A 21st Century Study of Global Seawater Reverse Osmosis Operating and Capital Costs

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Abstract

Five years ago, a definitive study was published on seawater reverse osmosis (SWRO) capital and operating costs at various plant capacities in the different feed compositions existing throughout the world (Ref. 1). Since that time, many improvements have occurred in desalination technology, which, when coupled within a highly competitive environment, have out-dated this earlier study. Seawater membrane desalting costs have undergone a significant reduction, but there are no published articles that analyze these systems on a common basis. Reports on international tenders record capital, O&M (Operating and Maintenance) charges and/or delivered water prices, which are unique to a project's locality. The Tampa Bay Florida seawater proposal in the United States cannot be compared, for example, to the Limassol Cyprus project. While it is true that these bids differ somewhat in size, their individual financing arrangements, intake and outfall infrastructures and feed water compositions are so site specific as to make a comparison difficult even though both are privatization projects.

The purpose of this paper is to evaluate current SWRO desalination costs, capital and operating, at comparable conditions. Costs derived from global experiences in international tenders are employed as the basis for all calculations at the capacities and prices that are normally present in the sites studied. This study does not include "special" individual project design and pricing seen in some very recent cases.

Five worldwide locations are examined; Oceanic (Atlantic, Pacific, Indian, etc.), Caribbean Sea, Mediterranean Sea, Red Sea and Arabian Gulf. Plant sizes (expressed in m^3/d or US gallons/d) are varied from 4,000 m^3/d (1.06 MGD) to 90,000 m^3/d (23.8 MGD). Both wells and surface intakes are evaluated, using seawater compositions and temperatures that are indigenous to the area. Energy, labor and chemicals are at local prices or, if internally unavailable, on an imported basis. Results are given as absolute dollars and also on a sale-of-water basis. The data is presented in such a manner that the reader can translate the numbers into any specific global situation.

INTRODUCTION

Current evaluation of seawater desalting (SWRO) costs must take into account the rapid changes in RO technology, membranes and associated equipment, and the impact of these improvements on the total costs for owning and operating a plant. Over the course of the last few years, competitive pressures have put a strain on the prices obtained for all SWRO projects. Costs need now to be presented on a uniform basis, using accepted criteria to permit project evaluations and comparisons, not only within a given desalination process, but also between technologies. This paper updates an earlier cost evaluation study (Ref. 1) and significantly expands on its content.

Total water cost (TWC) is now widely accepted as the prevailing criteria for the evaluation of seawater desalination, as compared with earlier years, when first cost, or capital cost was the norm. The various desalination plant global locations make direct comparisons of the individual items comprising TWC difficult. The standardized format for TWC, as presented here, has allowed for detailed analyses.

TWC includes amortized plant capital and all operating and maintenance costs. A line entry for profit has been added to reflect the price charged for a privatized project. This analysis employed the WTCost© computer program as developed by the US Bureau of Reclamation, I. Moch & Associates, Inc. and Boulder Research Enterprises, Inc. (Ref. 2 and 3).

CAPITAL COST

The term " Capital Cost" as commonly defined in construction projects includes:

- Direct Capital Costs: Installed process equipment and associated piping and instrumentation; site civil works; intake and outfall infrastructures; buildings, roads and laboratories (see Table 1).

TABLE 1
DIRECT CAPITAL COST COMPONENTS

Sea Water Intake Structure	Control Room(s)
Pretreatment Equipment	Instrumentation & Control Panels
Cartridge Filters	Water Flush System
High Pressure Pumps & Motors	Motor Control Center & Transformers
Energy Recovery Systems	Transfer Pumps & Motors
RO Modules & Racks	Process Computer
Feed Water Chemical Additive Systems	Water Testing Laboratory
Brine Discharge Infrastructure	Building, Offices, Roads & Storage Areas
Product Water Treatment & Storage	Spare Parts
Cleaning Facilities	Maintenance Shop
High & Low Pressure Piping	Safety & Fire Fighting Equipment
Site Development Civil Works	
High & Low Pressure Piping	

- Indirect Capital Costs: Interest during construction, working capital, insurance, contingency, project management and architectural and engineering (A&E) fees. These costs are usually calculated as percentages of the Direct Capital Costs (see Table 2).

