricity consumed by the pump and other electricity consuming devices in the RO plant should have a significant effect on the water production cost. We assume in this analysis that the electricity is supplied from the grid or another central source in the region.

4.5 Water Cost Reduction Factors

An increase in recovery rate and permeate flux (rate of fresh water passing through RO membrane) in seawater systems can improve the economics of the desalting process. Implementation of high recovery (permeate rate to total feed water flow), high flux operation requires better quality of the feed water.

New capillary membrane technology used as a pretreatment step has the potential to produce feed water quality which will enable to operate seawater membranes at a higher flux rate. The new technology has demonstrated reliable operation at variety of operating conditions.

The associated conceptual design for the proposed 240,000 cubic meters per day SWRO plant is exhibited in Appendix A.

Appendix A

Proposed Conceptual Design
For
El-Hammam Desalination Water Project
240,000 Cubic meters per day SWRO Desalination Plant

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1. Process Flow Diagram
2. Intake Data & Design guidelines
3. Equipment Sizing
4. Preliminary Auxiliary Equipment Electrical Load
5. Site Selection Criteria

1.0 Introduction:

Water scarcity had been serious concern amid scientists, politicians and business communities over last several decades. Available surface or fresh water (river, lakes and ground water) isn't enough for ever growing world population. Climate change and urban growth continue to widen the shortfall of drinking water availability globally. A sustainable solution to meet water demand of this century must come from sea water.

Egypt has long experience of operating desalination plants built with both thermal and membrane technologies. Over last two decades, considerable performance improvement of membrane technologies made Sea Water Reverse Osmosis (SWRO) desalination plant commercially viable method of producing drinking water at a lower capital cost and electricity consumption. Approximately, 40 desalination plants in Egypt produce desalinated water to meet demand for drinking water. Egypt's current development plan looks for additional SWRO plants to meet future demands of drinking water through 2050. A business proposal for 240,000 m^3/day SWRO Desalination plant under "Build, Operate and Own (BOO)" or "Build, Operate, Own and Transfer (BOOT)" schemes well align with Egypt’s current economic plans. Currently, Egypt has surplus electric power generation. The driving economic consideration is to utilize this excess power reserve to operate large scale SWRO desalination projects.

The selection of a cost effective and environmentally acceptable desalination plant depends on thorough evaluation of key project components including source water quality, design of the Intake system, selection of pre-treatment water equipment, selection of RO systems equipment, requirement of concentrate discharge, post-treatment facilities and product water distribution network. Since no specific site is selected at this time, the proposed design remains conceptual.

A conceptual Flow Diagram in **Attachment 1** presents the system configuration, process flows, equipment and associated piping. It also includes important process parameters from water intake to product water output to the Municipality network distribution header.

The type and configuration of sea water intake has significant impact on nature and quantity of foulants that needs to be considered in selection of pre-treatment equipment and RO membranes. The source water constituents comprise of (1) dissolved minerals and gases, (2) colloidal and suspended solids, (3) organics and (4) micro-organisms.

This conceptual design is based on an open intake system, typically used in large desalination plants. Other option is subsurface saline water intake. This method has qualitative advantages in terms of low salinity, TSS, TDS concentrations and pathogen. Therefore, sub-surface sea water intake may also be reviewed for site selection.

2.0 Process Description:

The Flow Diagram exhibited in Attachment 1 shows the details of the entire desalination plant process and design data. A 3-D perspective of a typical Membrane filtration and RO Module is presented in Figure-1 below for a quick understanding of the proposed SWRO Desalination plant. The design includes state-of-the-art membrane filtration technology to pre-treat the source water and final reverse osmosis (RO) modules to produce clean drinking water. Membrane technology consisting of bank of micro-filters (MF) and Ultra-filters (UF) will be used to remove suspended solids (TSS), viruses and bacteria of sizes greater 0.01 microns. However, operating experience of Desalination plants has shown that membrane pretreatment is not always effective where TSS and colloidal levels are high.

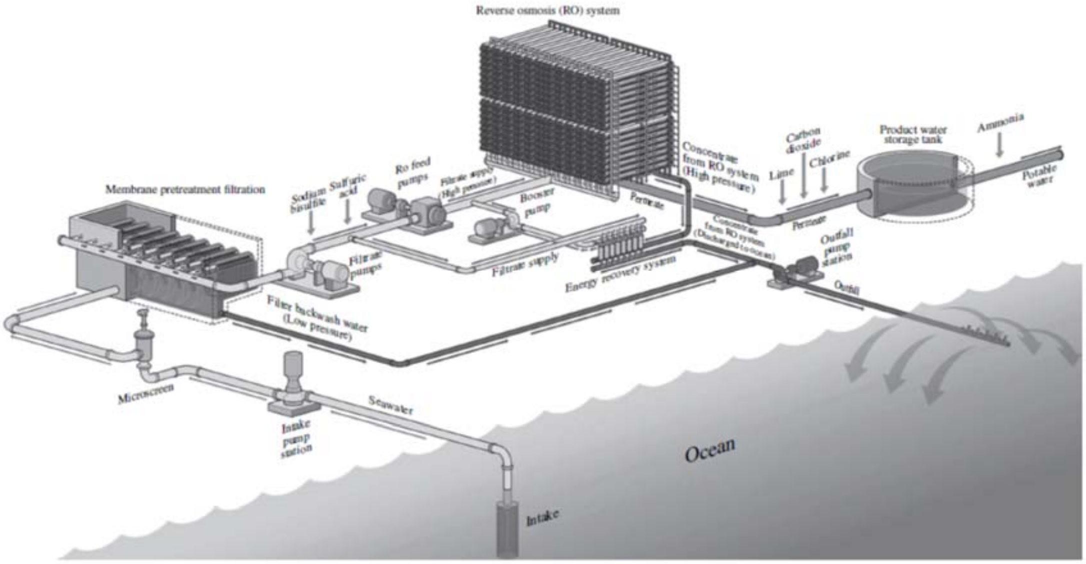


Figure -1 - 3D Perspective of a Typical Desalination Plant with Membrane Filters and RO Modules

(Reference: Desalination Engineering – Planning & Design by Nikolay Voutchkov)

Coarse and micro-screens are used to reduce fouling of particulates on membrane filters. This design includes pressure filters upstream of the membrane filtration as shown in Attachment 1. Brief description of system equipment/components used in the design is discussed below:

2.1 Velocity Cap and Offshore Intake Pipe:

The sea water is collected either through an open intake system or from underground aquifers (subsurface intake). This proposal includes open intake design. The sea water will be drawn through two (2) offshore intake pipes with octagonal velocity cap on each pipe as shown in Attachment-1. As the marine species per unit volume of water decreases with depth, location of the velocity cap further from the shoreline not only lower environmental impact but also significantly reduces turbidity and suspended solids. The design of velocity cap must comply with US EPA recommendation of 0.15 m/sec (0.5 ft/sec) inlet velocity at the velocity cap to avoid impingement of marine life. The preliminary size of the velocity cap is estimated as 6m in diameter and 3m in height. Two 1500 mm HDPE offshore intake pipes are considered in the design.

2.2 Intake Structure and Intake Pumps:

The source water will be collected in one large intake basin suitably located away from the shoreline. The Intake structure is furnished with stationary bar screens and traveling water screens to remove large debris, algae and metals. The Intake is an open structure (30m long x 20m wide x 6m deep) with four vertical turbine type pumps mounted on top of the concrete basin. Each pump is sized for 33.3% of total plant flow of 360,000 m^3/day (15,000 m^3/hr.). The desalination plant consists of three Trains. Each train receives 120,000 m^3/day (5,000 m^3/hr.) of source water and consists of identical Pre-treatment equipment, RO unit and Re-mineralization Unit. The Intake pump design basis is to provide one pump per Train with one standby pump common to three Trains. Each intake pump is sized for 5,000 m^3/hr (22,000 gpm) and 12 bar total dynamic head.

A Gantry crane of capacity of 15 Ton main hook and 5 Ton capacity auxiliary hook are provided to maintain pumps and traveling water screens. The design of intake basin and hydraulic study of intake pumps and basin will be performed during detailed design phase.

2.3 Source water Pretreatment:

The pretreatment system comprises of (1) vertical pressure filters, (2) Cartridge filters and Membrane filtration with media-filters (MF) or ultra-filters (UF).

<u>Vertical pressure filters:</u> Included to remove coarse sands and silts and any sharp objects that can damage downstream membrane filter's fabric. Key advantages of vertical pressure filter over gravity type filtration is (1) lower construction cost, (2) simpler installation because of prefabricated design, (3) smaller footprint taking less real estate and (4) unlike gravity filter no algal growth due to sunlight. Estimated 6-8 filter bank/Train is required considering 12-15 m3/m2-hr filtration performance.

