RECLAMATION

Managing Water in the West

Desalination and Water Purification Research and Development Report No. 114

Industry Consortium Analysis of Large Reverse Osmosis/Nanofiltration Element Diameters

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14. ABSTRACT

Reverse osmosis (RO) and nanofiltration (NF) technology is of increasing importance in the production of safe drinking water. The current industry standard size for RO and NF membrane elements is a diameter of 8-inches with a length of 40 inches. A consortium of membrane element suppliers (Consortium) developed a project to create a new element diameter standard. By establishing a standard that has been agreed upon by several membrane element suppliers, the end users will be able to realize the maximum economic benefits of the larger diameter elements through use of competitive bidding in their projects. A primary component of the project was the conduct of an economic analysis, regarded as accurate and unbiased by the general industry, to determine a new element diameter greater than 8-inches for three broad applications (seawater, brackish groundwater and surface water desalting or reuse). The project takes into account element manufacturability, system design limitations, handling and capital and life-cycle cost reductions. The project resulted in the Consortium recommendation of nominal 16-inches as the large diameter standard for the next generation of reverse osmosis and nanofiltration elements.

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Reverse osmosis, nanofiltration, element, desalination, membrane, standard

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Industry Consortium Analysis of Large Reverse Osmosis/Nanofiltration Element Diameters

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Disclaimer

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The Consortium would like to express its appreciation to those who responded to the industry surveys for this project. End users, engineering consultants, system suppliers, and operators have contributed valuably to the success of this project by supplying input.

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Finally, the Consortium wishes to thank the Bureau of Reclamation for their financial support for this project.

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List of Abbreviations and Acronyms

bgd	billion gallons per day
BOM	bills of materials
BW	brackish water
CPES	CH2M HILL Parametric Cost Estimating System
DRIP	Desalination Research and Innovative Partnership
FRP	fiberglass reinforced plastic
gfd	gallons per square foot per day
gfd/psi	gallons per square foot per day per psi
GW	groundwater
KMS	Koch Membrane Systems
KWH	kilowatt-hour
Lmh	liters per square meter per hour
mgd	million gallons per day
MWD	Metropolitan Water District of Southern California
NF	nanofiltration
O&M	operations and maintenance
RO	reverse osmosis
SW	seawater
TDH	total dynamic head
TWC	Total Water Cost
UF	ultrafiltration
WTP	water treatment plant
YDP	Yuma Desalting Plant

1. Summary

Reverse osmosis (RO) and nanofiltration (NF) technologies are becoming more popular as treatment processes to meet the water supply and quality needs of the drinking water industry as more reliance is placed on the use of impaired waters. Historically, RO and NF systems have used standardized 8-inch diameter by 40-inch long elements (8040). Use of 8040 elements has been recognized as constraining cost-competitive RO/NF designs for larger capacity plants. Recent cost and pilot studies conducted by the Metropolitan Water District (MWD) of Southern California have shown that the use of larger diameter elements (diameters of 16 inches or greater) can significantly reduce the capital cost of RO facilities.

A consortium of RO/NF membrane element manufacturers (Consortium) undertook this project to select a diameter greater than 8 inches that will become the new standard element size for use in large capacity RO/NF facilities. By working together in a cooperative arrangement, the Consortium's primary objective was to identify a large diameter element standard that would preserve element interchangeability and competitive procurement while reducing the capital and operating costs of large capacity RO/NF systems. The project encompassed discussion and consensus on the standard itself, but did not include development or discussion of products or design of products. Anti-trust guidelines were strictly enforced throughout all project discussions and meetings. Project facilitation was provided by Metcalf and Eddy, Inc. to ensure the group held closely to the project objectives and anti-trust restrictions throughout the project life.

The Consortium is composed of the following membrane element manufacturers:

- FilmTec Corporation
- Hydranautics
- Toray Membrane America, Inc.
- Trisep Corporation

In order to make an unbiased and accurate decision, the Consortium endeavored to understand the economic impact, as well as the perceived issues and benefits related to large diameter elements. The Consortium recognized the need of consumers to have multiple suppliers of both elements and vessels as their disposal. The Economic Study, conducted by CH2M HILL, Inc. considered multiple desalting applications (brackish groundwater, brackish surface water and open intake seawater) and was designed to accurately estimate and compare capital costs, operations and maintenance (O&M) costs and life-cycle costs of standard 8040 RO designs to candidate large diameter element RO designs considering RO train, system and overall facility costs. The candidate large diameters evaluated were 16 inch and 20 inch. Cost curves were generated based on the economics of 8-, 16- and 20-inch elements at five plant capacities ranging from 12.5 to 150 million gallons per day (mgd) (47,000 to 568,000 m^3/day).

The scope of the Economic Study involved the generation of 45 different cost models based on three different water quality applications, five plant capacities and three element diameters to develop comprehensive capital, O&M and life-cycle costs. The cost estimates developed as part of the Economic Study are based on an "order of magnitude" engineering estimate and represent plants built to standards used in the United States utilizing the assumptions described in this Section 4.

The results of the study were as follows:

1. Design of RO trains and treatment facility with 16-inch and 20-inch elements reduces plant construction costs for all cases. Cost savings are most significant for the brackish groundwater case, where the percent savings (relative to 8-inch costs) ranged from 18.5 percent for the 12.5 mgd (47,000 m3/day) capacity case to 27 percent for the 150 mgd (568,000 m3/day) case. Savings were less significant (7 percent to 17 percent) for the other source waters due to the leveling effect of the microfiltration (MF)/ultrafiltration (UF) pretreatment, whose costs are equivalent for the three RO element diameters.

2. The majority of the construction cost reduction is realized when element diameter is increased from 8-inch to 16-inch diameter. For the brackish groundwater case, the relative cost saving from 8-inch to 16-inch was 24%; it increased only marginally to 27% from 8-inch to 20-inch.

3. The most significant portion of the plant construction cost to be positively impacted by the use of increased diameter elements is the RO train. For the brackish groundwater cases, installed RO train cost was reduced from \$0.33/gpd to \$0.22/gpd (\$87 per m3/day to \$58 per m3/day) when 16-inch elements are used in place of 8-inch elements for the 50 mgd case (189,000 m3/day), a 50 percent savings. In contrast, the largest plant construction cost savings (150 mgd case or 568,000 m3/day) for this source water was 24 percent or only one-half of the train cost savings. Savings were somewhat less for the surface brackish and seawater cases because of the smaller train sizes used for the 16-inch element designs.

4. Savings in O&M costs from use of larger diameter elements were small and comparable for all cases. For the 50-mgd cases, O&M costs decreased from \$0.62/1000 gals to \$0.60/1000 gals (\$0.164/m3 to \$0.158/m3). Given that the basic performance characteristics are the same for all diameter elements (all use the same membrane), the power, chemical and replacement intervals are unaffected. The primary O&M savings associated with larger-diameter designs is from reductions in repair and maintenance. The fewer numbers of elements, pressure vessels and RO skid components should translate into lower repair and maintenance costs.

5. Life cycle cost savings can also be realized from large diameter element use, however savings are less than for construction costs due to the leveling impact of the similar O&M costs. In evaluation of the O&M and life-cycle costs, O&M costs between the three diameter sizes are more comparable and dilute the capital cost savings in the life-cycle cost comparison. For the brackish groundwater cases, the plant life-cycle cost savings range from 8 to11 percent for 16-inch and 9 to 12 percent for 20-inch element cases. For the surface water cases, the life-cycle cost savings range from 5 to 8 percent for 16-inch and 6 to 9 percent for 20-inch element cases. Finally, for the seawater cases the life-cycle cost savings range from 4 to 6 percent for 16-inch and 4 to 7 percent for 20-inch element cases. Although the percentage savings in life-cycle costs are less than those for construction costs, they nonetheless represent millions of dollars over the life of the RO plant. Relative to 8-inch elements the life-cycle cost savings over a 20-year period for the 50 mgd (189,000 m^3/day) brackish groundwater, brackish surface water, and seawater cases are $22 to $24 million, $21 to $24 million, and $25 to $30 million, respectively for 16-inch and 20-inch diameter elements.

An understanding of the perceived issues and benefits related to large diameter elements was gained through surveys conducted with industry experts including end users, engineering consultants, and system suppliers. Input from these stakeholders regarding their concerns and expected benefits was obtained via written and electronic surveys. A website was developed (www.bigmembranes.com) to facilitate stakeholder input and education. Handling challenges associated with the increased element weight was perceived to be the most significant obstacle to the use of large diameter elements. Concerns regarding vessel issues (cost, availability, and end-cap weight) and element efficiency and performance were also raised by the survey respondents. Benefits were perceived to be improved economics, reduced facility footprint and reduced element connections.

As a result of the concern expressed by end users, the Consortium investigated handling options, including discussions with engineering and operations staff at the Yuma Desalting Plant regarding equipment used to load/unload 12-inch diameter RO elements. As was the case at the Yuma Desalting Plant, it is the Consortium's expectation that the necessary mechanical handling devices will be developed in concert with the large diameter elements to facilitate use. Other industries have experienced similar product handling challenges and have responded with development of suitable handling equipment. It is the opinion of the Consortium that development of suitable and affordable handling equipment can be developed once larger element diameter and associated vessel characteristics are established.

Limitations regarding manufacturability of large diameter vessels that incorporate state-of-the-art features (i.e. flow through ports, ASME Section 10 certification, etc.) strongly influenced the element diameter selected by the Consortium. To minimize vessel development costs it is desirable to utilize the same large diameter standard for all feedwater water quality applications: brackish groundwater, brackish surface water and open intake seawater desalination. Through vessel manufacturer input solicited at key stages of the project, the Consortium learned that the high pressure requirements for seawater desalination (up to 1,200 psi (83 bar)) creates significant engineering challenges in vessel design at very large diameters. Their input played a paramount role in the development and consensus of a large diameter standard as it represented a quantifiable diameter limit which cannot presently be easily overcome.

As a result, the Consortium had to balance the inherent cost benefits of larger diameter elements with the associated risks. The results indicate that the majority of the cost savings available can be achieved in the transition from 8-inch to 16-inch diameter. The cost savings obtained from a further increase to 20-inch is less substantial. This information, combined with the recognition of risk and the limitations and recommendations from the vessel manufacturers results in a large diameter standard consensus by the Consortium of 15.90 +/- 0.01 inches (nominal 16 inches).

Subsequent to the submittal and acceptance of this Final Report by the Bureau of Reclamation, a commercial 18-inch seawater vessel has entered the marketplace. As presented in this report, the development of such a vessel was deemed difficult, but not impossible. Based on the input we received from vessel manufacturers, the Consortium determined that such a development would be cost-intensive and risky from a commercial standpoint. Additionally, the Consortium did not want to risk loss of accepted vessel features available on 8-inch vessels such as multi-ports and side-ports. The availability of an 18-inch seawater vessel does not negate the outcome of this study. Which diameter ultimately becomes the large diameter of choice will depend on commercial forces in the marketplace. However, the ultimate objective of this project was to agree on an industry standard that the membrane industry can adopt and all major U.S. membrane manufacturers were invited to participate in the Consortium at the outset. The Consortium recommends the 16-inch industry standard for large-diameter elements as the preferred diameter based on the asymptotic decrease in cost savings with increased element diameter above 16 inches combined with potential increased manufacturing risks as the diameter increases above 16 inches.

2. Background and Introduction

With the continued growth of dense population areas, there is a greater demand on potable water source supplies. Also, improved analytical technology has identified an ever increasing number of contaminants in water supplies that have harmful impact to public health, in some cases at very low levels. This has created a need for the application of water treatment technologies that are broad spectrum (removal multiple contaminants) and efficient (provide high levels of contaminant removal). Membrane processes, in particular, reverse osmosis (RO) and nanofiltration (NF), represent two such technologies. Both can desalt saline water and remove dissolved organic contaminants that can be harmful. RO technology can remove the large majority of salt and organic species. NF removes most organic species and those salt ions which contribute to water hardness, i.e. divalent ions such as Ca^{2+} and Mg^{2+}. The report primarily utilizes the term RO when referring to the applicable membrane processes due to its predominance in the marketplace, but it should be assumed that the results and conclusions can also apply to NF because of the similar physical design features of the two processes.

To date most RO systems have been small to medium size, due to the unfavorable economies of scale for RO systems. Unlike many other technologies in water treatment which achieve lower per gallon treatment costs with increasing plant capacity, savings for RO typically plateaus in the range of 10-20 mgd (38,000 -76,000 m^3/day) range. In contrast, most municipalities utilize large-scale treatment plants to achieve low water costs. For example, Metropolitan Water District of Southern California operates five treatment plants, each having a treatment capacity between 350 mgd and 750 mgd (1,326,000 m^3/day to 2,841,000 m^3/day) (Gabelich, et al, 1999). The very large size of these plants is a result of favorable economies-of-scale associated with clarifiers, sedimentation tanks and multimedia filters.

The reason for the low economy of scale for RO is that the RO system is designed around 8-inch by 40-inch spiral wound elements and typical train sizes of 0.5 to 3 mgd (1,900 to 11,000 m^3/day). The small size of the element allows them to be handled by a single individual and allows easy fabrication or expansion of a variety of sized plants. However, the small, modular nature of these elements reduces the potential economy of scale. A typical train may contain hundreds of the 8-inch elements. To produce even larger plants, engineers do not put more elements in the train, but rather add more trains containing the same number of elements. The large number of connections, elements, pressure vessels and seals limits the cost competitiveness of membrane technology for extremely large-scale treatment plants. Also, since each train consists of the same hardware of the same size, there is very little economy of scale. Still, optimized RO process designs and lower RO element costs have made larger plants economical compared to other technologies. A 50 mgd (189,000 m^3/day) brackish water RO plant would require about 8,000 standard 8-inch diameter RO elements. Very little economy-of-scale can be achieved when producing and installing so many individual pieces; the cost of producing a system that is 150 mgd (568,000 m^3/day) would roughly be three times the amount of a 50 mgd (189,000 m^3/day) plant.

There have been a few large-scale RO plants constructed, including the brackish water Yuma Desalting Plant in southwestern Arizona (72 mgd or 273,000 m^3/day), the Mery-sur-Oise NF plant in the Paris region of France (36 mgd or 136,000 m^3/day), the 40 mgd (152,000 m^3/day) NF plant in Boca Raton, Florida, and the Fujairah seawater plant in United Arab Emirates (46 mgd or 174,000 m^3/day). The latter has over 21,000 8-inch diameter elements. In 2001, there were over 50 plants of 6 mgd (23,000 m^3/day) capacity or larger (Wangnick, 2002). It is expected that the increasing demand for this technology would result in many more large-scale plants if greater economy of scale could be realized. In contrast, larger RO elements should allow more convenient and economical construction of very large RO plants. In regards to this issue and others limiting the economical feasibility of desalting, costs can be reduced by the development of large-scale RO elements which are designed for large-scale plants.

One potential means to lower costs for large RO plants is to use a larger diameter element. This approach has been pursued by one RO/NF membrane supplier, Koch Membrane Systems (KMS). In 1998 they introduced a prototype 16-inch diameter element through a cooperative effort with a consortium of industry stakeholders called Desalination Research and Innovation Partnership (DRIP), including the water agencies Metropolitan Water District of Southern California and Orange County (CA) Water District, both of whom were interested in constructing large capacity RO facilities. With further development, KMS increased the diameter first to 17.3 inches and then to 18 inches.

The 16-inch KMS element was 60-inches long and had a surface area of 2031 ft^2 (189 m^2). This was approximately five times the area of the conventional 8-inch by 40-inch RO element (400 ft^2 (37 m^2). The initial studies showed that although the performance efficiency of this was not equal to the conventional 8040 element (Gabelich, et al, 2001), further work demonstrated that large element performance could be optimized to have a similar efficiency to a conventional 8-inch diameter element (Yun, et al, 2002). The final specific flux was 0.31 gfd/psi (7.6 Lmh/bar). The primary difference between the performance of the 8040 element and the 16-inch by 60-inch element was the efficiency of cleaning and fouling rate (Yun, et al, 2002). The large diameter element fouled at a rate of 0.02 gfd/psi (0.49 Lmh/bar) per 1000 hours operation on Colorado River water, while the conventional 8040 element did not display flux loss due to fouling at the same operation conditions (Yun, et al, 2002). Various factors were proposed that could have contributed to the higher fouling rate. Further tests were required to understand these phenomena in detail.

However, a detailed cost analysis of a hypothetical 185 mgd (700,000 m^3/day) RO plant performed for MWD demonstrated the financial value of the 16-inch diameter element. The hypothetical design used 16.8 mgd (64,000 m^3/day) trains, nearly 3 times larger than conventional train sizes. Capital cost for this capacity facility was reduced by 27 percent by using the 16-inch diameter. The savings were primarily due to reduced piping and instrumentation. There was little change in the O&M costs of a large diameter element compared to a conventional sized element, because fouling rates and cleaning frequencies were assumed to be equal. The overall systems costs, including O&M and amortized capital, decreased by 12% compared to the conventional case. For such a large project, this amounts to a savings of 40 to 50 million dollars (Yun, 2002).

Although this study has shown the potential savings of a large diameter element for a specific plant configuration, it has not sought to determine the optimum size of the element or the benefit as a function of plant size. Instead, the study focused on the actual performance of one such large element, a 16-inch (or later a 17.3-inch) diameter element as well as the calculated cost advantage. The study did not consider the potential savings of using these large diameter elements for RO plants of various sizes. This is an important question since favorable economics for only very large scale plants (>50 mgd or 189,000 m^3/day) would likely mean that this technology would still need more time to reach maturity. However, favorable economics for mid-size plants (10-50 mgd or 38,000 -189,000 m^3/day) would mean that large diameter elements could have a more immediate impact.

Additionally, Koch Membrane Systems has now formalized their product offering, and has settled on a 18-inch by 60-inch RO element (UltraPure, 2004). Currently, they are only offering this product for brackish water applications. It is unknown whether they will or can offer this 18-inch diameter for seawater applications. This element is available for 5 element pressure vessels, which makes them uniquely suited to 60-inch elements, since 40 inch elements would not fit as a whole multiple. It would take 7.5 of the 40-inch long elements to fill such a vessel.

The previous study also did not consider the practical limits for extremely large diameter elements or the limits for large diameter elements suitable for the high pressure seawater applications. The latter is particularly important because a high percentage of large systems which are being built or currently under design, are for treating seawater. These would likely benefit greatly from such economy of scale, but the application is much more difficult due to the greater forces on the end of the pressure vessel.

Thus, the Consortium was formed for the express purpose of considering these additional issues and to establish an optimum large diameter element standard agreed upon by the consortium, which would enable competitive project bidding, consider pressure tube manufacturability, system design limitation and cost reductions.

One of the primary goals of the Consortium was to create a new element standard that would allow customers to purchase both elements and pressure vessels from multiple suppliers. It was decided early on that it would be highly desirable to create a single new standard that could be used for both brackish and seawater applications, as this would generate the highest probability that multiple suppliers would be available.

With this assumption, one of the primary constraints in selecting a new diameter was the ability to design and build a large diameter pressure vessel with the capability to operate at seawater pressures of 1,000 to 1,200 psi (69 - 83 bar). With these new pressure vessels, we would want to incorporate all the features and benefits currently available on 8-inch pressure vessels such as through ports, ASME Section 10, and using existing FRP technology.

The Consortium had many discussions with pressure vessel companies to determine suitable pressure vessel sizes. It was the conclusion of the Consortium that a 16-inch diameter vessel was pushing the edge of the current FRP pressure vessel technology for high pressure applications. Increasing the diameter from 16-inch to 18-inch would significantly increase the risk and cost of designing a pressure vessel, possibly requiring the use of new technologies not currently available. More detail will be given on this in the following sections.

3. Approach

3.1 Administrative Considerations

3.1.1 Parties Involved

FilmTec Corporation, a wholly owned subsidiary of The Dow Chemical Company, submitted the project proposal to Reclamation on behalf of the Consortium. All North American membrane RO/NF manufacturers and Toray of Japan were invited to participate in the Consortium with Hydranautics, Toray Membrane America, Inc. and TriSep Corporation electing to join. Although FilmTec Corporation was listed as the offeror, this was purely to meet the administrative requirements of Reclamation. Each participant had equal standing.

Due to the unique nature of the Consortium and its objectives, a key role identified was that of an independent and objective industry consultant to act as the Project Facilitator. The involvement of an independent party in this role was needed to provide unbiased leadership, maintain objectivity, and add a dimension of credibility from an alternative source. Ms. Lisa Henthorne, Vice President and Membrane Technology Leader of Metcalf and Eddy, Inc. was hired for this role. The purpose of this role was to facilitate the Consortium meetings, write and distribute meeting minutes, hold the group accountable to commitments, and guide the general direction of the project using her industry knowledge.

In addition, the Consortium members agreed an engineering firm was needed to conduct several evaluations to determine the impact larger diameter elements will have on capital and the life-cycle total water cost. CH2M HILL, Inc. was hired to conduct this Economic Study. Mr. Jim Lozier, Global Director of Membrane Technology, acted as the CH2M HILL Economic Study Manager with Mr. Bob Bergman, Membrane Treatment Technical Manager, as the System Design and Cost Modeling Task Leader.

Support from Reclamation involved a cost sharing contribution of up to $100,000. These funds were used to cover the costs associated with hiring the Project Facilitator and the conducting the Economic Study.

3.1.2 Joint Work Agreement

A Joint Work Agreement was written to establish the obligations required of the participants with regard to the scope of work, cost sharing, handling of confidential information, and dispute resolution. Consortium member cost sharing contributions involved providing a subject matter expert(s) at an estimated time contribution of approximately 400 hours and covering their own incurred costs (time, travel, etc.). The Joint Work Agreement is contained in Appendix A.

3.1.3 Antitrust Considerations

To address the antitrust issues associated with meetings between competitors, antitrust guidelines were established. Each Consortium meeting began with a review of the guidelines in order to ensure these were strictly adhered to. The guidelines include the following:

1. Adhere to prepared agendas for all meetings and object any time meeting minutes do not accurately reflect the matters which transpire.

2. Understand the purposes and authority of the Consortium.

3. Protest against any discussions or meeting activities which appear to violate the antitrust or competition laws; do not continue until you are assured it is proper or the discussion is redirected. Otherwise, discontinue the meeting.

4. Don't, in fact or appearance, discuss or exchange information regarding:

   a. Individual company prices, price changes, price differentials, mark-ups, discounts, allowances, credit terms, or data that bear on price, costs, production, capacity, inventories, sales.

   b, Industry pricing policies, price levels, price changes, differentials, etc.

   c. Changes in industry production, capacity or inventories.

   d. Bids on contracts for particular products; procedures for responding to bid invitations.

   e. Plans of individual companies concerning the design, production, distribution or marketing of particular products, including proposed territories or customers, except as part of a distributorship relationship.

   f. Matters relating to actual or potential individual suppliers that might have the effect of excluding them from any market or of influencing the business conduct of firms towards such suppliers or customers.

   g. Termination of manufacturing as a quid pro quo for supply of a product.

5. Don't discuss or exchange information, even in jest, regarding the above matters during social gatherings incidental to any meetings.

These guidelines are also provided in Appendix B.

3.1.4 Project Goals and Objectives

The Consortium was formed for the purpose of identifying an industry standard element diameter (>8-inch) to reduce the cost of RO/NF treated water. This project was designed to enable the delivery of value provided by larger diameter elements that can only be achieved throughout the general industry when there are multiple suppliers. This value, realized through capital savings, will make the treatment of water with RO/NF technology more affordable for large systems.

To implement the project purpose the following tasks were conducted:

1. Develop the parameters, outline and scope of an objective and comprehensive Economic Study.

2. Conduct the Economic Study including capital and life cycle cost analyses of different element diameters in different applications.

3. Develop consensus between the Consortium members regarding optimum parameters.

4. Communicate recommended standard and supporting documentation to industry and water treatment community.

Acceptance of the results of this project by all players in the water treatment industry is key to meeting the project goal. With this in mind, the Consortium took special measures to ensure its work product is unbiased and objective. This was accomplished through the incorporation of input from other members of the value chain during key stages of the project. This included:

- direct involvement of the Project Facilitator and Economic Study Manager with the Consortium during all stages of the project

- significant dialogue with pressure vessel manufacturers

- surveying of end users, system suppliers and engineering firms

- inviting the broader industry to provide input through a survey located at www.bigmembranes.com

3.2 Assumptions

The Consortium members initiated the large element study by setting the assumptions and different plant configurations that would be used to run the Economic Study models. A summary of the key assumptions are shown in Table 3-1. The plant size of the base case was assumed to be 50 mgd (189,000 m^3/day), as this would likely capture the advantage of the large trains associated with large elements. This value was also considered to be a probable plant size for future, next generation large RO plants. Additional RO plant sizes were considered, including 12.5 mgd (47,000 m^3/day), 25 mgd (95,000 m^3/day), 100 mgd (379,000 m^3/day) and 150 mgd (568,000 m^3/day). This range of plant sizes was expected to incorporate current large plants to future mega plants, thus demonstrating potential benefit for a broad range of applications.

For each plant size, three water types were considered to evaluate the effect of water type. The three water types were brackish groundwater, brackish surface water, and open intake seawater. The first application would give an example of a case with high flux rate (15 gfd or 26 Lmh), the second would represent either a lower flux surface water, or wastewater treatment after MF/UF membrane pretreatment (10 gfd or 17 Lmh), and the last application is at low flux (9 gfd or 15 Lmh), considered to be typical for SWRO, and operating at high pressure. The latter two cases were designed based on utilizing membrane pretreatment. There has been a rapid rise in the popularity and use of this type of pretreatment due to the improved water quality it provides for RO or NF, and the possibility for RO design with more aggressive flux rates with the higher quality feed water

Three element diameters were chosen for the various designs: the current industry standard 8-inch diameter by 40-inch long, the 16-inch diameter by 40-inch long element and the 20-inch diameter by 40-inch long element. These were chosen based on the fact that the 8-inch by 40-inch product is the most popular element currently being sold, and therefore represents the “baseline” case. 16-inch diameter by 40-inch element represents a 4x increase in surface area over the 8-inch diameter product, and is similar to the size that is being trialed at some current sites. The 20-inch diameter by 40-inch long element is another step increase that is significantly larger than the16-inch by 40-inch element, but is not so large as to cause problems with train size.

For the 50 mgd (189,000 m^3/day) plants, the train size for 8-inch elements was determined based on current train sizes of large scale commercial plants. The brackish groundwater train contained 99 pressure vessels, the brackish surface water contained 149 pressure vessels, and the seawater case contained 179 pressure vessels. Each 8-inch train produced 4.17 mgd, or 16,000 m^3/day. The 16-inch element train size was chosen to have a similar physical size, so the number of pressure vessels for the three water types was 75, 90 and 90. The permeate capacity from these three train sizes was 12.5, 10 and 8.33 mgd (47,000, 38,000 and 32,000 m^3/day). For the 20-inch element, the number of pressure vessels was 48, 72 and 86, which gave flows of 12.5, 12.5 and 12.5 mgd (47,000 m^3/day) for all three feedwater applications). The latter design reflects our adopted philosophy that the minimum number of trains would not be less than four, since it was felt that four trains would be required to allow some measure of flexibility when a train was shut down for service or cleaning. In such a case, no more than 25% of the flow would be lost during that down time.

Train sizes stayed the same as the plant size was increased, except in the cases where the 50 mgd (189,000 m^3/day) plant was at four trains and the train size was reduced to prevent needing less than four trains. When the plant size decreased, the number of vessels in the train decreased as needed to prevent running with less than four trains.

A major assumption in the Economic Study was that the designs would all be made using a centralized pumping center (and energy recovery center for the seawater application). This is not a new idea, and is being implemented on large scale plants today (Faigon and Liberman, 2003). The result of this assumption is far reaching, as it effectively eliminates the pumps and energy recovery devices from consideration with respect to economic comparison. The pumps are no longer individually dedicated to a train, but can be sized based on the plant flow requirements with acceptable standby capacity. The pumping center is thus identical for any element diameter, train size and number of trains selected, provided the plant capacity remains the same. Though this assumption reduces the potential benefits of large diameter elements, the Consortium believes this to be a realistic assumption for design of future large-scale desalination plants.

Table 3-1.
Assumption Values for Economic Study Parameters
for 8″, 16″ and 20″ Diameter Scenarios – 50 mgd Base Case
REVISED 6-06-04

Parameter	Brackish Groundwater – High Flux	Brackish Surface Water or Reuse Application– Low Flux	Seawater
Plant size (mgd)- Base case	50	50	50
Train size (mgd) – 20″	12.5	12.5	12.5
Train size (mgd) – 16″	12.5	10.0	8.33
Train size (mgd) – 8″ Diameter	4.17	4.17	4.17
Trains per plant for Base case – 20″	4	4	4
Trains per plant for Base case – 16″	4	5	6
Trains per plant for Base case – 8″	12	12	12
Pretreatment	Standard[a]	Screening; MF/UF with optional coag feed plus Standard	Screening; MF/UF with optional coag feed plus Standard
No. of Stages	2	3	1
Total Vessels per train – 16″ Large Size	75	90	90
Total Vessels per train – 20″ Large Size	48	72	86
Total Vessels per train – 8″	99	149	179
Elements per vessel	7	7	7
Feedwater salinity (mg/L)	2,200	930	38,000
Avg. system flux (gfd)	15	10	9
Recovery (%)	75	85	45

[a]Standard pretreatment = acid & scale inhibitor addition and 5-micron cartridge filtration

3.3 Project Strategy

3.3.1 Consortium Meetings

In order to facilitate effective and regular communication, the Consortium held biweekly (on average) conference calls. At least three Consortium member companies had to be present for the meeting to occur. Additionally, two in-person meetings were held by the Consortium: a kick-off meeting and consensus-building meeting.

The meeting minutes from each conference call and in-person meeting are provided in Appendix C.

3.3.2 Industry Survey

As previously mentioned, broad acceptance of the results of the project by stakeholders in the water treatment industry is critical to meeting the project goal. Therefore, the team solicited the expertise of approximately 50 industry experts (end users, system suppliers and engineering firms) to gain additional insight regarding perceived advantages/ disadvantages of large diameter elements and identify information needed for general acceptance. This input was used to influence the development of the Economic Study framework. The survey questions were:

1. Please briefly describe the most significant advantages you perceive with the application of large-diameter RO elements.