TABLE 2
INDIRECT CAPITAL COST COMPONENTS AS PERCENT OF DIRECT CAPITAL COST

Interest During Construction	2-5%
Working Capital	3-5%
Insurance	1-2%
Contingency	6-13%
Architectural & Engineering Fees	10%
Project Management	8-10%
	30-45%

Total capital costs vary significantly from one part of the world to another. Plant size and availability, quality and temperature of the raw seawater, and other local site conditions have a major impact. For this study, waters of the world have been divided into five general categories:

- A - Oceanic Sea Waters (35 g/L, 18º C)
- B - Caribbean Sea (36 g/L, 26º C)
- C - Mediterranean Sea (38 g/L, 18-24º C)
- D - Red Sea (44 g/L, 22-33º C)
- E - Arabian Gulf (46 g/L, 18-35º C)

Each area is unique and requires a special analysis. Table 3 defines each Case and is the basis for determining costs (capital and operating) in the respective location. Sea wells are employed in Cases A, B and D 1, while Cases C, D 2, E 1 and E 2 are open sea intakes. The seawater plant high-pressure pumps are designed for a maximum pressure of 69 bar (1000 psig); each has a NPSH (Net Positive Suction Head) of 2 bar (29 psig). Pressure vessel pressure drop is assumed at 2 bar (29 psi) for purposes of calculating energy to be recovered. Conversions, temperatures, etc. are specific to the site being studied. Plant capacities in each case are what can be found in these locations

Table 4 shows the Capital Costs for each case examined. Direct capital costs can vary significantly depending on actual local site conditions. This study assumes that the plants are constructed in locations in which the seawater feeds are of "normal" quality. For unusual situations, the individual items in this study can be adjusted to reflect a different condition. Indirect capital costs have been calculated as a constant percentage (35% total) of direct capital.

TABLE 3
BASIS OF DESIGN

	OCEANIC WATERS	CARIBB. SEA	MEDIT. SEA	RED SEA		ARABIAN GULF	
CASE	A	B	C	D 1	D 2	E 1	E 2
Intake	WELL	WELL	OPEN	WELL	OPEN	OPEN	OPEN
Capacity, m³/d	4,000	12,000	20,000	1,000	45,000	20,000	90,000
MGPD	1.06	3.17	5.28	0.264	11.89	5.28	23.78
Feed, G/L	35	36	38	44	44	46	46
Temperature, ºC	18	26	18 TO 24	30	22 TO 33	18 TO 35	18 TO 35
1STStage Max. (HPP-NPSH) Pressure, bar/psig	67/972	67/972	67/972	67/972	67/972	67/972	67/972
2ND Stage HPP Pressure, bar/psig	NA	NA	NA	NA	7.4/107	6.9/100	7.5/109
1ST Stage Conversion %	45	45	45	35	35	35	35
2ND Stage Conversion %	NA	NA	NA	NA	90	90	90
Product, MG/L	<350	<450	<450	<400	<450	<450	<400
ΔP PV + pipe, bar/psi	2.5/36	2.5/36	2.5/36	2.5/36	2.5/36	2.5/36	2.5/36
Replacement Rate, %/yr	8	10	18	33	18 TO 33	12 TO 20	12 TO 20
Availability, %	97	97	95	95	95	>90	>90
Year Production, km³	1,416	4,249	6,935	347	15,604	6,570	29,565

MGAL	374	1,122	1,832	0.915	4,122	1,734	7,811
Power, US$/kWh	0.1	0.15	0.1	0.06	0.04	0.04	0.04
1^{ST} Stage Motor Eff.*, %	93	95	95	92	96	95	96
2^{ND} Stage Motor Eff.*, %	NA	NA	NA	NA	93	93	93
1^{st} HPP Efficiency, %	90	80	80	90	81	80	85
2^{ND} HPP Efficiency**, %	NA	NA	NA	NA	90	90	90
ERD Efficiency*, %	86	87	87	85	88	87	89
Transfer Pumps Efficiency, %	78	79	82	78	84	82	86
Number Of Trains	3	4	6	2	10	6	12
Design Term, Years	5	3	3	1	3	3	3
Amortization, Years/%	20/8	20/8	20/8	20/8	20/8	20/8	20/8
System Guarantee, Yrs	1	3	3 TO 5	1	1 TO 3	3 TO 5	3 TO 5

* Includes Coupling
** Positive Displacement Pump

HPP – High Pressure Pump; ERD – Energy Recovery Device; PV – Pressure Vessel; NPSH – Net Pressure Suction Head; NA - Not Applicable

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The magnitude of the amount of capital required for a specific project has markedly decreased over the last few years. The change is the result of competitive pressures and the many advances made in the seawater desalting process itself. These improvements have primarily been directed at membrane productivity and ion rejection and a better understanding and control of pretreatment and RO plant operations on surface seawater intakes. Process designs that incorporate the new technologies have resulted in a very significant enhancement in plant availability and reliability, all of which have lowered capital requirements. Risk factors have also been lowered as experience in plant operation has been gained.

