Title

Transitioning from Thermal Desalination to Reverse Osmosis – The Benefits and Process Hurdles

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Abstract

In 2003 the US Bureau of Reclamation released the *Desalting Handbook for Planners, Third Edition*. This report developed a comprehensive comparison of water costs for various desalination technologies. The economic basis of this study centered on prices from the second quarter of 1999. At this time the average cost for a barrel of crude oil was $16.87. Since this time, the cost of crude oil has peaked at $145.29 and has averaged $53.31. Currently the US Virgin Islands Water and Power Authority (VIWAPA) pay $128 per barrel.

This paper evaluates both the theoretical as well as operational costing of both Thermal and Reverse Osmosis desalinated water. While all plant conditions are not equal, this paper demonstrates a significant cost savings through the use of Reverse Osmosis. The theoretical data is based on the US Bureau of Reclamation's *Desalting Handbook for Planners, Third Edition.* The operational data is based on current MED operation at both the Randolph Harley Production Facility in St. Thomas and the Richmond Production Facility in St. Croix compared to the Seven Seas Water SWRO price to VIWAPA.

Keywords

Thermal Desalination, Reverse Osmosis, Oil, Steam, Power, Build Own Operate

Abbreviations and Notations

Build, Own, Operate - (BOO), facility built, owned, and operated by third party
Consumer Price Index - (CPI), adjustment factor used to scale costs between years
Desalination Recovery - as based on the volume ratio of Product to Desal Feed
Low Temperature Horizontal Tube ME - (LT-HT-ME), thermal desalination processes utilizing steam
Multi-Effect Distillation - (MED), thermal desalination processes utilizing steam
Multimedia Filter - (MMF), prefilter comprised of multiple layers of filter media
Sea Water Reverse Osmosis - (SWRO), desalination process utilizing pressure
Seven Seas Water - (7Seas), BOO Company focusing on water treatment in Caribbean and Americas
Total Dissolved Solids - (TDS), as measured in mg/L
Total Power Consumption – as measured in kilowatt-hours per 1000 gallons (kWhr/kgal)
Total Recovery - as based on the volume ratio of Product to Total Feed
US Virgin Islands Water and Power Authority - (VIWAPA), water and power utility supplying all US Virgin Islands
Ultra Pure Water - (UPW), water at 10 M-Ohm or greater
Volume – as measured in thousand gallons (kgal)

Introduction

For the last 30 years, US Virgin Islands Water and Power Authority (VIWAPA) have utilized Low-Temperature Horizontal Tube ME (LT-HT ME) desalination. With the rising costs of oil and the existing process units reaching the end of their useful life, VIWAPA management conducted an extensive cost saving study with the help of R.W. Beck in 2008. The report concluded that VIWAPA could improve the cost of "water production through systematic installation of RO facilities." It also suggested "a refined study of converting all or a portion of the existing MED facilities to RO facilities."

While management has embarked on as many cost saving measures such as oil prices hedging, distribution loss reduction, and alternative energy initiatives; the need to reduce the actual water production cost was paramount to both VIWAPA and the USVI residents. Their current water production implements Multi-Effect Distillation (MED), which uses both high-pressure (150 psi) and low-pressure (23 psi) steam. While a portion of this does beneficial work in the steam turbines of the power plant and is hence a free resource, there is a substantial portion that must be generated to produce water.

By switching the MED units to Sea Water Reverse Osmosis (SWRO) units, the need for this additional steam can be eliminated, hence saving the fuel that is required to produce the steam. The SWRO also has a significant, consistent electrical load, which can allow the power plant to more easily balance their production and allows them to reach higher efficiencies. As a further benefit, the relatively fast startup and shutdown of the SWRO compared to the MED allows for the SWRO to be a major load shedding source.

From an environmental standpoint the land use and water use are greatly reduced from the transition to SWRO. Use of SWRO also mitigates temperature increases in the outfall; however, there is a slight elevation in effluent Total Dissolved Solids (TDS). Co-locating this with the power plant effluent allows the SWRO to dilute elevated temperatures while the power plant dilutes the SWRO TDS. The future use of alternative energy supplies such as wind and solar also favor SWRO as the requirement to produce steam for electrical generation is reduced.