2. Please briefly describe the most significant disadvantages or challenges you perceive with the application of large-diameter RO elements.

3. What magnitude of savings would be required of large-diameter elements for you to consider using them?

4. What type of information would you most want from this investigation to help you determine the suitability of large-diameter elements for your next project?

5. What is the potential size of your future plants?

6. What level of demonstration would be needed before you would be willing to purchase or specify large diameter elements for your next project?

The survey results showed the industry perceives the primary advantages of large diameter elements to be footprint reduction, lower capital costs, and fewer element connections. Perceived disadvantages include element and vessel end-cap handling issues, vessel issues (availability, cost) and reduced element efficiencies. The survey data also suggests significant capital and/or lifecycle costs savings (~20%), as well as, a comprehensive full scale demonstration plant will be needed to gain broad acceptance of this technology. Tables and charts showing the results of all survey questions are included in Appendix D.

In addition to the survey that was sent to specific people recognized in the industry, an electronic survey was conducted on the project website, www.bigmembranes.com. A total of 22 people responded to the website questionnaire. The results from the electronic survey were similar to that of the written survey. The results of the electronic survey are contained in Appendix E.

3.3.3 Limitations

3.3.4.1 Element Handling

The Consortium discussed at-length the requirements associated with the physical handling of a proposed large diameter element and end-cap. Beyond projected reductions in RO system capital and operating costs, RO system suppliers and end users must be able to install, service and replace a large diameter element in a manner that is as equally (or more) convenient and safe, as methods currently used with traditional 8-inch diameter elements. "Equivalency in handling" was a priority based on the industry survey conducted by the Consortium and discussed elsewhere in this report.

Estimated weight of the proposed large diameter element (16-inch diameter by 40-inch long), following operation and draining in place, is 150 pounds (68 kg). Based on discussions with several pressure vessel manufacturers, estimated weight of an end-cap assembly used with an ASME code seawater pressure vessel designed for 1000 psi (69 bar) service, is 145 pounds each (66 kg). These element and end cap weights are considerably greater than existing 8-inch systems [35 pounds (16 kg) and 25 pounds (11.3 kg), respectively] and demonstrate the need for special element and end-cap handling equipment to achieve the "equivalency in handling" goal.

The Consortium considered various approaches to large diameter loading and unloading (including end-cap installation and removal) and the need for and nature of related mechanical hardware to facilitate these tasks. To better assess what approach(es) would be necessary, the Consortium contacted operations staff at the Bureau of Reclamation's Yuma Desalting Plant (YDP), which employs non-traditional size RO elements, including 8.5-inch diameter by 40-inch long and 12-inch diameter by 60-inch long, weighing approximately 120 pounds drained (54 kg). YDP staff utilizes relatively inexpensive lift platforms that have been modified to enable safe and convenient lifting and installation of these larger and heavier elements in RO trains, where uppermost pressure vessels are 12 to 15 feet (3.6 to 4.6 m) above ground level. See Figures 3-1 through 3-3. Based on the YDP approach and experience, the Consortium is convinced that large diameter element handling and end-cap installation/removal can be very practical with a myriad of possible mechanical methods, and this requirement is not

Figure 3-1.—YDP Membrane Loading Assembly in Docked Position

Figure 3-2.—YDP Membrane Assembly Handling Devices

Figure 3-3.—YDP Crane Assembly for Removing Pressure Vessels

considered to be a deterrent to the future use of large diameter elements in large-capacity RO trains using current mechanical and hydraulic design. The Consortium envisions that, once large diameter element and associated pressure vessel designs have been standardized, third party, specialty equipment suppliers or RO system service companies, will develop the requisite handling equipment. Such equipment will be made available for purchase by utilities having large capacity RO trains (and plants) for routine use. Operators of smaller plants, with limited capital budgets, may prefer to lease such equipment on an as-needed basis.

Beyond the projected RO system cost savings, use of large diameter elements will significantly reduce the number of elements necessary (to produce an equivalent flow of treated water) and the resulting ancillary handling costs, which will provide additional industry benefits, including:

1. Reduced volumes for packaged elements (corrugated boxes, pallets, related dunnage, etc.). This will reduce space required for temporary storage of elements prior to plant commissioning and for storage of spare elements as well as reduce costs associated with disposal of such packaging once elements are placed into service.

2. Reduced manpower and costs associated with element installation/maintenance and removal/replacement.

3. Lastly, reduced material element unit volume [element volume per gallon (meter^3) of water produced], results in reduced landfill space required for disposal of spent elements.

3.3.4.2 Vessels

One of the primary goals of the Consortium was to create a new element standard that would allow customers to purchase large diameter elements and pressure vessels from multiple suppliers, thereby addressing a common concern identified by the industry survey. It is highly desirable to have a single new standard that can be used for both brackish and seawater applications, as this generates the highest probability that multiple suppliers will be available. The Consortium did not want to create a standard that would introduce a high level of risk. Failure of any component would slow the acceptance of the new standard by the marketplace.

It was also decided that any new vessel standard should incorporate state-of-the-art design concepts that are currently available in 8-inch diameter pressure vessels. These include side mounted through ports, ASME Section 10 certification, high quality, competitive pricing, and with the same safety factors as are currently being used on the 8-inch pressure vessels.

The Consortium solicited input from several pressure tube suppliers: Bekaert Progressive Composites, Bel Composite, Knappe Composite, Pentair CodeLine, and Phoenix Vessel. A list of questions was sent to two of the pressure tube manufacturers in December of 2003. The questionnaire is provided Appendix F. The answers have not been presented as they were given in confidence. The responses to these written questions resulted in several follow-up telephone conference calls and a final request for information on 16-June 2004. A copy of the final request is also presented in Appendix F along with a response from one manufacturer.

The responses from the pressure vessel manufacturers varied as did their experience level in manufacturing and designing large diameter pressure vessels. Some of the companies have designed, and to a limited extent produced, brackish water pressure vessels in the 16-inch to 18-inch diameter range. The Consortium placed an emphasis on finding a common ground and managing risk.

One of the primary constraints in selecting a new diameter was the ability to design and build a large diameter pressure vessel with the capability to operate at seawater pressures of 1,000 to 1,200 psi (69 - 83 bar). For a 16-inch or 20-inch diameter pressure vessel, the forces on the pressure vessel end-caps are four times and six times higher, respectively, than with an 8-inch diameter pressure vessel. We also asked the pressure vessel manufacturers to only consider designs using existing FRP pressure vessel technology.

Given the listed assumptions, and based on the feedback from several pressure vessel manufacturers, it is the conclusion of the Consortium, that a 16-inch diameter vessel is a fitting standard to encourage multiple suppliers while pushing the limit of the current FRP pressure vessel technology. In order to allow for use of commonly available steel pipe to create the pressure vessel mandrels, which reduces the cost of implementing new pressure tubes, a specific diameter of 15.90 +/- 0.01-inch was chosen as the inside diameter of the pressure vessel.

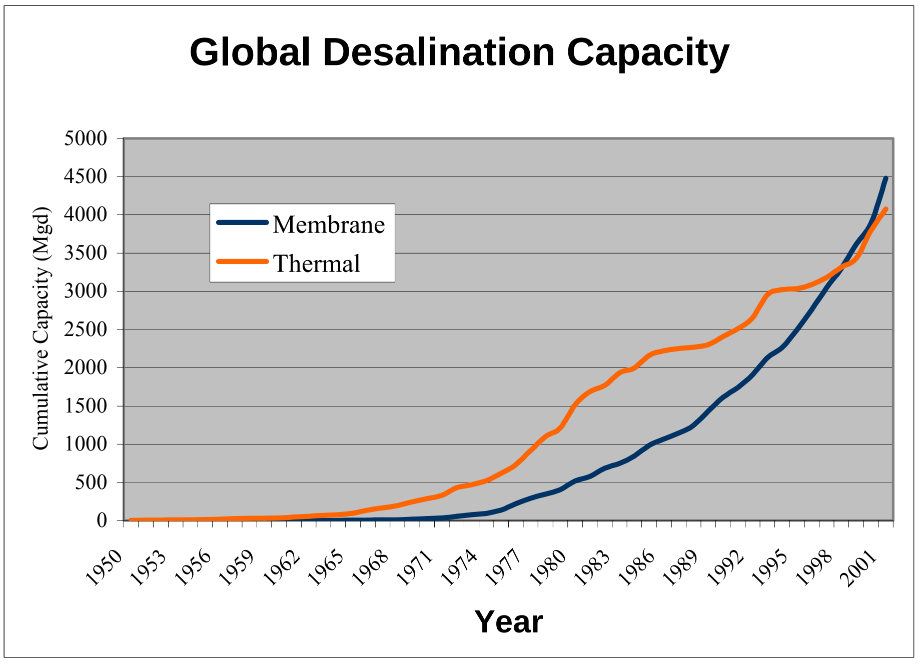
3.3.4.3 Market for Large Diameter Elements

One of the limitations of utilization of large diameter elements is the demand of the market for these products. In the process of developing a standard for the large diameter element, the Consortium thought it important to evaluate the market demand, in order to fully understand the implications of the market both for development of the large-diameter element and vessel. This evaluation was also useful in making the decision as to whether to recommend the same standard diameter for both brackish and seawater applications.

Figure 3.4 provides a graphical representation of the growth of membrane and thermal desalination worldwide, based on cumulative installed capacity. The primary source for the market information described herein is the most recently published Wangnick/IDA Desalination Plant Inventory Report #17, which is published every two years. The graph demonstrates that the growth in RO and NF capacity is approximately 11.4% per year. Based on this growth rate, it is expected that 3.6 billion gal/day (bgd) (13.6 million m^3/day) of new RO/NF capacity will be contracted for installation over the next six years.

In evaluating the market for large diameter elements, it is particularly important to understand the growth of large capacity plants, as these plants are more likely to utilize large diameter elements. In evaluating the last two years of reporting, approximately 50% of the new contracted capacity was installed in only nine plants totaling 380 million gal/day (1.4 million m^3/day). This results in an average plant capacity for these large-capacity plants of 42 million gal/day (159,000 m^3/day). In reality, two of the nine plants each had capacities of approximately 85 mgd (322,000 m^3/day). If these two plants are eliminated, the average plant capacity for the seven remaining plants is 30 million gal/day (114,000 m^3/day).

Figure 3-4.—Cumulative Capacity of Membrane and Thermal Desalination Capacity Installed Worldwide



In evaluating the NF market, a growth rate of 18.7% per year in new contracted installed capacity has been demonstrated over the last six years. Approximately 0.4 bgd (1.5 million m^3/day) of new NF capacity is expected to be contracted over the next six-year period. In the last two-year period, 56% of the new plant capacity contracted existed in two plants, totally 40 mgd (151,000 m^3/day). This results in an average 20 mgd (76,000 m^3/day) for these two large capacity NF plants.

Continued trends in the market which favor a continued growth of large-capacity RO and NF plants include the following:

- Co-location of seawater RO plants at power facilities or other industrial facilities. This trend encourages large-capacity facilities due to the opportunity to blend large quantities of concentrate in the existing outfall, thereby diluting any potential environmental impacts of large-scale plants.

- Continued reduction in the Total Water Cost (TWC) for the large-capacity plants. TWC prices from the privatized large-scale Singapore and Ashkelon seawater RO projects encourage the economy-of-scale benefits offered at these facilities.

- Privatization of desalination facilities. Because privatization shifts the capital and technology risk away from the public sector, privatization of desalination facilities worldwide is growing in popularity. Private sector developers favor large-scale facilities due to the increased potential for economy-of-scale benefits, which can be optimized to achieve maximum profit.

  Based on the growth in the desalination market exhibited historically, the trends toward larger-capacity plants as seen in the last few years and the expectation that these trends will continue, we estimate the following:

- 40-45 new RO plants with capacities above 25 mgd (95,000 m^3/day) will be contracted over the next six years. Ten of these plants will have capacities in excess of 50 mgd (189,000 m^3/day). It is expected that approximately two-thirds of these 40-45 plants will be seawater RO plants and the remaining brackish RO plants. This results in about four seawater and two brackish water RO plants contracted per year, with capacities greater than 25 mgd (95,000 m^3/day).

- 15-20 new NF plants with capacities over 15 mgd (57,000 m^3/day) is expected to be contracted over the next six years. This results in two-three large-scale NF plants per year.

The results of the market evaluation indicate that there will be a sufficient number of large-scale facilities constructed in the upcoming years to warrant development of both large diameter elements and vessels. Because the potential market is not overwhelmingly large, it suggests that the same diameter be used for both seawater and brackish water elements. This will decrease manufacturing costs for both the element and vessel manufacturers, thereby increasing the economic feasibility of development of large-diameter systems.

4. Economic Study

4.1 Engineering Design

The cost estimates provided herein are based on an "order of magnitude" engineering estimate and represent plants built to standards used in the United States utilizing the assumptions described in this section.

Process flow diagrams were developed for the three source water treatment systems, all incorporating reverse osmosis (RO) membrane treatment: (1) brackish groundwater, (2) brackish surface water, and (3) open intake seawater. [It is assumed tertiary treatment for reuse would use a process flow diagram and design criteria similar to those assumed for the surface water case.]

Figure 4-1 shows the groundwater process flow diagram. Groundwater is pumped to the water treatment plant (WTP) site where it receives acid and scale inhibitor addition (for scaling control) and passes through a 5-micron cartridge filter system into the RO feed pumping center suction header. The RO feed pumps increase the pressure to the parallel RO process trains as necessary to produce the desired product flow at design recovery. Permeate from the trains are combined and pass to a degasifier for removal of carbon dioxide (which increases pH) and hydrogen sulfide, if present in the groundwater. The degasified permeate falls into a clearwell and is then pumped to ground storage. As the permeate flows from the degasifier clearwell to ground storage, chlorine is dosed for disinfection (free chlorine residual) and caustic (sodium hydroxide) is fed to raise the pH for corrosion control and stabilization. High service pumps deliver the finished water to the distribution system. The waste RO concentrate is discharged to an off-site disposal location directly from the RO trains.

Figure 4-2 presents the brackish surface water process flow diagram. Surface water is pumped from an intake pumping system to the WTP site where it is treated by dual membrane treatment facilities – vacuum-type microfiltration (MF) or ultrafiltration (UF) followed by RO. It is assumed that the MF/UF system receives feedwater after (limited) coagulant addition and has passed through a strainer to protect the MF/UF membranes. Filtrate from multiple parallel MF/UF trains is pumped to a break tank which provides a continuous supply of feedwater to the RO system and provides a source of filtrate for MF/UF backwashing. After acid and scale inhibitor addition, the filtrate is pressurized by a centralized RO feed pumping system and flows to multiple parallel RO process trains. Permeate from the RO trains is combined and passes to a clearwell before being pumped to ground storage. Between the clearwell and ground storage, the permeate is dosed with chlorine for disinfection (free chlorine residual) and caustic (sodium hydroxide) to raise pH for corrosion control and stabilization before ground storage. High service pumps deliver the finished water to the distribution system. Waste flows from the strainers and MF/UF systems are directed to settling ponds. Pond supernatant is discharged, along with the RO concentrate, to an off-site disposal location.

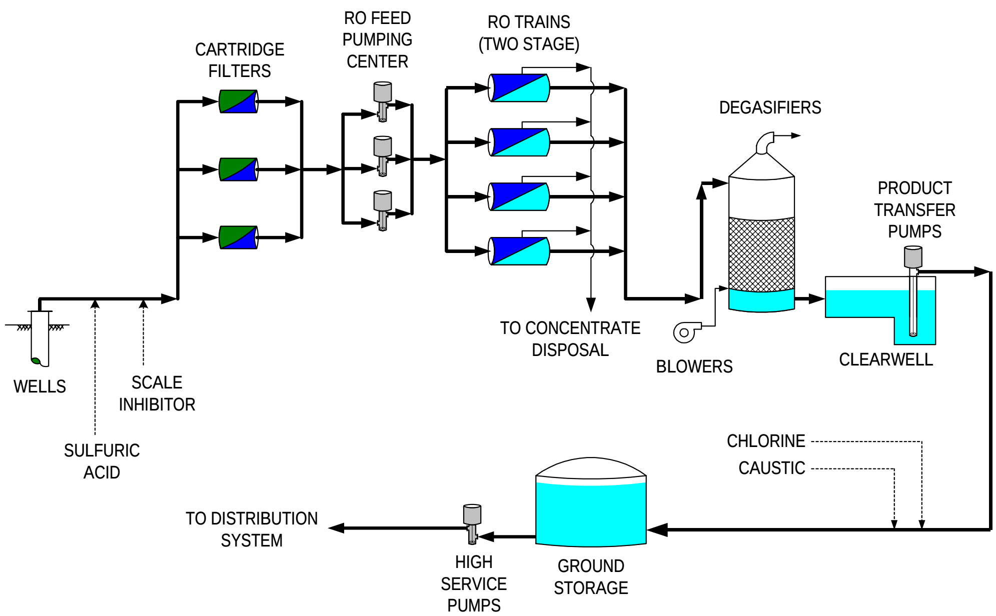


Figure 4-1. Brackish Groundwater Process Flow Diagram

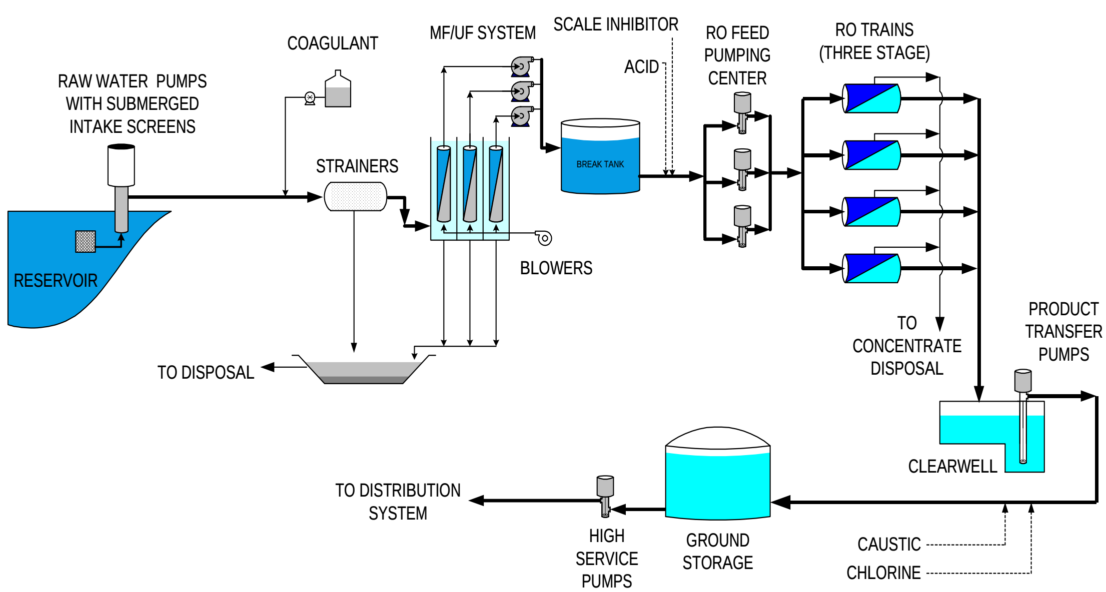


Figure 4-2.—Brackish Surface Water Process Flow Diagram

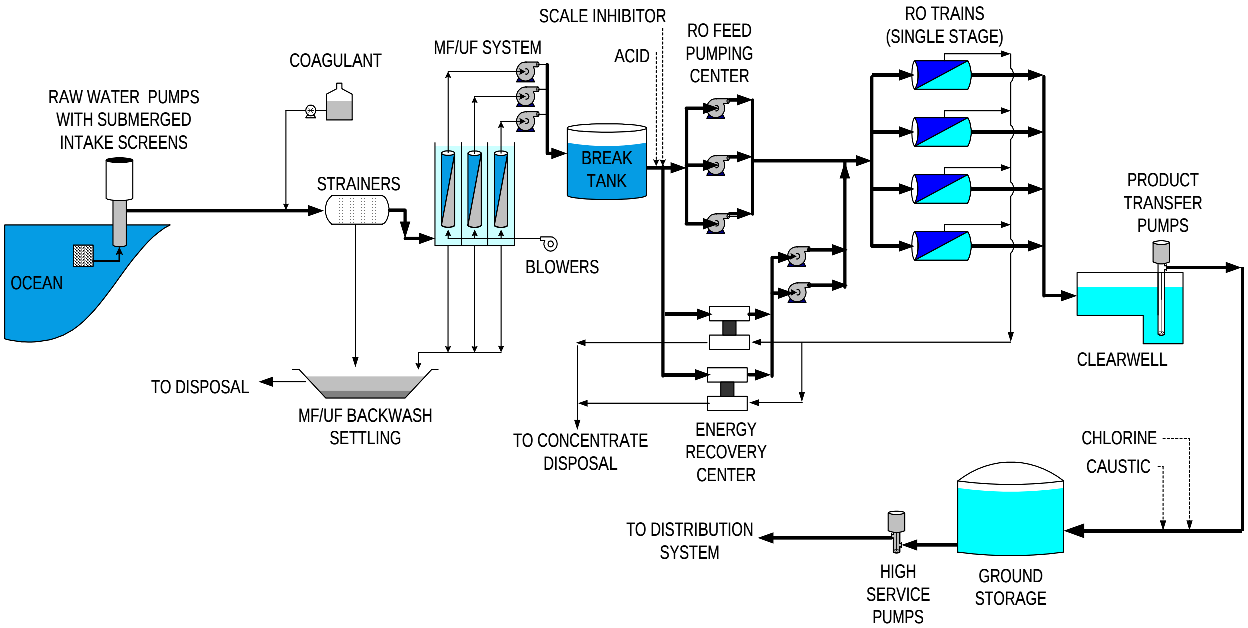


Figure 4-3.—Seawater Process Flow Diagram

Figure 4-3 shows the seawater process flow diagram. Surface seawater is pumped from an intake pumping system to the WTP site where it is treated by dual membrane facilities – vacuum-type MF/UF followed by RO. The seawater passes through strainers, and is dosed with a low concentration of coagulant prior to entering the MF/UF system. MF/UF filtrate is pumped to a break tank which provides a continuous supply of feedwater to the RO system and a supply of filtrate for backwashing of the MF/UF system. After acid and scale inhibitor addition, the filtrate is pressurized by a centralized RO feed pumping system and flows to multiple parallel RO process trains. Permeate from the RO trains passes to a clearwell and then is pumped to ground storage. Chlorine is added for disinfection and caustic is fed to raise the pH before ground storage. High service pumps deliver the finished water to the distribution system. As in the case for the surface water facility, is it assumed that the strainer and MF/UF systems backwash waters are sent to settling ponds and the supernatant is discharged, along with the RO concentrate, to an off-site disposal location.

Computer performance projections using The Dow Chemical Company, ROSA® software, version 5.4, were prepared based on the RO system design criteria listed in Table 4-1. Based on the projections, the average feed pressures that were used in the economic analyses were as follows:

- groundwater : 220 psi (15.2 bar),
- surface water: 185 psi (12.8 bar),
- seawater: 920 psi (63.4 bar).

The design parameters listed in Table 4-1 (for 8-inch diameter performance projections) were also used for 16-inch by 40-inch and 20-inch by 40-inch elements, although fewer elements and pressure vessels are needed for the large diameter elements because they have greater active membrane area.

Table 4-1.—RO System Design Criteria used in Computer Performance Projections

Criterion	Brackish Groundwater	Brackish Surface Water	Seawater
Membrane type	polyamide composite	polyamide composite	polyamide composite
Element size (diameter x length), inches	8 x 40	8 x 40	8 x 40
Membrane area, ft^2	400	400	380
Elements/vessel	7	7	7
No. of stages	2	3	1
Recovery	75	85	45
Source TDS, mg/L	2,200	930	38,000
Average flux, gfd	15	10	9

Table 4-2.—Membrane Area for Standard and Large Diameter RO Elements

Element Size (diameter by length), inches	Membrane Area, ft^2		
	B-GW	B-SW	SW
8 x 40	400	400	380
16 x 40	1,600	1,600	1,480
20 x 40	2,500	2,500	2,312
B-GW – brackish groundwater; B-SW – brackish surface water; SW - seawater			

Membrane areas for the large diameter elements, shown in Table 4-2, were directly proportioned up from those shown in Table 4-1 for the 8-inch by 40-inch elements.

4.2 Isometrics

A computer-derived isometric model of an RO train design was developed in three dimensions (3-D) by CH2M HILL based on the pressure vessel staging from the 8-inch by 40-inch RO membrane element performance projections and a RO train size of 4.17 mgd (16,000 m^3/day) permeate capacity (12 trains for a 50 mgd WTP). The 4.17-mgd (16,000 m^3/day) train capacity was selected based on the approximate optimum number of vessels (90-95) per train as discussed in Liberman (2003). This optimum vessel number was reduced in the 16-inch and 20-inch cases at the lower plant capacities to ensure a minimum of four trains. Also see description in Section 3.2.

The isometric model was developed for the purpose of RO train costing for each of the fifteen 8-inch diameter cases (three water sources multiplied by five plant capacities). The model was constructed using multi-port, side entry pressure vessels and piping manifolds based on a maximum of four vessels through-ported to each manifold. A front and back view isometric for the 8-inch diameter element/pressure vessel trains for groundwater, surface water, and seawater cases are shown in Figures 4-4, 4-6, and 4-8, respectively.

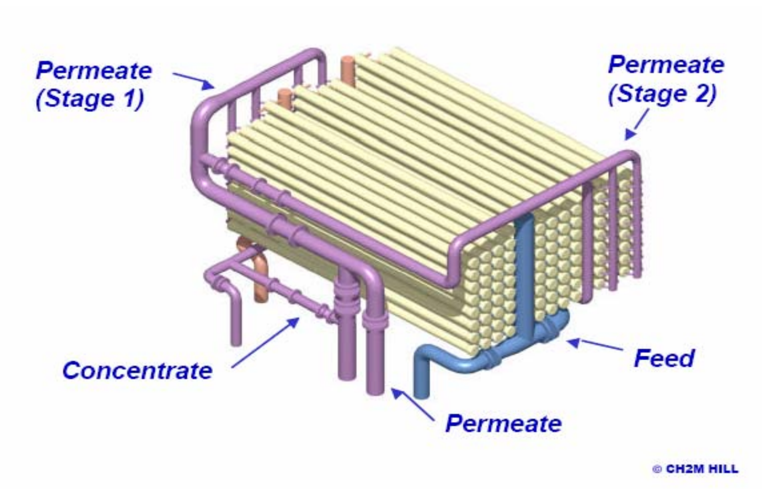
Similar 3-D computer models were then developed for a RO train treating each type of source water using the 16-inch diameter RO element and pressure vessel. The design of the 16-inch train was based on the following assumptions:

- Minimum of four trains for the 50- to 150-mgd plant capacities. Four trains were considered the minimum number to maintain 75% plant capacity with one train out of service for cleaning.\

- Maximum overall train height of 24 feet (including piping). This height was selected to constrain the height at which personnel and equipment must access for purposes of element loading/unloading and train maintenance.

Based on these design assumptions, the train capacity of the brackish groundwater, surface brackish water and seawater 16-inch RO trains calculated at 12.5, 10.0 and 8.33 mgd (47,000, 38,000, 32,000 m^3/day), respectively. A front and back view isometric for the 16-inch based trains for the brackish groundwater, brackish surface water, and seawater cases are shown in Figures 4-5, 4-7, and 4-9, respectively.

