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COST EFFECTIVENESS OF EVAPORATIVE TREATMENT PROCESSES

POST, BUCKLEY, SCHUH & JERNIGAN, INC.

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EXECUTIVE SUMMARY

The evaluation of the cost effectiveness of evaporative treatment processes has been completed for the St. Johns River Water Management District (SJRWMD) as part of Post, Buckley, Schuh & Jernigan Inc.'s (PBS&J's) contract assessing water conservation and reuse of reclaimed water as effective alternative water supply strategies. This report specifically addresses Task V - Cost Effectiveness of Evaporative Treatment Processes.

The scope of work included: 1) contacting evaporative treatment equipment suppliers and pilot and full-scale installations for the purpose of obtaining cost and non-cost information; 2) developing present value cost estimates for evaporative treatment of reclaimed water and brackish water; 3) developing present value cost estimates for one alternative treatment method (reverse osmosis or RO) for reclaimed water and brackish water; 4) comparing present value costs for evaporative treatment and RO; and 5) developing and comparing non-cost factors that could potentially affect the feasibility of evaporative treatment technology.

Most manufacturers and other experts contacted stated that the cost of evaporative treatment is competitive with RO treatment only for large-scale sea water desalination systems. Evaporative treatment cost is proportional to the volume of water treated and is not a function of the salt content. RO treatment cost is related to salt content and is most effective when salt concentrations are low. Even if a low cost energy source is available to an evaporative treatment facility, such as may be available at a cogeneration facility site, from this study it appears that RO treatment is still more cost effective than evaporative treatment.

Evaporative and RO treatments are comparable in terms of concerns with disposal of the byproducts produced. The permitting issues associated with reject/concentrate disposal would be essentially equal.

There has been greater experience with the use of RO treatment on both brackish ground water and reclaimed water. No installations were identified in this study where evaporative treatment is used for either of these water sources.

Evaporative treatment is technically feasible for producing potable water from brackish water. However, the treatment costs, even when low cost steam and electricity are available, are not cost effective compared to other available treatment processes.

Evaporative treatment appears technically feasible for producing potable water from reclaimed water based upon limited pilot testing conducted to date. However, the treatment costs, even when low cost steam and electricity are available, are not cost effective compared to RO treatment. In addition, for the treatment of reclaimed water, evaporative treatment would most likely be one process in a multiple barrier approach to ensure a safe water supply.

RO treatment is technically feasible for producing potable water from brackish water and is currently used in many coastal areas of Florida. This treatment is cost effective compared to other available treatment processes for brackish waters.

RO treatment appears to be technically feasible for producing potable water from reclaimed water based upon pilot testing and full-scale applications in the United States. RO treatment costs are competitive compared to other available treatment processes. However, because of membrane fouling and other issues, RO treatment has not always been the selected method of treatment. In addition, for the treatment of reclaimed water, RO treatment would most likely be one process in a multiple barrier approach to ensure a safe water supply.

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BACKGROUND

The St. Johns River Water Management District (SJRWMD) is responsible for managing ground water resources in a nineteen county area of northeastern Florida. Ground water aquifers are currently the primary sources of potable water supply in the SJRWMD. The most dependable ground water source is the Floridan aquifer. However, the *Water Supply Needs and Sources Assessment* (Vergara 1994) projected shortfalls in available water supply in certain critical areas throughout the SJRWMD boundaries by the year 2010. Areas with existing or 2010 projected water supply problems were designated as water resource caution areas (WRCAs).

As a result of the *Water Supply Needs and Sources Assessment*, the SJRWMD embarked on an *Investigation of Alternative Water Supply Strategies*. Strategies being investigated include using lower quality ground water supplies, using surface water, using reclaimed water, aquifer recharge, aquifer storage and recovery, mitigation and avoidance, and the effectiveness of various conservation techniques.

The SJRWMD contracted with Post, Buckley, Schuh & Jernigan, Inc. (PBS&J) to perform various tasks for the purpose of assessing water conservation and the reuse of reclaimed water as effective alternative water supply strategies. This report specifically addresses Task V - Cost Effectiveness of Evaporative Treatment Processes.

Evaporative treatment (i.e., distillation) uses thermal energy to separate suspended and most of the non-volatile dissolved constituents from water. The water is converted to steam and recovered as water, leaving behind most of the constituents. In potable water treatment, the material left behind is a waste product that must be disposed. The process has been used extensively to produce potable water from sea water throughout the world. It has also been used for industrial purposes where there is a need to separate water from other products. In Florida, evaporative processes have been used to produce citrus juice concentrates. There has been recent interest in Florida regarding the use of this process to produce potable water from brackish water and reclaimed water.