These conclusions are supplemented by both theoretical and real operational data. The theoretical data is based on the US Bureau of Reclamation's *Desalting Handbook for Planners, Third Edition.* The operational data is based on current MED operation at both the Randolph Harley Production Facility in St. Thomas and the Richmond Production Facility in St. Croix compared to the Seven Seas Water SWRO price to VIWAPA. Since the SWRO price is an all-inclusive Build, Own, Operate contract, the contracted water price plus the guaranteed maximum consumption of electricity provides a true comparison of the total costs between the two approaches.

Theoretical Costs

In 2003 the US Bureau of Reclamation released the *Desalting Handbook for Planners, Third Edition*. This report developed a comprehensive comparison of water costs for various desalination technologies. The economic basis of this study centered on prices from the second quarter of 1999. At the time, the average cost for a barrel of crude oil was $16.87. Since that time, the cost of crude oil has peaked at $145.29 and has averaged $53.31. Currently, VIWAPA pays approximately $128 per barrel.

The relative water costs for various desalting technologies were taken from Table 7.6, below (*Desalting*, p 162). High temperature MSF was set as the base consideration at 10 MGD. From this all other technologies were proportioned. These proportions were used in Table 1 below to begin to adjust the cost for both price of oil and a Consumer Price Index (CPI).

Table 7-6.—Plant investment and product water cost for a 37,850 m^3/day (10 mgd) MSF base case plant

Process	Feed water	Relative plant unit capital costs, percent relative to base, m^3/d (mgd)[1]				Relative unit water costs[2], percent relative to base, m^3/d (mgd)			
Plant size, m^3/d		3,785	18,925	37,850	189,250	3785	18,925	37,850	189,250
Plant size, mgd		(1)	(5)	(10)	(50)	(1)	(5)	(10)	(50)
Low-temperature MSF (once through)	Seawater	302	172	135	77	211	141	119	79
High-temperature MSF (once through)	Seawater	213	126	100	57	191	128	100	72
Low-temperature MSF (recirculation)	Seawater	302	172	135	77	211	141	119	79
High-temperature MSF (recirculation)[3]	Seawater	213	126	**100 (basis)**	57	191	128	**100 (basis)**	72
Low-temperature horizontal tube multi-effect	Seawater	135	79	63	36	136	87	79	53
High-temperature vertical tube multi-effect	Seawater	135	79	63	36	136	87	79	53
Stacked vertical tube multi-effect[4]	Seawater	NA	NA	NA	21	NA	NA	NA	32
MVC[5]	Seawater	96	86	82	NA	119	84	81	NA
SWRO	Seawater	78	44	35	20	75	50	44	25
BWRO	5,000 mg/l	55	26	22	11	30	20	16	8
Brackish water RO	2,500 mg/l	38	17	14	7	28	17	12	6
ED/EDR	5,000 mg/l	66	52	49	36	122	100	85	68
ED/EDR	2,500 mg/l	41	29	23	18	60	46	38	27

[1] All costs include the intake, pretreatment, process, post-treatment, product storage, buildings and distribution system pumps.
[2] Water costs are annual costs divided by annual production.
[3] Assumes recycle type, at 112.8 °C (235 °F) top operating temperature.
[4] All distillation processes use the same performance ratio, except the stacked vapor thermal compression MED
[5] The MVC process assumes that the largest unit size at 3,785 m^3/d (1.0 mgd). All other costs are multiples of 3,785 m^3/d (1.0 mgd).

After inputting the numbers given by *Desalting,* the price per 1000 gallons was computed. Steam and electrical costs were also provided in Chapter 7 of *Desalting* and these numbers were added as a % of total water costs in Table 1. While the handbook had SWRO electrical costs at 24% for 1 MGD and 7% for 10 MGD, we felt this to be too conservative due to the fact that all electricity on islands is generated by oil so we took an average of these numbers at 15%. From these percentages we calculated the cost of water represented by oil in 1999. We then used the ratio of the 2011 price of $128/barrel to the 1999 price of $16.87 a barrel or 759% to escalate 1999 oil costs to 2011.