Figure 4-4.—8-inch Diameter Element 2-Stage Brackish Groundwater RO Train Isometric



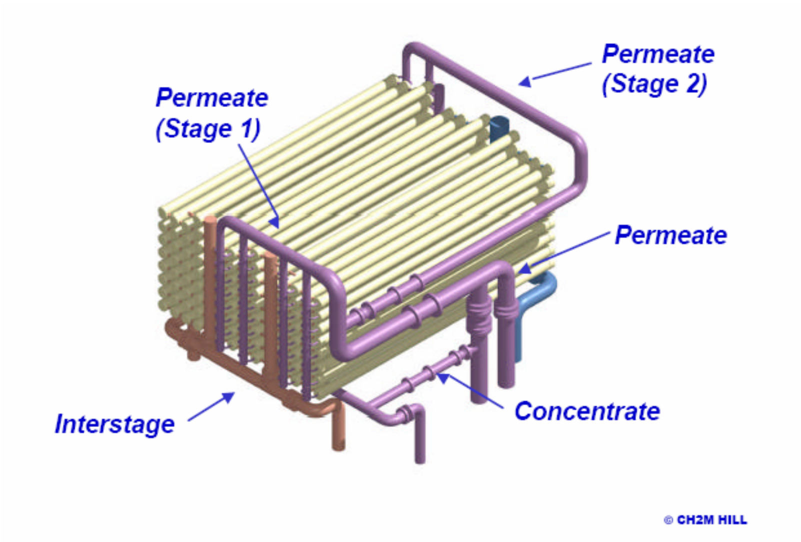
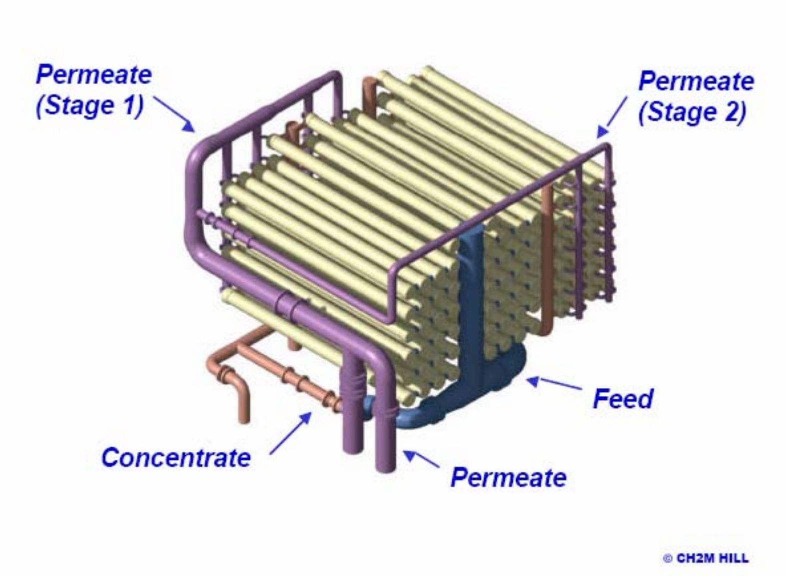


Figure 4-5.—16-inch Diameter Element 2-Stage Brackish Groundwater RO Train Isometric



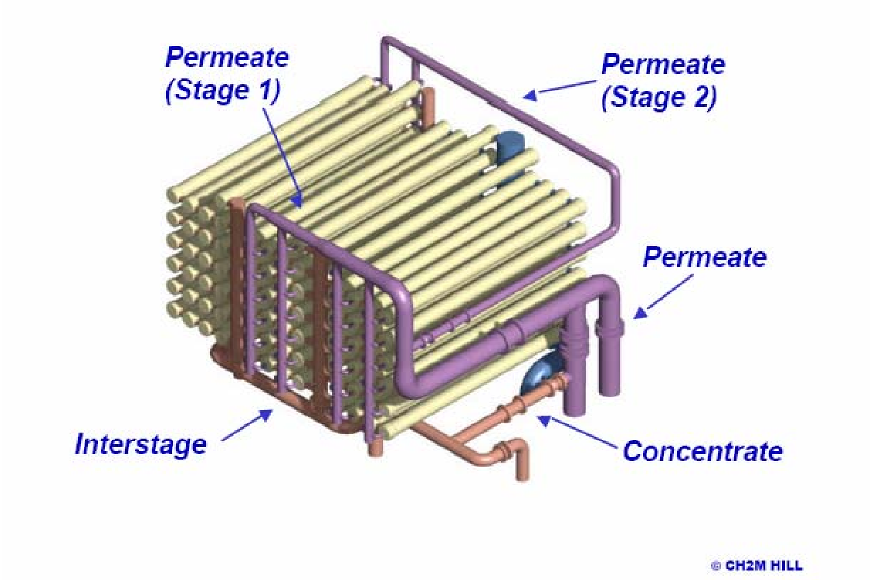


Figure 4-6.—8-inch Diameter Element 3-Stage Brackish Surface Water RO Train Isometric

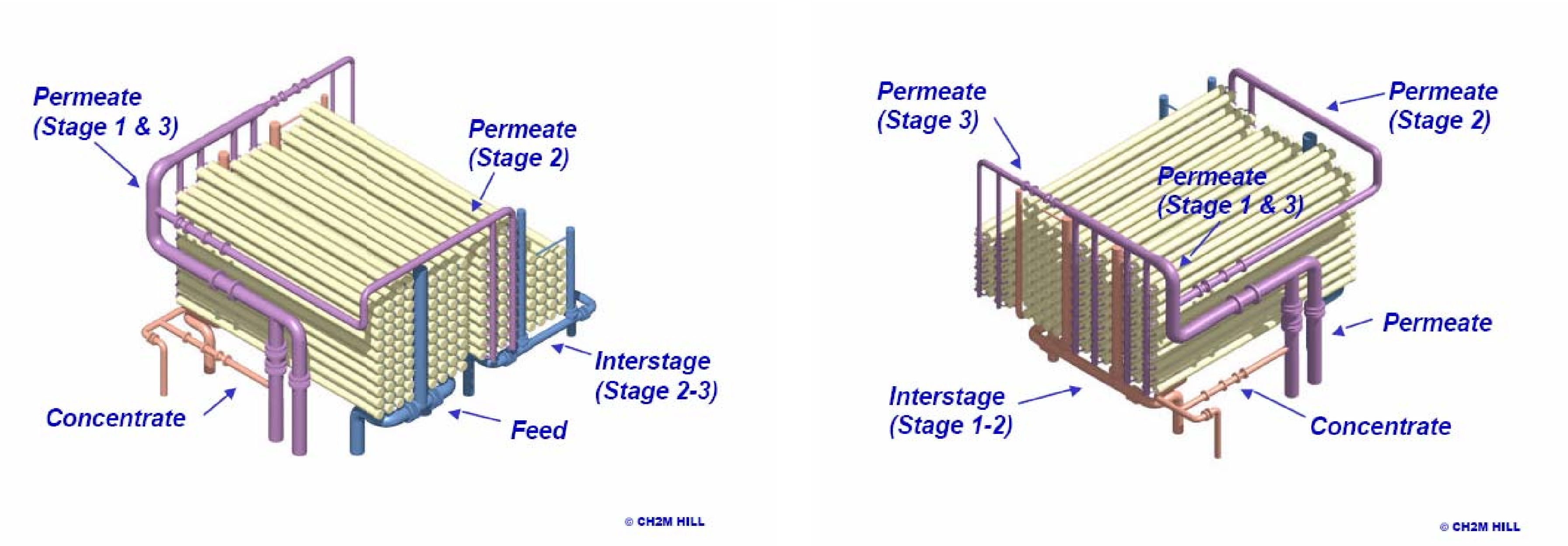
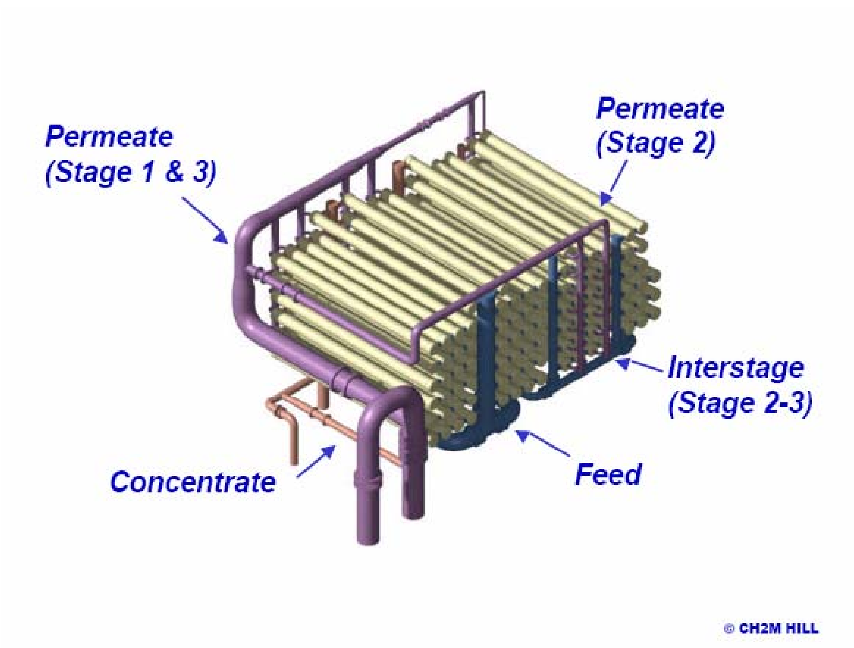


Figure 4-7.—16-inch Diameter Element 3-Stage Brackish Surface Water RO Train Isometric



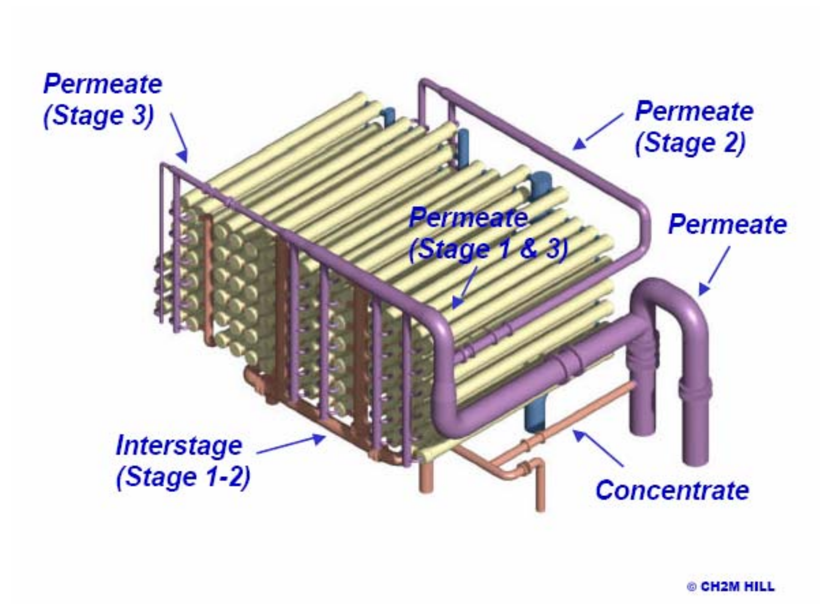
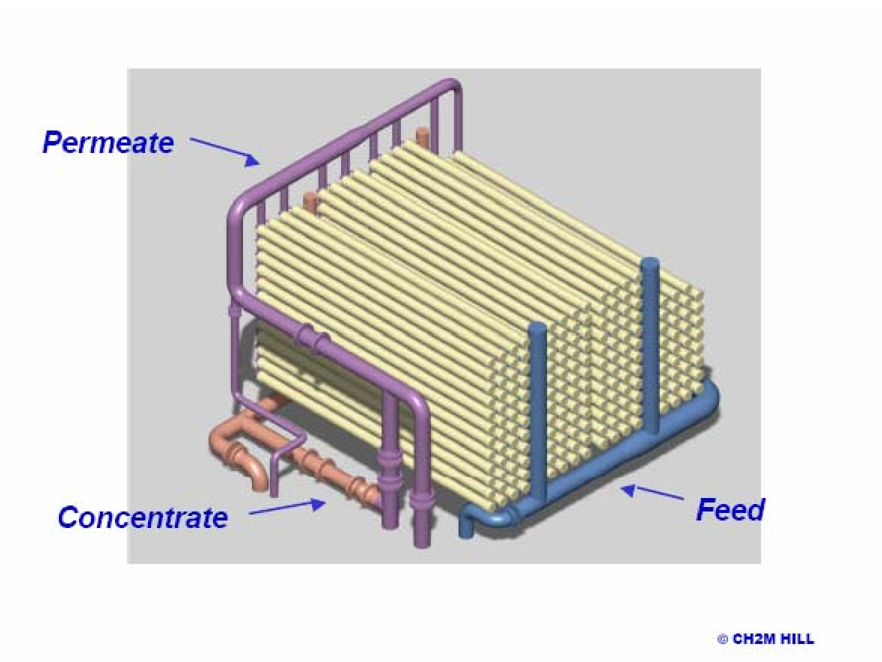


Figure 4-8.—8-inch Diameter Element 1-Stage Seawater RO Train Isometric



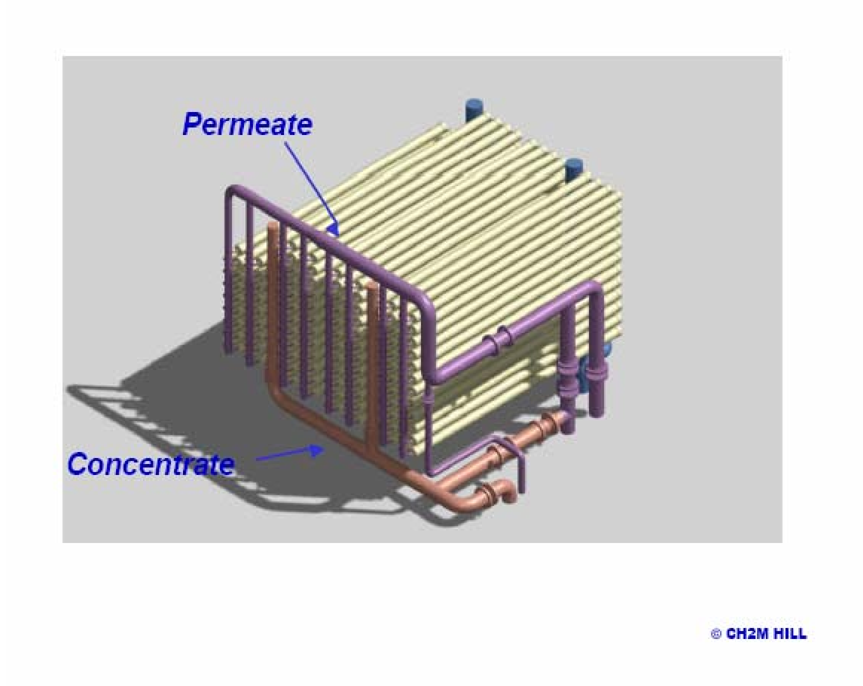
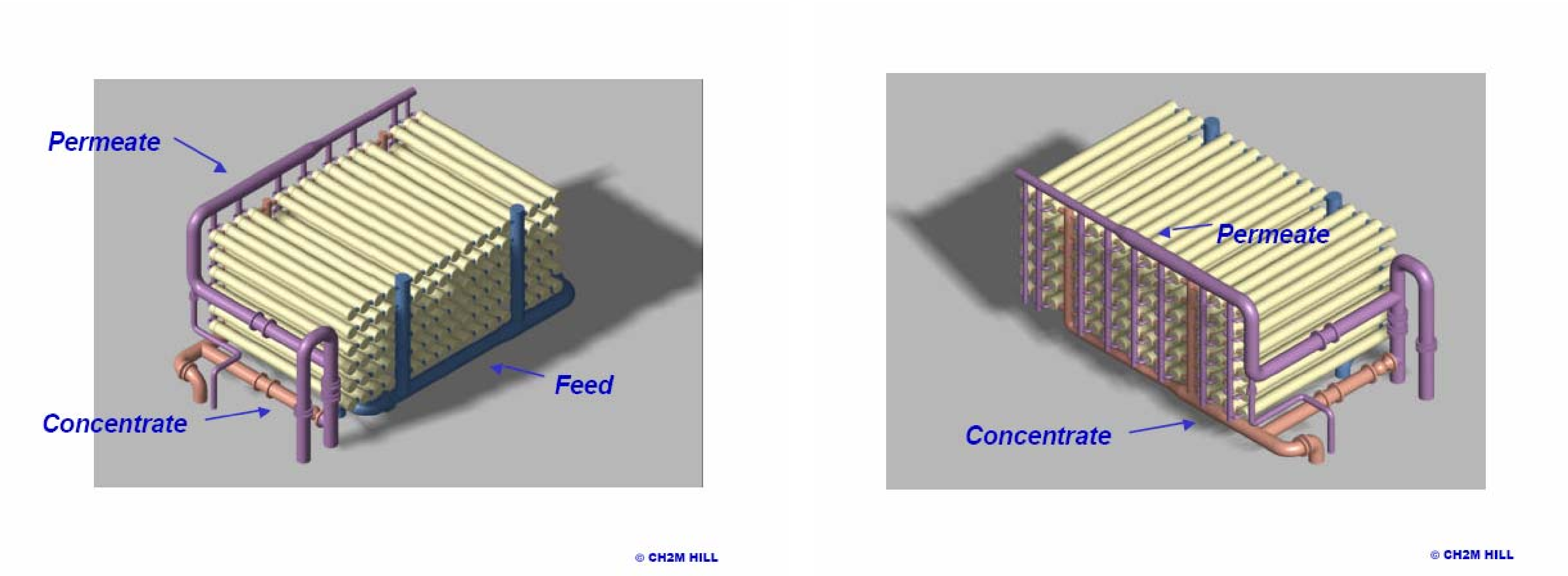


Figure 4-9.—16-inch Diameter Element 1-Stage Seawater RO Train Isometric



The approximate dimensions of the trains, including the piping above the floor level, are shown in Table 4-3. The table gives values for the 8-inch, 16-inch and 20-inch diameter element RO trains used in the economic evaluation for all plant capacities. The vessel numbers shown in Table 4-3 are for trains 50 mgd or larger.

Table 4-3.—RO Train Size and Footprint [a]

	Groundwater	Surface Water	Seawater
8-inch Diameter Elements			
Train capacity, mgd	4.17	4.17	4.17
Number of Pressure Vessels	99	149	179
Train Size (WxLxH) [b], ft	20.5x27x14.5	29x27x17	29x27x20
Height - Top Vessel Row, ft [c]	12	14.5	16.5
Train Area (Footprint), ft^2	554	783	783
16-inch Diameter Elements			
Train capacity, mgd	12.5	10.0	8.33
Number of Pressure Vessels	75	90	90
Train Size (WxLxH) [b], ft	35.5x28.5x24	45x30x23.5	44.5x28x21.5
Height - Top Vessel Row, ft [c]	20.5	20	17.5
Train Area (Footprint), ft^2	1,012	1,350	1,246
20-inch Diameter Elements			
Train capacity, mgd	12.5	12.5	12.5
Number of Pressure Vessels	48	72	86
Train Size (WxLxH) [b], ft	35.5x29.5x25	49x31x24.5	50.5x29x23.5
Height - Top Vessel Row, ft [c]	21.5	21	19.5
Train Area (Footprint), ft^2	1,047	1,519	1,465

[a] Assumed for the economic evaluation; based on the 3-D models for trains in 50 mgd and larger plant capacities
[b] W = width, L = length, H = height
[c] Assumed distance from floor to centerline of top row of pressure vessels

4.3 RO Train Cost

The seawater design models and isometrics described in the previous sections were used to develop detailed Bills of Materials (BOMs). From these, uninstalled and installed RO train equipment costs were calculated for each of the three element diameters. The BOMs included RO train membrane elements, pressure vessels, weldments, panels, and valves, piping and other appurtenances located above floor elevation. Equipment and other items not installed on the RO skids, such as cartridge filters, RO feed pumps and energy recovery pressure exchangers (for seawater cases only), were not included in the RO train BOMs.

The groundwater and surface water RO train uninstalled and installed costs were then developed based on adjustments to the seawater train cost. These adjustments accounted for cost differences in high pressure piping materials and larger diameter (and rated pressure) RO elements and pressure vessels. Higher-priced AL6XN alloy was used in piping materials for seawater cases while less-expensive 316L was used for ground and surface water cases.

As RO elements and pressure vessels represent the majority of the RO train costs, these costs are presented in Table 4-4 for the three different element diameters used in the study. Uninstalled costs for the 8-inch diameter elements and pressure vessels were estimated from representative commercial costs currently being used in large capacity municipal membrane systems. Uninstalled costs for the 16-inch and 20-inch diameter elements and pressure vessels were calculated as 4 and 6.25 times, respectively, of the 8-inch diameter costs. These cost multipliers represent the membrane area ratio for 16-inch:8-inch and 20-inch:8-inch elements, respectively, as previously stated. The installation cost was assumed to be 20 percent of the uninstalled cost.

Table 4-4.—Assumed RO Membrane Element and Pressure Vessel Costs

	Groundwater & Surface Water			Seawater		
	8-inch	**16-inch**	**20-inch**	**8-inch**	**16-inch**	**20-inch**
Membrane Elements						
Membrane area, ft^2	400	1,600	2,500	370	1,480	2,312
Uninstalled cost per element, $	450	1,800	2,812	625	2,500	3,906
Installed cost per element[a], $	540	2,160	3,375	750	3,000	4,687
Pressure Vessels[b]						
Uninstalled cost per element, $	1,500	6,000	9,375	2,500	10,000	15,625
Installed cost per element [a], $	1,800	7,200	11,250	3,000	12,000	18,750

[a] Assumed to be 1.2 times the uninstalled cost
[b] Vessels can hold seven 40-inch long RO elements (7M vessels)

A detailed installed cost estimate of the 8-inch, 16-inch, and 20-inch diameter seawater RO trains were made from the BOMs. These detailed estimates and the associated unit cost summary are presented in Appendix G.

The RO train installed unit costs for the three element diameter cases (8-inch, 16-inch, and 20-inch) for each source water (groundwater, surface water, and seawater) are shown in Table 4-5   These unit costs are applicable to the full range of plant capacities evaluated (12.5 mgd to 150 mgd).

Table 4-5.—Assumed RO Train Installed Unit Costs (All Plant Capacities)

	Installed Cost ($/gpd)		
	8-inch	**16-inch**	**20-inch**
Groundwater Trains	0.333	0.217	0.201
Surface Water Trains	0.400	0.284	0.268
Seawater Trains	0.609	0.462	0.440

Notes:
1. Units costs based on permeate flow rate and are applicable to all plant capacities studied (12.5, 25, 50, 100, and 150 mgd)
2. Installation costs assumed to be 20 percent of the uninstalled costs

4.4 RO Feed Pumping and Energy Recovery

The design assumed that the RO feed pumps would be installed in parallel in a “pumping center”. One spare pump (and one spare energy recovery device for the seawater facilities) was assumed for each case and installation was assumed to be 20 percent of the uninstalled pump cost.

For each seawater case, a pressure exchanger “energy recovery center” is used. Based on an assumed recovery of 45 percent, the waste concentrate flow (from which pressure energy can be recovered) represents 55 percent of the feed flow. With the pressure exchanger system, the waste concentrate exiting the RO trains passes through a series of parallel pressure exchangers, where the pressure energy in the concentrate is directly transferred to a portion of RO feed flow. The energy transfer increases the pressure of the RO feed. The increased-pressure RO feed is then further pressurized with a separate boost pump to that required by the RO train (800 to1,000 psi, 55 to 69 bar). The remainder of the low pressure RO feed flow (the portion which does not pass through the pressure exchanger, approximately equal to the permeate flow rate) is pressurized by the RO feed pumping center. The discharge from the RO feed pumping and energy recovery centers are blended and flows to the parallel RO trains via the RO feed header. The energy recovery system reduces the RO system feed pumping energy requirement by approximately 50 percent.

Table 4-6 presents the assumed pump and energy recovery design criteria for all plant capacities.

Table 4-6.—Assumed RO Pumping and Energy Recovery Equipment

	Groundwater	Surface Water	Seawater
RO Train Capacity: 12.5 mgd			
RO Feed Pump			
Pump Flow Rate, mgd	16.7	14.7	12.8
TDH, psi	235	190	1,000
Energy Recovery Boost Pump			
Pump Flow Rate, mgd each			15.0
TDH, psi			45
Energy Recovery Pressure Exchanger			
Concentrate Flow Rate, mgd			15.3
Concentrate TDH, psi			940
RO Train Capacity: 25 mgd			
RO Feed Pump			
Pump Flow Rate, mgd	33.3	29.4	25.5
TDH, psi	235	190	1,000
Energy Recovery Boost Pump			
Pump Flow Rate, mgd each			30.0
TDH, psi			45
Energy Recovery Pressure Exchanger			
Concentrate Flow Rate, mgd			30.6
Concentrate TDH, psi			940
RO Train Capacity: 50 mgd			
RO Feed Pump			
Pump Flow Rate, mgd	66.7	58.8	51.1
TDH, psi	235	190	1,000
Energy Recovery Boost Pump			
Pump Flow Rate, mgd each			60.0
TDH, psi			45
Energy Recovery Pressure Exchanger			
Concentrate Flow Rate, mgd			61.1
Concentrate TDH, psi			940

Table 4-6.—Assumed RO Pumping and Energy Recovery Equipment

	Groundwater	Surface Water	Seawater
RO Train Capacity: 100 mgd			
RO Feed Pump			
Pump Flow Rate, mgd	133	118	102
TDH, psi	235	190	1,000
Energy Recovery Boost Pump			
Pump Flow Rate, mgd each			120
TDH, psi			45
Energy Recovery Pressure Exchanger			
Concentrate Flow Rate, mgd			122
Concentrate TDH, psi			940
RO Train Capacity: 150 mgd			
RO Feed Pump			
Pump Flow Rate, mgd	200	176	153
TDH, psi	235	190	1,000
Energy Recovery Boost Pump			
Pump Flow Rate, mgd each			180
TDH, psi			45
Energy Recovery Pressure Exchanger			
Concentrate Flow Rate, mgd			183
Concentrate TDH, psi			940

Notes:

1. Assumed design based upon Calder AG's DWEER system
2. The TDH values shown are assumed to be the maximum total dynamic heads for each case

4.5 MF/UF System

The surface (brackish) water and seawater cases use MF/UF as RO feedwater pretreatment. Multiple, parallel immersed UF trains (including one spare train for each case) were employed. Instantaneous flux rates for the surface water and seawater cases were 20 gfd (34 Lmh) and 25 gfd (42.5 Lmh), respectively. For both cases, UF system recovery was 95 percent and the maximum transmembrane pressure was 11 psi (0.8 bar) (vacuum).

4.6 Building Area

It was assumed that all membrane process equipment and appurtenances and all pumps were housed in buildings. Table 4.7 presents a summary of the assumed building areas for the RO system and the entire treatment facilities for all of the cases. The areas were calculated by the computer model used for the cost estimates using input from the RO train areas (see Table 4-3), the number of trains, and other design criteria which can be seen in the CD which supplements this report. Areas for operator facilities, laboratory, maintenance, or storage are not included.

4.6.1 Groundwater Cases

The groundwater RO facility and total plant building areas ranged from 5,500 to 6,500 ft^2 (510 to 600 m^2) and 10,500 to 11,500 ft^2 (975 to 1070 m^2) respectively, for the12.5 mgd (47,000 m^3/day) plant to about 59,000 to 75,000 ft^2 (5,500 to 6,700 m^2) and 79,000 to 95,000 ft^2 (7,300 to 8,800 m^2) for the 150 mgd (568,000 m^3/day) plant. The unit RO facility area ranged from 380 to 520 ft^2 /mgd (0.009 to 0.013 m^2/[m^3/day]) finished water capacity. Considering all plant capacities, RO facility building area savings ranged from 15 to 25 percent by using elements with diameters larger than 8 inch. The RO facility areas saving did not change much between the 16-inch and 20-inch diameter element cases and the savings were least for the smaller plant capacity cases. The common facility area elements, such as the membrane cleaning system, are a greater fraction of the total area in the smaller plants. The total plant building area savings ranged from 9 to 22 percent by using larger diameter elements.

4.6.2 Surface Water Cases

For surface water cases, the RO facility and total plant building areas ranged from 8,900 to 10,200 ft^2 (827 to 948 m^2) and 23,300 to 24,600 ft^2 (2,170 to 2,290 ft^2) respectively, for the12.5 mgd (47,000 m^3/day) plant to about 74,000 to 96,000 ft^2 (6,880 to 8,920 m^2) and 142,000 to 164,000 ft^2 (13,200 to 15,200 m^2) for the 150 mgd (568,000 m^3/day) plant. The unit RO facility area ranged from 490 to 820 ft^2 /mgd (0.012 to 0.020 m^2/[m^3/day]) finished water capacity. Considering all plant capacities, RO facility building area savings ranged from 9 to 23 percent by using elements with diameters larger than 8 inch. The total plant building area savings ranged from 4 to 13 percent by using larger diameter elements. As in the ground water cases, the greatest savings in area were realized in the larger capacity plants.

4.6.3 Seawater Cases

The RO facility and total plant building areas for the seawater cases ranged from 12,300 to 13,000 ft^2 (1,140 to 1,200 m^2) and 30,100 to 30,800 ft^2 (2,800 to 2,860 m^2) respectively, for the12.5 mgd (47,000 m^3/day) plant to about 133,000 to 150,000 ft^2 (12,400 to 14,000 m^2) and 238,000 to 254,000 ft^2 (22,100 to 23,600 m^2) for the 150 mgd (568,000 m^3/day) plant. The unit RO facility area ranged from 890 to 1,040 ft^2 /mgd (0.022 to 0.026 m^2/[m^3/day]) finished water capacity. Considering all plant capacities, RO facility building area savings ranged from 0 to 11 percent by using elements with diameters larger than 8 inch. The total plant building area savings ranged from 0 to 6 percent by using larger diameter elements. Again, the area savings were greatest in the larger capacity plants.

Table 4-7.—Assumed Building Area

Parameter	Brackish Groundwater			Brackish Surface Water			Seawater		
RO Element Diameter:	**8”**	**16”**	**20”**	**8”**	**16”**	**20”**	**8”**	**16”**	**20”**
12.5 mgd Plant									
RO facility, 1,000 ft^2	6.5	5.4	5.5	10.2	9.3	8.9	13.0	13.0	12.3
% of 8” dia. area	100	84	84	100	91	87	100	100	95
1,000 ft^2 area/mgd	0.52	0.43	0.44	0.82	0.74	0.71	1.04	1.04	0.98
Total Plant, 1,000 ft^2	11.5	10.5	10.5	24.6	23.7	23.3	30.7	30.8	30.1
% of 8” dia. area	100	91	91	100	96	95	100	100	98
25 mgd Plant									
RO facility, 1,000 ft^2	12.8	10.7	10.9	16.4	14.5	13.7	25.1	25.3	23.9
% of 8” dia. area	100	84	85	100	88	83	100	101	95
1,000 ft^2 area/mgd	0.51	0.43	0.43	0.66	0.58	0.55	1.00	1.01	0.96
Total Plant, 1,000 ft^2	18.9	16.8	16.9	36.5	34.6	33.8	52.1	52.3	50.9
% of 8” dia. area	100	89	90	100	95	93	100	100	98
50 mgd Plant									
RO facility, 1,000 ft^2	25.3	18.9	19.7	32.0	26.3	24.6	50.0	47.9	44.5
% of 8” dia. area	100	75	78	100	82	77	100	96	89
1,000 ft^2 area/mgd	0.51	0.38	0.39	0.64	0.53	0.49	1.00	0.96	0.89
Total Plant, 1,000 ft^2	34.1	27.7	28.5	64.2	58.5	56.8	96.8	94.7	91.3
% of 8” dia. area	100	81	84	100	91	88	100	98	94
100 mgd Plant									
RO facility, 1,000 ft^2	50.5	39.1	39.4	64.0	52.8	49.4	99.5	95.4	88.6
% of 8” dia. area	100	77	78	100	82	77	100	96	89
1,000 ft^2 area/mgd	0.51	0.39	0.39	0.64	0.53	0.49	1.00	0.95	0.89
Total Plant, 1,000 ft^2	65.2	53.7	54.1	119	107	104	181	177	170
% of 8” dia. area	100	82	83	100	91	88	100	98	94
150 mgd Plant									
RO facility, 1,000 ft^2	75.3	58.2	58.7	96.1	79.2	74.2	150	143	133
% of 8” dia. area	100	77	78	100	83	77	100	96	89
1,000 ft^2 area/mgd	0.50	0.39	0.39	0.64	0.53	0.50	1.00	0.96	0.89
Total Plant, 1,000 ft^2	95.1	77.9	78.5	164	147	142	254	248	238
% of 8” dia. area	100	82	83	100	90	87	100	98	94

Note:

1. Unit area based on finished water flow rate in mgd
2. Areas based on the RO train design models and building area calculations by CH2M HILL’s proprietary cost estimating model, CH2M HILL Parametric Cost Estimating System (CPES)

4.7 Chemical Usage

The design established for the economic analysis used several process chemical feeds depending on the specific feedwater source (refer to the process flow diagrams, Figures 4-1 through 4.3). Table 4-8 list chemicals and associated doses for each source water case. A small acid fed (5 mg/L) was assumed for seawater RO -- although there are many seawater RO desalting plants not feeding acid. Although not included in the table, chemical systems and associated costs were also included for off-line membrane cleaning (CIP) and spent cleaning solution neutralization.