<u>Cartridge filter:</u> Passing through the vertical pressure filters, effluent is admitted into Cartridge filter unit. Cartridge filters are typically required downstream of granular media filters to remove fine sands and silts. However, if the source water is of very good quality and silt density index (SDI) is below 2 NTU, vertical pressure filter can be eliminated as Cartridge filter alone can remove particulates to an inlet quality level required for MF/UF Module. Cartridge filters effectively remove suspended solids and colloids. Cartridges are available to remove 1 to 25 µm particle sizes. This design includes 5 µm and 16 mm (40 inch) in length cartridge tubes that are widely used in Desalination plants. Approximately, 1200 cartridge tubes/Train made of spun polypropylene are considered in the design.

<u>MF/UF filtration:</u> effluent from cartridge filter unit is admitted into MF/UF membrane filtration unit. Particulates, colloidal and some organic foulants can be successfully removed by microfiltration (MF) or Ultrafiltration (UF) method. Particulate separation by UF method is twice as more effective than in MF filtration. The UF membranes reject solutes ranging 0.03 micron (µm) and larger. Selection of MF or UF method of filtration or a combination of MF

and UF will depend on cost and upstream water quality. This determination will be made during the detailed design phase. Considering UF filtration only, approximately 2,000 number of tube elements/Train are required. Feed pressure for UF is taken as 4 bar (60 psi). Filtrate rate at this pressure through UF is estimated as 80 liter/m^2.hr (48 gallon/ft^2.day) and 33m^2 surface area. Based on 4 bar liquid pressure at the UF inlet plus losses in piping, vertical pressure filter unit and cartridge filter module, Intake pump dynamic head is estimated to be 12 bar.

2.4 Desalination Reverse Osmosis (RO):

Permeate water from UF membrane unit is stored in the dedicated Filter water storage tank for each Train. Two 50% low pressure pumps (2,500 m^3/hr, 4 bar TDH) for each train supply filtered water to high pressure pumps upstream of RO unit for further processing. For large SWRO desalination plant as this, RO system will be two-stage process with an energy recovery system (ERS). Refer to the Attachment 1 for two-stage RO and ERS operation. Permeate from the first stage RO modules flow to the product tank. The brine-concentrate from the first stage RO flows to the Pelton wheel assembly. The hydraulic force turns Pelton wheel, which is coupled with the high-pressure pump motor shaft. The additional driving energy applied to pump shaft reduces motor shaft power. The concentrate brine from Pelton wheel enters the second stage RO membrane. The permeate from second stage RO module flows to the product tank and the brine will be discharged to the Brine outfall.

Since membrane filtration can’t remove gases like oxygen, carbon dioxide and ammonia etc. from the permeate, De-gasifier tower is needed to remove dissolved gases. Finally, permeate is stored in the Product tank. The product water is not yet good for drinking as it needs to be disinfected and mineral needs to be added before it is ready to supply to the water distribution network. Disinfectant chemicals such as sodium hypo-chloride or sodium sulfate will be added in the product water discharge piping through static mixer.

Estimated 20,000 RO membrane tubes of 200 mm diameter (8 inch) are required for the plant based on permeate rate of 0.95 m^3/hr. RO membranes are made of fiberglass or polypropylene material for higher strength. Standard RO tubes are 1016 mm (40 inch) long. RO element rejects 99.5% salts and 90% boron.

Pressure filters, Cartridge filters, MF/UF and RO membrane elements are to be backwashed on a regular basis. Waste from filters will be piped to an outfall suitably permitted by the appropriate Authority having jurisdiction. Additionally, membrane elements require periodic cleaning equipment to maintain their performance and useful life. Backwash pumps and piping and clean-in-place (CIP) arrangements are schematically shown in Attachment-1. Details of backwash and CIP arrangement will be developed in the design phase.

To be conservative, 40% recovery is used in the design. This means that approximately 40% of the feed water will be rejected with saline concentration of approximately 60,000 ppm. The brine reject is discharged considerable depth below the water level and approximately at 1500 meter away from the shoreline. The requirement is that brine outfall must be downstream of the intake point so that brine can be well mixed with the sea water and flow down along the direction of the prevailing sea water current.

2.5 Brine Discharge Management:

The primary factors in locating the outfall for brine discharge is the absence of natural submerged sills, spits and manmade jetties. These features would create restrictions to the flow and could also create eddies that would lead to chemical build up between the shoreline and the outfall collation. Detailed knowledge of the offshore bathymetric shoreline configurations is essential in selecting locations. Field experience in various global locations shows a location typically of deep water and far offshore type. Prior to the design the brine outfall hydrographic survey is performed to collect water samples for the determination of physical and chemical water quality data and to survey the sea bottom bathymetry.

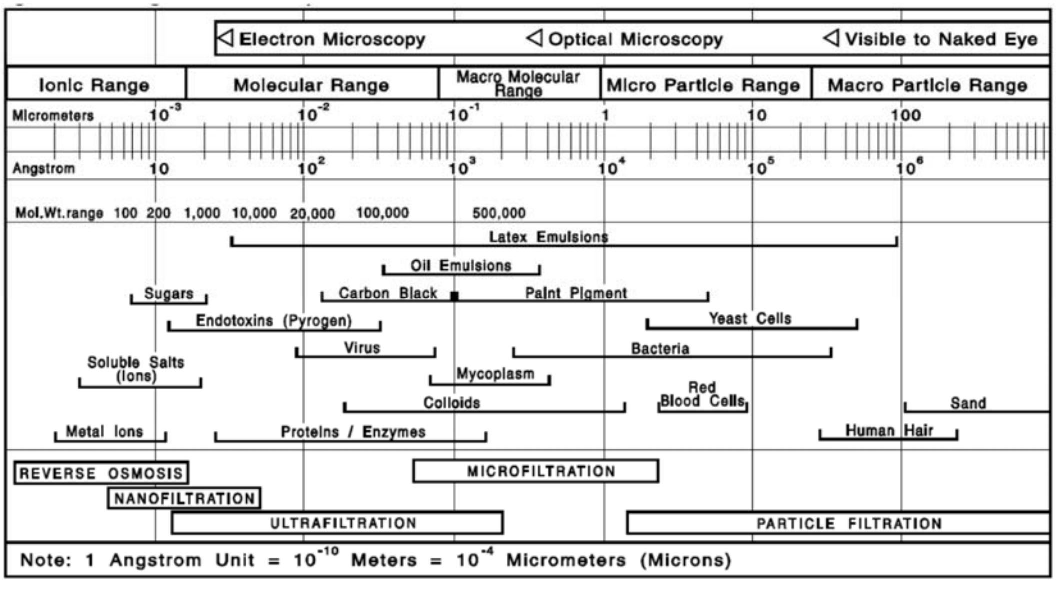
Pre-treatment of brine discharge is important from environmental permit considerations. Typically, a SWRO desalination plant effluent discharges to the outfall contains concentrated brine reject, most of the minerals and contaminants of the source water and pretreatment additives in the concentrated form. If chemical pretreatment is used, the discharge may contain other contaminants such as coagulants, antiscalants, polymers and disinfectants.

From the data collected and the treatment made the quality of the brine discharge water is determined. These data will establish a baseline for comparison with the data that will be collected and analyzed during the operation of the plant. This will be achieved through a monitoring program and per regulatory requirements.

3.0 Desalination Plant Design Bases:

3.1 **Benefits of Membrane Technology:**

Diagram- 1



The diagram-1 above presents recommended filtration process based on particle sizes. The particle separation is performed through (1) Particle Filtration, (2) Microfiltration, (3) Ultrafiltration, (4) Nano filtration and (5) Reverse osmosis. Range of particle size as shown above is in Angstrom and micrometer scale.

Angstrom scale: 1 to 10^7
Micrometer scale: 10^{-4} to 1000
Corresponding Micron (µ) conversion: 1 micrometer (µm) =1 micron (µ)
Therefore, the selection of filtration equipment can be chosen as below:

a) Particle Filtration: This falls under conventional water treatment employing media filtration such as gravity filters and or pressure filters. The range of particle size that it can handle particles larger than 100 micron

b) Microfiltration (MF): This applies to membrane filtration process. The particle size that MF filtration can handle is 0.1 micron to 1 micron.

c) Ultrafiltration (UF): This applies to membrane filtration process. The particle size that UF filtration can handle is 0.01 to 0.1 micron.

d) Nano filtration (NF): From performance standpoint, NF is almost equal to UF membranes. So, either membrane filters can be used. This design proposes UF filtration only as it is widely used in the desalination industry.

e) Reverse Osmosis (RO): The RO membrane process is superior to all other filtration methods. The particles that RO membrane can separate is up to micron to 0.01 micron. The subject design includes MF, UF and RO membranes to produce permeate water.