Brackish water supplies are currently used throughout the state for potable purposes. The Floridan aquifer contains water with chloride concentrations above the Florida Department of Environmental Protection Secondary Drinking Water Standard of 250 mg/l for public water supplies in many coastal and other areas. When these sources are utilized for potable purposes, reverse osmosis (RO) treatment typically has been considered more cost effective and, therefore, has been the preferred alternative used to remove the salts and other potential contaminants.

Reclaimed water is not being used for direct potable purposes in Florida. Although wastewater treated to reclaimed water standards (secondary treatment followed by filtration and high-level disinfection) meets many of the EPA drinking water standards, there are still concerns with organic compounds, viruses, and other constituents that may remain in the reclaimed water. Several facilities in the United States and in other parts of the world have treated reclaimed water to meet potable standards using a multiple barrier approach. RO is sometimes used as one of the multiple barriers to ensure a safe potable-quality water is produced.

For the purposes of this study, evaporative treatment was compared to RO for producing potable quality water from both brackish water and reclaimed water.

PURPOSE

The purpose of this study was to assess the economic feasibility of using evaporative treatment processes for the treatment of both brackish water and reclaimed water sources. Non-cost factors were also to be developed.

SCOPE OF WORK

Specific services performed were as follows:

1. Identify and contact suppliers of evaporative treatment process equipment and existing pilot and full scale installations.

2. Contact by phone up to three installations where the process is being utilized on either a pilot or full scale basis to obtain operational and cost information.

3. Develop cost estimates for evaporative treatment technology and compare with other technologies:

   (a) Prepare present value cost estimate (for reclaimed water and brackish water) on a per 1,000 gallon basis to implement this technology using the data acquired from existing installations and the information provided by equipment suppliers.

   (b) Prepare present value cost estimate for one alternative conventional treatment method (i.e., RO) based on PBS&J's in-house cost data base for similar projects.

   (c) Compare the present value costs of the evaporative and conventional treatment technologies.

4. Develop and compare non-cost factors that could potentially affect the feasibility of evaporative treatment technology.

METHODS

GENERAL

The general methodology for conducting this study was as follows:

1) Develop typical water quality parameters for brackish and reclaimed water to be used as the basis of cost estimates.

2) Contact equipment suppliers and installations to develop cost and non-cost factors for evaporative treatment.

3) Develop cost curves on a dollar per 1,000 gallon basis for evaporative and RO treatment.

4) Summarize non-cost factors.

BRACKISH WATER ANALYSIS

Technical publications by Mercer et al. (1984), Toth, (1988), and Toth et al. (1989) which discuss ground water quality were reviewed to develop a typical analysis for the brackish water supply source. Chloride concentrations in ground waters were found to vary widely from less than 100 mg/l to over 12,000 mg/l. Many of the ground water analyses indicated chloride concentrations ranging from 150 mg/l to 700 mg/l. A few of the analyses showed chloride concentrations in the 1,000 mg/l to 2,500 mg/l range. For the purposes of this study, a chloride concentration of approximately 2,200 mg/l was assumed for the brackish water supply source. Analyses of seawater in the Atlantic Ocean were also used to estimate the concentrations of some of the elements in the typical brackish water analysis.

The typical brackish water analysis upon which the evaporative and RO treatment process costs were based is presented in Table 1.

Table 1. Typical brackish water analysis

Parameter Name	Concentration (mg/l)
Calcium	92
Magnesium	102
Sodium	1,294
Potassium	32
Chloride	2,157
Sulfate	325
Bicarbonate	156

RECLAIMED WATER ANALYSIS

The "Reclaimed Water or Effluent Analysis Report" for the Iron Bridge Regional Water Pollution Control Facility (Iron Bridge) was used to develop a typical analysis for the reclaimed water supply source. The report used was for the reporting period beginning September 1, 1994 to August 31, 1995. Iron Bridge is an advanced wastewater treatment plant consisting of biological nutrient removal followed by effluent filtration and disinfection. For this study, it was assumed that reclaimed water would be treated to similar levels prior to evaporative or RO treatment.

The typical reclaimed water analysis upon which the evaporative and RO treatment process costs were based is presented in Table 2.

Table 2. Typical reclaimed water analysis

Parameter Name	Concentration (mg/l)
Calcium	26
Magnesium	19
Sodium	41
Potassium	2
Chloride	65
Sulfate	42
Bicarbonate	120
BOD	3
Total Suspended Solids	2
Total Nitrogen	2
Total Phosphorus	0.8

INFORMATION FROM EQUIPMENT SUPPLIERS AND OTHER SOURCES

Suppliers of evaporative treatment process equipment were contacted to determine if their equipment was applicable for treatment of brackish or reclaimed water to potable water quality. Specific references to suppliers contacted are included in the Discussion section of this report. If their equipment was applicable, copies of the typical brackish and reclaimed water analyses were sent to them. A memorandum was also sent describing the purposes of this study and the information that was needed from them in order to complete the study.