Table 4-8.—Assumed Chemical Dosages and Unit Costs

	Groundwater	Surface Water	Seawater
MF/UF Pretreatment Coagulant			
Ferric Chloride (40% strength)			
Dose, mg/L	N/A*	25	25
RO Pretreatment			
Sulfuric Acid (93% strength)			
Dose, mg/L	45	11	5
Scale Inhibitor (100% strength)			
Dose, mg/L	3	3	3
RO Post-treatment			
Sodium Hydroxide (50% strength)			
Dose, mg/L	20	20	20
Sodium Hypochlorite (12.5% strength)			
Dose, mg/L as Chlorine	4	4	4
* N/A – Not applicable			

4.8 Labor

The assumed operation and maintenance (O&M) labor staff for each case is shown in Table 4-9. These estimates were developed based on CH2M HILL's extensive experience in developing O&M cost estimates for full-scale NF and RO plants over the last 30 years, including work performed for the Bureau of Reclamation for the operation of the Yuma Desalting Plant (CH2M HILL, 1993) and a published cost survey of full-scale NF plants in Florida (Bergman, 1995).

Table 4-9.—Assumed Plant O&M Staff

	WTP Capacity, mgd				
	12.5	**25**	**50**	**100**	**150**
Groundwater					
Operators	6	8	12	18	23
Maintenance staff	2	3	5	8	10
Office	1	2	3	4	5
Management	2	3	4	5	5
Total	11	16	24	35	43
Surface Water					
Operators	10	12	18	27	34
Maintenance staff	4	6	9	14	18
Office	1	2	3	4	5
Management	2	3	4	5	5
Total	17	23	34	50	62
Seawater					
Operators	10	12	18	27	34
Maintenance staff	6	9	14	21	26
Office	1	2	3	4	5
Management	2	3	4	5	5
Total	19	26	39	57	70

4.9 Results

A summary of the major assumptions and RO design criteria used in the study is shown in Table 4-10.

Table 4-10.—Assumed Values for Economic Study

Parameter	Brackish Groundwater (High Flux)			Brackish Surface Water or Water Reuse Application (Low Flux)			Seawater		
RO Element Diameter:	**8-inch**	**16-inch**	**20-inch**	**8-inch**	**16-inch**	**20-inch**	**8-inch**	**16-inch**	**20-inch**
Feedwater Salinity									
Total Dissolved Solids, mg/L	2,200			930			38,000		
RO Pretreatment									
Standard [a]	Yes			Yes			Yes		
Screening; MF/UF with optional coagulant feed plus "Standard"	No			Yes			Yes		
Number of RO Trains									
12.5 mgd WTP	3	2	2	3	2	2	3	2	2
25 mgd WTP	6	4	4	6	4	4	6	4	4
50 mgd WTP	12	4	4	12	5	4	12	6	4
100 mgd WTP	24	8	8	24	10	8	24	12	8
150 mgd WTP	36	12	12	36	15	12	36	18	12
RO Train Permeate Capacity, mgd									
12.5 mgd WTP	4.17	6.25	6.25	4.17	6.25	6.25	4.17	6.25	6.25
25 mgd WTP	4.17	6.25	6.25	4.17	6.25	6.25	4.17	6.25	6.25
50 mgd WTP	4.17	12.5	12.5	4.17	10.0	12.5	4.17	8.33	12.5
100 mgd WTP	4.17	12.5	12.5	4.17	10.0	12.5	4.17	8.33	12.5
150 mgd WTP	4.17	12.5	12.5	4.17	10.0	12.5	4.17	8.33	12.5
Pressure Vessels per RO Train									
Number of Pressure Vessels – Plants of less than 50 mgd	99	38	24	149	57	36	179	68	43
Number of Pressure Vessels – Plants of 50 mgd or larger	99	75	48	149	90	72	179	90	86
Number of Stages	2			3			1		
Array/Staging – Vessel Taper (approx.)	2:1			4:2:1			1		
Number of 40-inch Long RO Elements Per Pressure Vessel	7			7			7		
Pressure Vessel – Pressure Rating, psi	400			400			1,000		

Table 4-10.—Assumed Values for Economic Study

Parameter	Brackish Groundwater (High Flux)			Brackish Surface Water or Water Reuse Application (Low Flux)			Seawater		
RO Element Diameter:	**8-inch**	**16-inch**	**20-inch**	**8-inch**	**16-inch**	**20-inch**	**8-inch**	**16-inch**	**20-inch**
RO Membranes									
Permeate Flux, gfd	15			10			9		
Specific Flux, gfd/psi [b]	0.13			0.10			0.024		
Recovery, %	75			85			45		
Fouling rate, %	5			10			5		
Brine/permeate ratio (minimum)	5:1			5:1			5:1		
Active RO Membrane Element Area, ft^2									
-- 8-inch x 40-inch Element	400			400			370		
-- 16-inch x 40-inch Element [c]	1,600			1,600			1,480		
-- 20-inch x 40-inch Element [d]	2,500			2,500			2,312		
O&M & Life Cycle Cost Analyses Data [i]									
Feed Pressure (average), psi	220			185			920		
Feedwater Temperature (average), ^oC	25			25			25		
RO Membrane Life, year	5			5			5		
RO Membrane Cleaning frequency, [2]Number per year	1			3			2		
Plant Operating Factor (% of time)	95			95			95		
RO Feed Pump Wire-to-Water Efficiency, %	68			68			68		
Power Costs ($/KWH) [e]	0.06			0.06			0.04		
Labor Cost, $/year [f]									
-- Operators	50,000			50,000			50,000		
-- Maintenance Staff	50,000			50,000			50,000		
-- Office Staff	30,000			30,000			30,000		
-- Management	80,000			80,000			80,000		
Chemical Cost, $/pound (bulk chemical) [g]									
-- Ferric Chloride	N/A			0.153			0.153		
-- Sulfuric Acid	0.075			0.075			0.075		
-- Scale Inhibitor	1.15			1.15			1.15		
-- Sodium Hydroxide	0.146			0.146			0.146		
-- Sodium Hypochlorite	0.532			0.532			0.532		

Table 4-10.—Assumed Values for Economic Study

Parameter	Brackish Groundwater (High Flux)			Brackish Surface Water or Water Reuse Application (Low Flux)			Seawater		
RO Element Diameter:	**8-inch**	**16-inch**	**20-inch**	**8-inch**	**16-inch**	**20-inch**	**8-inch**	**16-inch**	**20-inch**
O&M Repair and Maintenance Cost									
-- Annual, % of Construction Cost	2			2			2		
Construction Cost Contingency									
-- % of Construction Cost [h]	20			20			20		

[a] Standard pretreatment = acid & scale inhibitor addition and 5-micron cartridge filtration
[b] Calculated as flux/net driving pressure
[c] Assumed to be 4 times area of 8-inch element
[d] Assumed to be 6.25 times area of 8-inch element
[e] Assumed reduced unit power cost for the seawater case reflects assumed co-location the RO plant with a power plant
[f] Salary plus fringe benefits
[g] Process chemicals (fed continuously)
[h] Construction cost contingency (calculated after contractor markup)
[i] Capital cost amortization: 20 year period, 5 percent annual discount rate

CH2M HILL's proprietary cost estimating model, CPES (CH2M HILL Parametric Cost Estimating System), was used to develop construction, O&M, and life cycle costs for 12.5, 25, 50, 100, and 150 mgd (47,000, 95,000, 189,000, 379,000, and 568,000 m^3/day) WTPs for each source water (brackish groundwater, brackish surface water, and open intake seawater). Only treatment plant facilities were considered. Costs for off-site facilities such as raw water supply, waste disposal (including concentrate disposal), and finished water distribution system were not included. A plant operating factor of 95 percent was used for the annualized unit costs. A tabular summary of the CPES model results for each plant capacity is included in Appendix G. Detailed costs are available in the supplemental CD with this report.

A breakdown of the construction cost for each of the forty-five cases is shown in Tables 4-11 through 4-15. The unit costs (dollars per gpd of finished water capacity) decrease as the plant capacity increases, reflecting an economy of scale. The 8-inch diameter RO element plant total construction costs for the groundwater, surface water, and seawater cases from 12.5 mgd (47,000 m^3/day) through 150 mgd (568,000 m^3/day) ranged from $1.67-1.82, $3.04-3.63, and $4.69-5.34 per gpd, ($440-480, $802-958, and $1,238-1,410 m^3/day) respectively. The 16-inch diameter RO element plant total construction costs for the groundwater, surface water, and seawater cases from 12.5 mgd (47,000 m^3/day) through 150 mgd (568,000 m^3/day) ranged from $1.33-1.49, $2.70-3.30, and $4.31-4.97 per gpd ($351-393, $713-871, and $1,138-1,312 m^3/day) , respectively. Finally, the 20-inch diameter RO element plant total construction costs for the groundwater, surface water, and seawater cases from 12.5 mgd through 150 mgd ranged from $1.29-1.45, $2.65-3.25, and $4.24-4.89 per gpd ($341-383, $700-858, and $1,119-1,291 m^3/day) , respectively.

Table 4-11.—Treatment Plant Construction Cost – 12.5 mgd

CH2M HILL CPES CONSTRUCTION COST SUMMARY 12.5 mgd	Brackish Ground Water 8" ($ Million)	Brackish Ground Water 16" ($ Million)	Brackish Ground Water 20" ($ Million)	Brackish Surface Water 8" ($ Million)	Brackish Surface Water 16" ($ Million)	Brackish Surface Water 20" ($ Million)	Seawater 8" ($ Million)	Seawater 16" ($ Million)	Seawater 20" ($ Million)
UF system (Note 1)	0.00	0.00	0.00	10.23	10.23	10.23	13.24	13.24	13.24
RO System (Note 2)	8.00	5.74	5.47	9.90	7.67	7.30	18.13	15.69	15.17
Degasifier (Note 3)	0.12	0.12	0.12	0.00	0.00	0.00	0.00	0.00	0.00
Clearwell (Note 4)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Product Transfer Pumps (Note 5)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Ground Storage & High Service Pumping (Note 6)	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.88
Chemical Storage & Handling (Note 7)	0.92	0.92	0.92	1.07	1.07	1.07	1.25	1.25	1.25
Subtotal - Facilities	**12.24**	**9.98**	**9.71**	**24.39**	**22.16**	**21.79**	**35.81**	**33.37**	**32.85**
Additional Project Costs									
Sitework	0.61	0.50	0.49	1.22	1.11	1.09	1.79	1.67	1.64
Yard Piping	1.22	1.00	0.97	2.44	2.22	2.18	3.58	3.34	3.29
Yard Electrical	0.98	0.80	0.78	1.95	1.77	1.74	2.86	2.67	2.63
Plant Computer	0.61	0.50	0.49	1.22	1.11	1.09	1.79	1.67	1.64
Subtotal - Additional Project Costs	3.43	2.79	2.72	6.83	6.20	6.10	10.03	9.34	9.20
Subtotal - Facilities plus Additional Project Costs	**15.66**	**12.77**	**12.42**	**31.22**	**28.36**	**27.90**	**45.83**	**42.71**	**42.05**
Contractor Mark-ups (Note 8)	3.33	2.72	2.64	6.64	6.03	5.93	9.75	9.09	8.95
Contingency	3.80	3.10	3.01	7.57	6.88	6.77	11.12	10.36	10.20
Total Construction Cost	**22.79**	**18.58**	**18.08**	**45.44**	**41.27**	**40.60**	**66.70**	**62.16**	**61.19**
Total Construction $/gpd	**$1.824**	**$1.487**	**$1.446**	**$3.635**	**$3.302**	**$3.248**	**$5.336**	**$4.973**	**$4.895**
% of 8" dia cost	**100.0%**	**81.5%**	**79.3%**	**100.0%**	**90.8%**	**89.3%**	**100.0%**	**93.2%**	**91.7%**

Notes:

1. Includes pretreatment strainers, immersed UF membrane trains with permeate pumps, CIP and neutralization systems, multiple backwash ponds (based on CPES sludge drying beds model), below grade filtrate tank for backwash supply and RO feed, and building
2. Includes cartridge filters, RO feed pumps, membrane elements, pressure vessels, other RO train components, CIP system, product water flush (surface water and seawater cases), and building. Assumed costs for RO feed pumps based upon Torishima pump budgetary prices and energy recovery costs based upon Calder AG DWEER pressure exchanger system budgetary prices.
3. Ground water cases only (shown as air stripper in CPES models); includes blowers
4. Assumes below-grade rectangular clearwell
5. Called In-Plant Pumping Station in CPES; also assumes building
6. Ground storage cost based on CPES Clearwell Model; assumes two circular above ground concrete tanks
7. Includes bulk storage and chemical pumps for al process chemicals and RO spent cleaning neutralization system
8. Overhead, profit, mobilization, bonds, insurance costs

Table 4-12.—Treatment Plant Construction Cost – 25 mgd

CH2M HILL CPES CONSTRUCTION COST SUMMARY 25 mgd	Brackish Ground Water 8" ($ Million)	Brackish Ground Water 16" ($ Million)	Brackish Ground Water 20" ($ Million)	Brackish Surface Water 8" ($ Million)	Brackish Surface Water 16" ($ Million)	Brackish Surface Water 20" ($ Million)	Seawater 8" ($ Million)	Seawater 16" ($ Million)	Seawater 20" ($ Million)
UF system (Note 1)	0.00	0.00	0.00	15.82	15.82	15.82	21.12	21.12	21.12
RO System (Note 2)	16.29	11.73	11.18	18.91	14.38	13.65	35.48	30.44	29.41
Degasifier (Note 3)	0.23	0.23	0.23	0.00	0.00	0.00	0.00	0.00	0.00
Clearwell (Note 4)	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Product Transfer Pumps (Note 5)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Ground Storage & High Service Pumping (Note 6)	4.25	4.25	4.25	4.25	4.25	4.25	4.25	4.25	4.25
Chemical Storage & Handling (Note 7)	1.15	1.15	1.15	1.36	1.36	1.36	1.59	1.59	1.59
Subtotal - Facilities	**22.40**	**17.83**	**17.29**	**40.82**	**36.29**	**35.56**	**62.92**	**57.88**	**56.85**
Additional Project Costs									
Sitework	1.12	0.89	0.86	2.04	1.81	1.78	3.15	2.89	2.84
Yard Piping	2.24	1.78	1.73	4.08	3.63	3.56	6.29	5.79	5.69
Yard Electrical	1.79	1.43	1.38	3.27	2.90	2.84	5.03	4.63	4.55
Plant Computer	1.12	0.89	0.86	2.04	1.81	1.78	3.15	2.89	2.84
Subtotal - Additional Project Costs	6.27	4.99	4.84	11.43	10.16	9.96	17.62	16.21	15.92
Subtotal - Facilities plus Additional Project Costs	**28.67**	**22.83**	**22.13**	**52.24**	**46.45**	**45.51**	**80.53**	**74.09**	**72.77**
Contractor Mark-ups (Note 8)	6.10	4.86	4.71	11.12	9.88	9.68	17.13	15.76	15.48
Contingency	6.96	5.54	5.37	12.67	11.27	11.04	19.53	17.97	17.65
Total Construction Cost	**41.73**	**33.22**	**32.21**	**76.03**	**67.59**	**66.23**	**117.20**	**107.82**	**105.90**
Total Construction $/gpd	**$1.669**	**$1.329**	**$1.288**	**$3.041**	**$2.704**	**$2.649**	**$4.688**	**$4.313**	**$4.236**
% of 8" dia cost	**100.0%**	**79.6%**	**77.2%**	**100.0%**	**88.9%**	**87.1%**	**100.0%**	**92.0%**	**90.4%**

Notes:

1. Includes pretreatment strainers, immersed UF membrane trains with permeate pumps, CIP and neutralization systems, multiple backwash ponds (based on CPES sludge drying beds model), below grade filtrate tank for backwash supply and RO feed, and building
2. Includes cartridge filters, RO feed pumps, membrane elements, pressure vessels, other RO train components, CIP system, product water flush (surface water and seawater cases), and building. Assumed costs for RO feed pumps based upon Torishima pump budgetary prices and energy recovery costs based upon Calder AG DWEER pressure exchanger system budgetary prices.
3. Ground water cases only (shown as air stripper in CPES models); includes blowers
4. Assumes below-grade rectangular clearwell
5. Called In-Plant Pumping Station in CPES; also assumes building
6. Ground storage cost based on CPES Clearwell Model; assumes two circular above ground concrete tanks
7. Includes bulk storage and chemical pumps for al process chemicals and RO spent cleaning neutralization system
8. Overhead, profit, mobilization, bonds, insurance costs

Table 4-13.—Treatment Plant Construction Cost – 50 mgd

CH2M HILL CPES CONSTRUCTION COST SUMMARY 50 mgd	Brackish Ground Water 8" ($ Million)	Brackish Ground Water 16" ($ Million)	Brackish Ground Water 20" ($ Million)	Brackish Surface Water 8" ($ Million)	Brackish Surface Water 16" ($ Million)	Brackish Surface Water 20" ($ Million)	Seawater 8" ($ Million)	Seawater 16" ($ Million)	Seawater 20" ($ Million)
UF system (Note 1)	0.00	0.00	0.00	25.86	25.86	25.86	35.24	35.24	35.24
RO System (Note 2)	32.43	22.77	21.71	37.84	28.17	26.84	70.94	59.63	57.55
Degasifier (Note 3)	0.46	0.46	0.46	0.00	0.00	0.00	0.00	0.00	0.00
Clearwell (Note 4)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Product Transfer Pumps (Note 5)	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Ground Storage & High Service Pumping (Note 6)	6.89	6.89	6.89	6.89	6.89	6.89	6.89	6.89	6.89
Chemical Storage & Handling (Note 7)	1.63	1.63	1.63	1.95	1.95	1.95	2.40	2.40	2.40
Subtotal - Facilities	**42.24**	**32.68**	**31.62**	**73.37**	**63.71**	**62.37**	**116.28**	**104.98**	**102.90**
Additional Project Costs									
Sitework	2.11	1.63	1.58	3.67	3.19	3.12	5.81	5.25	5.14
Yard Piping	4.22	3.26	3.15	7.34	6.37	6.24	11.63	10.50	10.29
Yard Electrical	3.38	2.61	2.52	5.87	5.10	4.99	9.30	8.40	8.23
Plant Computer	2.11	1.63	1.58	3.67	3.19	3.12	5.81	5.25	5.14
Subtotal - Additional Project Costs	11.83	9.12	8.82	20.54	17.84	17.46	32.56	29.40	28.81
Subtotal - Facilities plus Additional Project Costs	**54.07**	**41.70**	**40.34**	**93.92**	**81.54**	**79.83**	**148.86**	**134.38**	**131.71**
Contractor Mark-ups (Note 8)	11.50	8.87	8.58	19.98	17.35	16.98	31.67	28.59	28.02
Contingency	13.11	10.12	9.78	22.78	19.78	19.36	36.10	32.59	31.95
Total Construction Cost	**78.68**	**60.69**	**58.71**	**136.68**	**118.67**	**116.18**	**216.62**	**195.56**	**191.68**
Total Construction $/gpd	**$1.574**	**$1.214**	**$1.174**	**$2.734**	**$2.373**	**$2.324**	**$4.332**	**$3.911**	**$3.834**
% of 8" dia cost	**100.0%**	**77.1%**	**74.6%**	**100.0%**	**86.8%**	**85.0%**	**100.0%**	**90.3%**	**88.5%**

Notes:

1. Includes pretreatment strainers, immersed UF membrane trains with permeate pumps, CIP and neutralization systems, multiple backwash ponds (based on CPES sludge drying beds model), below grade filtrate tank for backwash supply and RO feed, and building
2. Includes cartridge filters, RO feed pumps, membrane elements, pressure vessels, other RO train components, CIP system, product water flush (surface water and seawater cases), and building. Assumed costs for RO feed pumps based upon Torishima pump budgetary prices and energy recovery costs based upon Calder AG DWEER pressure exchanger system budgetary prices.
3. Ground water cases only (shown as air stripper in CPES models); includes blowers
4. Assumes below-grade rectangular clearwell
5. Called In-Plant Pumping Station in CPES; also assumes building
6. Ground storage cost based on CPES Clearwell Model; assumes two circular above ground concrete tanks
7. Includes bulk storage and chemical pumps for al process chemicals and RO spent cleaning neutralization system
8. Overhead, profit, mobilization, bonds, insurance costs

Table 4-14.—Treatment Plant Construction Cost – 100 mgd

CH2M HILL CPES CONSTRUCTION COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
100 mgd	($ Million)	($ Million)	($ Million)	($ Million)	($ Million)	($ Million)	($ Million)	($ Million)	($ Million)
UF system (Note 1)	0.00	0.00	0.00	43.26	43.26	43.26	60.38	60.38	60.38
RO System (Note 2)	65.64	45.78	43.65	76.50	56.72	53.99	142.45	119.24	114.82
Degasifier (Note 3)	0.92	0.92	0.92	0.00	0.00	0.00	0.00	0.00	0.00
Clearwell (Note 4)	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Product Transfer Pumps (Note 5)	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Ground Storage & High Service Pumping (Note 6)	12.08	12.08	12.08	12.08	12.08	12.08	12.08	12.08	12.08
Chemical Storage & Handling (Note 7)	2.74	2.74	2.74	3.23	3.23	3.23	4.23	4.23	4.23
Subtotal - Facilities	**82.70**	**62.84**	**60.71**	**136.39**	**116.60**	**113.87**	**220.46**	**197.26**	**192.83**
Additional Project Costs									
Sitework	4.13	3.14	3.04	6.82	5.83	5.69	11.02	9.86	9.64
Yard Piping	8.27	6.28	6.07	13.64	11.66	11.39	22.05	19.72	19.28
Yard Electrical	6.62	5.03	4.86	10.91	9.33	9.11	17.64	15.78	15.43
Plant Computer	4.13	3.14	3.04	6.82	5.83	5.69	11.02	9.86	9.64
Subtotal - Additional Project Costs	23.15	17.60	17.00	38.19	32.65	31.88	61.73	55.23	53.99
Subtotal - Facilities plus Additional Project Costs	**106.86**	**80.44**	**77.71**	**174.58**	**149.26**	**145.76**	**282.18**	**252.47**	**246.82**
Contractor Mark-ups (Note 8)	44.39	17.11	16.53	37.14	31.75	31.01	60.03	53.71	52.51
Contingency	3.80	19.51	18.85	42.34	36.20	35.35	68.44	61.24	59.87
Total Construction Cost	**164.04**	**117.06**	**113.09**	**264.07**	**217.21**	**212.12**	**410.66**	**367.43**	**359.20**
Total Construction $/gpd	**$1.640**	**$1.171**	**$1.131**	**$2.641**	**$2.172**	**$2.121**	**$4.107**	**$3.674**	**$3.592**
% of 8" dia cost	**100.0%**	**78.0%**	**73.4%**	**100.0%**	**86.6%**	**83.5%**	**100.0%**	**89.6%**	**87.5%**

Notes:

1. Includes pretreatment strainers, immersed UF membrane trains with permeate pumps, CIP and neutralization systems, multiple backwash ponds (based on CPES sludge drying beds model), below grade filtrate tank for backwash supply and RO feed, and building
2. Includes cartridge filters, RO feed pumps, membrane elements, pressure vessels, other RO train components, CIP system, product water flush (surface water and seawater cases), and building. Assumed costs for RO feed pumps based upon Torishima pump budgetary prices and energy recovery costs based upon Calder AG DWEER pressure exchanger system budgetary prices.
3. Ground water cases only (shown as air stripper in CPES models); includes blowers
4. Assumes below-grade rectangular clearwell
5. Called In-Plant Pumping Station in CPES; also assumes building
6. Ground storage cost based on CPES Clearwell Model; assumes two circular above ground concrete tanks
7. Includes bulk storage and chemical pumps for al process chemicals and RO spent cleaning neutralization system
8. Overhead, profit, mobilization, bonds, insurance costs

Table 4-15.—Treatment Plant Construction Cost – 150 mgd

CH2M HILL CPES CONSTRUCTION COST SUMMARY 150 mgd	Brackish Ground Water 8" ($ Million)	Brackish Ground Water 16" ($ Million)	Brackish Ground Water 20" ($ Million)	Brackish Surface Water 8" ($ Million)	Brackish Surface Water 16" ($ Million)	Brackish Surface Water 20" ($ Million)	Seawater 8" ($ Million)	Seawater 16" ($ Million)	Seawater 20" ($ Million)
UF system (Note 1)	0.00	0.00	0.00	59.25	59.25	59.25	83.51	83.51	83.51
RO System (Note 2)	99.10	68.84	65.64	115.55	85.47	81.35	215.83	180.18	173.27
Degasifier (Note 3)	1.38	1.38	1.38	0.00	0.00	0.00	0.00	0.00	0.00
Clearwell (Note 4)	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Product Transfer Pumps (Note 5)	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Ground Storage & High Service Pumping (Note 6)	17.34	17.34	17.34	17.34	17.34	17.34	17.34	17.34	17.34
Chemical Storage & Handling (Note 7)	3.75	3.75	3.75	4.47	4.47	4.47	6.00	6.00	6.00
Subtotal - Facilities	**123.36**	**93.09**	**89.90**	**198.39**	**168.31**	**164.18**	**324.47**	**288.82**	**281.90**
Additional Project Costs									
Sitework	6.17	4.65	4.49	9.92	8.42	8.21	16.22	14.44	14.10
Yard Piping	12.33	9.31	8.99	19.84	16.83	16.42	32.45	28.88	28.19
Yard Electrical	9.87	7.45	7.19	15.87	13.46	13.13	25.96	23.11	22.55
Plant Computer	6.17	4.65	4.49	9.92	8.42	8.21	16.22	14.44	14.10
Subtotal - Additional Project Costs	34.54	26.07	25.17	55.55	47.13	45.97	90.85	80.87	78.93
Subtotal - Facilities plus Additional Project Costs	**157.89**	**119.16**	**115.07**	**253.93**	**215.43**	**210.15**	**415.32**	**369.69**	**360.84**
Contractor Mark-ups (Note 8)	33.59	25.35	24.48	54.02	45.83	44.71	88.36	78.65	76.77
Contingency	38.30	28.90	27.91	61.59	52.25	50.97	100.74	89.67	87.52
Total Construction Cost	**229.77**	**173.41**	**167.46**	**369.55**	**313.52**	**305.84**	**604.41**	**538.00**	**525.12**
Total Construction $/gpd	**$1.532**	**$1.156**	**$1.116**	**$2.464**	**$2.090**	**$2.039**	**$4.029**	**$3.587**	**$3.501**
% of 8" dia cost	**100.0%**	**75.5%**	**72.9%**	**100.0%**	**84.8%**	**82.8%**	**100.0%**	**89.0%**	**86.9%**

Notes:

1. Includes pretreatment strainers, immersed UF membrane trains with permeate pumps, CIP and neutralization systems, multiple backwash ponds (based on CPES sludge drying beds model), below grade filtrate tank for backwash supply and RO feed, and building
2. Includes cartridge filters, RO feed pumps, membrane elements, pressure vessels, other RO train components, CIP system, product water flush (surface water and seawater cases), and building. Assumed costs for RO feed pumps based upon Torishima pump budgetary prices and energy recovery costs based upon Calder AG DWEER pressure exchanger system budgetary prices.
3. Ground water cases only (shown as air stripper in CPES models); includes blowers
4. Assumes below-grade rectangular clearwell
5. Called In-Plant Pumping Station in CPES; also assumes building
6. Ground storage cost based on CPES Clearwell Model; assumes two circular above ground concrete tanks
7. Includes bulk storage and chemical pumps for al process chemicals and RO spent cleaning neutralization system
8. Overhead, profit, mobilization, bonds, insurance costs

Figure 4-10 graphically presents the unit construction costs in $/gpd for all forty-five cases. For each source water, the unit construction costs decrease as the RO element diameter increases. The unit cost differential decreases as the plant capacity increases – the incremental benefit of economy of scale lessens as the capacities get larger. Additionally, the drop in unit cost is much greater going from 8-inch to 16-inch diameter elements than from 16-inch to 20-inch elements. This can be seen in Figure 4-11 (and Tables 4-11 through 4-15). As an example, for the 50 mgd (189,000 m^3/day) brackish groundwater case the plant construction cost is 23 percent less for 16-inch and 25 percent less for 20-inch element plants than for 8-inch. For the 50 mgd (189,000 m^3/day) surface water cases, the plant construction cost is 13 percent less for 16-inch and 15 percent less for 20-inch element plants. Finally, for the 50 mgd (189,000 m^3/day) seawater cases the plant construction cost is 10 percent less for 16-inch and 11 percent less for 20-inch element plants.