TABLE 4
CAPITAL COSTS, US $1,000

	OCEANIC WATERS	CARIBB. SEA	MEDIT. SEA	RED SEA		ARABIAN GULF	
CASE	A	B	C	D1	D2	E1	E2
Direct Capital							
RO Modules Installed	400	1150	2,000	225	6,200	3,500	12,500
Site Development	75	150	500	50	1,000	500	1,500
Intake & Outfall	250	600	1,850	100	3,250	2,350	7,150
Process Equip.	2,000	5,000	12,500	1,000	21,000	15,000	45,000
SUB TOTAL	2,725	6,900	16,850	1.375	31,450	21,350	66,150
Indirect Capital							
Interest	55	138	337	27	629	427	1,323
Working Capital	109	276	674	55	1,258	854	2,646
Insurance	27	69	169	14	315	214	662
Contingency	245	621	1,517	124	2,831	1,922	5,954
Arch. & Eng. Fees	273	690	1,685	138	3,145	2,136	6,615
Project Mgt.	245	621	1,517	124	2,831	1,922	5,954

SUB TOTAL	954	2,415	5,899	482	11,009	7,475	23,154
TOTAL CAPITAL	3,679	9,315	22,749	1,857	42,459	28,925	89,304
US $/M³/D	920	776	1,137	1,857	944	1,441	992
US $GD	3.48	2.94	4.31	7.03	3.57	5.46	3.76

TOTAL WATER COST (TWC)

Operating costs contained within the TWC are charges incurred in running a desalination plant. The components of operating expenses are as follows:

1. AMORTIZATION (FIXED CHARGE)

The capital cost for installing a desalination plant is usually recovered (or amortized) over a period of 10 years to 30 years. Annual interest is charged for the use of this money. The total (recovered capital and interest) becomes one of the most important components (generally 30% to 50%) included in the TWC. The lowering of the direct capital requirements for a RO plant that has occurred in the last decade as a result of improved process technology, equipment design and plant availability and reliability has had a major impact on reducing this very important component of the TWC.

For the five cases considered, the amortization rate selected is 8% interest for 20 years. From the amortization equation, the annual rate is 0.1004, which is multiplied by the total plant capital cost (direct plus indirect) to give the fixed charge.

2. MEMBRANES

Computer projections, employing the Toray Industries – Ropur program (Ref. 4), were used to calculate the number of modules and pressure vessels (PV) required to satisfy the quality and quantity requirements of each of the 7 cases under study. The seawater elements were priced at US $800 each with the associated PVs at US $1,500 each. Where a second pass brackish train was needed, the elements were priced at US $600 each and the PV at US $800 each. Twenty per cent was added to these costs for shipping, handling, insurance etc. To obtained membrane capital installed costs, US $900 was added for each seawater PV and US $600 for each brackish PV. These factors include the costs for racks, associated piping and instrumentation, loading elements into PVs and their mounting. All prices are assumed supplied by the OEM as opposed to the membrane manufacturer’s charges. Table 5 summarizes the membrane capital costs.

TABLE 5
MEMBRANE CAPITAL AND OPERATING COSTS

	CAPITAL,			REPLACEMENT,	
	US $K	US $/m³/d	US$/G/D	US $/m³	US $/KG
Case A – Oceanic Waters	400	100	0.38	0.016	0.059
Case B – Caribbean Sea	1,150	96	0.36	0.018	0.069
Case C – Mediterranean Sea	2,000	100	0.38	0.035	0.132
Case D-1 – Red Sea	225	225	0.85	0.141	0.534
Case D-2 – Red Sea	6,200	138	0.52	0.061	0.229
Case E-1 – Arabian Gulf	3,500	175	0.66	0.048	0.181

Case E-2 – Arabian Gulf	12,500	139	0.53	0.038	0.143

Actual membrane replacements in correctly designed and maintained plants are normally less than the system guarantees provided by the OEM and membrane suppliers. In the cases studied, membrane replacement rates are shown in Table 3 and reflect the quality of water that is derived from the different intake systems and pretreatment. Well water is the very best quality and requires little pretreatment and the life of the membranes is adjusted accordingly. Since the quality of the feed water entering the second pass is so superior, replacement rate for the second pass cartridges has been assumed to be 1 %/year. Where there are spreads in replacement rates (Cases D2, E1 and E2), a result of variability in operations, the average value of the numbers presented has been used. Membrane O & M charges in Table 5 reflect these replacement rates and element prices plus the 20% up-charge. No PV replacements are included.