In addition to equipment suppliers, the Metropolitan Water District of Southern California, which is operating a 2,000 gpd pilot system to treat sea water was contacted. Several technical papers, as referenced later in this report, were also reviewed for cost and non-cost data.

COST ESTIMATES

Capital, operation and maintenance (O&M), and present value costs were developed for different sizes of water treatment facilities based upon the information received from the evaporative treatment process equipment suppliers. Costs were developed for treatment of both brackish and reclaimed water supply sources. Present value cost curves were then plotted for treatment of both brackish water and reclaimed water.

Cost curves were also developed for RO treatment of brackish and reclaimed water sources. PBS&J's in-house cost data base and the Water Cost Model (Culp·Wesner·Culp, 1986) were used to develop costs for different sizes of water treatment facilities.

All capital cost estimates prepared by PBS&J were based on November 1995 dollars or converted to November 1995 dollars by using an Engineering News Record Construction Cost Index (ENRCCI) value of 5519 for November 1995. Present value costs were based on a 20-year period of analysis and 8 percent interest rate.

For the treatment of reclaimed water, evaporative or RO treatment would most likely be just one process in a multiple barrier approach to ensure a safe water supply. The costs of these other processes were not developed for this study so that evaporative and RO treatment costs could be directly compared.

The costs of evaporative treatment and RO treatment were compared and discussed. Non-cost factors that could potentially affect the feasibility of evaporative treatment technology were developed and are discussed in this report.

DISCUSSION

EVAPORATIVE TREATMENT

Several manufacturers of evaporative treatment process equipment were contacted (Brock 1995; Ciszewski 1995; Dickinson 1995; and Elovic 1995). Several technical papers were reviewed (Aqua-Chem-undated; Brock 1995; Lamendola 1994; Leitner 1994; Aqua-Chem 1985; and Thomas 1995) and contact was made to the Metropolitan Water District of Southern California (Dean 1995) regarding their pilot facility. No installations were identified that use this treatment process to produce potable water from brackish or reclaimed water. All the identified facilities were used to produce potable water from sea water. Because of the nature of the process, there is not a significant cost difference between treating brackish water, reclaimed water, or sea water. Costs associated with producing potable water from sea water may be applicable for comparison purposes.

Four full-scale evaporative treatment sea water facilities were identified in the United States, including one in Key West, Florida. Because of the expense to operate (over $10.00 per 1,000 gallons), the Key West facility, which was started in 1967, has not been used since the mid-1980's. The other three operating facilities are in California.

Operating costs for a 1.6 mgd facility in Aruba to produce potable water from sea water were provided by the equipment manufacturer, Aqua-Chem. Total cost based on operating data was $6.89 per 1,000 gallons in 1990.

A 5.4 mgd facility in the U.S. Virgin Islands began operating in 1981. It had an audited operating cost in 1991 of $7.81 per 1,000 gallons (Leitner 1994). This was reported to be on the low side since only part of the capital cost was included in the debt service.

The Metropolitan Water District of Southern California pilot plant is operating to test materials, and operating costs are not being evaluated.

Their experience is that small scale plants (around 0.125 mgd) have an operating cost of approximately $18.00 per 1,000 gallons. Plants larger than 5 mgd have operating costs of approximately $6.00 per 1,000 gallons.

All but one of the contacts stated that evaporative treatment was not cost-competitive with RO except in high-volume sea water treatment applications and would not provide estimated costs for treating brackish and reclaimed water. According to the contacts, the only time it may be more cost effective to use evaporative treatment in non-sea water applications is if an inexpensive source of steam is available such as at a cogeneration facility.

Gumaco, a manufacturer of evaporative treatment equipment for the production of citrus juice concentrate, conducted a pilot-scale study in Florida to determine if evaporative treatment is effective in the removal or inactivation of viruses and other potential pathogens (Rose, et al - undated). The study was conducted to support use of the process in the treatment of reclaimed water to meet potable standards. The study was conducted by Dr. Joan Rose, a virologist with the University of South Florida. The pilot plant had a capacity of 1.2 gallons per minute and used three stages (multiple effect evaporators) in series to treat a synthetically prepared secondary wastewater treatment plant effluent. The study showed that evaporative treatment was successful in removing or inactivating pathogens in the synthetic wastewater.

Gumaco, provided an estimate for using evaporative treatment to produce potable water from reclaimed water. The estimated cost for a 2.5 mgd facility was $3.66 per 1,000 gallons assuming availability of a low cost source of steam ($2.40/1,000 lbs), low electricity costs ($0.03/KWH), depreciation over a 30 year period with 0 percent interest, low cost maintenance, and no cost for disposal of concentrate. If a low cost steam and electricity supply are not available, and if the more typical capital recovery period of 20 years and 8 percent interest are used, the cost increases to $10.87 per 1,000 gallons. Concentrate disposal would add to this cost.