Figure 4-10.—Unit Construction Costs

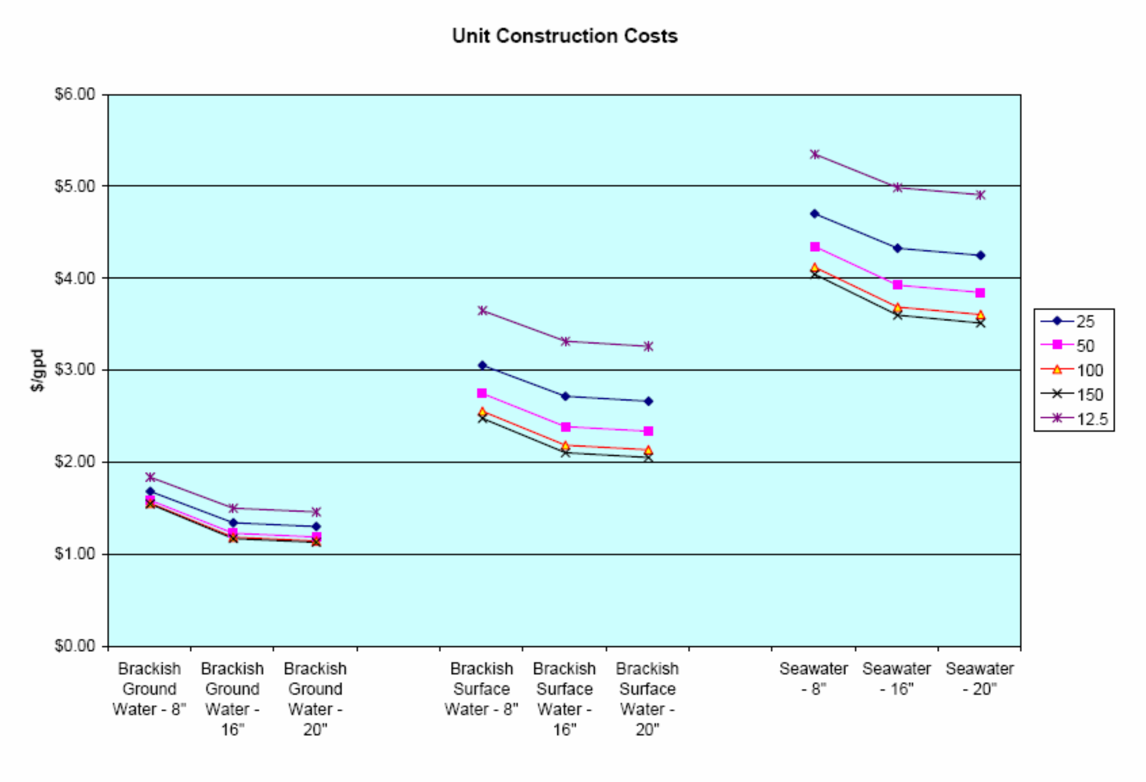
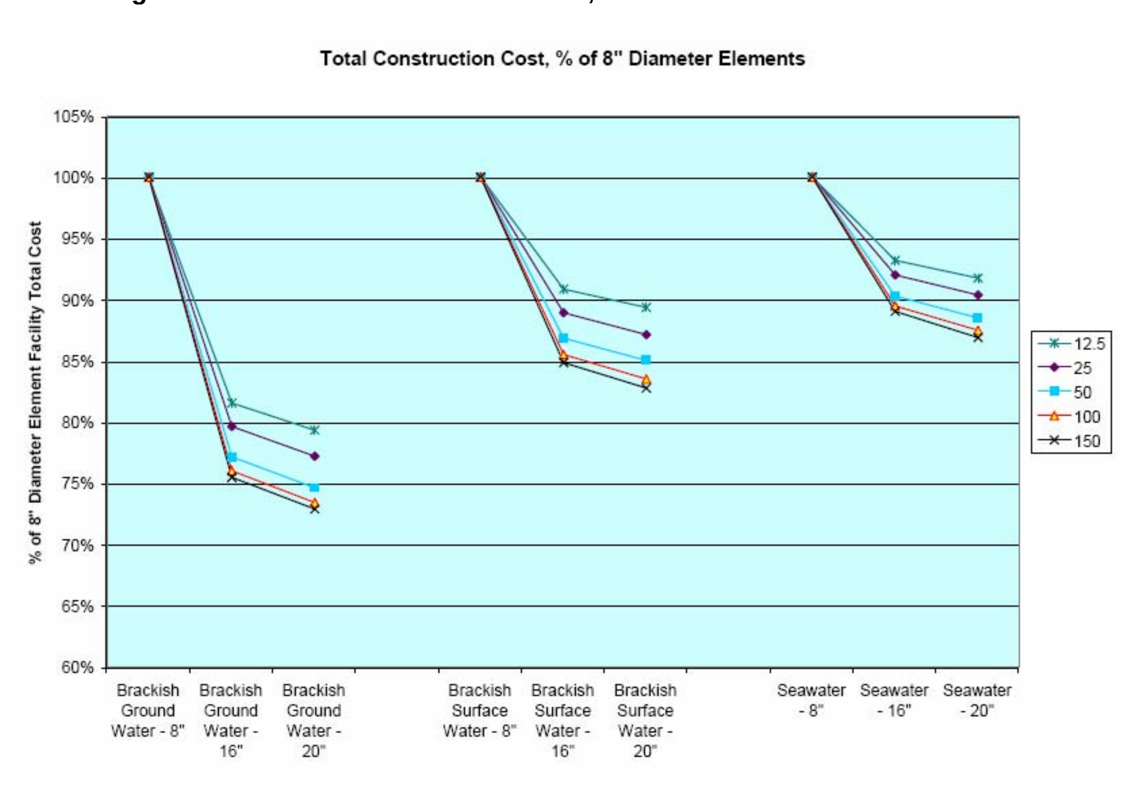
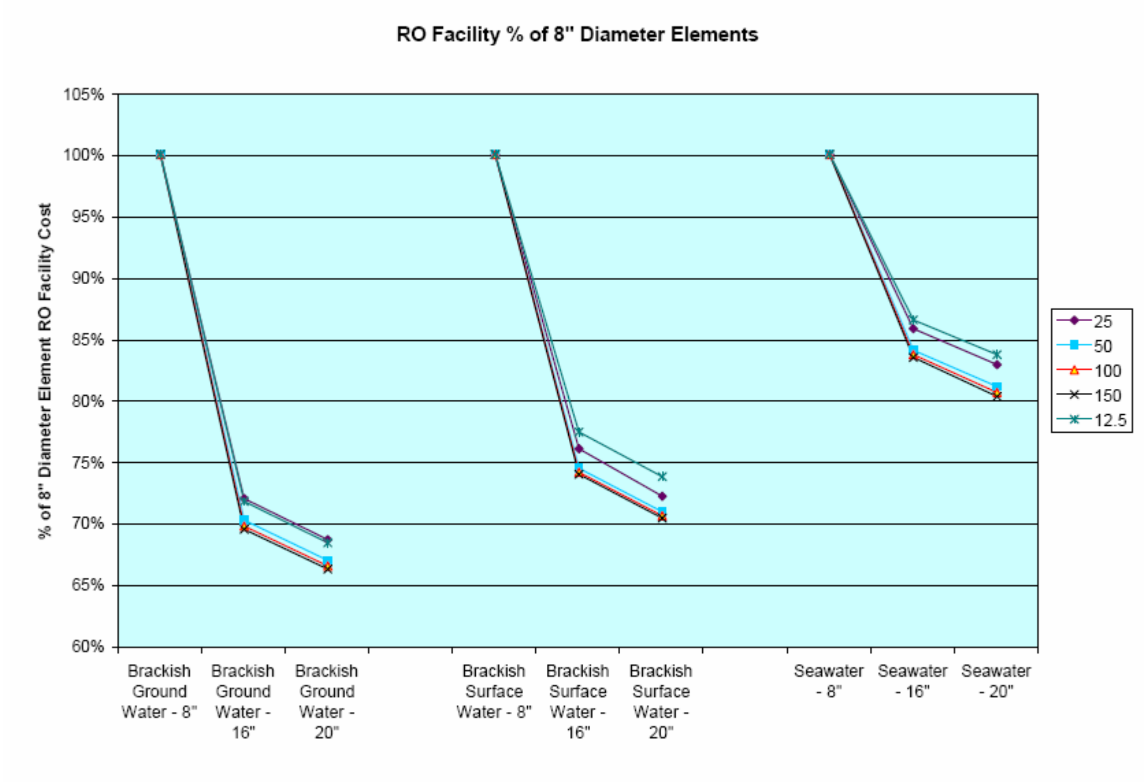


Figure 4-11.—Total Construction Cost, % of 8-inch Diameter Element Plant



The percent cost savings realized by increasing RO element diameter from 8-inch to 16-inch and 20-inch is most pronounced with respect to RO facility cost -- as shown in Figure 4-12 and presented in Appendix G. Again using the 50 mgd (189,000 m^3/day) capacity plants as examples, for the brackish groundwater case, the RO facility cost is 30 percent less for 16-inch and 33 percent less for 20-inch element plants than for 8-inch. For the surface water cases the RO facility construction cost is 25 percent less for 16-inch and 29 percent less for 20-inch element plants. Finally, for the 50 mgd (189,000 m^3/day) seawater cases the plant construction cost is 16 percent less for 16-inch and is 19 percent less for 20-inch element plants.

Figure 4-12.—RO Facility Construction Cost, % of 8-inch Diameter Element Facility



Tables 4-16 through 4-20 present the operations and maintenance (O&M) costs for all of the cases, broken down by facility. The unit costs (dollars per 1,000 gallons of production at 95 percent plant operating factor) decrease somewhat as the plant capacity increases (but not as significantly as for construction costs). The 8-inch diameter total O&M costs for the groundwater, surface water, and seawater cases ranged from $0.60-0.70, $0.80-1.05, and $1.31-1.58 per 1,000 gallons ($0.16-0.19, $0.21-0.28, and $0.35-0.42 per m^3) respectively over the plant capacity range examined in this study. The 16-inch diameter O&M costs ranged from $0.58-0.68, $0.78-1.04, and $1.29-1.56 per 1,000 gallons ($0.153-0.180, $0.206-0.275, and 0.341-0.412 per m^3, respectively, while the 20-inch diameter O&M costs ranged from $0.58-0.68, $0.78-1.04, and $1.28-1.56 per 1,000 gallons ($0.153-0.180, $0.206-0.275, and $0.338-0.412 per m^3), respectively. These ranges are illustrated in Figure 4-13.

Table 4-16.—O&M Cost By Facility – 12.5 mgd

CH2M HILL CPES O&M COST SUMMARY 12.5 mgd	Brackish Ground Water 8" ($ Million/yr)	Brackish Ground Water 16" ($ Million/yr)	Brackish Ground Water 20" ($ Million/yr)	Brackish Surface Water 8" ($ Million/yr)	Brackish Surface Water 16" ($ Million/yr)	Brackish Surface Water 20" ($ Million/yr)	Seawater 8" ($ Million/yr)	Seawater 16" ($ Million/yr)	Seawater 20" ($ Million/yr)
UF system (Note 1)	$0.00	$0.00	$0.00	$1.23	$1.23	$1.23	$1.72	$1.72	$1.72
RO System (Note 2)	$1.17	$1.11	$1.10	$1.20	$1.15	$1.14	$2.85	$2.79	$2.78
Degasifier (Note 3)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Clearwell (Note 4)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Product Transfer Pumps (Note 5)	$0.06	$0.06	$0.06	$0.06	$0.06	$0.06	$0.04	$0.04	$0.04
Ground Storage & High Service Pumping (Note 6)	$0.67	$0.67	$0.67	$0.67	$0.67	$0.67	$0.48	$0.48	$0.48
Chemical Storage & Handling (Note 7)	$0.48	$0.48	$0.48	$0.42	$0.42	$0.42	$0.61	$0.61	$0.61
Repair & Maintenance (Note 8)	$0.05	$0.04	$0.04	$0.09	$0.08	$0.08	$0.14	$0.13	$0.12
O&M Labor	$0.59	$0.59	$0.59	$0.89	$0.89	$0.89	$0.99	$0.99	$0.99
Total	**$3.03**	**$2.96**	**$2.95**	**$4.56**	**$4.51**	**$4.50**	**$6.83**	**$6.77**	**$6.75**
$/1,000 gallons (Note 9)	**$0.699**	**$0.682**	**$0.680**	**$1.053**	**$1.041**	**$1.038**	**$1.576**	**$1.561**	**$1.557**

Notes
1. Includes pretreatment strainers, immersed UF membrane trains with permeate pumps, CIP and neutralization systems, multiple backwash ponds (based on CPES sludge drying beds model), below grade filtrate tank for backwash supply and RO feed, and building
2. Includes cartridge filters, RO feed pumps, membrane elements, pressure vessels, other RO train components, CIP system, product water flush (surface water and seawater cases), and building
3. Ground water cases only (shown as air stripper in CPES models); includes blowers
4. Assumes below-grade rectangular clearwell
5. Called In-Plant Pumping Station in CPES; also assumes building
6. Ground storage cost based on CPES Clearwell Model; assumes two circular above ground concrete tanks
7. Includes bulk storage and chemical pumps for al process chemicals and RO spent cleaning neutralization system
8. Called Standard Items in CPES
9. Annual production at 95% plant factor = 4,334,375 Kgal/yr

Table 4-17.—O&M Cost By Facility – 25 mgd

CH2M HILL CPES O&M COST SUMMARY 25 mgd	Brackish Ground Water 8" ($ Million/yr)	Brackish Ground Water 16" ($ Million/yr)	Brackish Ground Water 20" ($ Million/yr)	Brackish Surface Water 8" ($ Million/yr)	Brackish Surface Water 16" ($ Million/yr)	Brackish Surface Water 20" ($ Million/yr)	Seawater 8" ($ Million/yr)	Seawater 16" ($ Million/yr)	Seawater 20" ($ Million/yr)
UF system (Note 1)	$0.00	$0.00	$0.00	$2.12	$2.12	$2.12	$3.10	$3.10	$3.10
RO System (Note 2)	$2.35	$2.22	$2.22	$2.24	$2.13	$2.11	$5.65	$5.52	$5.49
Degasifier (Note 3)	$0.01	$0.01	$0.01	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Clearwell (Note 4)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Product Transfer Pumps (Note 5)	$0.12	$0.12	$0.12	$0.12	$0.12	$0.12	$0.08	$0.08	$0.08
Ground Storage & High Service Pumping (Note 6)	$1.30	$1.30	$1.30	$1.30	$1.30	$1.30	$0.91	$0.91	$0.91
Chemical Storage & Handling (Note 7)	$0.92	$0.92	$0.92	$0.80	$0.80	$0.80	$1.19	$1.19	$1.19
Repair & Maintenance (Note 8)	$0.08	$0.07	$0.07	$0.15	$0.14	$0.13	$0.24	$0.22	$0.22
O&M Labor	$0.85	$0.85	$0.85	$1.20	$1.20	$1.20	$1.35	$1.35	$1.35
Total	**$5.64**	**$5.49**	**$5.49**	**$7.95**	**$7.82**	**$7.79**	**$12.53**	**$12.38**	**$12.34**
$/1,000 gallons (Note 9)	**$0.650**	**$0.633**	**$0.633**	**$0.917**	**$0.902**	**$0.899**	**$1.445**	**$1.428**	**$1.424**

Notes
1. Includes pretreatment strainers, Immersed UF membrane trains with permeate pumps, CIP and neutralization systems, multiple backwash ponds (based on CPES sludge drying beds model), below grade filtrate tank for backwash supply and RO feed, and building
2. Includes cartridge filters, RO feed pumps, membrane elements, pressure vessels, other RO train components, CIP system, product water flush (surface water and seawater cases), and building
3. Ground water cases only (shown as air stripper in CPES models); includes blowers
4. Assumes below-grade rectangular clearwell
5. Called In-Plant Pumping Station in CPES; also assumes building
6. Ground storage cost based on CPES Clearwell Model; assumes two circular above ground concrete tanks
7. Includes bulk storage and chemical pumps for al process chemicals and RO spent cleaning neutralization system
8. Called Standard Items in CPES
9. Annual production at 95% plant factor = 8,668,750 Kgal/yr

Table 4-18.—O&M Cost By Facility – 50 mgd

CH2M HILL CPES O&M COST SUMMARY 50 mgd	Brackish Ground Water 8" ($ Million/yr)	Brackish Ground Water 16" ($ Million/yr)	Brackish Ground Water 20" ($ Million/yr)	Brackish Surface Water 8" ($ Million/yr)	Brackish Surface Water 16" ($ Million/yr)	Brackish Surface Water 20" ($ Million/yr)	Seawater 8" ($ Million/yr)	Seawater 16" ($ Million/yr)	Seawater 20" ($ Million/yr)
UF system (Note 1)	$0.00	$0.00	$0.00	$3.89	$3.89	$3.89	$5.82	$5.82	$5.82
RO System (Note 2)	$4.68	$4.41	$4.38	$4.43	$4.22	$4.22	$11.28	$10.99	$10.95
Degasifier (Note 3)	$0.01	$0.01	$0.01	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Clearwell (Note 4)	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
Product Transfer Pumps (Note 5)	$0.24	$0.24	$0.24	$0.24	$0.24	$0.24	$1.78	$1.78	$1.78
Ground Storage & High Service Pumping (Note 6)	$2.58	$2.58	$2.58	$2.58	$2.58	$2.58	$0.16	$0.16	$0.16
Chemical Storage & Handling (Note 7)	$1.82	$1.82	$1.82	$1.58	$1.58	$1.58	$2.34	$2.34	$2.34
Repair & Maintenance (Note 8)	$0.16	$0.12	$0.12	$0.28	$0.24	$0.24	$0.44	$0.40	$0.39
O&M Labor	$1.26	$1.26	$1.26	$1.76	$1.76	$1.76	$2.01	$2.01	$2.01
Total	**$10.75**	**$10.45**	**$10.42**	**$14.75**	**$14.51**	**$14.50**	**$23.86**	**$23.52**	**$23.48**
$/1,000 gallons (Note 9)	$0.620	$0.603	$0.601	$0.851	$0.837	$0.836	$1.376	$1.357	$1.354

Notes
1. Includes pretreatment strainers, immersed UF membrane trains with permeate pumps, CIP and neutralization systems, multiple backwash ponds (based on CPES sludge drying beds model), below grade filtrate tank for backwash supply and RO feed, and building
2. Includes cartridge filters, RO feed pumps, membrane elements, pressure vessels, other RO train components, CIP system, product water flush (surface water and seawater cases), and building
3. Ground water cases only (shown as air stripper in CPES models); includes blowers
4. Assumes below-grade rectangular clearwell
5. Called In-Plant Pumping Station in CPES; also assumes building
6. Ground storage cost based on CPES Clearwell Model; assumes two circular above ground concrete tanks
7. Includes bulk storage and chemical pumps for al process chemicals and RO spent cleaning neutralization system
8. Called Standard Items in CPES
9. Annual production at 95% plant factor = 17,337,500 Kgal/yr

Table 4-19.—O&M Cost By Facility – 100 mgd

CH2M HILL CPES O&M COST SUMMARY 100 mgd	Brackish Ground Water 8" ($ Million/yr)	Brackish Ground Water 16" ($ Million/yr)	Brackish Ground Water 20" ($ Million/yr)	Brackish Surface Water 8" ($ Million/yr)	Brackish Surface Water 16" ($ Million/yr)	Brackish Surface Water 20" ($ Million/yr)	Seawater 8" ($ Million/yr)	Seawater 16" ($ Million/yr)	Seawater 20" ($ Million/yr)
UF system (Note 1)	$0.00	$0.00	$0.00	$7.31	$7.31	$7.31	$11.17	$11.17	$11.17
RO System (Note 2)	$9.37	$8.80	$8.75	$8.84	$8.34	$8.30	$22.55	$21.91	$21.81
Degasifier (Note 3)	$0.03	$0.03	$0.03	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Clearwell (Note 4)	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
Product Transfer Pumps (Note 5)	$0.47	$0.47	$0.47	$0.47	$0.47	$0.47	$0.32	$0.32	$0.32
Ground Storage & High Service Pumping (Note 6)	$5.23	$5.23	$5.23	$5.23	$5.23	$5.23	$3.60	$3.60	$3.60
Chemical Storage & Handling (Note 7)	$3.62	$3.62	$3.62	$3.13	$3.13	$3.13	$4.67	$4.67	$4.67
Repair & Maintenance (Note 8)	$0.31	$0.24	$0.23	$0.52	$0.44	$0.43	$0.83	$0.75	$0.73
O&M Labor	$1.82	$1.82	$1.82	$2.57	$2.57	$2.57	$2.92	$2.92	$2.92
Total	**$20.86**	**$20.22**	**$20.15**	**$28.08**	**$27.50**	**$27.45**	**$46.08**	**$45.36**	**$45.24**
$/1,000 gallons (Note 9)	$0.602	$0.583	$0.581	$0.810	$0.793	$0.792	$1.329	$1.308	$1.305

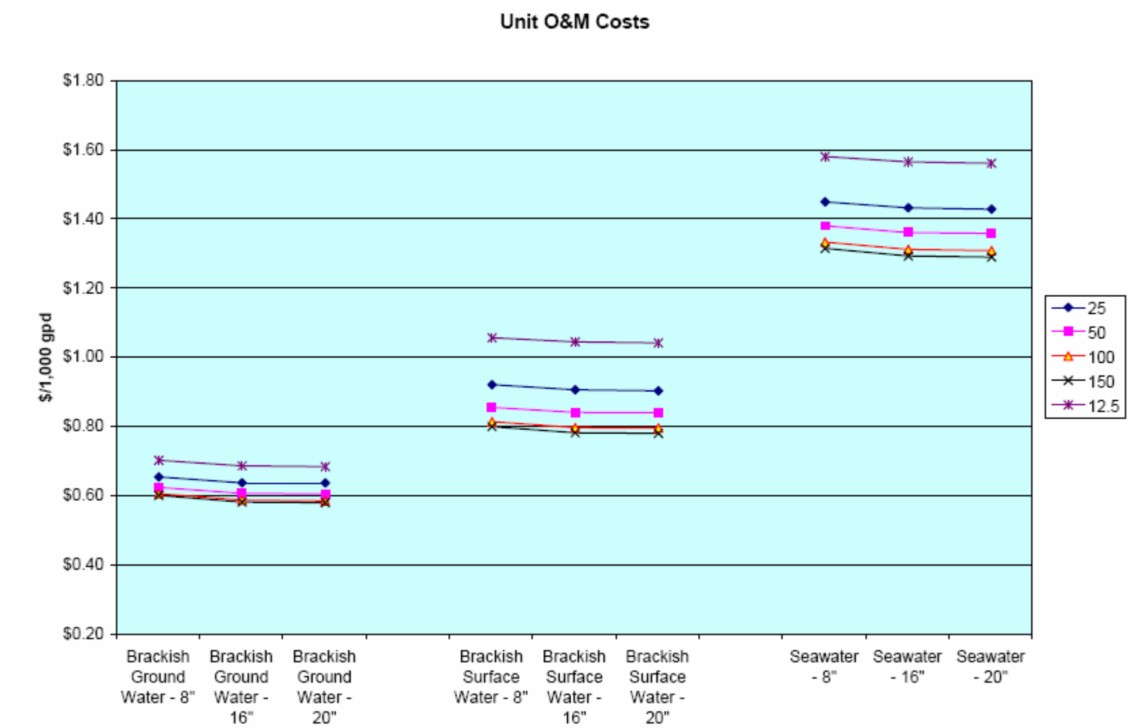
Notes
1. Includes pretreatment strainers, immersed UF membrane trains with permeate pumps, CIP and neutralization systems, multiple backwash ponds (based on CPES sludge drying beds model), below grade filtrate tank for backwash supply and RO feed, and building
2. Includes cartridge filters, RO feed pumps, membrane elements, pressure vessels, other RO train components, CIP system, product water flush (surface water and seawater cases), and building
3. Ground water cases only (shown as air stripper in CPES models); includes blowers
4. Assumes below-grade rectangular clearwell
5. Called In-Plant Pumping Station in CPES; also assumes building
6. Ground storage cost based on CPES Clearwell Model; assumes two circular above ground concrete tanks
7. Includes bulk storage and chemical pumps for al process chemicals and RO spent cleaning neutralization system
8. Called Standard Items in CPES
9. Annual production at 95% plant factor = 34,675,000 Kgal/yr

Table 4-20.—O&M Cost By Facility – 150 mgd

CH2M HILL CPES O&M COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
150 mgd	($ Million/yr)	($ Million/yr)	($ Million/yr)	($ Million/yr)	($ Million/yr)	($ Million/yr)	($ Million/yr)	($ Million/yr)	($ Million/yr)
UF system (Note 1)	$0.00	$0.00	$0.00	$10.69	$10.69	$10.69	$16.46	$16.46	$16.46
RO System (Note 2)	$14.07	$13.20	$13.11	$13.27	$12.47	$12.40	$33.87	$32.87	$32.70
Degasifier (Note 3)	$0.04	$0.04	$0.04	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Clearwell (Note 4)	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02
Product Transfer Pumps (Note 5)	$0.71	$0.71	$0.71	$0.71	$0.71	$0.71	$0.48	$0.48	$0.48
Ground Storage & High Service Pumping (Note 6)	$8.12	$8.12	$8.12	$8.12	$8.12	$8.12	$5.58	$5.58	$5.58
Chemical Storage & Handling (Note 7)	$5.41	$5.41	$5.41	$4.67	$4.67	$4.67	$6.99	$6.99	$6.99
Repair & Maintenance (Note 8)	$0.47	$0.35	$0.34	$0.75	$0.64	$0.62	$1.23	$1.09	$1.07
O&M Labor	$2.20	$2.20	$2.20	$3.15	$3.15	$3.15	$3.55	$3.55	$3.55
Total	**$31.04**	**$30.06**	**$29.96**	**$41.38**	**$40.47**	**$40.39**	**$68.18**	**$67.06**	**$66.85**
$/1,000 gallons (Note 9)	**$0.597**	**$0.578**	**$0.576**	**$0.796**	**$0.778**	**$0.776**	**$1.311**	**$1.289**	**$1.285**

Notes
1. Includes pretreatment strainers, immersed UF membrane trains with permeate pumps, CIP and neutralization systems, multiple backwash ponds (based on CPES sludge drying beds model), below grade filtrate tank for backwash supply and RO feed, and building
2. Includes cartridge filters, RO feed pumps, membrane elements, pressure vessels, other RO train components, CIP system, product water flush (surface water and seawater cases), and building
3. Ground water cases only (shown as air stripper in CPES models); includes blowers
4. Assumes below-grade rectangular clearwell
5. Called In-Plant Pumping Station in CPES; also assumes building
6. Ground storage cost based on CPES Clearwell Model; assumes two circular above ground concrete tanks
7. Includes bulk storage and chemical pumps for al process chemicals and RO spent cleaning neutralization system
8. Called Standard Items in CPES
9. Annual production at 95% plant factor = 52,012,500 Kgal/yr

Figure 4-13.—Unit O&M Costs



Tables 4-21 through 4-25 present a breakdown of the O&M costs by category (power, chemicals, membrane and cartridge filter replacements, repair and maintenance, and labor) for all forty-five cases. Power costs, primarily for process equipment power usage, were the greatest single O&M cost item. For brackish groundwater cases, equipment power costs for all element diameter systems were about $0.32-0.33 per 1,000 gallons ($0.084-0.087 per m^3) over the range of capacities. Power costs for all surface (brackish) water cases were similar at approximately $0.30 per 1,000 gallons ($0.079 per m^3). For seawater cases, power costs were approximately $0.55-0.56 per 1,000 gallons ($0.145 to 0.148 per m^3) or nearly twice that for the brackish cases due to the significantly greater RO feed pressure requirements and lower recoveries. Chemical costs were the second highest O&M cost for all cases, except for the 12.5 mgd (47,000 m^3/day) groundwater system (where it was third). Chemical costs for groundwater, surface water, and seawater plants ranged were approximately $0.10, $0.20 to 0.24, and $0.31 to 0.34 per 1,000 gallons ($0.026, $0.053 to 0.063, and 0.082 to 0.090 per m^3), respectively. Again, seawater costs were highest due to the RO feedwater flows and associated chemical costs for pretreatment.