To escalate other costs the base cost was calculated without oil by taking the $/kgal and subtracting the 1999 oil price. This new 1999 Base Cost w/o Oil was then adjusted using a 3% CPI to get 2011 Base Cost w/o Oil. Finally the 2011 Cost of Oil was added to the 2011 Base Cost w/o Oil (w/CPI) to arrive at the 2011 Total Cost w/ Oil and CPI. As can be seen the water cost of Low Temperature Horizontal Tube ME (LT-HT-ME) is approximately **3.11** times the cost of SWRO. This calculation however does not take into account any prior beneficial use of the steam. Since a portion of this steam maybe considered waste from the power plant, a discount can be applied to the beneficial use by the power plant. Assuming a very conservative 50% discount for all thermal processes but not for the SWRO, the final theoretical cost showed the LT-HT-ME to be **1.87** times more expensive than a SWRO plant water costs.

Table 1

Technology	Low-Temp MSF (once-through)	High-Temp MSF (once-through)	Low-Temp MSF (recirculation)	High-Temp MSF (recirculation)	Low-Temp Horizontal Tube ME	High-Temp Vertical Tube ME	Mechanical Vapor Compression	Sea Water Reverse Osmosis
%Cost	119	100	119	100	79	79	81	44
$/kgal	$ 6.43	$ 5.40	$ 6.43	$ 5.40	$ 4.27	$ 4.27	$ 4.37	$ 2.38
%of SWRO	270%	227%	270%	227%	180%	180%	184%	100%
Steam and Electrical %	25	25	25	25	43	43	51	15
1999 Cost of Oil	$ 1.61	$ 1.35	$ 1.61	$ 1.35	$ 1.83	$ 1.83	$ 2.23	$ 0.36
2011 Cost of Oil	$ 12.19	$ 10.24	$ 12.19	$ 10.24	$ 13.92	$ 13.92	$ 16.93	$ 2.70
1999 $/kgal Without Oil	$ 4.82	$ 4.05	$ 4.82	$ 4.05	$ 2.43	$ 2.43	$ 2.14	$ 2.02
2011 $/kgal Without Oil (Assume 3% CPI)	$ 6.87	$ 5.77	$ 6.87	$ 5.77	$ 3.47	$ 3.47	$ 3.06	$ 2.88
2011 $/kgal With Oil (Assume 3% CPI)	$ 19.06	$ 16.02	$ 19.06	$ 16.02	$ 17.39	$ 17.39	$ 19.98	$ 5.58
%of SWRO without Oil	341%	287%	341%	287%	311%	311%	358%	100%
2011 $/kgal With Oil (Assume 3% CPI) - Discounted	$ 12.97	$ 10.90	$ 12.97	$ 10.90	$ 10.43	$ 10.43	$ 11.52	$ 5.58
%of SWRO without Oil	232%	195%	232%	195%	187%	187%	206%	100%
1999 Oil	$ 16.87							
Current Oil	$ 128.00							
Oil Price Ratio	7.59							

Actual Plant Production Costs

VIWAPA implemented the suggestions of their Senior Management and R.W. Beck by contracting Seven Seas Water Corporation to install and operate a 1.5 MGD SWRO Plant, Figure 1 below, at the Richmond, St. Croix Facility. This plant utilized six Multimedia Filter (MMF) containers and six 250,000 gpd SWRO containers as well as intake, product forwarding and backwashing facilities. The plant was constructed in 92 days and was operational on April 30, 2009. Since this time, the Seven Seas Water has operated the plant under a Build, Own, Operate (BOO) contract which allowed VIWAPA to get a firm understanding of the economic and operational considerations of a SWRO facility without incurring substantial capital expenditures. In this manner, their operations staff has been able to see the benefits and see how it correlates to their existing thermal desalination trains.

Figure 1

During the initial year of operation, the potential lower cost of water was evident in the lower overall fuel costs needed for the SWRO. VIWAPA realizing this and the need to reduce water costs throughout the territory released a Request for Proposals on outsourcing water production to a BOO company for both St. Thomas and St. Croix. Seven Seas Water was awarded this contract to supply all water in the US Virgin Islands. By choosing this method, VIWAPA is able to minimize its own capital expenditures while reducing the overall water costs significantly.