3.2 **Source Water Constituents:**

Source water (Feed Water) constituents are critical parameters in design and selection of pre-treatment equipment. The key factor of designing a desalination plant is to collect detailed water analysis and seasonal data with high, low and average numbers of the following constituents:

a) *Silt density index (SDI):* This parameter indicates the particulate fouling potential of the source water. Generally, RO supplier prefers SDI level less than 5. Membrane filtration can bring the SDI down below 3. The design includes SDI 5 in source water. It may be noted that a SDI greater than 4 would require pre-treatment. Since this design considers SDI level as 5, Pre-treatment is included.

b) *Total suspended solids (TSS) and Turbidity:* TSS is a measure of weight of the particulates in the sea water expressed in mg/L unit. Turbidity is the haziness of the fluid caused by particulates. It is indicative of clay, silt, suspended organic matters and microscopic aquatic life. Turbidity is expressed as NTU

(Nephelometric turbidity unit). The ratio of TSS and Turbidity is important design parameter for selection of pre-treatment equipment. The maximum TSS considered in the design is 8 mg/L and turbidity 5. Therefore, TSS and Turbidity ratio is 1.6. TSS could increase to a high level due to algal growth impacting membrane performance. Therefore, location of the sea water intake is critical where TSS and turbidity ratio falls within the specification limits of MF/UF filters. Usually, turbidity of the filtered water below 0.1 NTU is desirable for RO membranes.

c) *Total Dissolved Solids (TDS):* Refer to Attachment 2 for a typical Mediterranean Sea and Red sea water analysis and expected TDS level downstream of the RO Unit. This TDS level is an important water quality parameter in determining the feed pressure at the inlet to the RO membranes. Every 100 mg/L of TDS in the source water creates 0.07 bar (1 psi) osmotic pressure. This design includes 42,000 mg/L as maximum TDS level in Mediterranean Sea water (**Attachment 2**), osmotic pressure is 29.4 bar (426 psi). Based on this osmotic pressure and pressure losses through piping, valves and RO Modules, HP feed pump discharge pressure is selected at 50 bar.

d) *Total Organic carbon (TOC):* Saline water contains naturally occurring or man-made organic compounds and aquatic micro-organisms. Since micro-organisms and most organic molecules are large in size, they are rejected by RO membranes. However, small organisms may form cake layer that impact RO performance. Typically, sea water contains TOC less than 0.2 mg/L. However, TOC level of 2 to 2.5 mg/L triggers accelerated bio-fouling of RO membranes. Therefore, historical data of the organic constituents should be reviewed during site selection process.

e) *Dissolved Gases:* Sea water contains oxygen, hydrogen, carbon dioxide and ammonia gases. Open intake system doesn’t contain hydrogen sulfide gas. These gases pass through RO membranes. These gases are to be degasified to make desalinated water suitable for drinking.

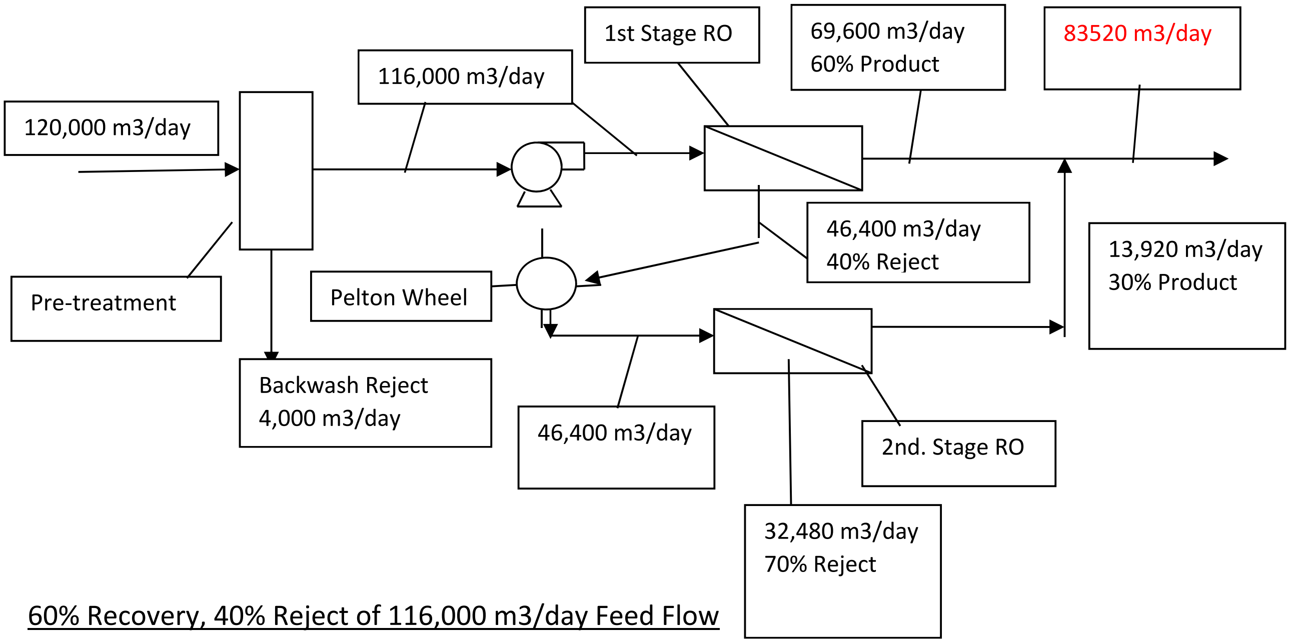
3.3 **Product (Permeate) Recovery Factor:**

Percent Recovery is the amount of water that is being recovered as permeate water. The higher the recovery percentage means that less water is directed to drain as concentrate and saving more permeate water. However, if the recovery percentage is too high for the RO design then it can lead to larger problems due to scaling and fouling. The percentage recovery for a RO system is established based on numerous factors such as feed water chemistry and RO pre-treatment before the RO system. The percentage recovery is the ratio of permeate flow to the feed flow:

$$\% \text{ Recovery} = \frac{Permeate\ Flow\ Rate}{Feedwater\ Flow\ Rate} x100$$

Large commercial RO system typically run anywhere from 50% to 85% recovery depending on the feed water characteristics and other design consideration. This design is based on 40% brine reject and 10% backwash requirements for vertical pressure filters, cartridge filters, UF membranes and RO membranes.

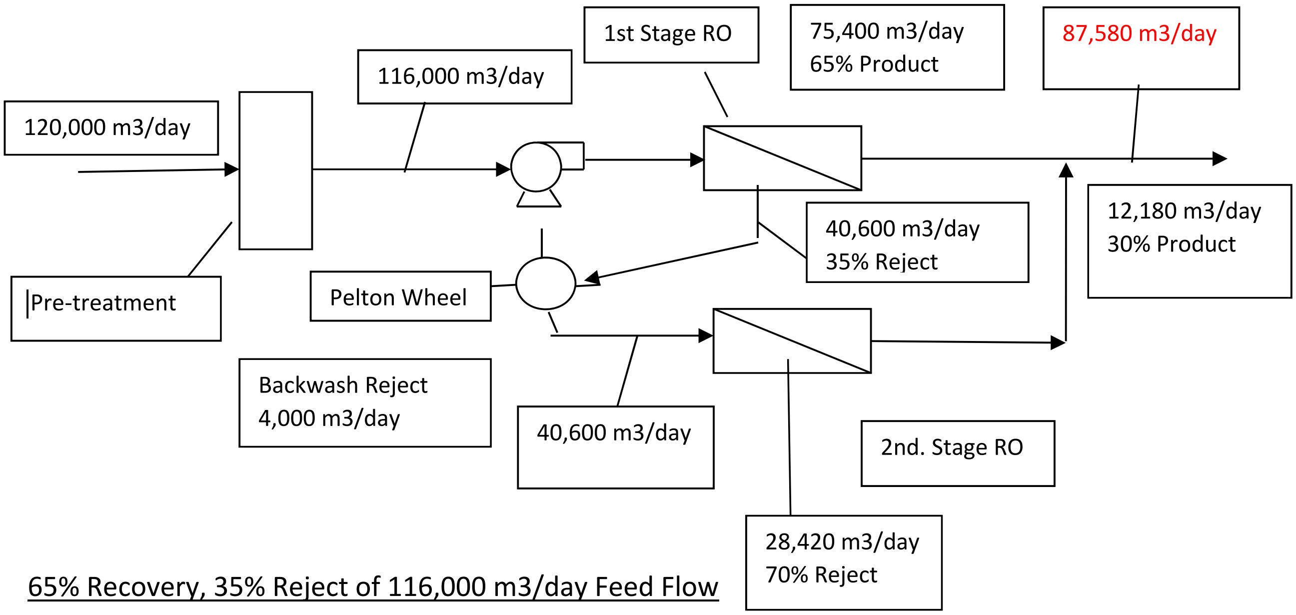
Diagram - 2



60% Recovery, 40% Reject of 116,000 m3/day Feed Flow

Recovery shown in the Diagram – 2 above is for one Train only. Other Train's recovery is identical.

Diagram - 3



65% Recovery, 35% Reject of 116,000 m3/day Feed Flow

3.4 Product (Permeate) Recovery Factor:

The concentration factor is related to the RO system recovery and is an important consideration for RO system design. The more water recovered as permeate (the higher the percentage recovered), the more concentrated salts and contaminants are collected in the concentration rejected stream.

This can lead to higher potential for scaling on the surface of the RO membrane when the concentration factor is too high for the system design and feed water composition.