Table 4-21.—O&M Cost By O&M Category – 12.5 mgd

CH2M HILL CPES O&M COST SUMMARY (Note 1)	Brackish Ground Water 8"		Brackish Ground Water 16"		Brackish Ground Water 20"		Brackish Surface Water 8"		Brackish Surface Water 16"		Brackish Surface Water 20"		Seawater 8"		Seawater 16"		Seawater 20"	
12.5 mgd	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total
Power																		
Equipment Power	$1.39	46.0%	$1.39	47.1%	$1.39	47.3%	$1.31	28.8%	$1.31	29.1%	$1.31	29.2%	$2.39	34.9%	$2.39	35.3%	$2.39	35.4%
$/1,000 gallons	$0.322		$0.322		$0.322		$0.303		$0.303		$0.303		$0.550		$0.550		$0.550	
Building Power	$0.01	0.4%	$0.01	0.4%	$0.01	0.4%	$0.03	0.6%	$0.02	0.5%	$0.02	0.5%	$0.02	0.3%	$0.02	0.3%	$0.02	0.3%
$/1,000 gallons	$0.003		$0.002		$0.002		$0.006		$0.006		$0.006		$0.006		$0.006		$0.005	
Subtotal - Power	$1.41	46.4%	$1.40	47.5%	$1.40	47.6%	$1.34	29.3%	$1.34	29.6%	$1.34	29.7%	$2.41	35.2%	$2.41	35.6%	$2.41	35.7%
$/1,000 gallons	$0.324		$0.324		$0.324		$0.309		$0.308		$0.308		$0.556		$0.556		$0.555	
Chemicals (Note 2)	$0.45	14.9%	$0.46	15.4%	$0.46	15.4%	$1.02	22.3%	$1.04	23.1%	$1.04	23.1%	$1.47	21.5%	$1.48	21.9%	$1.48	21.9%
$/1,000 gallons	$0.104		$0.106		$0.105		$0.235		$0.240		$0.240		$0.338		$0.341		$0.341	
UF Membrane Element Replacements	$0.00	0.0%	$0.00	0.0%	$0.00	0.0%	$0.27	5.9%	$0.27	6.0%	$0.27	6.0%	$0.37	5.5%	$0.37	5.5%	$0.37	5.6%
$/1,000 gallons	$0.000		$0.000		$0.000		$0.062		$0.062		$0.062		$0.086		$0.086		$0.086	
RO Membrane Element Replacements	$0.14	4.7%	$0.14	4.8%	$0.14	4.8%	$0.21	4.7%	$0.21	4.7%	$0.21	4.7%	$0.35	5.2%	$0.35	5.2%	$0.35	5.3%
$/1,000 gallons	$0.033		$0.033		$0.033		$0.049		$0.049		$0.049		$0.082		$0.082		$0.082	
Cartridge Filter Replacements	$0.04	1.2%	$0.04	1.3%	$0.04	1.3%	$0.03	0.7%	$0.03	0.7%	$0.03	0.7%	$0.06	0.9%	$0.06	0.9%	$0.06	0.9%
$/1,000 gallons	$0.009		$0.009		$0.009		$0.008		$0.008		$0.008		$0.014		$0.014		$0.014	
Repair & Maintenance	$0.40	13.3%	$0.33	11.1%	$0.32	10.8%	$0.80	17.6%	$0.73	16.2%	$0.72	15.9%	$1.18	17.2%	$1.10	16.2%	$1.08	16.0%
$/1,000 gallons	$0.093		$0.076		$0.074		$0.185		$0.168		$0.165		$0.272		$0.253		$0.249	
O&M Labor	$0.59	19.5%	$0.59	20.0%	$0.59	20.0%	$0.89	19.5%	$0.89	19.7%	$0.89	19.8%	$0.99	14.5%	$0.99	14.6%	$0.99	14.7%
$/1,000 gallons	$0.136		$0.136		$0.136		$0.205		$0.206		$0.205		$0.228		$0.228		$0.228	
Total	$3.03	100.0%	$2.96	100.0%	$2.95	100.0%	$4.56	100.0%	$4.51	100.0%	$4.50	100.0%	$6.83	100.0%	$6.77	100.0%	$6.75	100.0%
$/1,000 gallons	$0.699		$0.682		$0.680		$1.053		$1.041		$1.038		$1.576		$1.561		$1.557	

1. Annual production at 95% plant factor = 4,334,375 Kgal/yr

Table 4-22.—O&M Cost O&M Category – 25 mgd

CH2M HILL CPES O&M COST SUMMARY (Note 1)	Brackish Ground Water 8"		Brackish Ground Water 16"		Brackish Ground Water 20"		Brackish Surface Water 8"		Brackish Surface Water 16"		Brackish Surface Water 20"		Seawater 8"		Seawater 16"		Seawater 20"	
25 mgd	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total
Power																		
Equipment Power	$2.78	49.3%	$2.78	50.7%	$2.78	50.7%	$2.54	32.0%	$2.54	32.5%	$2.54	32.6%	$4.76	38.0%	$4.76	38.5%	$4.76	38.6%
$/1,000 gallons	$0.321		$0.321		$0.321		$0.293		$0.293		$0.293		$0.550		$0.550		$0.550	
Building Power	$0.02	0.3%	$0.02	0.3%	$0.02	0.3%	$0.04	0.5%	$0.04	0.5%	$0.04	0.5%	$0.04	0.3%	$0.04	0.3%	$0.04	0.3%
$/1,000 gallons	$0.002		$0.002		$0.002		$0.004		$0.004		$0.004		$0.004		$0.004		$0.004	
Subtotal - Power	$2.80	49.7%	$2.80	51.0%	$2.80	51.0%	$2.58	32.4%	$2.58	32.9%	$2.58	33.0%	$4.80	38.3%	$4.80	38.8%	$4.80	38.9%
$/1,000 gallons	$0.323		$0.323		$0.323		$0.297		$0.297		$0.297		$0.554		$0.554		$0.554	
Chemicals (Note 2)	$0.89	15.8%	$0.90	16.3%	$0.91	16.6%	$1.86	23.4%	$1.88	24.1%	$1.88	24.2%	$2.80	22.4%	$2.82	22.8%	$2.82	22.8%
$/1,000 gallons	$0.103		$0.103		$0.105		$0.215		$0.217		$0.217		$0.323		$0.326		$0.325	
UF Membrane Element Replacements	$0.00	0.0%	$0.00	0.0%	$0.00	0.0%	$0.47	6.0%	$0.47	6.1%	$0.47	6.1%	$0.67	5.4%	$0.67	5.4%	$0.67	5.5%
$/1,000 gallons	$0.000		$0.000		$0.000		$0.109		$0.109		$0.109		$0.158		$0.158		$0.158	
RO Membrane Element Replacements	$0.28	5.0%	$0.28	5.2%	$0.28	5.2%	$0.42	5.3%	$0.43	5.4%	$0.43	5.5%	$0.71	5.8%	$0.71	5.7%	$0.71	5.7%
$/1,000 gallons	$0.033		$0.033		$0.033		$0.049		$0.049		$0.049		$0.082		$0.082		$0.082	
Cartridge Filter Replacements	$0.08	1.3%	$0.08	1.4%	$0.08	1.4%	$0.07	0.8%	$0.07	0.8%	$0.07	0.8%	$0.13	1.0%	$0.13	1.0%	$0.13	1.0%
$/1,000 gallons	$0.009		$0.009		$0.009		$0.008		$0.008		$0.008		$0.014		$0.014		$0.014	
Repair & Maintenance	$0.74	13.1%	$0.59	10.7%	$0.57	10.4%	$1.34	16.8%	$1.19	15.3%	$1.17	15.0%	$2.07	16.5%	$1.90	15.4%	$1.87	15.1%
$/1,000 gallons	$0.085		$0.068		$0.066		$0.155		$0.138		$0.135		$0.239		$0.220		$0.216	
O&M Labor	$0.85	15.1%	$0.85	15.5%	$0.85	15.5%	$1.20	15.1%	$1.20	15.3%	$1.20	15.4%	$1.35	10.8%	$1.35	10.9%	$1.35	10.9%
$/1,000 gallons	$0.098		$0.098		$0.098		$0.138		$0.138		$0.138		$0.156		$0.156		$0.156	
Total	$5.64	100.0%	$5.49	100.0%	$5.49	100.0%	$7.95	100.0%	$7.82	100.0%	$7.79	100.0%	$12.53	100.0%	$12.38	100.0%	$12.34	100.0%
$/1,000 gallons	$0.650		$0.633		$0.633		$0.917		$0.902		$0.899		$1.446		$1.428		$1.424	

1. Annual production at 95% plant factor = 8,668,750 Kgal/yr

Table 4-23.—O&M Cost O&M Category – 50 mgd

CH2M HILL CPES O&M COST SUMMARY (Note 1)	Brackish Ground Water 8"		Brackish Ground Water 16"		Brackish Ground Water 20"		Brackish Surface Water 8"		Brackish Surface Water 16"		Brackish Surface Water 20"		Seawater 8"		Seawater 16"		Seawater 20"	
50 mgd	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total
Power																		
Equipment Power	$5.58	51.9%	$5.58	53.4%	$5.58	53.5%	$5.10	34.6%	$5.10	35.1%	$5.10	35.2%	$9.54	40.0%	$9.54	40.6%	$9.54	40.6%
$/1,000 gallons	$0.322		$0.322		$0.322		$0.294		$0.294		$0.294		$0.550		$0.550		$0.550	
Building Power	$0.04	0.3%	$0.03	0.3%	$0.03	0.3%	$0.07	0.5%	$0.06	0.4%	$0.06	0.4%	$0.07	0.3%	$0.07	0.3%	$0.06	0.3%
$/1,000 gallons	$0.002		$0.002		$0.002		$0.004		$0.004		$0.003		$0.004		$0.004		$0.004	
Subtotal - Power	$5.61	52.2%	$5.61	53.7%	$5.61	53.8%	$5.16	35.0%	$5.16	35.6%	$5.16	35.6%	$9.61	40.3%	$9.60	40.8%	$9.60	40.9%
$/1,000 gallons	$0.324		$0.323		$0.323		$0.298		$0.298		$0.297		$0.554		$0.554		$0.554	
Chemicals (Note 2)	$1.78	16.6%	$1.79	17.2%	$1.79	17.2%	$3.56	24.1%	$3.63	25.0%	$3.67	25.3%	$5.48	23.0%	$5.51	23.4%	$5.54	23.6%
$/1,000 gallons	$0.102		$0.104		$0.104		$0.205		$0.209		$0.212		$0.316		$0.318		$0.319	
UF Membrane Element Replacements	$0.00	0.0%	$0.00	0.0%	$0.00	0.0%	$0.88	6.0%	$0.88	6.1%	$0.88	6.1%	$1.27	5.3%	$1.27	5.4%	$1.27	5.4%
$/1,000 gallons	$0.000		$0.000		$0.000		$0.203		$0.203		$0.203		$0.284		$0.284		$0.284	
RO Membrane Element Replacements	$0.57	5.3%	$0.57	5.4%	$0.57	5.5%	$0.85	5.8%	$0.85	5.9%	$0.85	5.9%	$1.42	5.9%	$1.42	6.0%	$1.42	6.0%
$/1,000 gallons	$0.033		$0.033		$0.033		$0.049		$0.049		$0.049		$0.082		$0.082		$0.082	
Cartridge Filter Replacements	$0.15	1.4%	$0.15	1.4%	$0.15	1.4%	$0.13	0.9%	$0.13	0.9%	$0.13	0.9%	$0.25	1.1%	$0.25	1.1%	$0.25	1.1%
$/1,000 gallons	$0.009		$0.009		$0.009		$0.008		$0.008		$0.008		$0.014		$0.014		$0.014	
Repair & Maintenance	$1.39	12.9%	$1.07	10.3%	$1.04	10.0%	$2.41	16.4%	$2.10	14.4%	$2.05	14.1%	$3.82	16.0%	$3.45	14.7%	$3.38	14.4%
$/1,000 gallons	$0.080		$0.062		$0.060		$0.139		$0.121		$0.118		$0.221		$0.199		$0.195	
O&M Labor	$1.26	11.7%	$1.26	12.1%	$1.26	12.1%	$1.76	11.9%	$1.76	12.1%	$1.76	12.1%	$2.01	8.4%	$2.01	8.5%	$2.01	8.6%
$/1,000 gallons	$0.073		$0.073		$0.073		$0.102		$0.102		$0.102		$0.116		$0.116		$0.116	
Total	$10.75	100.0%	$10.45	100.0%	$10.42	100.0%	$14.75	100.0%	$14.51	100.0%	$14.50	100.0%	$23.86	100.0%	$23.52	100.0%	$23.48	100.0%
$/1,000 gallons	$0.620		$0.603		$0.601		$0.851		$0.837		$0.836		$1.376		$1.357		$1.354	

1. Annual production at 95% plant factor = 17,337,500 Kgal/yr

Table 4-24.—O&M Cost O&M Category – 100 mgd

CH2M HILL CPES O&M COST SUMMARY (Note 1)	Brackish Ground Water 8"		Brackish Ground Water 16"		Brackish Ground Water 20"		Brackish Surface Water 8"		Brackish Surface Water 16"		Brackish Surface Water 20"		Seawater 8"		Seawater 16"		Seawater 20"	
100 mgd	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total
Power																		
Equipment Power	$11.28	54.1%	$11.28	55.8%	$11.28	56.0%	$10.32	36.8%	$10.32	37.5%	$10.32	37.6%	$19.15	41.6%	$19.15	42.2%	$19.15	42.3%
$/1,000 gallons	$0.325		$0.325		$0.325		$0.298		$0.298		$0.298		$0.552		$0.552		$0.552	
Building Power	$0.07	0.3%	$0.06	0.3%	$0.06	0.3%	$0.12	0.4%	$0.11	0.4%	$0.11	0.4%	$0.13	0.3%	$0.12	0.3%	$0.12	0.3%
$/1,000 gallons	$0.002		$0.002		$0.002		$0.004		$0.003		$0.003		$0.004		$0.004		$0.003	
Subtotal - Power	$11.35	54.4%	$11.34	56.1%	$11.34	56.3%	$10.44	37.2%	$10.43	37.9%	$10.43	38.0%	$19.28	41.8%	$19.28	42.5%	$19.27	42.6%
$/1,000 gallons	$0.327		$0.327		$0.327		$0.301		$0.301		$0.301		$0.556		$0.556		$0.556	
Chemicals (Note 2)	$3.54	17.0%	$3.56	17.6%	$3.56	17.7%	$6.95	24.7%	$7.03	25.6%	$7.08	25.8%	$10.83	23.5%	$10.87	24.0%	$10.90	24.1%
$/1,000 gallons	$0.102		$0.103		$0.103		$0.200		$0.203		$0.204		$0.312		$0.313		$0.314	
UF Membrane Element Replacements	$0.00	0.0%	$0.00	0.0%	$0.00	0.0%	$1.67	5.9%	$1.67	6.1%	$1.67	6.1%	$2.47	5.4%	$2.47	5.5%	$2.47	5.5%
$/1,000 gallons	$0.000		$0.000		$0.000		$0.385		$0.386		$0.385		$0.670		$0.670		$0.670	
RO Membrane Element Replacements	$1.13	5.4%	$1.13	5.6%	$1.14	5.6%	$1.70	6.0%	$1.70	6.2%	$1.70	6.2%	$2.83	6.1%	$2.83	6.2%	$2.83	6.3%
$/1,000 gallons	$0.033		$0.033		$0.033		$0.049		$0.049		$0.049		$0.082		$0.082		$0.082	
Cartridge Filter Replacements	$0.30	1.4%	$0.30	1.5%	$0.30	1.5%	$0.27	0.9%	$0.27	1.0%	$0.27	1.0%	$0.50	1.1%	$0.50	1.1%	$0.50	1.1%
$/1,000 gallons	$0.009		$0.009		$0.009		$0.008		$0.008		$0.008		$0.014		$0.014		$0.014	
Repair & Maintenance	$2.72	13.0%	$2.07	10.2%	$2.00	9.9%	$4.49	16.0%	$3.84	13.9%	$3.75	13.6%	$7.25	15.7%	$6.49	14.3%	$6.34	14.0%
$/1,000 gallons	$0.078		$0.060		$0.058		$0.129		$0.111		$0.108		$0.209		$0.187		$0.183	
O&M Labor	$1.82	8.7%	$1.82	9.0%	$1.82	9.0%	$2.57	9.2%	$2.57	9.3%	$2.57	9.4%	$2.92	6.3%	$2.92	6.4%	$2.92	6.5%
$/1,000 gallons	$0.052		$0.052		$0.052		$0.074		$0.074		$0.074		$0.084		$0.084		$0.084	
Total	$20.86	100.0%	$20.22	100.0%	$20.15	100.0%	$28.08	100.0%	$27.50	100.0%	$27.45	100.0%	$46.08	100.0%	$45.36	100.0%	$45.24	100.0%
$/1,000 gallons	$0.602		$0.583		$0.581		$0.810		$0.793		$0.792		$1.329		$1.308		$1.305	

1. Annual production at 95% plant factor = 34,675,000 Kgal/yr

Table 4-25.—O&M Cost O&M Category – 150 mgd

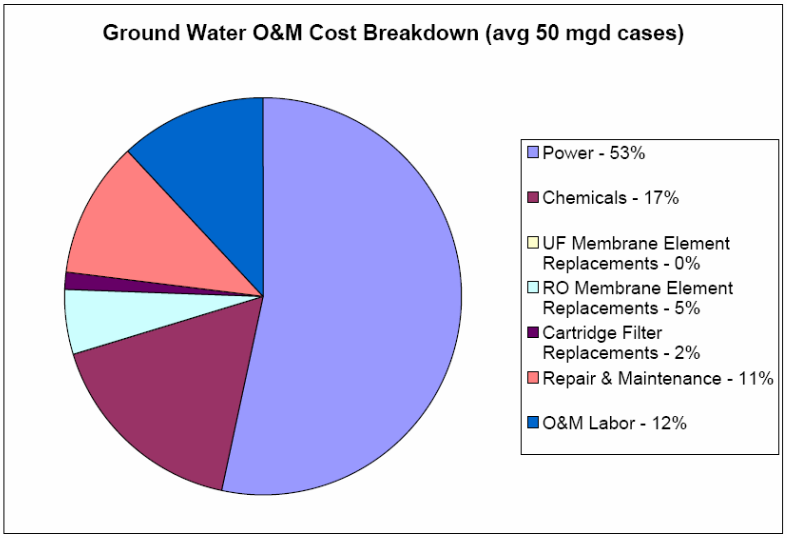
CH2M HILL CPES O&M COST SUMMARY (Note 1)	Brackish Ground Water 8"		Brackish Ground Water 16"		Brackish Ground Water 20"		Brackish Surface Water 8"		Brackish Surface Water 16"		Brackish Surface Water 20"		Seawater 8"		Seawater 16"		Seawater 20"	
150 mgd	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total	$ Million per Year	% of Total
Power																		
Equipment Power	$17.23	55.5%	$17.23	57.3%	$17.23	57.5%	$15.79	38.2%	$15.79	39.0%	$15.79	39.1%	$28.93	42.4%	$28.93	43.1%	$28.93	43.3%
$/1,000 gallons	$0.331		$0.331		$0.331		$0.304		$0.304		$0.304		$0.556		$0.556		$0.556	
Building Power	$0.10	0.3%	$0.08	0.3%	$0.08	0.3%	$0.18	0.4%	$0.16	0.4%	$0.16	0.4%	$0.19	0.3%	$0.18	0.3%	$0.18	0.3%
$/1,000 gallons	$0.002		$0.002		$0.002		$0.003		$0.003		$0.003		$0.004		$0.004		$0.003	
Subtotal - Power	$17.33	55.8%	$17.31	57.6%	$17.31	57.8%	$15.97	38.6%	$15.95	39.4%	$15.95	39.5%	$29.12	42.7%	$29.11	43.4%	$29.11	43.5%
$/1,000 gallons	$0.333		$0.333		$0.333		$0.307		$0.307		$0.307		$0.560		$0.560		$0.560	
Chemicals (Note 2)	$5.31	17.1%	$5.33	17.7%	$5.33	17.8%	$10.33	25.0%	$10.42	25.8%	$10.48	25.9%	$16.18	23.7%	$16.22	24.2%	$16.26	24.3%
$/1,000 gallons	$0.102		$0.102		$0.102		$0.199		$0.200		$0.202		$0.311		$0.312		$0.313	
UF Membrane Element Replacements	$0.00	0.0%	$0.00	0.0%	$0.00	0.0%	$2.46	5.9%	$2.46	6.1%	$2.46	6.1%	$3.67	5.4%	$3.67	5.5%	$3.67	5.5%
$/1,000 gallons	$0.000		$0.000		$0.000		$0.567		$0.567		$0.567		$0.847		$0.847		$0.847	
RO Membrane Element Replacements	$1.70	5.5%	$1.70	5.7%	$1.70	5.7%	$2.55	6.2%	$2.55	6.3%	$2.55	6.3%	$4.25	6.2%	$4.25	6.3%	$4.25	6.4%
$/1,000 gallons	$0.033		$0.033		$0.033		$0.049		$0.049		$0.049		$0.082		$0.082		$0.082	
Cartridge Filter Replacements	$0.45	1.5%	$0.45	1.5%	$0.45	1.5%	$0.40	1.0%	$0.40	1.0%	$0.40	1.0%	$0.75	1.1%	$0.75	1.1%	$0.75	1.1%
$/1,000 gallons	$0.009		$0.009		$0.009		$0.008		$0.008		$0.008		$0.014		$0.014		$0.014	
Repair & Maintenance	$4.06	13.1%	$3.06	10.2%	$2.96	9.9%	$6.52	15.8%	$5.54	13.7%	$5.40	13.4%	$10.67	15.6%	$9.50	14.2%	$9.27	13.9%
$/1,000 gallons	$0.078		$0.059		$0.057		$0.125		$0.106		$0.104		$0.205		$0.183		$0.178	
O&M Labor	$2.20	7.1%	$2.20	7.3%	$2.20	7.3%	$3.15	7.6%	$3.15	7.8%	$3.15	7.8%	$3.55	5.2%	$3.55	5.3%	$3.55	5.3%
$/1,000 gallons	$0.042		$0.042		$0.042		$0.061		$0.061		$0.061		$0.068		$0.068		$0.068	
Total	$31.04	100.0%	$30.06	100.0%	$29.96	100.0%	$41.38	100.0%	$40.47	100.0%	$40.39	100.0%	$68.18	100.0%	$67.06	100.0%	$66.85	100.0%
$/1,000 gallons	$0.597		$0.578		$0.576		$0.796		$0.778		$0.776		$1.311		$1.289		$1.285	

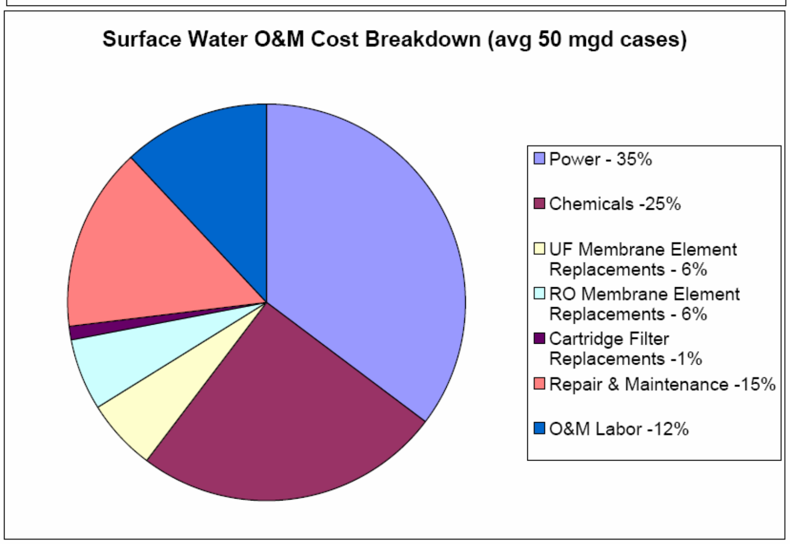
1. Annual production at 95% plant factor = 52,012,500 Kgal/yr

Tables 4-21 through 4-25 also show the O&M cost items as a percentage of the total for all cases. To provide an example of O&M cost itemization, Figure 4-14 shows the breakdown for the average of all brackish groundwater cases at 50 mgd (189,000 m^3/day) (average of costs for all element diameters). Power costs represented approximately 50% of the total O&M cost, while chemicals labor, and repair and maintenance were each between 10 and 20 percent. RO membrane replacement represented only 5% of O&M costs. For the "average" 50 mgd (189,000 m^3/day) brackish surface water case, power costs represented 35 percent, chemicals 25 percent, repair and maintenance 15 percent and labor 12 percent of O&M costs. For the "average" 50 mgd (189,000 m^3/day) seawater case, power costs were about 41 percent, chemicals were 23 percent, repair and maintenance was 15 percent, and labor was 9 percent.

Tables 4-26 to 4-30 presents the life-cycle and treated water costs for all cases. Construction costs were amortized at 5 percent over a 20 year period. A 95 percent plant operating factor was assumed. The 8-inch diameter RO element plant total treated water costs for the groundwater, surface water, and seawater cases from 12.5 mgd (47,000 m^3/day) through 150 mgd (568,000 m^3/day) ranged from \$0.95-1.12, \$1.37-1.89, and \$2.24-2.81 per 1,000 gallons, respectively (\$310-365, \$445-617, and \$731-916 per acre-foot or \$0.251 to 0.296, \$0.362 0.499, and \$0.591 to 0.742 per m^3). The 16-inch diameter RO element plant total O&M costs for the groundwater, surface water, and seawater cases from 12.5 mgd (47,000 m^3/day) through 150 mgd (568,000 m^3/day) ranged from \$0.85-1.03, \$1.26-1.80, and \$2.12-2.71 per 1,000 gallons, respectively (\$275-334, \$441-588, and \$691-884 per acre-foot or \$0.224 to 0.272, \$0.333 to 0.475, and \$0.560 to 0.715 per m^3). Finally, the 20-inch diameter RO element plant total O&M costs for the groundwater, surface water, and seawater cases from 12.5 mgd (47,000 m^3/day) through 150 mgd (568,000 m^3/day) ranged \$0.84 to 1.01, \$1.25 to 1.79, and \$2.09 to 2.69 per 1,000 gallons, respectively (\$272-331, \$407-583, and \$683-876 per acre-foot or \$0.222 to 0.267, \$0.808 to 0.473, and \$0.552 to 0.710 per m^3).

Figure 4-14.—Unit O&M Costs By O&M Category (50 mgd Plant Capacity)





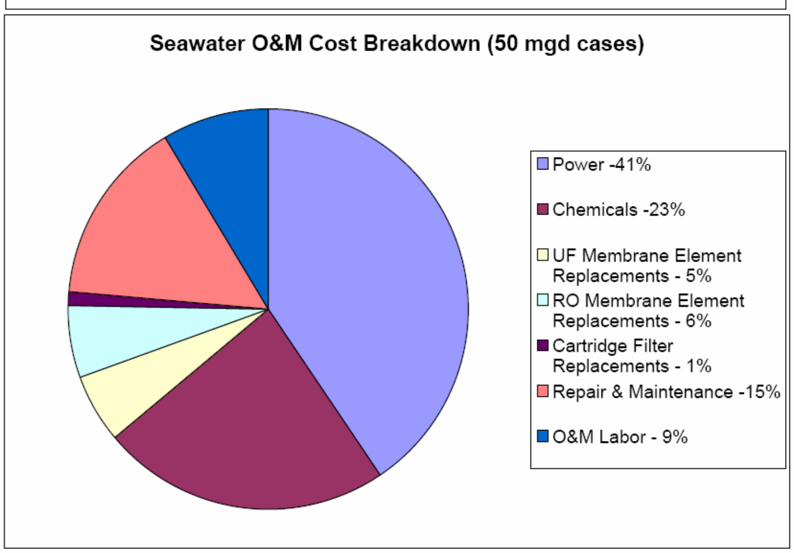


Table 4-26.—Life-Cycle and Treated Water Costs – 12.5 mgd

CH2M HILL CPES COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
12.5 mgd (Note 1)									
Life Cycle Cost, $ Million	$60.53	$55.44	$54.83	$102.29	$97.48	$96.65	$151.84	$146.47	$145.28
% of 8" dia cost	100.0%	91.6%	90.6%	100.0%	95.3%	94.5%	100.0%	96.5%	95.7%
Amortized Capital, $ Million/yr (Note 2)	$1.83	$1.49	$1.45	$3.65	$3.31	$3.26	$5.35	$4.99	$4.91
Amortized Capital, $/1000 gallons	$0.422	$0.344	$0.335	$0.841	$0.764	$0.752	$1.235	$1.151	$1.133
Total Annual Treated Water Cost $ Million/yr	$4.86	$4.45	$4.40	$8.21	$7.82	$7.76	$12.18	$11.75	$11.66
Total Treated Water Cost $/1000 gallons	$1.121	$1.026	$1.015	$1.894	$1.805	$1.789	$2.811	$2.712	$2.690
Total Treated Water Cost $/acre-foot	$365	$334	$331	$617	$588	$583	$916	$884	$876
Total Treated Water Cost $/m3	$0.296	$0.271	$0.268	$0.500	$0.476	$0.472	$0.742	$0.716	$0.710
% of 8" dia cost	100.0%	91.6%	90.6%	100.0%	95.3%	94.5%	100.0%	96.5%	95.7%

1. Annual production at 95% plant factor = 4,334,375 Kgal/yr
2. Amortization at 5% for 20 years

Table 4-27.—Life-Cycle and Treated Water Costs – 25 mgd

CH2M HILL CPES COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
25 mgd (Note 1)									
Life Cycle Cost, $ Million	$111.98	$101.63	$100.60	$175.09	$165.04	$163.37	$273.36	$262.11	$259.74
% of 8" dia cost	100.0%	90.8%	89.8%	100.0%	94.3%	93.3%	100.0%	95.9%	95.0%
Amortized Capital, $ Million/yr (Note 2)	$3.35	$2.67	$2.58	$6.10	$5.42	$5.31	$9.40	$8.65	$8.50
Amortized Capital, $/1000 gallons	$0.386	$0.307	$0.298	$0.704	$0.626	$0.613	$1.085	$0.998	$0.980
Total Annual Treated Water Cost $ Million/yr	$8.99	$8.16	$8.07	$14.05	$13.24	$13.11	$21.94	$21.03	$20.84
Total Treated Water Cost $/1000 gallons	$1.037	$0.941	$0.931	$1.621	$1.528	$1.512	$2.530	$2.426	$2.404
Total Treated Water Cost $/acre-foot	$338	$307	$303	$528	$498	$493	$824	$791	$783
Total Treated Water Cost $/m3	$0.274	$0.248	$0.246	$0.428	$0.403	$0.399	$0.668	$0.640	$0.635
% of 8" dia cost	100.0%	90.8%	89.8%	100.0%	94.3%	93.3%	100.0%	95.9%	95.0%

1. Annual production at 95% plant factor = 8,668,750 Kgal/yr
2. Amortization at 5% for 20 years

Table 4-28.—Life-Cycle and Treated Water Costs – 50 mgd

CH2M HILL CPES COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
50 mgd (Note 1)									
Life Cycle Cost, $ Million	$212.71	$190.93	$188.53	$320.56	$299.46	$296.85	$513.96	$488.66	$484.23
% of 8" dia cost	100.0%	89.8%	88.6%	100.0%	93.4%	92.6%	100.0%	95.1%	94.2%
Amortized Capital, $ Million/yr (Note 2)	$6.31	$4.87	$4.71	$10.97	$9.52	$9.32	$17.38	$15.69	$15.38
Amortized Capital, $/1000 gallons	$0.364	$0.281	$0.272	$0.633	$0.549	$0.538	$1.003	$0.905	$0.887
Total Annual Treated Water Cost $ Million/yr	$17.07	$15.32	$15.13	$25.72	$24.03	$23.82	$41.24	$39.21	$38.86
Total Treated Water Cost $/1000 gallons	$0.984	$0.884	$0.873	$1.484	$1.386	$1.374	$2.379	$2.262	$2.241
Total Treated Water Cost $/acre-foot	$321	$288	$284	$483	$452	$448	$775	$737	$730
Total Treated Water Cost $/m3	$0.260	$0.233	$0.230	$0.392	$0.366	$0.363	$0.628	$0.597	$0.592
% of 8" dia cost	100.0%	89.8%	88.6%	100.0%	93.4%	92.6%	100.0%	95.1%	94.2%

1. Annual production at 95% plant factor = 17,337,500 Kgal/yr
2. Amortization at 5% for 20 years

Table 4-29.—Life-Cycle and Treated Water Costs – 100 mgd

CH2M HILL CPES COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
100 mgd (Note 1)									
Life Cycle Cost, $ Million	$414.05	$369.06	$364.26	$603.97	$559.93	$554.25	$984.94	$932.65	$922.94
% of 8" dia cost	100.0%	89.1%	88.0%	100.0%	92.7%	91.8%	100.0%	94.7%	93.7%
Amortized Capital, $ Million/yr (Note 2)	$12.36	$9.39	$9.07	$20.39	$17.43	$17.02	$32.95	$29.48	$28.82
Amortized Capital, $/1000 gallons	$0.356	$0.271	$0.262	$0.588	$0.503	$0.491	$0.950	$0.850	$0.831
Total Annual Treated Water Cost $ Million/yr	$33.22	$29.61	$29.23	$48.46	$44.93	$44.47	$79.03	$74.84	$74.06
Total Treated Water Cost $/1000 gallons	**$0.958**	**$0.854**	**$0.843**	**$1.398**	**$1.296**	**$1.283**	**$2.279**	**$2.158**	**$2.136**
Total Treated Water Cost $/acre-foot	**$312**	**$278**	**$275**	**$455**	**$422**	**$418**	**$743**	**$703**	**$696**
Total Treated Water Cost $/m3	**$0.253**	**$0.225**	**$0.222**	**$0.369**	**$0.342**	**$0.339**	**$0.602**	**$0.570**	**$0.564**
% of 8" dia cost	100.0%	89.1%	88.0%	100.0%	92.7%	91.8%	100.0%	94.7%	93.7%

1. Annual production at 95% plant factor = 34,675,000 Kgal/yr
2. Amortization at 5% for 20 years

Table 4-30.—Life-Cycle and Treated Water Costs – 150 mgd

CH2M HILL CPES COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
150 mgd (Note 1)									
Life Cycle Cost, $ Million	$616.66	$547.99	$540.79	$865.28	$817.88	$809.15	$1,454.15	$1,373.66	$1,358.28
% of 8" dia cost	100.0%	88.9%	87.7%	100.0%	92.4%	91.4%	100.0%	94.5%	93.4%
Amortized Capital, $ Million/yr (Note 2)	$18.44	$13.92	$13.44	$29.65	$25.16	$24.54	$48.50	$43.17	$42.14
Amortized Capital, $/1000 gallons	$0.354	$0.268	$0.258	$0.570	$0.484	$0.472	$0.932	$0.830	$0.810
Total Annual Treated Water Cost $ Million/yr	$49.48	$43.97	$43.39	$71.04	$65.63	$64.93	$116.68	$110.23	$108.99
Total Treated Water Cost $/1000 gallons	**$0.951**	**$0.845**	**$0.834**	**$1.366**	**$1.262**	**$1.248**	**$2.243**	**$2.119**	**$2.095**
Total Treated Water Cost $/acre-foot	**$310**	**$275**	**$272**	**$445**	**$411**	**$407**	**$731**	**$691**	**$683**
Total Treated Water Cost $/m3	**$0.251**	**$0.223**	**$0.220**	**$0.360**	**$0.333**	**$0.329**	**$0.592**	**$0.559**	**$0.553**
% of 8" dia cost	100.0%	88.9%	87.7%	100.0%	92.4%	91.4%	100.0%	94.5%	93.4%

1. Annual production at 95% plant factor = 52,012,500 Kgal/yr
2. Amortization at 5% for 20 years

Figure 4-15 presents the treated water costs in dollars per 1,000 gallons for all cases. Figures 4-16 through 4-18 show the same total treated water costs in alternative units of dollars per acre-foot. As anticipated, treated water costs decrease with increasing RO element diameter, that is, the use of larger diameter elements in the RO system design reduces the total cost of treated water. The reduction in total treated water cost is most dramatic when the element size (diameter) is increased from 8-inch to 16-inch. A further increase in element size to 20-inch provides only a marginal additional reduction in cost.