Table 2, below, is a culmination of operational and design data for the existing VIWAPA MED units for both St. Croix and St. Thomas compared to the anticipated SWRO plants. It should be noted that while the SWRO produces potable water, an Ultra Pure Water (UPW) system is added to replace the existing ion exchange demineralizer to supply higher resistivity boiler feed water for the power plant. A more detailed description of the components is included beyond the table.

	MED Units	SWRO
Recovery Rate		
Desalination Recovery	36% - 47%	38% - 42%
Total Recovery	11% - 16%	38% - 42%
Cost Comparison		
Steam Cost	\$5.32 - \$6.44 per kgal	NA
Electricity Cost (@\$0.18 per kWh)	\$1.51 - \$2.01 per kgal	\$2.16 - \$2.70 per kgal
Consumables	\$0.12 - \$0.18 per kgal	Included in BOO Contract
Operations	\$0.73 - \$0.81 per kgal	Included in BOO Contract
Capital (@ 10-12% Rate of Return)	\$2.90 - \$3.30 per kgal	Included in BOO Contract
BOO Price without Electricity		\$3.30 - \$3.50 per kgal
Total Cost including Power	\$10.58 – \$12.74 per kgal	\$5.46 - \$6.20 per kgal
Other Considerations		
Product Temp	99.4 F	86.0 F
Outfall Temp	92.8 F	86.0 F
Outfall TDS	42,196 mg/L	59,167 mg/L
Area per Production Facility	5.77 - 8.73 ft^2 per kgal per day	3.73 – 4.25 ft^2 per kgal per day

Table 2. Cost Comparison of MED to SWRO

1) Units
   a) MED
      i) St. Croix and St. Thomas have four MED units each
      ii) St. Croix – Combined Capacity of 3.65 MGD
         (1) #3 – 1.25 MGD
         (2) #4 and #5 – 0.55 MGD each
         (3) #9 – 1.30 MGD
      iii) St. Thomas - Combined Capacity of 4.35 MGD
         (1) #1 and #2 – 1.25 MGD each
         (2) #6 – 0.55 MGD
         (3) #8 – 1.30 MGD
2) Recovery
   a) MED
      i) Each unit operates with a desalination recovery (Product to Desal Feed) between 36% and 47% with an average of 41%.
      ii) The total recovery (Product to Total Feed) between 11% and 16% with an average of 15%. This is much lower than the desalination recovery due to the cooling water that must also be pumped in as well.
3) Steam – MED Only
   a) Each MED unit needs both low and high pressure steam
   b) Low Pressure (23 psi)
      i) Total need is about 275,000 lbs per hour
      ii) $124.13 a barrel for No. 2 fuel
      iii) Based on the allocation of fuel to water production this equates to $13.09/ton of steam to the MED units
      iv) Average low pressure steam cost is $5.53 per kgal of water production
   c) High Pressure (150 psi)
      i) Total need is about 6,500 lbs per hour
      ii) $96.98 a barrel for No. 6 fuel
      iii) Based on the allocation of fuel to water production this equates to $36.33/ton of steam to the MED units
      iv) Average low pressure steam cost is $0.37 per kgal of water production
   d) Total Steam Cost is approximately **$5.90** per kgal of water production with a range of **$5.32 - $6.44** per kgal
4) Electrical Power Costs
   a) MED
      i) Total power consumption includes seawater pumping, desalination, and a 10% adder for ancillary equipment
      ii) St Thomas has a higher storage facility hence the higher intake pressure
      iii) Average total power consumption was **9.41** kWhr/kgal of production
      iv) Using a marginal power rate of **$0.18**/kWhr this gives a Total Electrical Power Cost which averages **$1.69** per kgal of water production with a range of **$1.51 - $2.01** per kgal.

b) SWRO should be between **$2.16 - $2.70** per kgal and is capped by the BOO contract to protect VIWAPA.