Improvements in membrane polymer, better pretreatment operations, higher skilled operators, and optimization of the RO device, itself, have led, over the years, to reductions in membrane costs, significantly affecting both capital and operating costs. Competition and module manufacturing automation have also greatly contributed to the reduced costs and improved membrane quality. In the last 2 decades, the average purchase price of seawater membranes has declined by more than 50% in absolute terms and by about 85% when adjusted for inflation.

A question raised is how best to manage membrane replacements, i.e. whether and when to add or replace an old membrane. Generally, if a membrane is producing satisfactory water quality, but flow is low, economically, it is better to keep the cartridge and add new pressure vessels to increase flow, providing, of course, that the hydraulics of the plant permit this addition. This approach should result in fewer new elements being required to restore flow. If a membrane is producing poor quality water after a rigorous cleaning, there is no alternate but to remove it and replace the unit with a new one. For large RO project design, it is recommended that 10% additional RO space be provided for potential future additions.

Membrane management becomes an important factor for an efficiently run, low cost plant. The objective is to maintain steady flow, and insure uniform quality at a high availability. Replacements, scheduled in advance, generally, are the most effective way to control costs and keep plant capacity consistently at design. When a plant waits too long to replace and/or add RO modules, there is an irreversible loss of production with time (low membrane flux resulting from fouling, scaling, etc.). Net production can be maintained at design or somewhat above capacity by routinely adjusting membrane replacements and/or additions as well as periodic membrane cleaning cycles.

3. ENERGY CONSUMPTION

A sea water RO process normally uses only electrical energy, either from a grid or generated from diesel fuel. The largest power consumer is the high-pressure pump. Reciprocating pumps (90% efficiency) are used for trains up to about 70 m^3/h (300 gpm) feed flow. Multi-stage centrifugal pumps (70-85% efficiency) are employed for trains above this flow rate. Energy recovery systems [reverse running pump, impulse turbine (Pelton wheel), hydraulic turbocharger or work and pressure exchangers] are now almost always employed to recover the energy from the high pressure RO brine stream. About 30% to 35% of total plant energy requirements can be recovered. The effectiveness of these different recovery devices varies and, for this study, a relatively average efficiency employing a full flow ERD (impulse turbine, turbocharger or reverse running pump) has been used (Table 3). Long term, with further demonstrations of advanced technology units, these consumptions will be lowered about a quarter. A comparison of energy recovery devices can be found in Reference 5.

Table 6 shows total energy consumption for all pumps and general services in the typical plants evaluated. Transfer pumps have an assumed pressure differential of 3 bars (45 psig) between inlet and outlet.

TABLE 6
TYPICAL SEAWATER RO TOTAL PLANT ENERGY REQUIREMENTS, KWH/M³ (KWH/KG)

	OCEANIC WATERS	CARIBB. SEA	MEDIT. SEA	RED SEA		ARABIAN GULF	
CASE	A	B	C	D1	D2	E1	E2
Raw Seawater Transfer Pumps	0.26 (0.97)	0.25 (0.93)	0.24 (0.90)	0.33 (1.26)	0.30 (1.12)	0.31 (1.16)	0.29 (1.09)
Raw Seawater Filter Pumps	NA	NA	0.24 (0.90)	0.33 (1.26)	0.30 (1.12)	0.31 (1.16)	0.29 (1.09)
High Pressure Pumps	4.94 (18.7)	5.44 (20.6)	5.44 (20.6)	6.42 (24.3)	6.84 (25.9)	7.00 (26.5)	6.52 (24.7)
Energy Recovery Devices	-2.00 (-7.6)	-2.07 (-7.8)	-2.07 (-7.8)	-3.10 (-11.7)	-3.14 (-11.9)	-3.14 (-11.9)	-3.18 (-12.0)
Brackish High Pressure Pump	NA	NA	NA	NA	0.17 0.63	0.22 0.85	0.21 0.79
Pretreatment & Chemical Dosing.	************************ (0.02) ************************ ************************ (0.08) ************************						
Product Transfer Pumps	************************ 0.12 ************************** ************************ (0.45) ************************						
Plant Services	************************ 0.12) ************************ ************************ (0.45) ************************						
TOTAL	3.46 (13.1)	3.88 (14.7)	4.11 (15.6)	4.24 (16.1)	4.73 (17.9)	4.96 (19.8)	4.39 (16.7)