Concentration Factor= $\frac{1}{1-Recovery\ \%}$

3.5 Energy Recovery:

There are three types of energy recovery systems are used in the desalination industry. These are:

- Pelton wheel
- Hydraulic Turbocharger
- Isobaric Pressure Exchange

A large portion of energy is stored in the concentrate produced in the RO system. This energy can be calculated as below:

ER_{max} -is the energy recovered from the RO system expressed as percentage of the energy the RO system with the feed flow.

P_{feed} - is the feed pressure applied to the RO modules (bar)

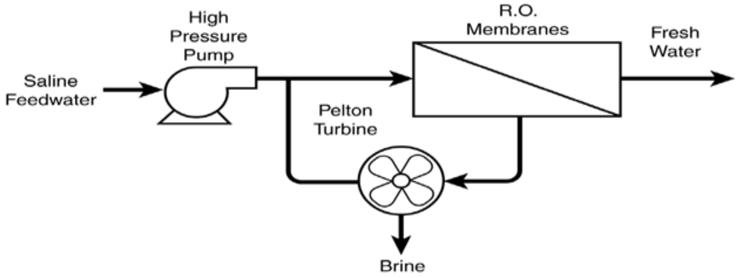
P_{drop} - is the pressure drop in the RO modules (bar)

R - RO system recovery (%)

$ER_{max} = [(P_{feed} - P_{drop}) \times (1-R)]/ P_{feed} = [(50-5) \times (1-0.4)]/50 = 54\%$

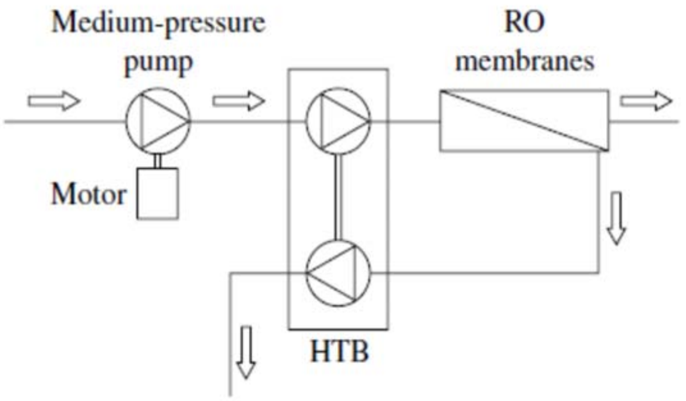
This means that if energy recovery equipment is 100% efficient, then it could recover 54% of the energy introduced in the RO system.

<u>Pelton Wheel:</u>



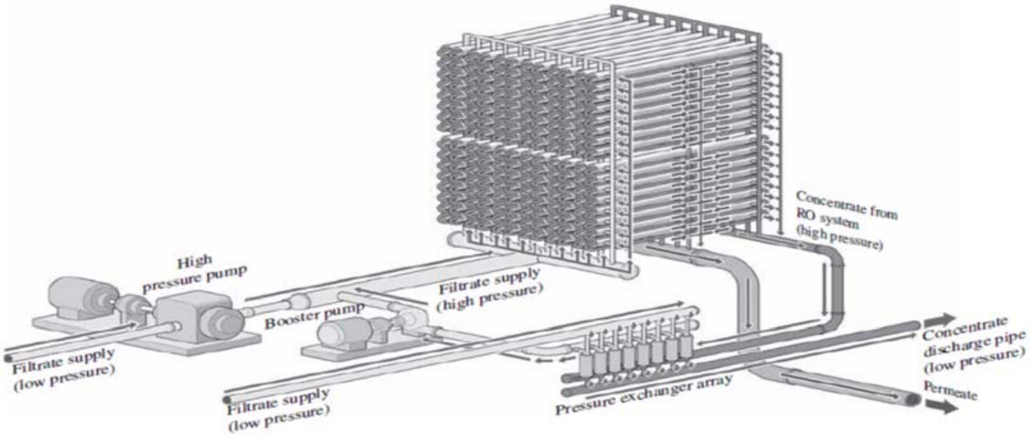
Pelton wheel is the nineteenth century technology developed for hydro-electric power generation. The subject design includes this method to recover the energy. However, it should be further reviewed for other methods and is to be optimized.

<u>TurboCharger:</u>



The Turbo-charger consists of a turbine and centrifugal pump on the same shaft. It is also called Hydraulic Turbo-booster (HTB). The pump boosts up the feed pressure to the RO system. The HTB system improves pumping efficiency 80 to 85%. The concentrate from the HTB will go to the second stage RO module.

<u>Isobaric Pressure Exchange:</u>



(Reference: Desalination Engineering – Planning & Design by Nikolay Voutchkov)

Energy recovery system working on the pressure exchange system delivers energy in the concentrate directly via piston and deliver new source water into the RO system. Flowserve Company developed Dual Work Exchanger Energy Recovery (DWEER) system that claims 98% energy is recovered from the brine stream. Therefore, Flowserve unique design should be reviewed while finalizing which energy recovery method to be used in the subject project.

4.0 Intake Water System:

The function of the water supply intake is to extract and deliver the water to the users such as power plants, municipal and other users. For desalination plants in coastal areas, the main source is the sea water, which is subject of this section.

The most important element in the design of an intake to extract water from a water body is selecting its location and configuration. Problems encountered in the operation of some intakes is improper selection of the intake location or improper design and construction to fit the site condition. Several factors affect such conditions: owner preference for the site, lack of adequate baseline site date, economics, constructability, and failure to provide documents to the engineer to address the siting criteria. Based on field experience, the following is a summary of factors considered in citing and locating a water intake:

a) Water availability and dependability
b) Water quality
c) Bathymetry of the sea in coastal and effect on water depth
d) Sediment transport and drift in coastal areas
e) Aquatic life protection
f) Wave condition in coastal areas
g) Intake hydraulics
h) Constructability
i) Initial and maintenance dredging including disposal of the dredged material
j) Operation and maintenance of the intake system.

4.1 Selection and Description of Intake Water System

1. Based on the above elements and past experience in locating and designing water intakes along the Mediterranean Sea Coast, an offshore intake system is proposed for the desalination plant.

2. An offshore intake consists of a vertical shaft protruding above the seabed and connected to an Octagonal velocity cap located below the minimum sea water level. The velocity cap and its vertical shaft are connected to the pipe that conveys the water to an onshore pump intake structure and related equipment. The velocity cap is provided to create a horizontal velocity field to enable the fish to avoid entrapment by the flowing water. It also includes trash bars to prevent the withdrawal of large floating objects and intruders from entering the intake water system. A concept design of octagonal velocity cap is shown in Attachment-1.

3. Based on the above elements and past experience in locating and designing water intakes along the Mediterranean Sea Coast, an offshore intake system is proposed for the desalination plant.

4. An offshore intake consists of a vertical shaft protruding above the sea bed and connected to a horizontal velocity cap located below the minimum sea water level. The velocity cap and its vertical shaft are connected to the pipe that conveys the water to an onshore pump intake structure and related equipment. The velocity cap is provided to create a horizontal velocity field to enable the fish to avoid entrapment by the flowing water. It also includes trash bars to prevent the withdrawal of large floating objects and intruders from entering the cooling water system.

5. Control biofouling in the offshore velocity cap and the water conveying pipes, Sodium Hypochlorite, which is a widely used chemical, is injected inside the velocity cap though a multiport diffuser.

6. Minimizing the withdrawal of sea bottom by the flowing water is an essential element in locating offshore velocity cap above the sea bed. Based on field experience water depth should not be less than 10 m below sea water level. This depth may be achieved at 1000 M offshore in the Egyptian coast of the Mediterranean Sea and shall be considered for the location of the velocity cap based on the associated bathymetric survey.

7. The total flow required for the proposed facilities is 360,000 m^3/day, the equivalent of approximately 4.16 m^3 /sec. To facilitate construction and to provide redundancy during operation, two offshore intakes velocity caps are proposed. Each is connected to an offshore pipe to convey the water to the onshore common pump intake structure.

8. The velocity caps will be identified by dolphins or floating buoys as a warning to boaters or navigators.

4.2 Water Conveying Pipes

1. Two HDPE pipes with a nominal diameter of 1800 mm (1.8m) is proposed. For a discharge of 4.16 m^3 /sec, the flow velocity in each pipe will be approximately 1.6 m/sec. This type of pipe is mostly used in desalination plants because of the low flow rate and ease of installation as compared to concrete pipes or GRP, which require trenching and protection by riprap and filter layers. This type of protection is needed to prevent

movement of the pipes by wave induced forces and currents, and by ambient sea currents. The HDPE pipe will be loaded with anchor blocks to protect the pipe from flotation due to buoyance and wave induced uplift and drag forces. At the entrance to the onshore pumping station, each pipe will be provided with a gate or a suitable valve for isolation.

2. The offshore pipes when reaching shallow water approximately (- 3 to - 4 m) below seawater level, they will be installed in dredged trenches or a combined trench. The pipes will be covered by filter layers and riprap to resist erosion and to prevent the pipe from the floatation. The completed sea bed in the shallow area shall be formed to match the local sea bed.
3. Between the shoreline and the pump intake structure, the pipes will be installed in a trench which is a continuation of the near shore trench. The top of the pipe must be below the hydraulic grade line to maintain gravity flow to the intake structure.