5) Consumables
   a) MED Consumables which included anti-scalants and anti-corrosives averaged **$0.16** per kgal of water production with a range of $0.12 - $0.18 per kgal.
   b) SWRO Consumables Included in BOO Contract
6) Operations
   a) MED
      i) On St. Croix the Operations water cost was $0.81 per kgal of water production
      ii) On St. Thomas the Operations water cost was $0.73 per kgal of water production
   b) SWRO Operations Included in BOO Contract
7) Total Water Costs without Steam & Depreciation
   a) MED average cost was **$2.05** per kgal of water production
8) Total Water Costs with Steam but no Depreciation
   a) MED average cost was **$7.94** per kgal of water production
9) Capital Cost Installed
   a) MED – Based on *Desalting* see Figure 2 below - $9 per GPD of water production
   b) Between a cost of capital of 10-12% this ranges between $2.90 - $3.30 per kgal

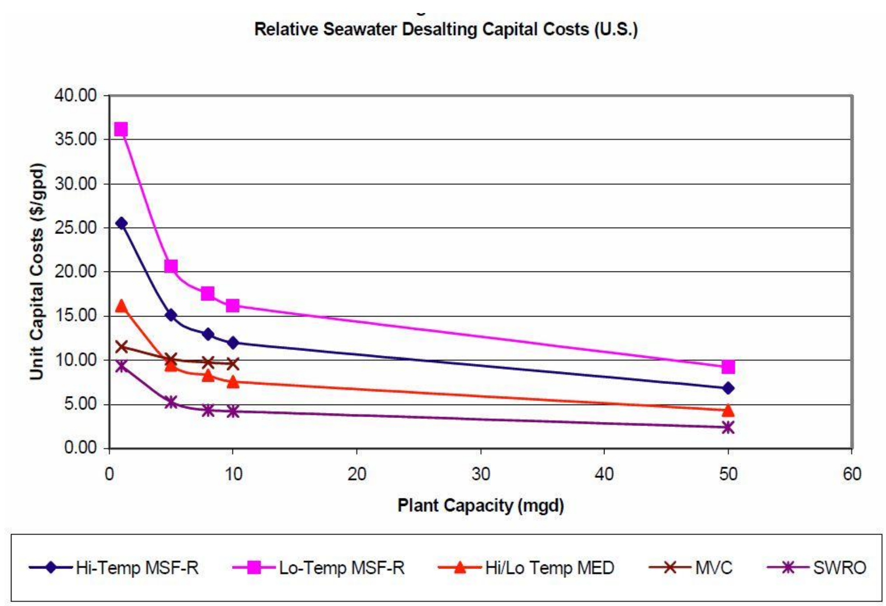

Figure 2. Seawater Desalting Capital Costs, *Desalting Handbook for Planners, p.* 158

10) Total Water Cost – All Inclusive
    a) MED total water cost is estimated at a low of **$10.58** and a high of **$12.74** per kgal of water production with an average of **$11.25.**
    b) SWRO total water cost is estimated between **$5.46 - $6.20** per kgal of water production depending on final BOO Contract and electrical costs.