Figure 4-15.—Total Treated Water Cost – All Cases

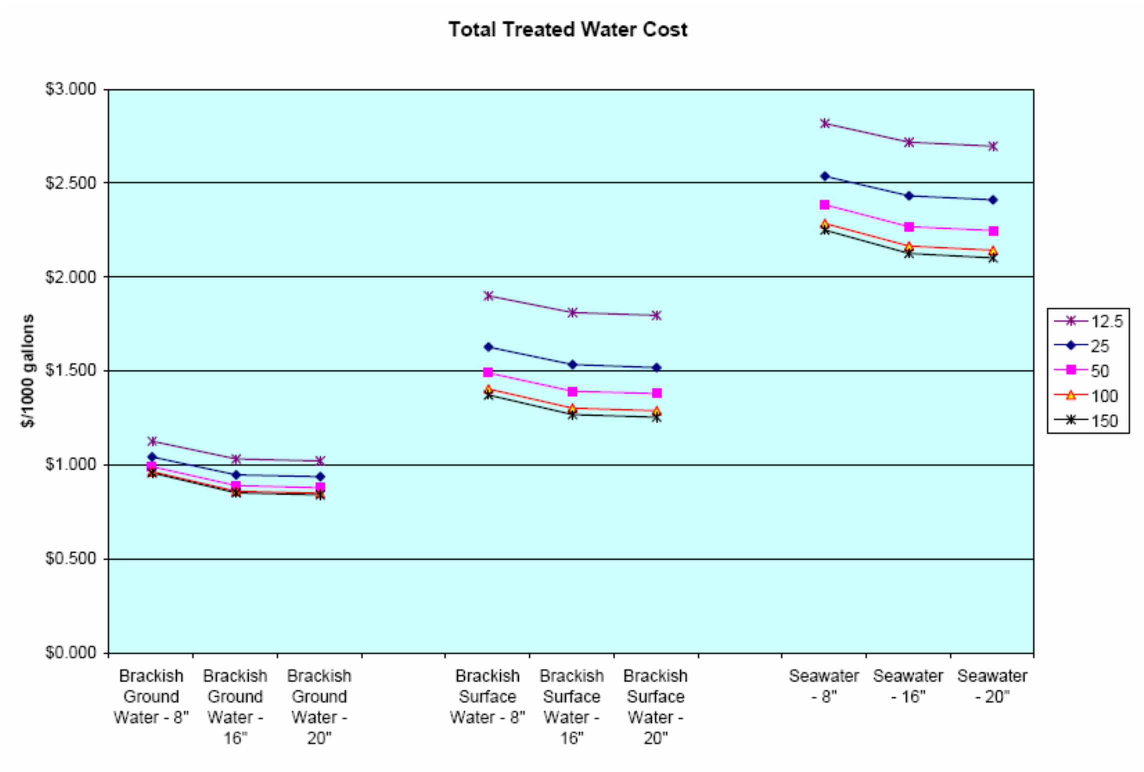


Figure 4-16.—Total Treated Water Cost – Brackish Groundwater

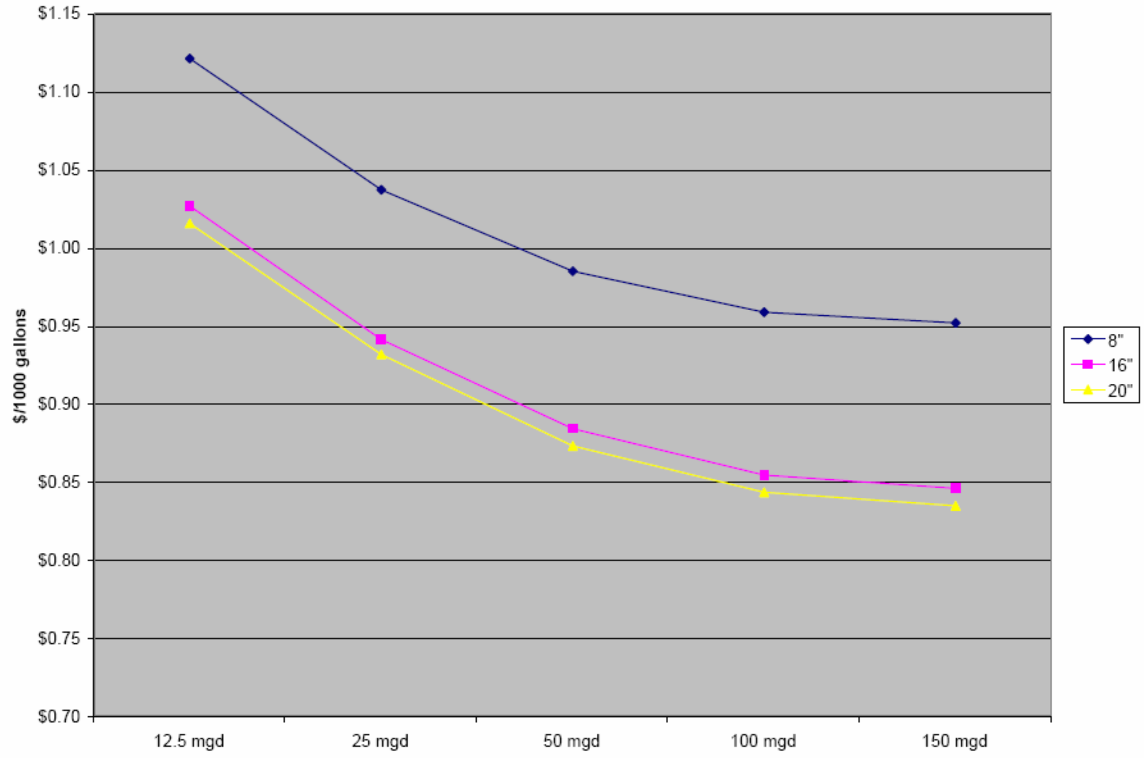


Figure 4-17.—Total Treated Water Cost – Brackish Surface Water

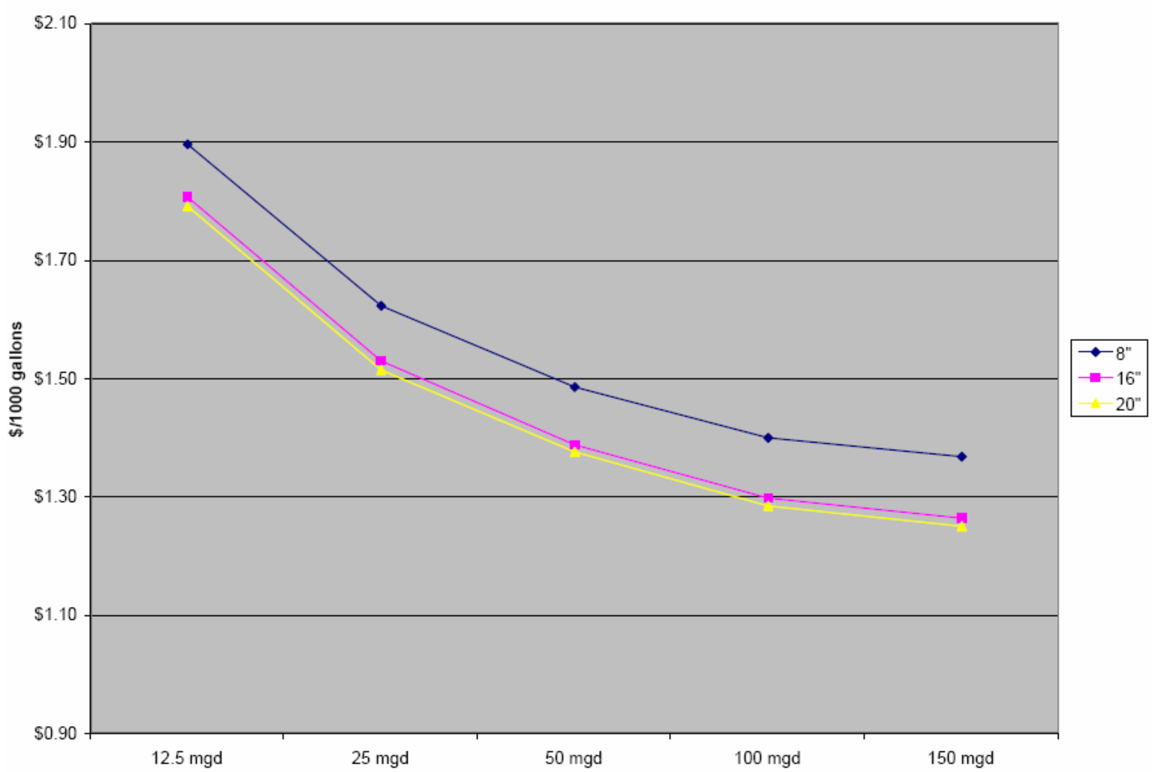


Figure 4-18.—Total Treated Water Cost – Seawater

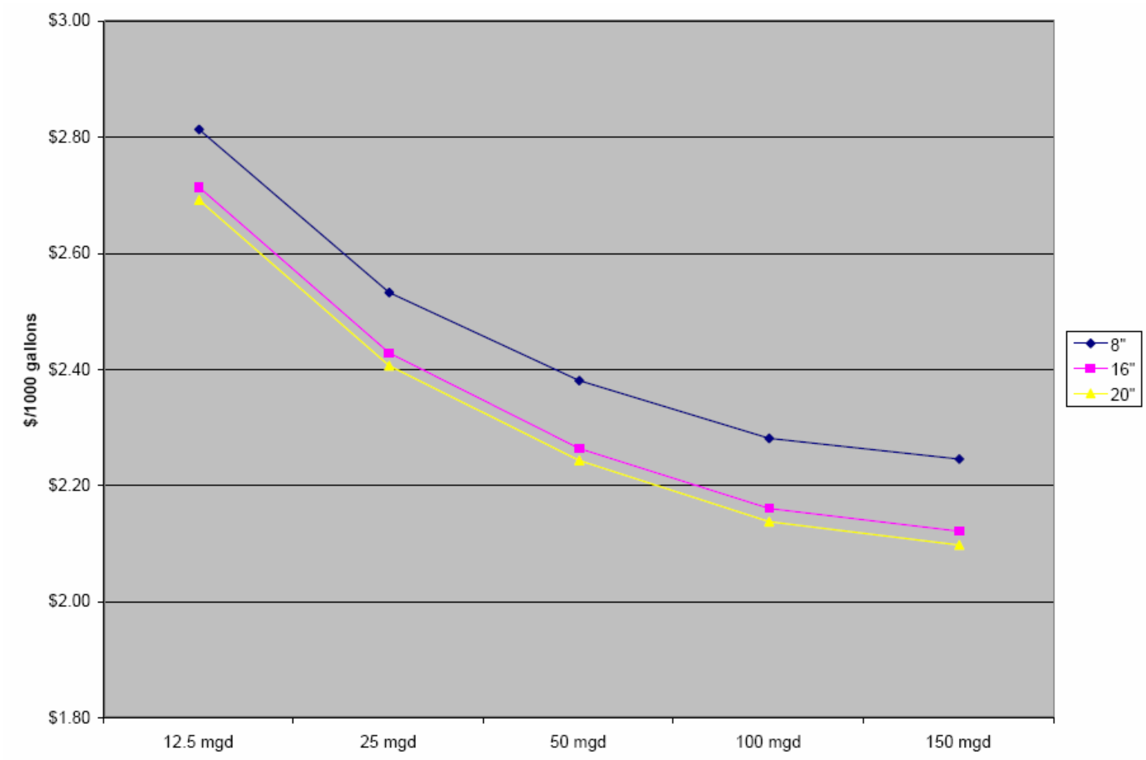
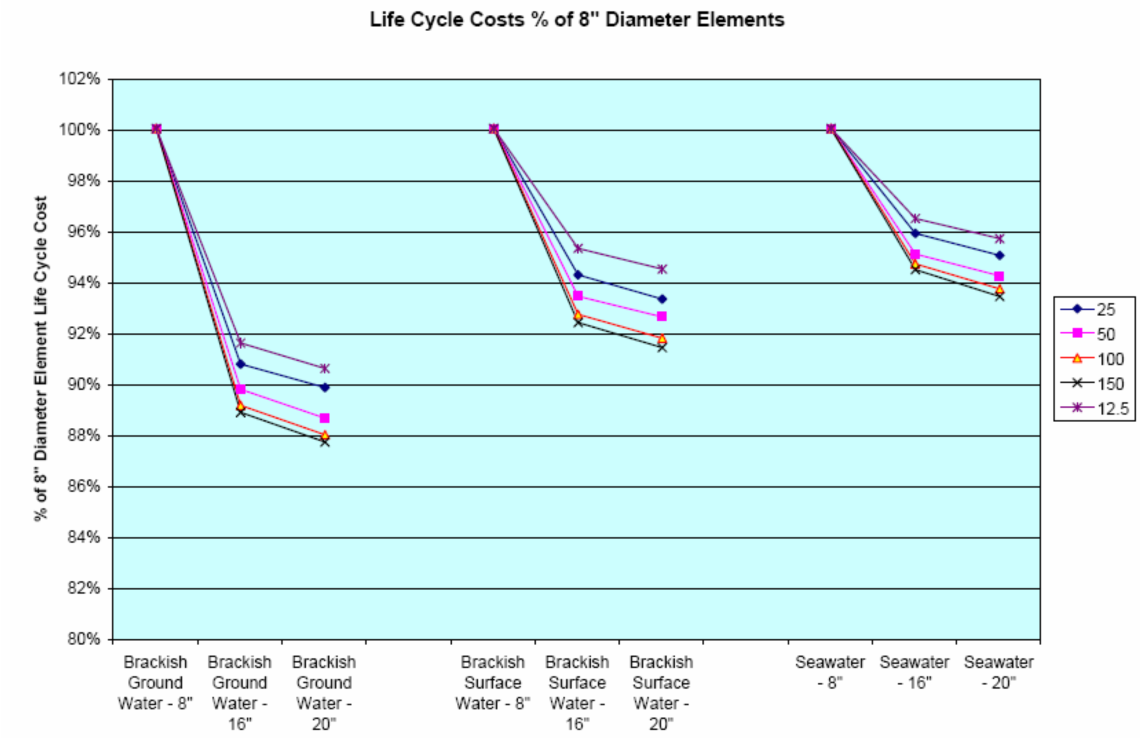


Figure 4-19 (and Tables 4-26 through 4-30) shows the life-cycle costs for each of the forty-five cases as a percentage of 8-inch diameter life cycle costs. The cost reductions for the larger diameter elements are clearly evident. The greatest percent reduction occurs for the construction cost ((Figure 4-11). O&M costs between the three diameter sizes are more comparable and dilute the construction savings in the life-cycle cost comparison. For the brackish groundwater cases, the plant life-cycle cost savings range from 8 to11 percent for 16-inch and 9 to 12 percent for 20-inch element cases . For the surface water cases, the life-cycle cost savings range from 5 to 8 percent for 16-inch and 6 to 9 percent for 20-inch element cases. Finally, for the seawater cases the life-cycle cost savings range from 4 to 6 percent for 16-inch and 4 to 7 percent for 20-inch element cases. Although the percentage savings in life-cycle costs are less than for construction costs, they nonetheless represent millions of dollars over the life of the RO plant. For example, the life-cycle cost savings for the 50 mgd (189,000 m^3/day) brackish groundwater, brackish surface water, and seawater cases are $22 to 24 million, $21 to 24 million, and $25 to 30 million, respectively, for 16-inch and 20-inch diameter elements compared with respective 8-inch diameter cases.

Figure 4-19.—Total Life-Cycle Cost, Percent of 8-inch Diameter Element Facility



5. Conclusions and Recommendations

Numerous issues must be considered when recommending a new large diameter element standard, which contains substantial increases in membrane active area, for the NF/RO industry. These items can be systematically grouped into three primary categories:

- Market application, size, growth rate, and forecasts
- Risk management across the industry value chain
- Economic savings estimate enabled by larger diameter elements for end-users

5.1 Market

Estimated market demand for large diameter elements over the foreseeable future is significant, albeit not tremendously large. Investment grade economics justifying research and development expenses and re-tooling costs incurred by element and pressure vessel manufactures for a new large diameter standard are more readily obtained when aggregate NF, BW, and SW markets are serviced by a single diameter.

5.2 Risk

For success, risk must be managed across the entire economic value chain. Such an approach addresses the concerns of element suppliers, pressure vessel suppliers, equipment suppliers, engineering consultants, owners, operators, and end-users. Via the Consortium's comprehensive industry-wide survey, the handling, quality, cost, and multiple sourcing of elements and pressure vessels were prioritized as primary concerns.

Understandably, any sizeable increase in element diameter will necessitate the development and utilization of mechanical handling equipment. However this was not identified as a limiting factor over the evaluated element diameter range (8 – 20 inches) since this type of equipment is commonly used in industries having similar needs.

Element and pressure vessel development cost and market acceptance risk increases dramatically with increasing diameter. Minimizing industry concerns associated with this cost and risk as well as concerns of handling, quality, and multiple sourcing requires minimizing the new diameter standard while still achieving the majority of the available savings.

5.3 Economic Study - Savings

RO plant design used in cost development reflected accepted engineering practice for large-capacity RO plants and incorporated the following features: chemical addition for scale control, cartridge filtration, a pumping center for RO feedwater pressurization, parallel RO trains of single or multiple stages, and for the seawater cases, an energy recovery center. For surface brackish water and seawater, additional pretreatment was provided in the form of screening and submerged MF/UF. Post-treatment consisted of chlorination and caustic addition to the RO permeate; degasification for removal of CO_2 and H_2S was assumed for the groundwater cases. Additional facilities included in the construction costs included clearwells and pumping for storage and transfer of MF/UF and RO permeates and finished water (ground) storage and high service pumping. A process building and yard piping were also included in the construction costs.

An important design assumption was that for all except the 12.5 mgd (47,000 m^3/day) case, there would be a minimum of four RO trains to ensure adequate permeate production while one train was out of service for cleaning. This resulted in a train size of 4.17 mgd (16,000 m^3/day) for the 8-inch diameter cases and train sizes ranging from 8.33 to 12.5 mgd (32,000 to 47,000 m^3/day) for the larger diameter cases. Larger train sizes and smaller number of trains was the primary means of realizing cost savings for the larger diameter element designs.

O&M costs included power for operation of process equipment and the building; process chemicals, where applicable, including pretreatment coagulant, antiscalant and acid, chlorine and caustic and chemicals for UF and RO cleaning and cleaning solution neutralization; MF/UF and RO membrane replacement and cartridge filter replacement, labor and equipment repair and maintenance.

The results of the study were as follows:

1. Design of RO trains and treatment facility with 16-inch and 20-inch elements results in reduced plant construction costs for all cases. Cost savings are most significant for the brackish groundwater case, where the percent savings (relative to 8-inch costs) ranged from 18.5% for the 12.5 mgd (47,000 m^3/day) capacity case to 27% for the 150 mgd (568,000 m^3/day) case. Savings were less significant (7% to 17%) for the other source waters due to the leveling effect of the MF/UF pretreatment, whose costs are equivalent for the three element diameters.

2. The greatest construction cost reduction is realized when element diameter is increased from 8-inch to 16-inch diameter. For the brackish groundwater case, the relative cost saving from 8-inch to 16-inch was 24%; it increased only marginally to 27% from 8-inch to 20-inch.

3. The most significant portion of the plant construction cost to be positively impacted by the use of increased diameter elements is the RO train. For the brackish groundwater cases, installed RO train cost was reduced from \$0.33/gpd to \$0.22/gpd (\$87 per m^3/day to \$58 per m^3/day) when 16-inch elements are used in place of 8-inch elements (50 mgd or 189,000 m^3/day case), a 50% savings. In contrast, the largest plant construction cost savings (150-mgd or 568,000 m^3/day case) for this source water was 24%

or only one-half of the train cost savings. Savings were somewhat less for the surface brackish and seawater cases because of the smaller train sizes used for the 16-inch element designs.

4. Savings in O&M costs from use of larger diameter elements were small and comparable for all cases. For the 50-mgd cases, O&M costs decreased from \$0.62/1000 gals to \$0.60/1000 gals (\$0.164/m^3 to \$0.158/m^3). Given that the basic performance characteristics are the same for all diameter elements (all use the same membrane), the power, chemical and replacement intervals are unaffected. The primary O&M savings associated with larger-diameter designs is from reductions in repair and maintenance. The fewer numbers of elements, pressure vessels and RO skid components should translate into lower repair and maintenance costs.

5. Use of a 16-inch diameter RO design would result in a significant life-cycle cost savings relative to 8-inch diameter design. For a 50 mgd (189,000 m^3/day) brackish groundwater plant , the savings over a 20-year period is estimated at 22 to 24 million dollars.

5.4 Consensus Recommendation

To insure industry success a new large diameter element standard needs to serve the broadest possible market, manage risk across the value chain, and deliver the majority of the available savings. This analysis pragmatically concludes that a 16-inch diameter element delivers across all three criteria. Due to availability of existing steel pipe for mandrels required for vessel construction, 15.90 +/- 0.01 inches is the consensus recommendation for a new RO/NF large diameter element standard.

6. References

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Bergman, R.A. Cost of Membrane Softening in Florida. Journal of AWWA. 88(5)32:43. 1996.

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Faigon, M., Liberman, B. Pressure Center and Boron Removal in Ashekelon Desalination Plant. Proc. 2003 International Desalination Association World Congress on Desalination and Water Reuse, Paradise Island, Bahamas, 2003.

Gabelich, et al., "Evaluating Ultra-Low-Pressure Reverse Osmosis for Surface Water Desalination", AWWA Membrane Conference, Long Beach, CA, 1999.

Gabelich, C. J.; Yun, T. I.; Coffey, B. M.; & Bergman, R. A. Performance and Economic Evaluation of a 16-Inch Diameter Reverse Osmosis Membrane for Surface Water Desalting. Proceedings of the 2001 AWWA Membrane Technology Conference, San Antonio, Texas, 2001.

Personal communication between Irv Shelby, Hydranautics and Brent Corbett, Burns & Rowe and Mike Norris and Angela Adams of the Bureau of Reclamation's Water Quality Improvement Center, Yuma, Arizona on March 15, 2004.

Personal communications between the Consortium and Doug Eisberg, Progressive Composites (Bekaert) on December 2, 2003.

Personal communication between the Consortium and Pentair CodeLine on December 2, 2003.

UltraPure Magazine, advertisement, May 2004.

Wangnick Consulting, 2000 IDA Worldwide Desalting Plants Inventory Report No. 17, International Desalination Association, Topsfield, Massachusetts, 2002..

Yun, T. I., Gabelich, C. J., Cox, M. R., Mofidi, A. A., & Lesan, R. Reducing Costs for Large-Scale Desalting Plants Using Large-Diameter, Reverse-Osmosis Membranes. Proceedings of the 2002 AMTA Biennial Conference, Tampa Bay, Florida, 2002.

Appendix A – Joint Work Agreement

Joint Work Agreement

This agreement, effective upon execution by all the parties, is entered into between

FilmTec Corporation, a Minnesota Corporation, having a place of business at 7200 Ohms Lane, Minneapolis MN 55439;

Hydranautics, a California Corporation, having a place of business at 401 Jones Road, Oceanside CA 92054;

Toray Membrane America, Inc., a Massachusetts Corporation, having a place of business at 65 Grove Street, Watertown, MA 02472; and

TriSep Corp., a California Corporation, having a place of business at 93 S. La Patera Lane, Goleta, CA 93117;

pursuant to and under U.S. Federal law by which the parties agree to be legally bound.

WHEREAS, reverse osmosis (RO) and nanofiltration (NF) technology is of increasing importance in the production of safe drinking water; and

WHEREAS the current standard size for RO and NF membrane elements is a diameter of 8 inches with a length of 40 inches; and a study by the Metropolitan Water District in Los Angeles has shown that larger diameter elements can result in substantial capital and operating cost savings; and

WHEREAS each of the Consortium Members believes that it would obtain benefit by cooperation with other Consortium Members in an economic study to set a standard for larger-sized RO and NF membrane elements;

WHEREAS the overall goal of the program is to share existing information on larger RO and NF membrane elements, research and analyze information to identify the best overall size of a new, larger element, and set an industry standard to allow elements to be interchanged;

THEREFORE the parties agree as follows:

Definitions

Architecture and Engineering Firm

A firm subcontracted by the Consortium for execution of the Economic Study, described in the Proposal in subsection 6.2.

Confidential Information

"Confidential Information" means Background Information of the designated Party and/or its Affiliates (collectively the "**Discloser**") as well as Project Information first developed or discovered by the Discloser, which is disclosed or otherwise made available to the another Party and/or the Consortium as a whole, (collectively the "**Recipient**") pursuant to this Agreement, provided that such Information is:

(a) disclosed in writing or other tangible form and labeled "[Discloser's name] - confidential," or

(b) disclosed orally or by observation and confirmed to the Recipient in writing as being "[Discloser's name] - confidential" within 30 days after the initial disclosure,

(c) except with respect to any particular Information that

(i) Recipient can prove was or became available to the public through no fault of Recipient, or

(ii) Recipient already possessed prior to receipt from Discloser, or

(iii) Recipient acquired from a third person without obligation of confidence, or

(iv) was independently developed by or for Recipient by one who did not have access to Discloser's Confidential Information or Samples.

Specific Information is not within any of the above exclusions merely because it is within the scope of more general information within an exclusion. A combination of features is not within any of the above exclusions unless the combination itself, including its principles of operation, is within the above exclusions.

Consortium

The organization formed by this Consortium Agreement, for the sole purpose of taking part in the Large Element Program.

Consortium Agreement

This Agreement, together with and Appendices and any properly executed amendments.

Consortium Members

Consortium Members are Corporations that are signatories to this Consortium Agreement. Initially the signatories shall include FilmTec Corporation, Hydranautics, TriSep Corporation, and Toray Membrane America.

Committee Members

Members of the Committee established for Program leadership under 3.01

Government Contribution

The Bureau of Reclamation shall reimburse out-of-pocket expenses of the Consortium, including fees for a Program Facilitator and an Architecture and Engineering Firm.

Large Element Program

Project described in ***Industry Consortium Analysis of Large Reverse Osmosis/Nanofiltration Element Diameters: Designed for Manufacturability, System Capital Reduction, and Industry Acceptance,*** attached to this Consortium Agreement in Appendix B.