Recent advances in membrane technology have permitted operation at higher and higher plant conversions than that which was the situation years ago. Potable water can now be produced in a single-pass operation on high salinity feeds. These improvements have the potential to further reduce total system energy consumption.

4. CONSUMABLES

The type and quantity of chemicals required for RO are established by the feed water quality and end use application. When feed water is supplied from sea wells, plants need little, and in some cases, no chemical treatment; also, membrane cleaning frequencies are low. Feed water from an open sea intake requires more pretreatment chemicals, system cleanings and disposables such as filter cartridges.

New technology, involving anti-fouling membranes, intermittent use of chlorine in the feed water and shock acid treatment plus improved cleaning chemicals have essentially brought biological fouling in open seawater surface intakes under control. Biological fouling was the single most important operational problem in seawater RO; with its control, especially on surface intakes, plants are now operating at over 90% availability and cleaning costs have been very significantly reduced.

TABLE 7
TYPICAL SEAWATER RO ANNUAL CHEMICAL CONSUMPTION

	OCEANIC WATERS	CARRIB. SEA	MEDIT. SEA	RED SEA		ARABIAN GULF	
CASE	A	B	C	D1	D2	E1	E2
Chemicals Used Continuously, $							
H2SO4 (96%)	900	2,700	5,300	850	38,000	16,000	72,000
Mg/L feed	2.6	2.6	3.1	7.7	7.7	7.7	7.7
Cl2	200	500	7,500	1,200	5,000	21,000	95,000
Mg/L feed.	----	----	2	3	3	5	5
Mg/L prod	0.5	0.5	0.5	0.5	0.5	0.5	0.5
NaHSO3	----	----	20,000	1,300	79,000	33,000	150,000
Mg/L feed	----	----	3	3	3	3	3
FeCl3	----	----	25,000	5,000	200,000	165,000	750,000
Mg/L feed	----	----	2	5	5	10	10
Lime prod	500	1,500	3,000	1,500	6,000	3,000	12,000
Caustic prod	100	300	600	300	1,200	600	2,400
SUBTOTAL	1,700	5,000	61,400	10,150	329,200	238,600	1,081400
Chemicals Used Periodically For Cleanings							
Cleanings/ year	1	1	3	2	4	4	4
Citric Acid	1,000	1,500	15,000	1,000	50,000	30,000	100,000
"Detergent"	1,500	2,500	25,000	1,500	80,000	50,000	150,000
"Biocide"	2,500	4,000	40,000	2,500	125,000	75,000	250,000
H2SO4 (96%)	250	350	3,000	250	10,000	6,000	25,000
Caustic	100	150	500	100	1,000	1,500	5,000
SUBTOTAL	5,350	8,500	83,500	5,350	266,000	162,500	530,000
TOTAL	7,000	13,500	144,900	15,500	595,200	401,100	1,611,000

<u>ASSUMED COST OF CHEMICALS, US $/LB</u>
H2S04 – 0.05; Cl2 – 0.10; NaHSO3 – 0.20; FeCl3 – 0.40; CITRIC ACID – 0.90

"DETERGENT" (Proprietary mixture) – 1.20; "Biocide" (proprietary mixture) – 2.00

Table 7 shows the chemicals involved and their utilization rates and costs for the typical plants under study. Both surface water intakes and wells are evaluated.

Other consumables include maintenance and repair items and parts and membrane replacements. Maintenance and parts have been generalized at 3% of Direct Capital less RO modules. Membrane replacements are not included in Consumables, but are discussed and listed separately above in Section 2. MEMBRANES.