Figure 3. Current Richmond Facility with MED

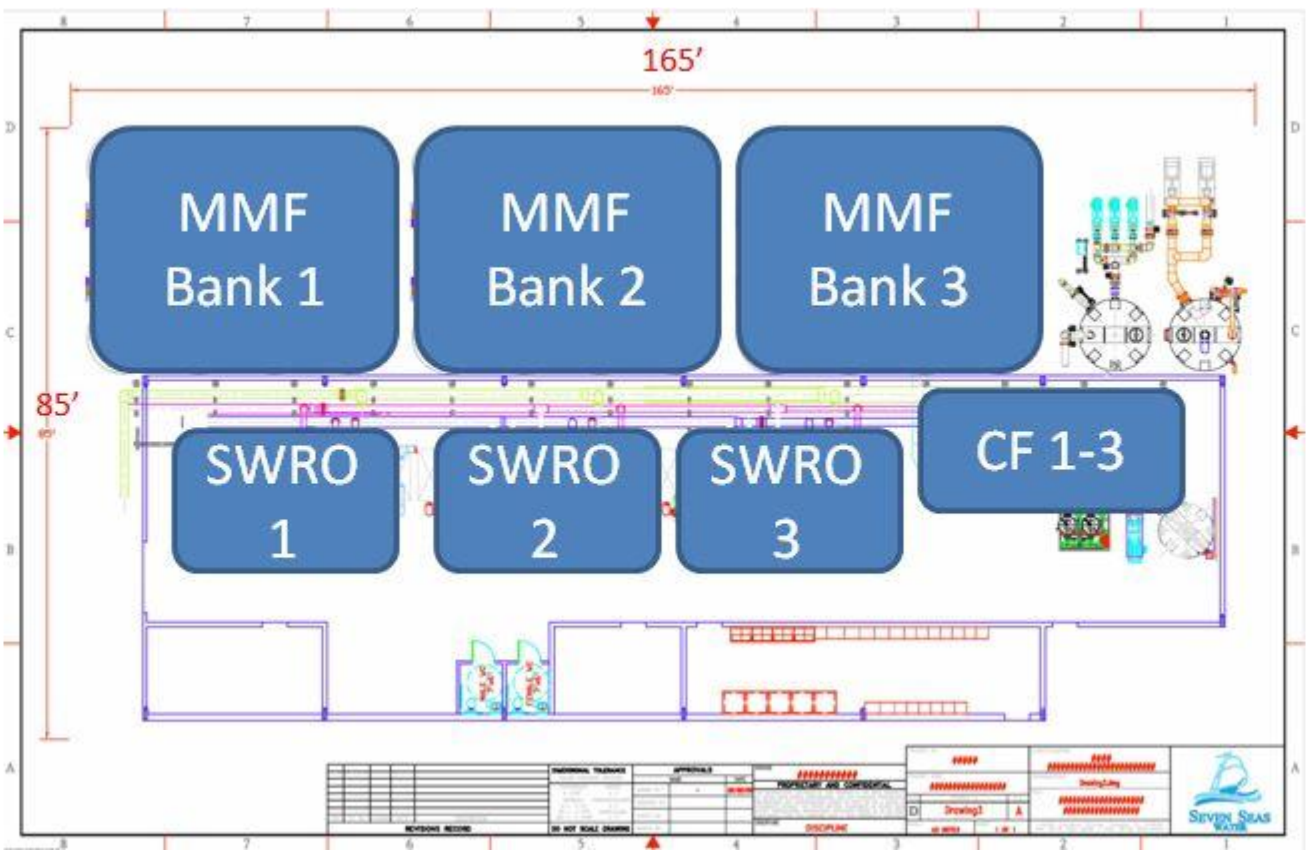

Figure 4. Future Richmond Facility with SWRO

Figure 5. Current Harley Facility with MED

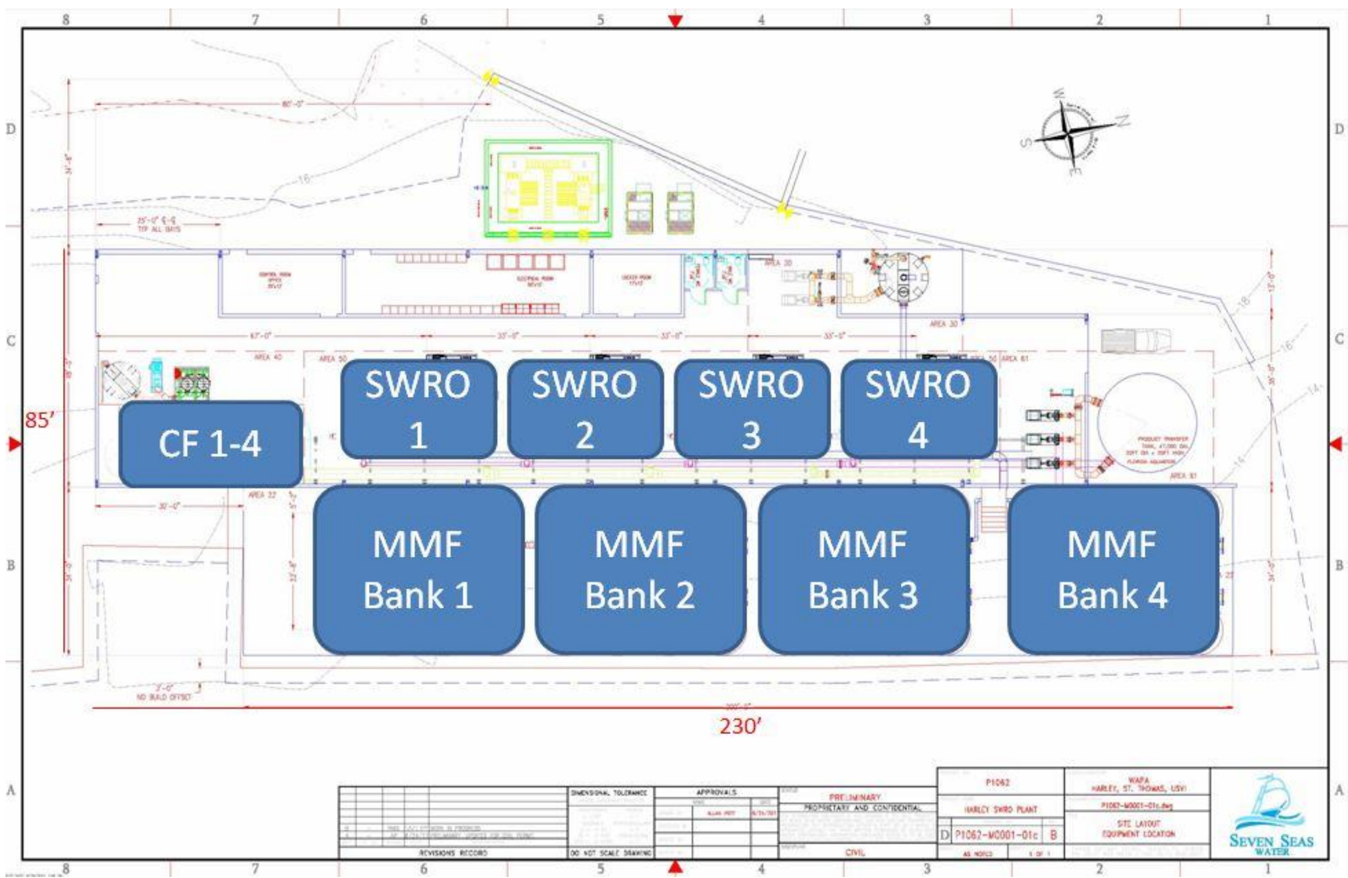

Figure 6. Future Harley Facility with SWRO

Comparison of Theoretical to Actual Production Costs

In a comparison of theoretical to actual production costs we found that the estimates provided in the *Desalting Handbook for Planners* were applicable to VIWAPA both the MED and SWRO processes. Theoretically VIWAPA should be able to save between $4.85 per kgal produced by switching to SWRO from MED and based on actual production numbers this could be as high as $7.28 or a 57% savings.

	MED	SWRO	Savings from SWRO	% Savings from SWRO
Theoretical Costs per kgal	$10.43	$5.58	$4.85	46.5%
Actual Costs per kgal	$10.58 – $12.74	$5.46 - $6.20	$4.38 - $7.28	41% - 57%

Table 3. Final Cost Comparison and Savings

Conclusions

VIWAPA in an effort to reduce the production price of water for the US Virgin Islands embarked on a rigorous exploration into treatment alternatives. Following the advice of their consultant, R.W. Beck, VIWAPA contracted a SWRO plant from Seven Seas Water. Due to the BOO contract, VIWAPA was able to see the construction and operation of a 1.5 MGD SWRO plant with limited capital expenditures of their own.

Based on the operations number provided by this plant and the oil price forecasts, VIWAPA decided to pursue outsourcing all of their production to a SWRO BOO provider. Seven Seas Water was again awarded the job and has begun the design and permitting for the new facilities.

Based on both the theoretical and actual operational data, VIWAPA expects to save over 50% compared to their current operation. The main driver for this savings is the escalating price of oil needed to make steam. As these fuel prices continue to rise the cost savings of a switch to SWRO from MED only become greater.

References

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