4.3 Pump Intake Structure

The pump intake structure should be located onshore and far inland from the maximum tide water level and the associated wave run-up. The location also should comply with local building regulations.

The function of this structure is to deliver the water to the desalination equipment. The structure includes:

1. Water filtration system: Trash racks and traveling water screens
2. Settling basin to allow for the deposition of coarse sea sediment that may be carried by the flow during adverse sea conditions. The sediment should be dredged as needed during plant operation.
3. Piers
4. Stop log slots
5. Pumps of various capacities and uses
6. Chemical injection manifold
7. Curtain walls to improve the flow conditions approaching the pumps
8. Baffle walls, filets, and splitters
9. Access hatches and ladders.

5.0 Brine Water Discharge:

The brine water discharged from the processing facilities contains highly concentrated chemicals. To minimize the impact on the aquatic habitats and recirculation into the offshore intakes, the water must be discharged in an acceptable method. This discharge is accomplished by the use of a multiport diffuser located near the seabed and away from the velocity caps.

The approximate total estimated brine discharge flow rate is 120,000 m^3 / day. The diameter of the discharge pipe could be similar to the offshore intake pipes. The diffuser ports are to be determined from numerical thermal model to achieve an acceptable configuration and location. The location would be approximately 1500 m offshore to minimize recirculation.

The installation of the brine pipe in the near shore, shall be similar in concept to that of the offshore the intake pipes. However, the onshore pipe between the plant and the shoreline shall be buried, but its grade shall meet the hydraulic design requirements of the discharge system.

6.0 Pre-treatment of Sea Water:

Pre-treatment system consists of Cartridge filter assembly and combination of micro-filters and ultra-filters as detailed below:

a) Cartridge filters - Cartridge filters can remove particles of sizes 1 through 25micron. For the subject design, 5micron size cartridge filters upstream of the MF/UF membranes is a conservative selection and typically used in the Desalination plants. Based on the loading rate of 5 gpm per 40" length and 8" element diameter, 1,200 cartridge filters (each filter 40” long) are required for each Train. Therefore, if TSS level is very low in the sea water analysis and good screening of sand and marine aquatic are ensured in the intake traveling water screen, pressure filters upstream of cartridge filters can be fully eliminated. The associated cost vs. the associated benefit must be evaluated during detailed design stage.

b) Micro-filter (MF) and Ultra-filter (UF)

Micro-filtration removes particles of 0.1 to 1micron size. In general, TSS and large colloids are rejected while micro-molecules and dissolved gases will pass through. It removes bacteria and some viruses.

Ultra-filtration provides macro molecular separation of micron size up to 0.1 micron. MF and UF filters are available in various diameters and lengths. The subject design includes 8" dia and 40" long UF filter elements.

c) Quantity and size

MF and UF membrane systems generally use hollow fibers that can be operated as outside-in or inside-out direction of flow. Refer to Attachment 3 that includes design basis and quantity of filters required per Train. MF/UF filters are arranged in horizontal configuration with piping, valve and controls.

7.0 Desalination RO System:

The high pressure pump continuously feed filter water into the RO membrane. Feed water is split into (1) low saline called permeate or product water and (2) high saline called brine concentrate. Permeate flux and salt rejection are key performance parameters for the RO system.

Permeate flux is given by the RO supplier.
Salt rejection is calculated as below:
TDS_{feed} = salt level in the feed water, 35,000 mg/l
$TDS_{concentrate}$ = salt level in the brine reject
$TDS_{permeate}$ = salt level in permeate, assume 200 mg/l
R= recovery =40% (as an example)

$$TDS_{concentrate} = \frac{\boxed{TDSfeed\ -\ TDSpermeate\ x\ \frac{40\%}{100}}}{1-\frac{R}{100}}$$

$$=\frac{35,000-200x0.4}{1-0.4} = 34,920/0.6 = 58,200\ \text{mg/l}$$

Flux and rejection are intrinsic properties of the membrane performance. These two are influenced by variable parameters like temperature, pressure, salt concentration in the feed water and recovery. Final design must take in consideration into these influence factors for best RO performance and cost optimization.

8.0 Degasification and Re-mineralization:

8.1 Degasification

RO membranes pass dissolved gases. These are oxygen, carbon dioxide, hydrogen sulfide and ammonia. Typically, Hydrogen sulfide is not present in sea water. All gases will be released through the de-gasifier tower as shown in Attachment 1.

8.2 Remineralization

Product water from Desalination plant is low on mineral content, hardness, alkalinity, and ph. Therefore, desalinated water must be conditioned prior to discharge to the Municipal distribution network. This post-treatment of the desalinated water is the re-mineralization process. It involves (1) mineral addition to protect public health (2) prevention of corrosion in downstream piping system, (3) disinfection to maintain biological stability and (4) removal of boron, silica, and gases that cause taste and odor.

a) Calcium addition: calcium hydroxide (hydrated lime) and carbon dioxide is added to provide hardness and alkalinity.

$$2CO_2 + Ca(OH)_2 \rightarrow Ca(HCO_3)_2$$

Calcium can be stored on site as powdered hydrated lime or as calcium oxide (pebbled lime). Carbon dioxide is delivered in liquefied form and stored under pressure in steel tank. The hardness level in the permeate water is 80 - 120 mg/l as $CaCO_3$. Sulfuric acid or carbonic acid is added to maintain pH and lime solubility. The re-mineralization is an important process to make the desalinated water good for drinking and will be further reviewed during detailed design phase.

Sodium hypo-chloride is added to disinfect water from bacteria. Sometime ultra-violet (UV) injection could be necessary.

Based on worldwide experience and economics, water quality after re-mineralization should be maintained at:

a) Alkalinity >80 mg/l as $CaCO_3$
b) 80 <Ca^{2+}<120 mg/l as $CaCO_3$
c) 3<CCPP<10 mg/l as $CaCO_3$
d) 7.5 <pH <8.5
e) Larson Ratio <5

Chemical consumption/day for the Remineralizer process is included in Attachment-1. Product water quality standard in USA is also shown in Attachment-1. A typical chemical injection points and their purpose are shown in Table-4 of Attachment-2.

8.3 Plant Equipment Sizing and Auxiliary Load

The plant equipment sizing for the proposed 240,000 m^3/day SWRO plant is exhibited in **Attachment 3**. The preliminary plant auxiliary load for the proposed plant is shown in **Attachment 4**.

8.4 Plant Automation:

Entire desalination plant will be controlled by Supervisory Control and Data Acquisition (SCADA) system. The control network consists of programmable logic controller (PLC), remote Input / Output panels and serial data link and Field devices.

Some of the alarm and monitoring parameters are shown in Attachment-1. However, detailed alarms and monitoring parameters will be developed during detailed design phase based on Desalination plant supplier design.

9.0 Conclusion:

There are many Desalination plants in the range of 170,000 – 350,000 m^3/day capacity are in successful operation worldwide. Water production cost can vary from $0.6 to $3.0 per m3. Cost variation from low end to high end will depend on energy cost and source water quality. A breakdown of cost components for water production is given in section 4.3 of the Conceptual section of this proposal.