5. SUPERVISION AND LABOR

Supervision and labor costs vary depending on plant size and location. If the RO unit is isolated from other facilities, it may be necessary to have personnel in attendance at all times. However, if the plant is part of a utility complex, the RO portion typically does not require more than occasional surveillance by operators having other assigned tasks. The trend is for desalination units to be automated, using programmable computers for operations and emergency shutdowns, thus reducing the need for operating personnel. Table 8 provides an outline of a typical work group for the plants discussed in this paper.

TABLE 8
TYPICAL PLANT STAFFING WITH SUPERVISION AND LABOR COSTS

	OCEANIC WATERS	CARIBB. SEA	MEDIT. SEA	RED SEA		ARABIAN GULF	
CASE	A	B	C	D1	D2	E1	E2
Managers	0.1	0.2	0.5	0.1	1	0.5	1
Supervisors	1	1	2	0.5	3	2	3
Operators	2	4	9	2	13	9	17
Mechanics	0.5	2	2	1	4	2	6
Laboratory	0.2	0.3	1	0.2	2	1	2
Office	0.5	1	2	0.2	2	2	2
TOTAL	4.3	8.5	16.5	4.0	25.0	16.5	31.0
ANNUAL COST, US $ K	93	155	265	50	345	220	415
US $/M³ PROD.	0.066	0.036	0.038	0.144	0.022	0.033	0.014
US $/KG PROD	0.249	0.138	0.145	0.545	0.084	0.127	0.053

The staff required reflects the high availability and reliability now being demonstrated throughout the world as a result of recent applications of improved technology, automation and equipment design. Staffing and associated costs take cognizance of production rate, number of unit operations and trains in service, and normal compensation given to personnel in the different localities studied.

6. TOTAL WATER COST

TWC (Table 9) is a summation of the above individual elements - amortization (fixed cost); membranes; energy utilization; consumables including chemicals and maintenance and repair parts and supervision and labor. These total annual costs divided by total water produced during the year, define the plant's total water cost as $/M³ or $/KG.

For the cases presented, TWC ranges from $0.60/m³ ($2.28/KD) for the high capacity plant in the Arabian Gulf to $1.13/m³ ($4.28/KG) for the low capacity tourist type facility on the Red Sea. Except for the low capacity facilities where labor costs are a significant item, the combination of power and amortization amounted to 75% to 90% of the TWC. Power, itself, can be a half to three quarters of the O & M costs. The challenge is, again, to improve the efficiencies of all pumps and especially the energy recovery devices so as to obtain reduced power costs. Improving membrane performance is a desired goal only if the improvements lead to reduced power costs, as by lowering the HPP pressure.

The RO capital and TWC costs developed in this paper, represent basic operational charges. Purchase prices of SWRO plants in these sizes at the localities cited may vary 5% to 15% or higher, reflecting the local conditions, the competitive situation, profitability and the supplier's view of the risks involved in executing the project.

TABLE 9
TOTAL WATER COST – TWC, US $1,000

	OCEANIC WATERS	CARRIB. SEA	MEDIT. SEA	RED SEA		ARABIAN GULF	
CASE	A	B	C	D 1	D2	E1	E2
Electric Power	490	2,473	2,850	88	2,952	1,303	4,665
Membranes	22	78	243	49	946	314	1,121
Chemicals	7	14	145	16	595	401	1,611
Maintenance & Parts	70	173	446	35	758	536	1,610
Supv. & Labor	93	155	265	50	345	220	415
SUBTOTAL	682	2,893	3,949	238	5,596	2,774	9,422
Amortization	369	935	2,284	186	4,263	2,889	8,966
TOTAL	**1,051**	**3,828**	**6,233**	**424**	**9,859**	**5,663**	**18,388**
US $/M³	**0.74**	**0.90**	**0.90**	**1.22**	**0.63**	**0.86**	**0.62**
US $/KG	**2.81**	**3.41**	**3.40**	**4.62**	**2.39**	**3.26**	**2.35**

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CONCLUSIONS

When the same format is used for calculating capital and total water costs (TWC) for RO plants, direct comparison seawater desalting costs can be made:

- Amortization and energy generally comprise about 80% of the TWC.
- Local application conditions (sea well versus open intake) and local prices (energy, labor rates, chemical costs) have a pronounced effect on TWC.

- Membrane management is a needed consideration for operating a cost effective RO desalination plant at design.
- When evaluating current costs for SWRO, the impacts of rapid technological improvements in RO and its associated equipment must be considered.
- Sale of water prices will be 5% to 15% higher than the values indicated in Table 9, reflecting profitability, risks and local conditions.

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