RO TREATMENT

RO is a common treatment technology used in many coastal areas of Florida to produce potable water from brackish ground water. It has also been used in pilot testing in Florida and in full-scale application in other areas of the United States as part of the treatment process to produce potable water from reclaimed water.

RO treatment was one process used in a 50-gallon per minute pilot-scale test conducted by the City of Tampa to test the treatment of reclaimed water to produce potable-quality water (CH_2M HILL - undated). RO treatment was not the selected process since it did not perform as well as the use of granular activated carbon in the removal of organic constituents and in toxicological screening tests for mutagenicity.

The cost of RO treatment is a function of the total dissolved solids and salt content of the water being treated. RO is, therefore, typically more cost effective on brackish water than sea water. In reclaimed water treatment, RO is used for removal of organic constituents and is usually compared to activated carbon treatment systems.

ESTIMATED COSTS

Evaporative Treatment

Because the cost effectiveness of evaporative treatment is dependent upon a low cost supply of steam and electricity, costs for evaporative treatment were developed with and without siting at a cogeneration facility. These were developed for the treatment of brackish ground water and reclaimed water to potable water standards.

Cost curves were developed based on equipment costs and operation and maintenance needs provided by the manufacturers. The estimated cost curves presented in Figures 1 and 2 are for brackish ground water treatment and reclaimed water treatment, respectively. Estimates are

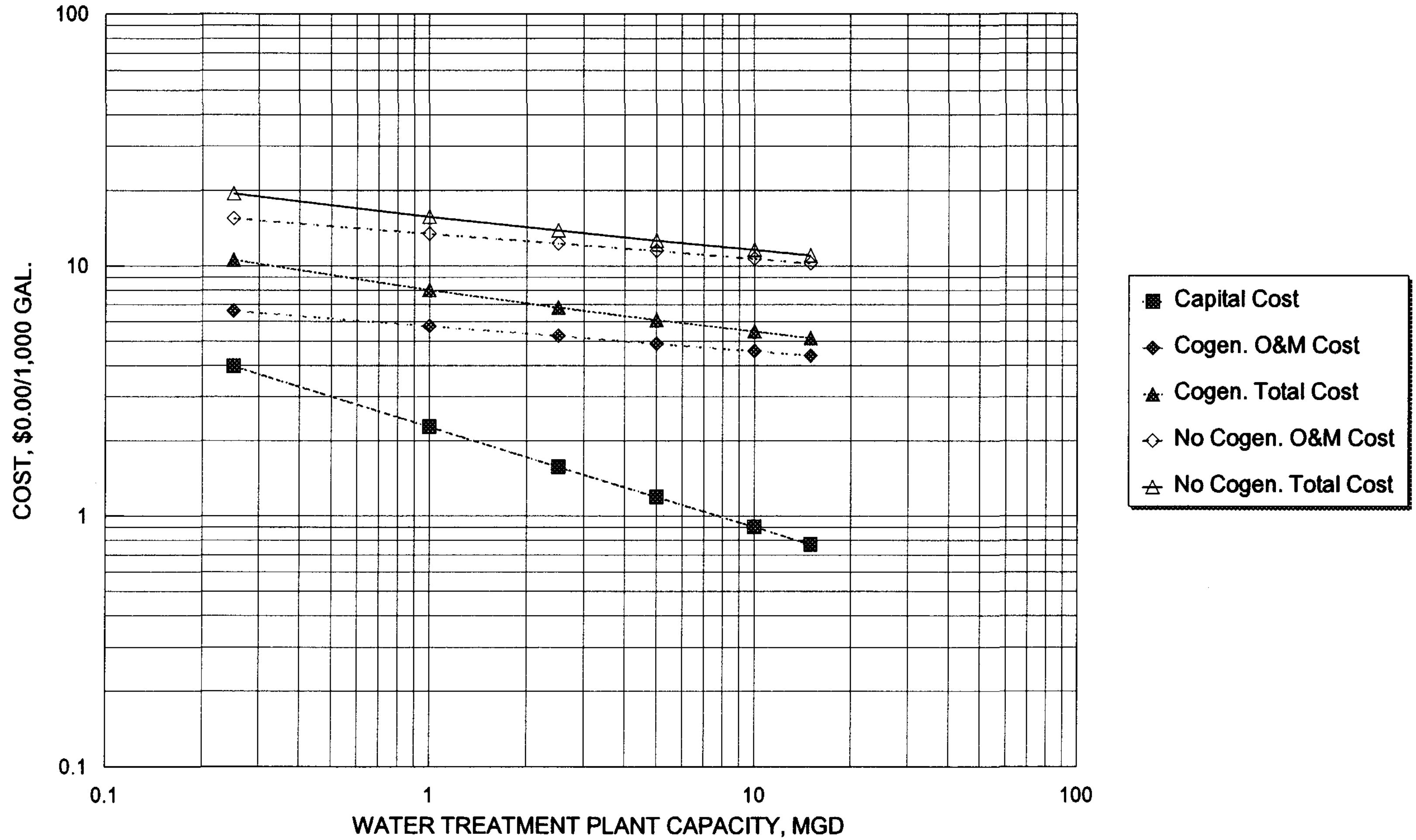

Figure 1. Estimated cost of producing potable water from brackish water using evaporative treatment (note: costs are for treatment only and do not include concentrate disposal)