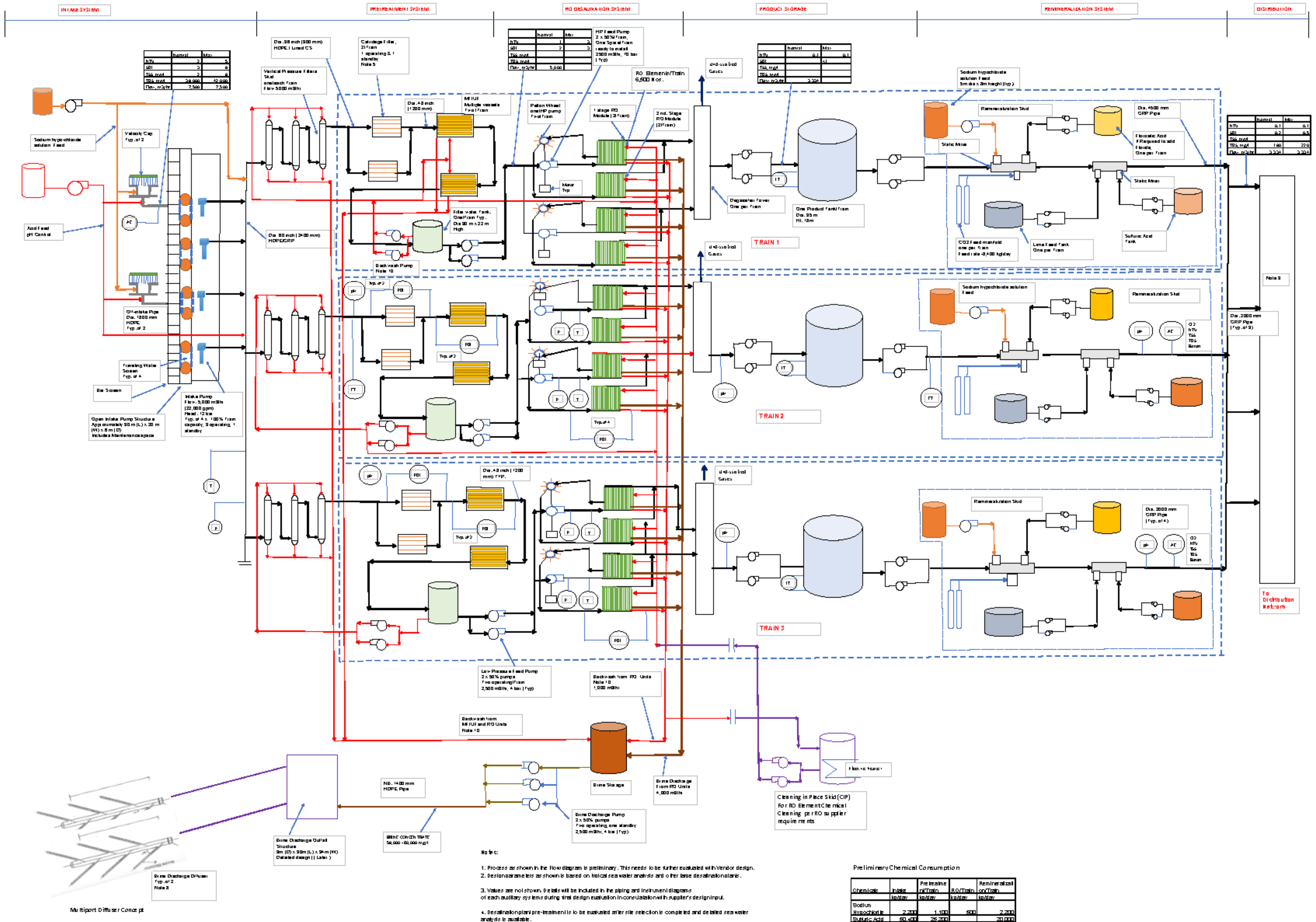
The capital cost and energy cost are two major contributing factors of overall production cost and corresponds to half of the total cost. Key components of the capital cost involve (1) Plant Intake configuration, (2) method of disposal of concentrate, (3) Equipment cost driven by sea water quality and (4) Permitting requirements.

The savings in Energy cost applies to appropriate selection of energy recovery system equipment. Emphasis should also be given to sizing of the Product water tank providing enough buffer storage capacity that can support off-peak water demand with minimum Trains in operation.

ATTACHMENT 1

240,000 m3/Day Product output SWRO Desalination Plant Flow Diagram

Attachment 1



Notes:

1. Process as shown in the Flow diagram is preliminary. This needs to be further evaluated with Vendor design.
2. Design parameters as shown is based on typical sea water analysis and other large desalination plants.

3. Values are not shown. Details will be included in the piping and instrument diagrams of each auxiliary systems during final design evaluation in consultation with supplier's design input.

4. Desalination plant pre-treatment is to be evaluated after site selection is completed and detailed sea water analysis is available.
5. Quantities of cartridge filters, MF/UF filters and RO membrane units are estimated quantity. There will be several vessels/units for each of them with piping, valves and instruments and control.
6. Dimensions for Intake structure and Brine Outfall structure are indicative only. Final design will be based on hydraulic study, site selection, bathymetric details etc.
7. Remineralization of the product water is conceptual and will be finalized after full sea water analysis is available.
8. Brine discharge diffuser reflects diagrammatic presentation only. Detail design will be based on site conditions.
9. Pumping arrangement for the Distribution network is not presented in the diagram. This should be evaluated based on local Municipality requirements
10. Backwash arrangement is schematically presented. Valving arrangement is not shown. Backwash will be a separate system with pumps and controls.
11. Limited instruments are shown for one Train. Other Trains will be identical. Details of instruments and controls will be shown during detailed design.
12. Multi-port Diffuser for Brine discharge is shown. It is preliminary concept pending final design developed for a specific site.

Preliminary Chemical Consumption

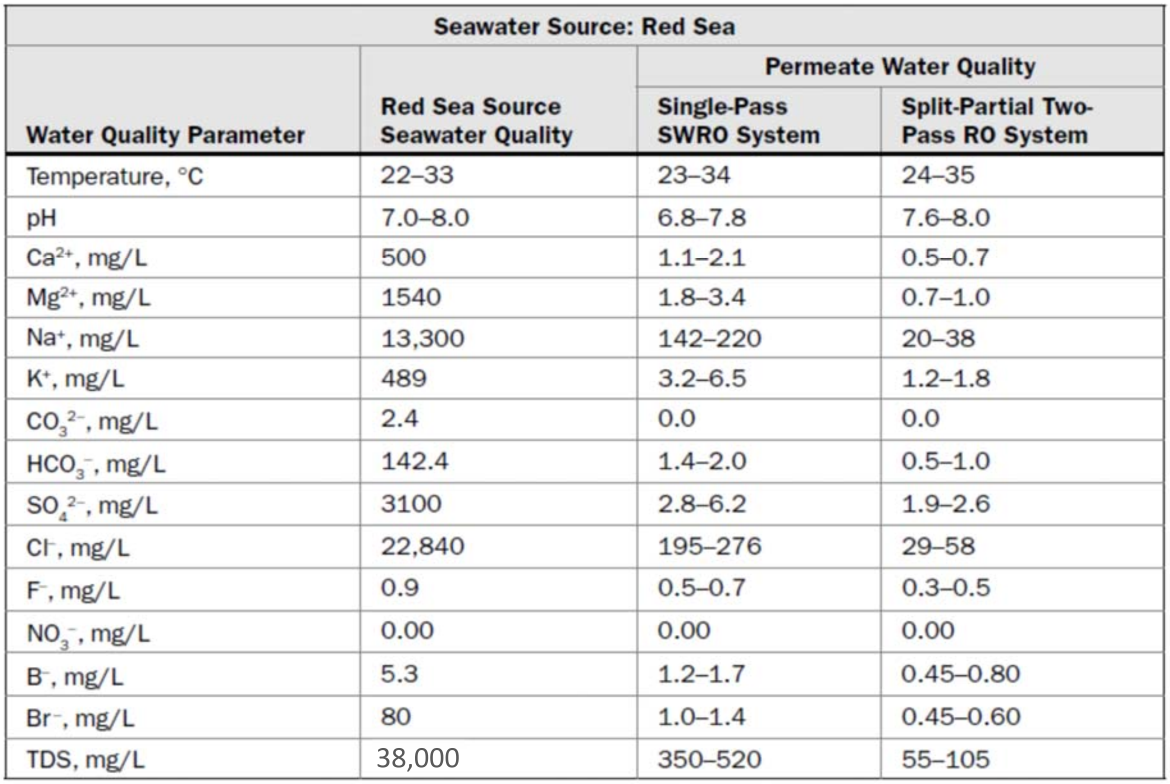
Chemicals	Intake	Pretreatment/Train	RO/Train	Remineralization/Train
	kg/day	kg/day	kg/day	kg/day
Sodium Hypochlorite	2,200	1,100	500	2,200
Sulfuric Acid	50,400	25,200		20,000
Lime				9500
CO2				8,400

ATTACHMENT 2

This attachment is based on data taken from the Desalination Engineering Planning and Design Manual by Voutch Nokolay – Water Use Association

Table 1: presents typical Red sea water analysis, permeate water analysis and final product water analysis following remineralization process.