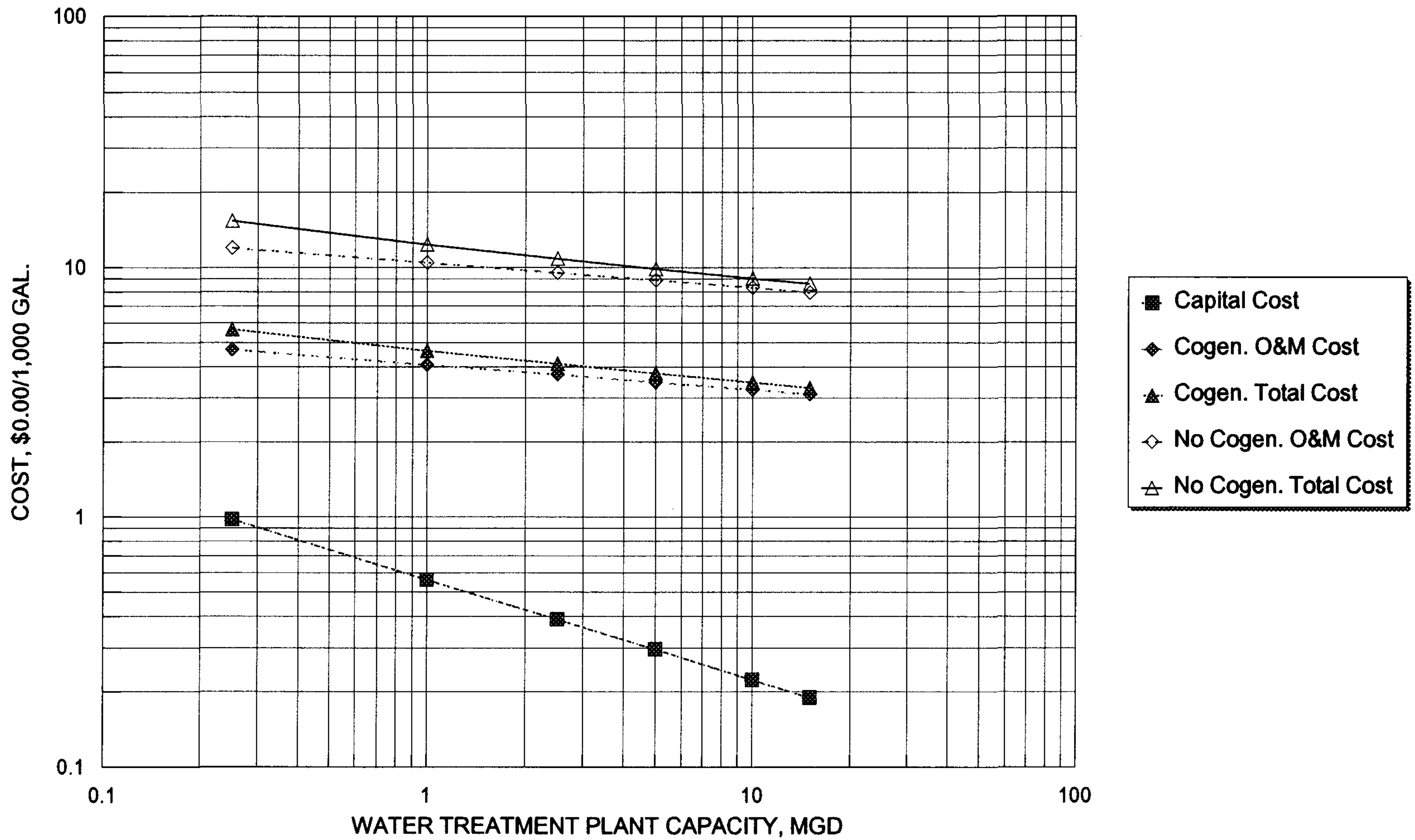

Figure 2. Estimated cost of producing potable water from reclaimed water using evaporative treatment (note: costs are for treatment only and do not include concentrate disposal)

presented on a cost per 1,000 gallon basis. Separate curves are shown for capital, O&M, and total present value cost. Costs are also shown to compare the operational cost advantages of siting the treatment facility at a cogeneration plant when low cost steam may be available.