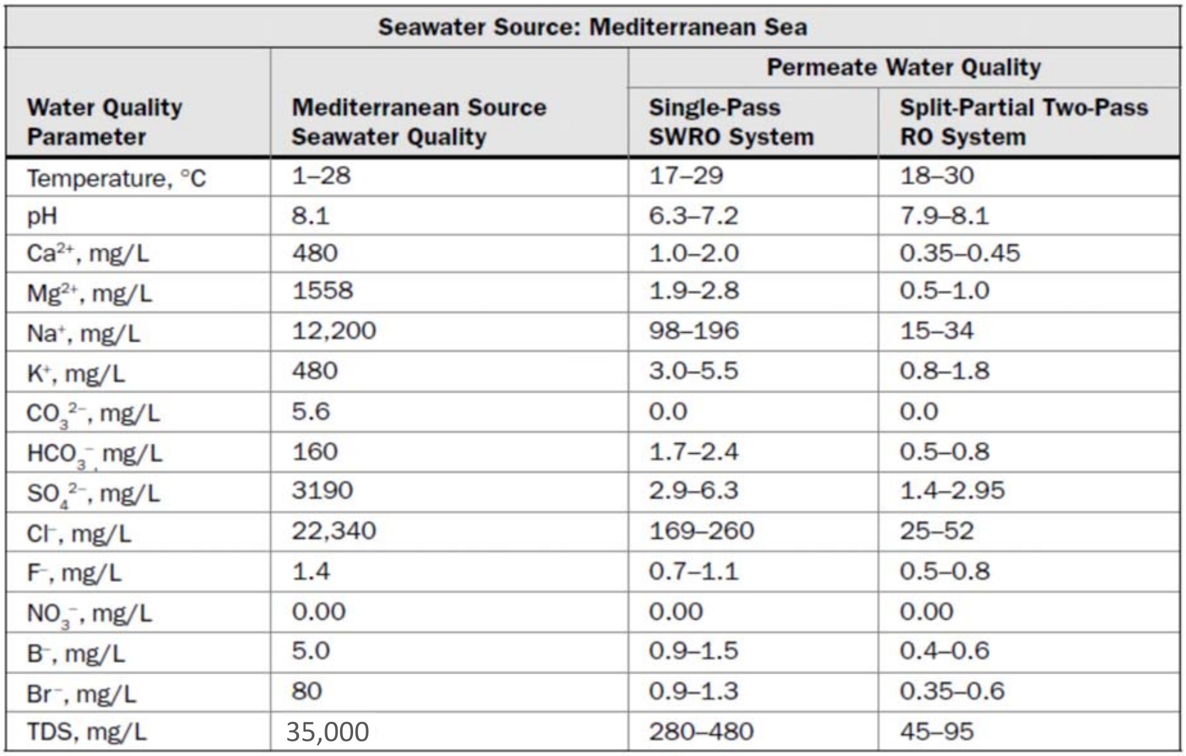
Table 1



Seawater Source: Red Sea			
Water Quality Parameter	**Red Sea Source Seawater Quality**	**Permeate Water Quality**	
		Single-Pass SWRO System	**Split-Partial Two-Pass RO System**
Temperature, °C	22–33	23–34	24–35
pH	7.0–8.0	6.8–7.8	7.6–8.0
Ca^{2+}, mg/L	500	1.1–2.1	0.5–0.7
Mg^{2+}, mg/L	1540	1.8–3.4	0.7–1.0
Na^{+}, mg/L	13,300	142–220	20–38
K^{+}, mg/L	489	3.2–6.5	1.2–1.8
CO_3^{2-}, mg/L	2.4	0.0	0.0
HCO_3^{-}, mg/L	142.4	1.4–2.0	0.5–1.0
SO_4^{2-}, mg/L	3100	2.8–6.2	1.9–2.6
Cl^{-}, mg/L	22,840	195–276	29–58
F^{-}, mg/L	0.9	0.5–0.7	0.3–0.5
NO_3^{-}, mg/L	0.00	0.00	0.00
B^{-}, mg/L	5.3	1.2–1.7	0.45–0.80
Br^{-}, mg/L	80	1.0–1.4	0.45–0.60
TDS, mg/L	38,000	350–520	55–105

Table 2 presents typical Mediterrenean sea water analysis, permeate water analysis and final product water analysis following remineralization process.

Table 2

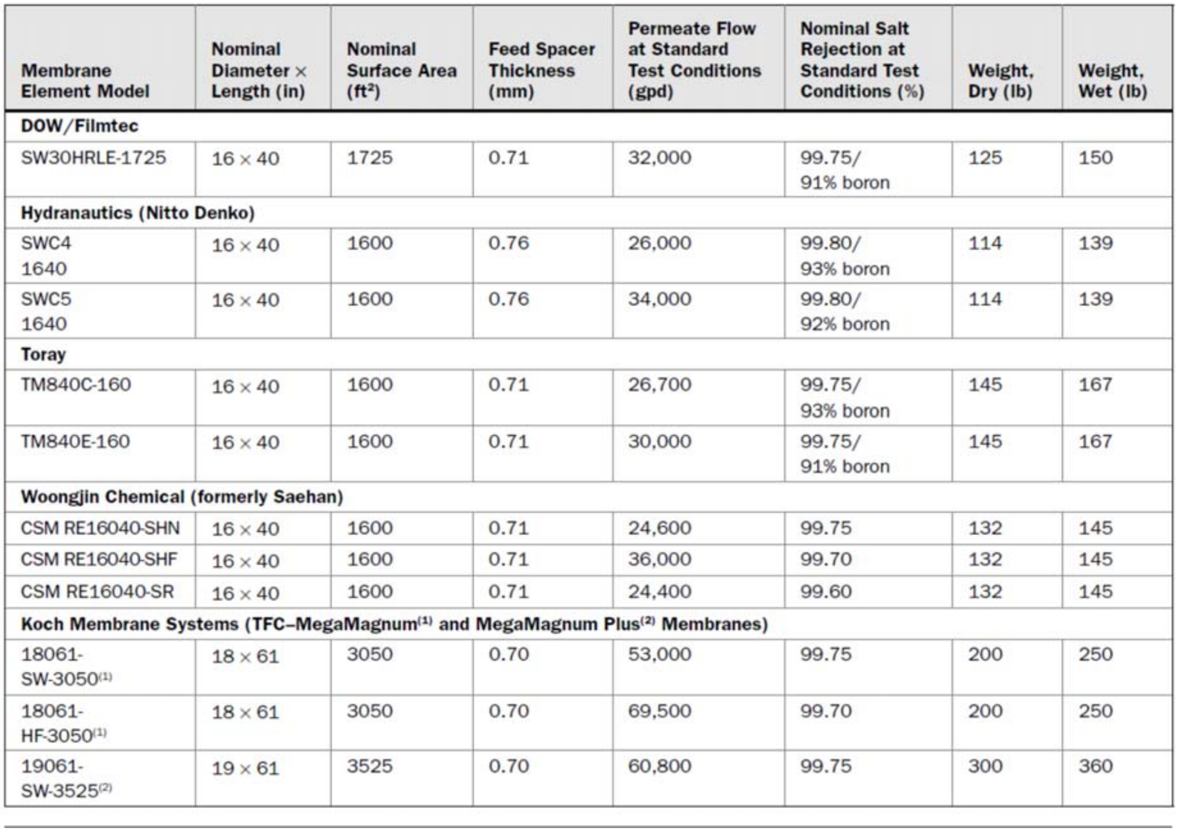


Seawater Source: Mediterranean Sea			
		Permeate Water Quality	
Water Quality Parameter	Mediterranean Source Seawater Quality	Single-Pass SWRO System	Split-Partial Two-Pass RO System
Temperature, °C	1–28	17–29	18–30
pH	8.1	6.3–7.2	7.9–8.1
Ca^{2+}, mg/L	480	1.0–2.0	0.35–0.45
Mg^{2+}, mg/L	1558	1.9–2.8	0.5–1.0
Na^+, mg/L	12,200	98–196	15–34
K^+, mg/L	480	3.0–5.5	0.8–1.8
CO_3^{2-}, mg/L	5.6	0.0	0.0
HCO_3^-, mg/L	160	1.7–2.4	0.5–0.8
SO_4^{2-}, mg/L	3190	2.9–6.3	1.4–2.95
Cl^-, mg/L	22,340	169–260	25–52
F^-, mg/L	1.4	0.7–1.1	0.5–0.8
NO_3^-, mg/L	0.00	0.00	0.00
B^-, mg/L	5.0	0.9–1.5	0.4–0.6
Br^-, mg/L	80	0.9–1.3	0.35–0.6
TDS, mg/L	35,000	280–480	45–95

Table 3 presents large RO membranes elements currently available in the market. RO element of 16 and 18 inch diameter and each 40 inch long is the latest RO elements used in the desalination plant. This large size RO elements is a remarkable progress in the RO design that increased permeate flow rate and reduced quantity of RO elements as compared to 8 inch dia x 40 inch long RO elements used a decade ago.

RO element of 16" dia x 40" long have been considered for the subject project.

Table 3



Membrane Element Model	Nominal Diameter × Length (in)	Nominal Surface Area (ft²)	Feed Spacer Thickness (mm)	Permeate Flow at Standard Test Conditions (gpd)	Nominal Salt Rejection at Standard Test Conditions (%)	Weight, Dry (lb)	Weight, Wet (lb)
DOW/Filmtec							
SW30HRLE-1725	16 × 40	1725	0.71	32,000	99.75/ 91% boron	125	150
Hydranautics (Nitto Denko)							
SWC4 1640	16 × 40	1600	0.76	26,000	99.80/ 93% boron	114	139
SWC5 1640	16 × 40	1600	0.76	34,000	99.80/ 92% boron	114	139
Toray							
TM840C-160	16 × 40	1600	0.71	26,700	99.75/ 93% boron	145	167
TM840E-160	16 × 40	1600	0.71	30,000	99.75/ 91% boron	145	167
Woongjin Chemical (formerly Saehan)							
CSM RE16040-SHN	16 × 40	1600	0.71	24,600	99.75	132	145
CSM RE16040-SHF	16 × 40	1600	0.71	36,000	99.70	132	145
CSM RE16040-SR	16 × 40	1600	0.71	24,400	99.60	132	145
Koch Membrane Systems (TFC–MegaMagnum(1) and MegaMagnum Plus(2) Membranes)							
18061-SW-3050(1)	18 × 61	3050	0.70	53,000	99.75	200	250
18061-HF-3050(1)	18 × 61	3050	0.70	69,500	99.70	200	250
19061-SW-3525(2)	19 × 61	3525	0.70	60,800	99.75	300	360