The cost of disposal of concentrate is not included in the estimates; however, RO treatment also produces a concentrate that must be disposed, so costs are developed on a comparable basis.

RO Treatment

The scope of this study was based on using planning-level information and PBS&J's in-house cost data base for developing costs for RO treatment. For planning-level alternative comparison purposes, PBS&J used the Water Cost model (Culp·Wesner·Culp, 1986) based on November 1995 cost indices for estimating the cost of treating brackish water to potable standards.

Cost curves developed by PBS&J in the "Wastewater Reuse Feasibility Study" prepared for the Miami-Dade Water and Sewer Department (PBS&J 1992) were used to estimate the cost of providing additional treatment for reclaimed water to meet potable standards. The RO treatment system was assumed to consist of RO membranes, and appurtenances. Based on findings of other investigations (Post, Buckley, Schuh & Jernigan, Inc., 1992 and CH_2M Hill - undated), it was assumed that feed water to the RO system would be treated to advanced wastewater treatment standards. The 1992 dollars were converted to November 1995 dollars by using an Engineering News Record Construction Cost Index value of 4946 for April 1992 and 5519 for November 1995.

The estimated cost curves for using the RO system to treat brackish ground water and reclaimed water are shown in Figures 3 and 4, respectively. The estimates are presented on a cost per 1,000 gallons basis. Separate curves are shown for capital, O&M, and total present value cost.

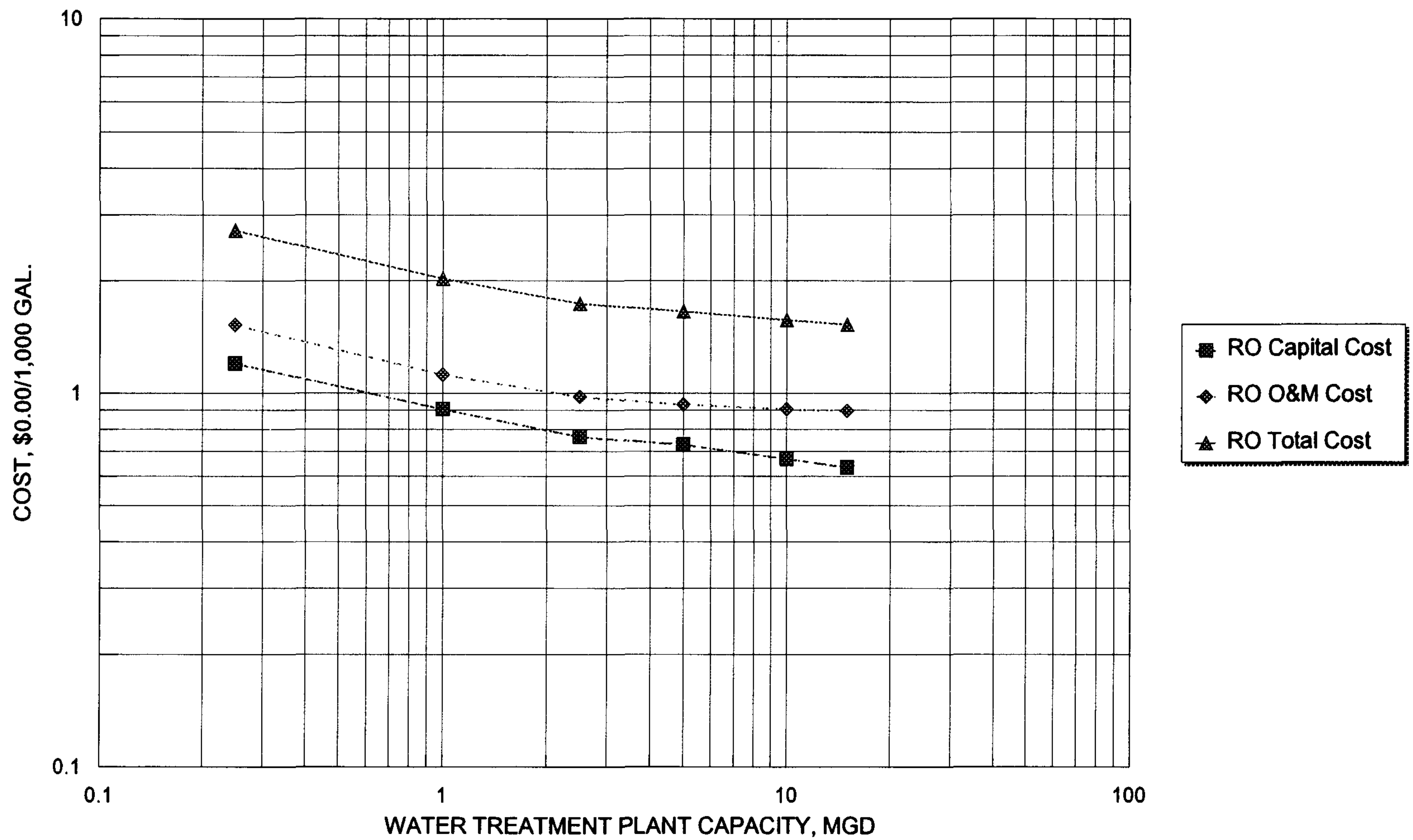

Figure 3. Estimated cost of producing potable water from brackish water using reverse osmosis treatment (note: costs are for treatment only and do not include concentrate disposal)

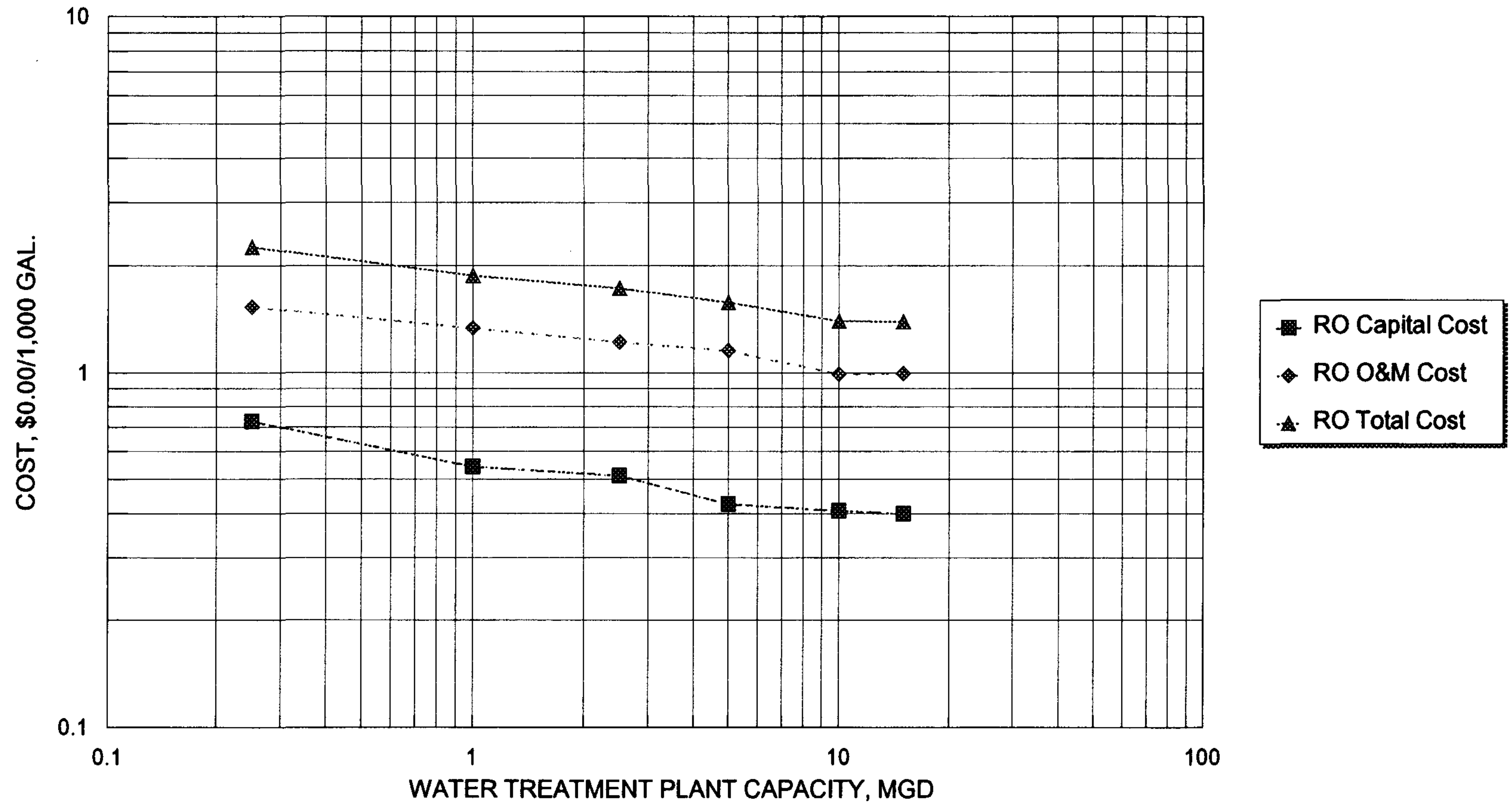

Figure 4. Estimated cost of producing potable water from reclaimed water using reverse osmosis treatment
(note: costs are for treatment only and do not include concentrate disposal)

Present Value Costs

The total present value costs presented on Figures 1, 2, 3 and 4 are also shown in Table 3. From review of Table 3, it is apparent that RO treatment costs are significantly lower than evaporative treatment costs even when low cost steam and electricity are available to the evaporative treatment process from a cogeneration facility.