Chemical Doses & Points of Application

Table 4

Chemical	Dosage, mg/L	Point of Application & Purpose	Remark
Ferric chloride or ferric sulfate	0.5 - 30	Upstream of pre-treatment system for removal of solids & silts	It is not required for the subject project as vertical pressure filter and membrane filters are able to remove solids & silts.
Sulfuric Acid	30-100	• Intake forebay • Upstream of pre-treatment • Upstream of RO for scale inhibition	

		Into permeate for reduction of pH and enhanced dissolution of calcite in post treatment system	
Sodium hypochlorite	0-15	Intake Forebay Upstream of membrane filters	
Sodium bisulfite	0-50	Upstream of RO system for removal of oxidant residual	To be determined in the final design
Antiscalant	0.5 - 2	Downstream of sodium bisulfite addition	To be determined in the final design
Sodium hydroxide	10-40	Into feed water of first or second RO passes to remove boron	
Lime	50-100	Into product water for addition of hardness and alkalinity	
Carbon dioxide	30-80	Product water for addition of alkalinity	

ATTACHMENT 3

Equipment Sizing Calculations:

Equipment	**Units**	**Calculations**	**Results**
PUMPS			
Intake Pump			
Intake Pump, Flow	m^3/day	$240,000 + 50\%(240,000) = 360,000$	360,000
Per Pump	m^3/day	$\frac{360,000}{3}$=120,000	120,000
Per Pump	m^3/hr.	$\frac{120,000}{24}$	5,000
Per Pump	lpm	$5000x1000/60$	83,333
Per Pump	gpm	83,333/3.8=21,930	Say 22,000
Pump Head	bar	2 bar pipe loss +2 bar Pressure filter loss + 2 bar Catridge filter loss + 2 bar MF/UF Filter loss +4 bar at the inlet to UF filter	12
Brine Pump			
Brine Discharge Flow	m^3/day	96,000 Rejected brine from RO + 24,000 backwash	120,000
Brine Discharge Flow	m^3/hr	$\frac{120,000}{24}$	5,000
Brine Discharge Flow	gpm	$\frac{5,000x264}{60}$	15,840
No. of operating Pump			3 x 50% Pumps 2 operating, 1 standby
Flow per Pump	gpm	$\frac{15,840}{2}$	7,920 Say 8,000
Pipe dia	mm	1400	
Pump Head	bar		4
Low pressure Feed Pump			
No. L.P. Pump/Train			2 x 50%
No. Filter Pump Operating			2
Flow	gpm	$\frac{5,000}{2}$	2,500
Head	bar	3 bar at MF/UF +1 bar piping & valve loss	4
HP Feed Pumps			2x 50% per Train

			2 operating, One full spare/Train
Flow	m^3/day		120,000
Flow	m^3/hr	$\frac{120,000}{24}$	5,000
Flow/Pump	m^3/hr	$\frac{5,000}{2}$	2,500
Flow/Pump	gpm	$\frac{2,500x264}{60}$	11,000
Head	bar	50 bar at RO +5 bar piping & valve loss +10 bar loss in Pelton wheel + 5 bar margin	70
Product Pumps			2 X 50% per Train 2 operating/Train 1 full spare
Flow	m^3/day		80,000
Flow/Pump	m^3/hr	$\frac{80,000}{2x24}$	1,667
Flow/Pump	gpm	$\frac{1,667x264}{60}$	7,334
Head	bar	5 bar Loss in Remenaralizer+10 bar at supply network	15
Catridge Filter			
Length	inch		40
Flow flux	5 gpm/10 inch		20
Flow per tube	gpm	$\frac{40x5}{10}$	20
Total Flow/Train	m^3/day		120,000
Total Flow/Train	m^3/hr	$\frac{120,000}{24}$	5,000
Total Flow/Train	gpm	$\frac{5,000x264}{60}$	22,000
Qty of Catridge Filter		$\frac{22,000}{20}$	1,100 Say 1,200/Train
MF/UF Filters			
Length	inch		40
Flow flux	5 gpm/10 inch		20
Total Flow/Train	m^3/day		120,000

Design Flux	Lmh		80
Total membrane Area required	m2	$\frac{120,000x1000}{80x24}$	62,500
Area/Module	m2		33
NO. of module		$\frac{62,500}{33}$	1893 Say 2000/Train
For Plant Total			6,000
RO Modules			
Permeate Flow	m3/hr	0.95	0.95
Flow/Train		5000	
Estimate with 16" dia & 40" length		$\frac{5,000}{0.95}$	5,263 tubes/Train
20% margin		$\frac{5263x1.2}{1}$	6315 Round up 6,500
Vessel (8 tube in 1 vessel)		$\frac{6,500}{2}$	3,250 vessels/Train
Tanks			
Filter water tank	m^3		1 hour storage, capacity 5,000
Dia x height	m		30 x 22
Product Tank	m^3		1 hour storage, capacity 3,334
Dia x height	m		35 x 18
Brine Storage Tank			2 hour storage, capacity 11,000
Dia x height	m		35 x 15

ATTACHMENT 4
PLANT AUXILIARY LOAD

Description	Total Qty/Train	Operating	Flow gpm	Head bar	Head ft	BHP	Qty	Train	Motor KW	Total Load KW	Remark
Intake											
Intake Pump	4	3	22,000	12	394	2,460	3		2734	8,200	Continuous
Screen Wash Pump		2	500	15	492	70	2		78	155	continuous
Chemical injection pumps										100	
Brine pump	3	2	11,000	4	131	410	6		456	2,734	continuous
Low Pressure Pump/Train	2	2	11,000	4	131	410	6		456	2,734	continuous
HP Feed Pump/Train	2	2	11,000	70	2,296	7,175	6		7,972	33,483	Continuous 30% ERS Credit
Product Water Pump	2	2	11,000	4	131	410	6		456	2,734	continuous
Degasifier Pump	2	2	11,000	4	131	410	6		456	2,734	continuous
Remineralization								3	160	480	continuous
Total										53,352	
Misc Electrical Load (30%)										16,006	
Lighting Load (20%)										10,671	
Control Power (20%)										10,671	
Margin (15%)										8,003	
Station Load, MW										98,703	
Rounding Station Load, MW											100

ATTACHMENT 5

Field and Analytical Studies for Siting and Designing Desalination Plant and Its Related Offshore Structures

A. Site Selection Studies

To select a coastal site for power plants or desalination plants requires a comprehensive evaluation of several widely used parameters. This evaluation will be used as a tool in selecting a favorable site from at least two potential sites.

The site selection includes a search for available data, performance of field surveys, and on-site observations as discussed below:

- Ease of access to the site from the land and the sea
- Space availability to accommodate the proposed facilities and laydown during construction with an estimated area of two square kilometers
- Site grade with respect to high seawater level
- Presence of transmission lines and location of a nearby existing power plant able of supplying power for desalination
- Geotechnical information on offshore conditions. This may be obtained from investigations made for existing power plants, nearby piers or jetties, and other sea front structures.
- Bathymetric survey of the sea in front of the site that extends to the high tide line and covers an area matching the width of the site at the shoreline as a minimum. The offshore survey should extend at least 1600 m measured from the low tide level. The onshore segment of the survey should extend beyond the high tide level.
- Historic sea water tide conditions and water quality. If the potential sites are in the same region of or at an existing power plant, the water quality is not critical for siting but is needed for design and equipment selection. This data can be collected from samples obtained during the bathometric survey. The survey and water quality sampling shall be made only after identifying the most suitable sites or site.
- Sea bottom sedimentation type and gradation
- Aquatic life type and environmental protections
- Presence of seaweed and floating trash. This should be identified at any site from field observations and experience gained from existing power plants or other marine installations.
- Other parameters as may be determined from field observations by specialist

B. Field and Analytical Studies and Design

The required data collection programs and studies for the design and construction of the water supply for the desalination plant depend on the site location, hydrographic and geotechnical onshore and offshore conditions. The selected contractor shall determine the applicable studies required for the given site. The following is a list of typical studies that are required at a given site for: licensing, design, and construction of a desalination plant. Additional studies also may be required depending on the site conditions and desalination plant requirements:

- Hydrographic data collection
- Historic tide levels
- Bathymetric and hydrographic surveys
- Historic site and /or regional wave climatic data
- Topographic surveys and subsurface investigations
- Site topographic surveys
- Offshore subsurface investigations
- Onshore subsurface investigation and geologic assessment
- Hydraulic analysis and design
- Seawater level and wind studies
- Determination of maximum and minimum water levels
- Plant grade and shore protection
- Brine discharge numerical modeling
- Wave force analysis and design of the offshore velocity caps and the brine outfall diffuser
- Wave uplift forces on the unburied pipe in the deep offshore water, including offshore pipes stability analysis to overcome uplift forces and buoyancy and design protection
- Riprap sourcing and laboratory testing
- Shore protection and trenching and protection of the intake pipes and the brine pipe near shore and offshore
- Pump intake physical hydraulic model study
- Pump performance test
- Other tests and studies.