Table 3. Present value costs in $1.00 per 1,000 gallons for treatment of brackish groundwater and reclaimed water to potable water standards using evaporative treatment and RO treatment processes.

Water Source	Water Treatment Plant Capacity	Evaporative Treatment Cost		Reverse Osmosis (RO) Treatment Cost
		Without Cogeneration Facility	With Cogeneration Facility	
	(mgd)	($1.00/1,000 gal.)	($1.00/1,000 gal.)	($1.00/1,000 gal.)
Brackish Groundwater	0.25	$19.44	$7.23	$2.76
	1.00	$15.75	$5.94	$2.05
	2.50	$13.87	$5.27	$1.76
	5.00	$12.66	$4.84	$1.68
	10.00	$11.61	$4.45	$1.59
	15.00	$11.05	$4.24	$1.55
Reclaimed Water	0.25	$15.36	$5.67	$2.27
	1.00	$12.37	$4.65	$1.88
	2.50	$10.87	$4.12	$1.74
	5.00	$9.91	$3.77	$1.59
	10.00	$9.06	$3.47	$1.40
	15.00	$8.62	$3.31	$1.40

NON-COST FACTORS

Brackish water is currently used throughout coastal areas of Florida for potable water supply using RO treatment. Evaporative treatment has been proven as an effective technology for treating sea water, and should be a readily accepted technology by the public and regulatory agencies to produce potable water from brackish supplies.

The use of reclaimed water, whether using evaporative or RO treatment, for potable purposes would be controversial from both a public acceptance and regulatory perspective.

Both evaporative and RO treatment produce a byproduct (concentrate) that must be disposed. The byproduct from evaporative treatment is typically more concentrated. Permitting the disposal of concentrate can be one of the most difficult issues confronting the use of brackish water supplies. Acquiring a permit for concentrate disposal would be expected to be even more difficult when reclaimed water is used.

CONCLUSIONS

The following summarizes the conclusions developed from the discussions presented in the previous section:

- Most of the manufacturers and other experts contacted stated that evaporative treatment is only competitive on a cost basis with RO treatment for large-scale sea water desalination systems. The cost of evaporative treatment is proportional to the volume of water to be treated and is not a function of salt content. The cost of RO, on the other hand, is related to salt content, and is most cost effective when salt concentrations are low.

- Cost estimates developed for this study to compare brackish ground water and reclaimed water treatment to produce potable water indicate that RO treatment is more cost effective than evaporative treatment.

- Even if a low cost energy source is available, such as may be available at a cogeneration facility site, it appears to be more cost effective to use RO.

- Evaporative and RO treatment are comparable in terms of concerns with disposal of the byproducts produced, although evaporative treatment generally produces a more concentrated byproduct. The permitting issues associated with reject/concentrate disposal would be essentially equal.

- There has been greater experience with the use of RO treatment on both brackish ground water and reclaimed water. No installations were identified in this study where evaporative treatment is used for either of these water sources.

- Evaporative treatment is technically feasible for producing potable water from brackish water. However, the relatively high treatment costs of $7.23 per 1,000 gallons (0.25 mgd capacity) and $4.24 per 1,000 gallons (15 mgd capacity), assuming low cost steam and electricity are available from a cogeneration facility, are not cost effective compared to other available treatment processes.

- Evaporative treatment appears to be technically feasible for producing potable water from reclaimed water based upon limited pilot testing conducted to date. However, the relatively high treatment costs of $5.67 per 1,000 gallons (0.25 mgd capacity) and $3.31 per 1,000 gallons (15 mgd capacity), assuming low cost steam and electricity are available from a cogeneration facility, are not cost effective compared to other available treatment processes. In addition, for the treatment of reclaimed water, evaporative treatment would most likely be just one process in a multiple barrier approach to ensure a safe water supply.

- RO treatment is technically feasible for producing potable water from brackish water and is currently used in many coastal areas of Florida. Treatment costs of $2.76 per 1,000 gallons (0.25 mgd capacity) and $1.55 per 1,000 gallons (15 mgd capacity) are cost effective compared to other available treatment processes for brackish waters.

- RO treatment appears to be technically feasible for producing potable water from reclaimed water based upon pilot testing and full-scale installations in the United States. RO treatment costs of $2.27 per 1,000 gallons (0.25 mgd capacity) and $1.40 per 1,000 gallons (15 mgd capacity) are cost competitive compared to other available treatment processes. However, because of membrane fouling and other issues related to organics removal and mutagenicity testing, RO treatment has not always been the selected method of treatment. In addition, for the treatment of reclaimed water, RO treatment would most likely be just one process in a multiple barrier approach to ensure a safe water supply.

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