Program Facilitator

The person fulfilling the role described in Subsection 6.1 of the Large Diameter Element Consortium Proposal.

Proposal

Document described in 2.02 of this Consortium Agreement.

Proprietary Information

"Proprietary Information" means information which embodies Trade Secrets developed at private expense or which is Confidential business, technical or financial information, provided that such information:

- **is not generally known or available from other sources without obligations concerning its confidentiality;**
- **has not been made available by the owners to others without obligation concerning its confidentiality;**
- **is not already available to the Government without obligation concerning its confidentiality; and**
- **is not independently developed by the recipient.**

Trade Secret

"Trade Secret" means information, including a formula, pattern, compilation, program, device, method, technique, or process that:

- **Derives independent economic value, actual or potential, from not being generally known to the public or to other persons who can obtain economic value from its disclosure or use; and**
- **Is the subject of efforts that are reasonable under the circumstances to maintain its secrecy.**

Program Invention

"Program Invention" means a novel, potentially patentable concept which is developed during the term of this Agreement under the work plans agreed by the Parties relating to the standard developed for large-scale reverse osmosis elements. Any new, novel design concepts of the spiral wound element itself, or the use or application of such elements, shall not be covered by this Agreement.

Program Technology

"Program Technology" shall mean novel concepts developed during the term of this Agreement or related to the size of RO or NF elements, or "Confidential Information" disclosed as stated in 1.02 of this Agreement.

Program Mission

Program Purpose

The mission of the Large Element Program is to combine the expertise of a Consortium of membrane element suppliers to create a new element diameter standard. The study is in response to Solicitation Number 03-FC-82-0846, subtask E, issued by the US Department Interior, Bureau of Reclamation (attached as Appendix A).

Proposal

A proposal (attached as Appendix B) that describes how the Consortium will accomplish the study has been submitted by FilmTec Corporation, a Consortium Member. The study will complete an economic analysis to determine a new element diameter greater than the current 8-inch standard, taking into account manufacturability, system design limitations, and capital cost reductions. The use of a consortium allows for an evaluation that will be less biased toward one supplier, and will allow competitive bidding for projects using the standard. The proposal requests that the government contribute **$100,000**, to be used for the cost of a Facilitator and an Architecture and Engineering Firm.

Program Leadership

Committee

The Consortium Members shall each appoint members to a Committee, whose function shall be to guide and direct the Large Element Program. The Committee Members shall select a Facilitator to be hired by the FilmTec Corporation, on behalf of the Consortium, for the term of the project.

Voting

Decisions that may have an impact on the Large Element Program direction and funding shall be made by vote of a majority of all the Committee Members. Each Committee Member shall have one vote. In the event of a tie, the vote shall not carry.

Minimum Meeting Requirements

The Committee Members shall meet at least once per calendar quarter to review the progress of the Large Element Program. Such meetings may take place in any convenient physical location or by videoconference or teleconference. The Facilitator will distribute an agenda prior to any meeting of the Committee. The Committee shall review, modify if necessary, approve, and follow the agenda during the meeting.

Meeting Minutes

The Facilitator shall keep minutes of all meetings of the Committee. Further, the Facilitator shall make meeting minutes available to all Project Managers for each of the Members within 10 days of the meeting, or before the next meeting of the Committee, whichever is sooner.

Contributed Technologies

Personnel and Resources

Agreement on Resource Contribution

The Consortium Members have laid out their planned contribution of time and expertise in Section 6.1 of the Proposal in Appendix B. Each Consortium Member expressly agrees to the time and resources in the Proposal, and their contribution to the Program.

Auditing

The Bureau of Reclamation has agreed to contribute funding to the Program based on the work contributed by the Consortium Members. Therefore, each Consortium Member agrees to keep adequate records of the time and money it spends on the Program so that it can respond to government audit of the Program.

Mechanism for shared funding and shared costs

Facilitator

FilmTec Corporation, a member of the Committee, will hire and pay for the Facilitator selected by the Committee. FilmTec will then submit its costs to the Bureau of Reclamation for reimbursement. FilmTec will keep adequate records and review the Facilitator costs at regular meetings of the Committee.

Architecture and Engineering Firm.

FilmTec Corporation, a member of the Committee, will hire and pay for the Architecture and Engineering Firm selected by the Committee. FilmTec will then submit its costs to the Bureau of Reclamation for reimbursement. FilmTec will keep adequate records and review the Architecture and Engineering Firm costs at regular meetings of the Committee

Costs in Excess of Government Contribution.

The Costs of the Facilitator and the Architecture and Engineering Firm are expected to fall within the money available from the Bureau of Reclamation for the Program. If the costs of the Facilitator and the Architecture and Engineering Firm together shall only be allowed to exceed the Government Contribution described in 2.01 based on a unanimous vote by all the Consortium Members. In such case the Consortium Members will agree to share the excess costs equally, unless changed by unanimous vote by all members. If approved, FilmTec shall continue pay the Facilitator and Architecture and Engineering Firm and request reimbursement from the Consortium. FilmTec shall prepare an invoice for each Consortium Member for its share of the services after the Committee has reviewed the costs. Each Consortium Member shall pay its amount due to FilmTec within 30 days of receipt.

Individual Costs

Each Consortium member shall be responsible for its own costs of contributing to the study.

Warranties and Indemnification

Warranty

Each Consortium Member makes no representation or warranty that the technology it provides to the Program (a) offers any benefit to water treatment, (b) is free from infringement of any third party patent, or (c) is free from claims of ownership by a third party. Each Consortium Member provides its technology on an "as is" basis. Nothing in this Consortium Agreement shall be construed as a warranty or representation of the validity or scope of any patent, or the validity of Confidential Information contributed to the Large Element Study.

Indemnification

Each Consortium Member understands that all uses, samples, experiments, modeling software, or demonstrations, of any technology contributed by any other Consortium Member, and any element or system which a Consortium Member uses is done at its own risk. Each Consortium Member shall hold harmless and indemnify all other Consortium Members for that Member's own use of the element or system provided by the other Consortium Members.

Scope of Joint Work

Scope

The Scope of the Joint Work is laid out under Section 4 of the Proposal (in Appendix B) and includes developing, executing, and the economic study. Additionally the Members if the Consortium will develop a consensus regarding an optimum diameter, and communicate the standard throughout the water treatment industry.

Review

The Committee shall review the Large Element Study as under Article III of this Consortium Agreement. Each of the Consortium Members shall have exclusive control and supervision over the conduct of all assigned work related to the Program at its facilities. The Consortium Members understand that the nature of this joint research and development work is such that the completion within the period of performance specified in the proposal, or within the limits of financial support allocated cannot necessarily be guaranteed. Accordingly, each Consortium Member agrees to use reasonable best efforts in performing its tasks and the joint work of the Program.

Confidential Information and Ownership

Consortium Member Technologies

All Confidential Information of a particular Consortium Member that is introduced to be part of the Large Diameter Study shall be maintained by all other Consortium Members as confidential and not disclosed to any third party without the prior written permission of the owner of the Confidential Information. To protect Confidential Information from disclosure under 5 USC §552(a)(3), ("FOIA") and similar state laws (See www4.law.cornell.edu/uscode/), each Consortium Member, at the time of providing information to the Large Element Study, will place a notice on the Confidential Information identifying it as Confidential or Proprietary

Program Developed Technology

Each Consortium Member shall maintain as confidential and not disclose to any third party, other than for the purpose of the Large Element Study, or for use authorized under this Consortium Agreement, all Program Technology without the prior consent of the owner(s) of such Program Technology.

Patent applications

The filing for and obtaining a patent on a Program Invention shall not be a violation of section 7.02 of this Agreement by the Consortium Member(s) owning the Program Invention. However, before filing any patent application on a Program Invention, the Consortium Member(s) wishing to file shall give the Committee sixty days to review the agreement, unless a shorter time is dictated by a statutory bar, to raise issues relating to disclosure of Confidential Information.

Disclosure to other government offices or the courts

Disclosure required by law shall not be a violation of paragraphs 7.1 or 7.2 by a Consortium Member. However, the Consortium Member shall inform the owner of the Program Information of such a requirement in sufficient time for the owner to intervene to stop or mitigate the disclosure.

Publication

Facilitator and Architecture and Engineering Firm

The Facilitator and the Architecture and Engineering Firm will develop a plan, for Consortium approval, to present the results of the Consortium work in at least one journal and at least one conference. The Consortium Members shall review and approve by majority vote any potential publication or conference presentation prior to public release of the information. A response from the Consortium Members must be made within 30 days of submittal by the author to the members otherwise the author is free to publish the work at the author's discretion.

Consortium Members

Subject to section 7.02, Consortium Members may publish information they developed in the course of work of this Consortium Agreement, or issue press release, subject to prior review by the Committee for patentable and/or Confidential Information. A copy of each manuscript proposed for publication or press release shall be submitted to the Committee for unanimous approval. Publication shall be deferred for up to ninety days at the request of the owner(s) of such information, until all necessary U.S. patent applications are filed relating to information in the manuscript or press release, or until all Confidential Information has been deleted from the manuscript or press release. The Consortium Members are free to individually publish their own papers and presentations on the concept of a large diameter element at their own discretion after October 1, 2005, however, they will still be subject to the terms of Section 7.02.

Ownership

The ownership of all Program Inventions below shall be subject to the rights of the U.S. Government as described in Solicitation Number 03-FC-82-0846, subtask E, in Appendix A.

Independently-Developed Inventions

Each Consortium Member owns and remains free to seek patent protection at its own cost on any Program Invention conceived and reduced to practice solely by one or more of its employees or agents. All such Program Inventions shall be the sole property of that Consortium Member. The owner of such Program Inventions shall grant to each Consortium Member a royalty-free license for use of the Program Invention during the Program and for five years thereafter.

Jointly-Developed Inventions

With respect to a Program Invention conceived or reduced to practice jointly by employees or agents of two or more Consortium Members, such Consortium Members shall attempt to mutually agree upon whether and how to seek patent protection. The owners of such Program Inventions shall grant to each of the other Consortium Member a royalty-free license for use of the Program Invention during the Program and for five years thereafter.

Program Developed Technologies

Permitted Uses

Each Consortium Member shall be free to use Program Technology developed, whether patented or not, if required to perform work in furtherance of the Large Element Study.

License for Outside the Study

Subject to the rights of the Government, each Consortium Member shall have a non-exclusive, royalty-free license for Program Inventions to be used outside of the Large Element Study, within the field of Desalination and Water Purification.

Contracts with Third Parties

Contracts between a Consortium Member and a third party for use of Program Technology owned by that Consortium Member are permissible upon disclosure to the

Committee. Such third party shall be subject to the obligations of nondisclosure and nonuse relating to Confidential Information in this Consortium Agreement.

Term and Termination

Term

Unless terminated or extended by unanimous consent of the Committee, this Consortium Agreement shall terminate two years after the effective date. All right accrued under this Agreement pertaining to grants, ownership, or confidentiality shall survive termination. All contributions in the form of facilities shall revert back to the owner(s) upon completion of the Large Element Study.

Membership

Due to the short length of the Program, the Consortium Members may not terminate their membership voluntarily or without cause. A Consortium Member may only terminate due to an unforeseeable event beyond its reasonable control where the event is not caused by that Member's fault or negligence. Such termination by any Consortium Member shall terminate all of its rights under this Consortium Agreement, other than those to use its own or partially-owned technology. Such termination shall not terminate any accrued rights of the other Consortium Members with respect to rights to continue using the terminating Consortium Member's contributed technology, information, or developed technology pursuant to the terms of this Consortium Agreement.

Miscellaneous

Express grant

No license or right is granted by implication or otherwise in respect of any patent, patent application, or non-patented technology except as specifically set forth in this Consortium Agreement.

Side Agreements Between Consortium Members

Any side agreements between Consortium members for the purposes of relating to the Consortium's research objectives shall be reviewed by all Committee Members and approved by a vote of a majority of all Committee Members.

Antitrust and Patent Issues Association with the Consortium

The Facilitator shall file notice of the formation of this “Joint Program” with the U.S. Department of Justice and the Federal Trade Commission, under 15 USC 4301, et seq. within ninety (90) days of complete signing of this Consortium Agreement. If a Facilitator has not yet been hired, FilmTec Corporation shall file such notice. Any Consortium Member may file additional information that may be relevant under 15 USC 4301, et seq. during the project.

New Membership in the Consortium

The Consortium intends that no new members will be admitted to the Consortium, because of the time line laid out in the Proposal.

Modification of the Agreement

This Consortium Agreement may only be modified or amended, in writing, by unanimous agreement of the Consortium Members.

Assignment

Except as otherwise permitted herein, neither this Agreement nor any rights or obligation of any Member may be assigned or otherwise transferred without the prior written consent of all other Members. However, each of the Members may assign this Consortium Agreement to the successors or assignees of the entire business interests to which this Consortium Agreement directly pertains.

If a Consortium Member has a prior obligation to assign its patent rights to a parent company, that Consortium Member shall present, within fifteen days after the effective date of this Consortium Agreement, evidence to each Consortium Member that the parent company agrees to provide all rights and licenses to the other Consortium Members in accordance with the terms of this Consortium Agreement.

Independent Parties

Neither this Consortium Agreement, nor any transaction relating to this Consortium Agreement, shall be deemed to create a business entity, agency, partnership, or joint venture relationship among the Consortium Members. Consortium Members are not employees of the Bureau of Reclamation. Should any provision of this Consortium Agreement be deemed to create such relationship, that provision shall be deemed to be void, with all other provisions remaining in full force and effect.

Dispute Resolution

ADR

Any controversy or claim relating to this Consortium Agreement or any breach of the Consortium Agreement shall be submitted to the Committee for resolution. If, however, the Committee is unable to resolve a dispute within thirty days, the Committee shall agree on a form of alternative dispute resolution ("ADR") in accordance with the Model ADR Procedures from the Center for Public Resources, Inc. (www.cpradr.org). If after an additional thirty days, the Committee cannot agree on a form of ADR, a party to the dispute may terminate the negotiations. The parties to the dispute may agree to alter the time limits of this paragraph.

Litigation

A Consortium Member may need to file litigation or other formal proceeding to preserve its rights under a statute of limitations or other deadline, during the pendency of the procedure under the 10.08(a). If so, and if allowed under applicable rules, that Consortium Member will not require the other party to file an answer or other responsive pleading until the above procedure is terminated. In any event, the filing Consortium Member will do all that is necessary to stay the action while the procedure in 10.08(a) is pending. Alternatively, if allowed under the rules, the defending Consortium member shall agree to toll the statute of limitations during the procedure in 10.08(a).

Notices and Reports

All notices and report pertaining to or required by this Consortium Agreement shall be in writing and shall be signed by an authorized representative and shall be delivered to the Project Managers for the other parties, addressed as follows:

FilmTec Corporation
Martin H Peery
Sr. Product Development Specialist
7400 Ohms Lane
Minneapolis MN 55439

Hydranautics
Craig R. Bartels, PhD
Vice President of Research, Development and Applications
Hydranautics
401 Jones Road
Oceanside CA 92054

Toray Membrane America, Inc.
John W. Arnold
Chief Operating Officer
65 Grove Street
Watertown, MA 02472

TriSep Corp.
Peter Knappe
V.P. Operations
93 S. La Patera Lane
Goleta, CA 93117

Complete Agreement

This agreement constitutes the entire agreement and understanding among the Members with respect to the subject matter, and merges and supersedes all prior discussion and writings concerning the subject matter.

The parties have caused this Agreement to be executed by their duly authorized representatives.

FILMTEC CORPORATION

By: ______________________________

Name: ____________________________

Title: _____________________________

Date:______________________________

HYDRANAUTICS

By:

Name: ____________________________

Title: _____________________________

Date:______________________________

TRISEP CORP.

By: ______________________________

Name: ____________________________

Title: _____________________________

Date:______________________________

TORAY MEMBRANE AMERICA, INC.

By:_______________________________

Name:_____________________________

Title: _____________________________

Date:______________________________

Appendix B – Anti-Trust Guidelines

1. Adhere to prepared agendas for all meetings and object any time meeting minutes do not accurately reflect the matters which transpire.

2. Understand the purposes and authority of the Consortium.

3. Protest against any discussions or meeting activities which appear to violate the antitrust or competition laws; do not continue until you are assured it is proper or the discussion is redirected. Otherwise, discontinue the meeting.

4. Don't, in fact or appearance, discuss or exchange information regarding:

    a. Individual company prices, price changes, price differentials, mark-ups, discounts, allowances, credit terms, or data that bear on price, costs, production, capacity, inventories, sales.

    b. Industry pricing policies, price levels, price changes, differentials, etc.

    c. Changes in industry production, capacity or inventories.

    d. Bids on contracts for particular products; procedures for responding to bid invitations.

    e. Plans of individual companies concerning the design, production, distribution or marketing of particular products, including proposed territories or customers, except as part of a distributorship relationship.

    f. Matters relating to actual or potential individual suppliers that might have the effect of excluding them from any market or of influencing the business conduct of firms towards such suppliers or customers.

    g. Termination of manufacturing as a quid pro quo for supply of a product.

1. Don't discuss or exchange information, even in jest, regarding the above matters during social gatherings incidental to any meetings.

Appendix C – Meeting Minutes and Progress Reports

Note that there are sections of the minutes that have been "whitened-out" in order to protect the confidentiality of the vessel manufacturers.

Consortium Meeting, September 29, 2003

Location: 2003 IDA Conference, Atlantis Resort, Paradise Island, Bahamas

Attendees: Craig Bartels (Hydranautics), John Arnold (Toray), Matthew Hallan (Filmtec), Lisa Henthorne (M&E)

Meeting Minutes

Initial discussion to bring Lisa up-to-date regarding administrative issues including:

- Contribution of 400 hours from each Consortium member
- Formal award of the cooperative agreement by the Bureau of Reclamation (Reclamation) to Dow Filmtec was made during the last week
- Anti-trust guidelines (to be provided by Filmtec to Lisa ASAP)
- Goal to have the Consortium Agreement finalized by October 10, 2003
- October 28, 2003 for the kick-off meeting in Denver
- October 9, 2003 for the next teleconference call

<u>Discussion of Koch Membrane Systems withdrawal from the Consortium</u> Discussion centered around issues related to their cost-share contributions impact on Reclamation funding. Filmtec has provided notification to Reclamation regarding Koch's withdrawal.

<u>Discussion of getting Lisa's subcontract in order</u> Lisa is to provide the standard M&E Confidentiality Agreement and sample Professional Services Contract for the Consortium members to review as soon as possible. It was determined that Lisa would prepare the quarterly technical progress reports to Reclamation, as well as the quarterly financial reports. In the financial reports to Reclamation, Lisa would provide full documentation of the individual Consortium member cost-share contribution. Blinded financial reports would be provided to the Consortium members, indicating the respective percent cost-share contribution and staff days of each Consortium member, as well as the itemized Reclamation funding expenditures-to-date.

<u>Brief discussion of A&E proposals</u> The objective will be for each Consortium member to review the proposals and be ready to informatively discuss and come to a decision during the October 9, 2003 conference call. The first and second "best" proposals should be

identified in case the first cannot fulfill any special requirements the Consortium may have. There was the concern that the Consortium should ensure to receive the A&E services from the staff identified in the proposal, not substitutes. The Consortium should maintain control of all publications made by the A&E firm, and ensure the A&E contract stipulates this. Some of the A&E proposals assumed the A&E firm would control the publication content and location.

Discussion of October 28, 2003 kick-off meeting It was determined that the A&E firm should not be present for the October 28, 2003 kick-off meeting. Lisa will prepare a draft agenda for circulation following the October 9, 2003 conference call. The meeting will be held in the Evergreen, Colorado area.

#

Teleconference Consortium Meeting, October 9, 2003

Attendees: Craig Bartels (Hydranautics), John Arnold (Toray), Peter Metcalfe (Toray) Matthew Hallan (Filmtec), Marty Peery (Filmtec), Peter Knappe (Trisep), Lisa Henthorne (M&E)

Meeting Minutes

Reminder of anti-trust guidelines and considerations.

Request of any changes/comments to the draft September 29, 2003 Consortium Meeting minutes. Lisa indicated they will become final after 7 days of receipt. If comments are received, Lisa will edit and they will be re-circulated after which 7 days will pass before they become "Final" minutes.

<u>Discussion on finalizing the Consortium Agreement</u>. Edits were discussed regarding 3.02 (remove majority voting on funding); 4.02 (c) (voting on funding allocation changes) and removal of all references to Koch Membrane Systems in the Agreement. Consensus was reached on all edits, including previous edits by Hydranautics. Filmtec will take the lead in making the edits and getting the originals out for signature as soon as possible. Everyone agreed to expedite the signing process once the documents were received by their company. Filmtec will check on the procedure to be utilized to obtain signatures from each Consortium member and provide this information to the group via email immediately.

<u>Discussion of A&E proposals</u>. Each Consortium member discussed the pros and cons of their 1st and 2nd choices for the A&E firm.

<u>In-depth discussion of CH2M .</u> Lisa and Marty will work together to negotiate the CH2M Hill contract. Specific issues to be addressed during the negotiation and included in the contract include:

- Contract language regarding publication rights to be held by Consortium

- Contract language to ensure staff utilized throughout the project is that which is offered in the proposal

- Lump sum contract to ensure all work is procured based on the budget as proposed (or negotiated)

- Immediate need of a Confidentiality Agreement between the Consortium and CH2M Hill

- Use of CH2M Hill's proprietary costing model versus WTCost (Consortium to determine benefits of verification using WTCost)

- Detailed budget breakdown by task including cost share allocation

- Lisa and Marty will hold off for a few days prior to notifying CH2M Hill, in order to focus on accomplishing the immediate project objectives of getting the Consortium Agreement signed and Lisa's contract and CA in place.

Discussion of Lisa's CA and Contract. Lisa will prepare an in-depth scope-of-work and circulate to the Consortium. Additionally, Marty has asked Lisa to prepare an amended budget to include expected travel and meeting expenses. The issue of funding travel to conferences for presentation in fiscal year 2005 was discussed. Marty will need to alert Randy Jackson of this "No-cost" extension required by the uniqueness of this project in order to be able to cover these 2005 costs. Lisa was directed in her role in the final report preparation, to coordinate and assist the Consortium members but not to be the primary author. Lastly, the Consortium discussed the pros/cons of including the conference call charges in Lisa's contract, instead of alternating this out-of-pocket expense between Consortium members. Lisa will check on more cost-competitive options in this regard and include it in her budget for discussion purposes.

Teleconference Consortium Meeting, October 15, 2003

Attendees: Craig Bartels (Hydranautics), Matthew Hallan (Filmtec), Lisa Henthorne (M&E), Peter Knappe (TriSep), Peter Metcalfe (Toray), Marty Peery (Filmtec), Irv Shelby (Hydranautics)

Meeting Minutes

Review of anti-trust guidelines and considerations.

Request of any changes/comments to the draft October 9, 2003 teleconference minutes. Marty suggested the language be slightly edited in the last paragraph to replace the wording regarding Lisa not being the primary author to read that "the preparation of the final report will be a Consortium team effort, with Lisa being the coordinating editor".

Consortium Agreement Status

Filmtec indicated the Consortium Agreement would be FedExed out today, with 4 copies being circulated. Once the Agreement is received, please sign all 4 copies and FedEx to the next recipient as quickly as possible. Filmtec will be the last Consortium member to receive the package, and will take the responsibility of sending an original fully executed (signed) Agreement to each member.

Kick-Off Meeting Agenda

The meeting agenda was presented. It was recommended that the Constraints and Limitations discussion be moved to the 9:30 am time slot. The Consortium reached consensus that the vessel manufacturers (Progressive and Pentair Codeline) be requested to participate in the Constraints section agenda relevant to vessel construction either by teleconference call or written recommendations. Doug Eisberg will be the contact person at Progressive and Lisa will contact George Fernandez (President, Codeline, 262-780-7310) to determine who in Codeline is the best technical contact. Lisa will prepare a draft email for the Consortium to review by 10/17/03 that will be sent to the contact people. Similarly, 2-3 pump manufacturers will be sent similar emails (What companies do we want to use here??)

There was significant discussion regarding the Constraints and Limitations topic (changed to Constraints, Limitation and Assumptions) regarding topic of potential anti-trust areas. It was resolved that the Consortium would just have to make agreed-upon assumptions regarding some of these topics. By beginning these discussions now, we could lessen the workload at the kick-off meeting.

As a result, we began discussing assumptions for some of the Study Parameters such as plant and train size. The plant size is only an issue relative to the minimum plant size for which the large-diameter element would be applicable. An excellent paper recently presented by Boris Libermann on the Ashkelon project was suggested as reading material for all Consortium members. This paper evaluated the issues regarding a centralized versus decentralized system design, which impacts the train size, control configuration, pumps sizing, etc. The paper will be circulated to all members to read prior to the next conference call. Additionally, Irv will send Lisa the paper by Rick Lesan regarding work on large element diameter membranes.

Follow-on discussion included determination of assumption values for the feedwater applications and flux rates to be evaluated. The Consortium agreed that rather than specific feedwater definitions, we would utilize the classifications of Brackish/High Flux, Brackish/Low Flux and Seawater/Low Flux as then three general categories to be evaluated. Average system flux rates determined by the Consortium are shown on the attached table. Because time was running short, Lisa indicated she would make suggested parameter recommendations for some of the remaining Economic Study Parameters, for discussion during the next conference call. Additionally, she will revise the Kick-Off Agenda for further discussion.

It was determined by unanimous vote that the Consortium would benefit by having the A&E Project Manager present at the kick-off meeting. The date for the meeting was changed to Tuesday, November 4, 2003 to include time to be able to include CH2M Hill in this meeting. Lisa will ensure that this date is acceptable to CH2M Hill during the initial discussions with him. If not, we will adjust the date accordingly.

<u>CH2M Hill Contract.</u> Lisa and Marty will work together to contact Jim Lozier as soon as possible regarding their potential contract award. She will begin the discussions of the contract negotiation including those items identified in the conference call minutes dated October 9, 2003. The other proposed A&E firms shall be notified as quickly as possible after it is determined that a successful contract negotiation will occur with CH2M Hill.

Discussion of Lisa's SOW and budget. The revised and detailed SOW prepared by Lisa was approved. Peter Knappe indicated he did not receive the budget via email, and Lisa will email it to him ASAP. Marty indicated the budget included the additions of one additional staff day in Tasks 1 and 2 for additional work being requested from Lisa over what she had proposed. Travel cost, meeting expenses and teleconferencing calls were also included in her non-labor budget. The cost-sharing is considerably more than the initial proposed level due to the additional cost-share being provided by M&E for Lisa's increased overhead rate as an M&E employee. The Bureau of Reclamation encourages as much cost-sharing as possible so this is a positive benefit to the project. With the exception of Peter Knappe, Lisa's budget was approved by the Consortium. After Peter receives the budget by email he will indicate his approval/disapproval in order to ensure the unanimous vote required on all budget issues according to the Consortium Agreement. It was determined that the combined budgets for Lisa and CH2M Hill were about $94,000, allowing only $6,000 unallocated. This may be needed for unforeseen financial needs during the project life and should be kept in reserve.

Next teleconference meeting. The next conference call is scheduled for October 22, 2003 at 10:00 am CST, 9:00 am MST and 8:00 am PST. Lisa will set up the conferencing call and notify all Consortium members of the arrangements.

Assumption Values for Economic Study Parameters for 8-inch and Large-Diameter Scenarios

Parameter	Brackish – High Flux	Brackish – Low Flux	Seawater
Plant size (mgd)*	50	50	50
Train size (mgd)			
Avg. system flux (gfd)	17-18	10	8-9
Inlet feed pressure (psi)	400	400	1,000
Pretreatment standards (SDI)	3	4	3
Specific flux (gfd/psi)			
Fouling rate (gfd/psi)			
Maximum velocity (ft/s)			
Minimum velocity (ft/s)			
8-inch membrane area per element (ft^2)	400	400	370
A - Large diameter membrane area per element (ft^2)			
B – Large diameter membrane area per element (ft^2)			

*Will want to identify approx. range of minimum plant sizes that large-diameter elements benefit

Teleconference Consortium Meeting, October 22, 2003

Attendees: Craig Bartels (Hydranautics), Matthew Hallan (Filmtec), Lisa Henthorne (M&E), Peter Knappe (TriSep), Peter Metcalfe (Toray), Marty Peery (Filmtec), Irv Shelby (Hydranautics)

Meeting Minutes

Review of anti-trust guidelines and considerations.

Request of any changes/comments to the draft October 15, 2003 teleconference minutes. None indicated. The Consortium has 7 days from date of receipt to make comments on the minutes prior to them becoming final. Once final, Lisa prints them out as Final and they are kept as a hard copy in a file in her office.

Consortium Agreement Status

Filmtec indicated the Consortium Agreement has not been sent out yet, as originally anticipated. It is expected that it will be sent out before the end of the week, in the manner discussed previously. Remember to expedite the signatures once received and FedEx to the next party.

CH2M Hill Contract Negotiation

Lisa provided an update to the status. Lisa and Marty talked with Jim Lozier on this past Monday afternoon (10/20/03) regarding notification of contract negotiation with CH2M Hill. In a separate telephone conversation with Jim, Lisa walked Jim through the specific issues to be finalized prior to contract award to CH2M Hill. Lisa followed this conversation up with an email to Jim documenting these issues. Lisa also provided Jim with her “sample” Confidentiality Agreement and Excel spreadsheet of her budget with the break-out by project tasks and cost-sharing, for CH2M Hill’s use.

Jim has indicated our suggested Kick-Off meeting date of November 4, 2003 in not workable for him, and his suggested dates of November 20 or 21 do not work for some of the Consortium members. The new date for the Kick-Off is Tuesday, December 2, 2003. Lisa will check with Jim ASAP to ensure this date works for him.

It was determined that the respective Consortium members should notify the unsuccessful A&E proposers as quickly as possible. Accordingly, Lisa will prepare a standard notification email for each individual to utilize, which will indicate the Consortium's present negotiation status with one of the other proposers and that their services are not required at this time.

Kick-Off Meeting Pre-Work

The Consortium members discussed the parameters shown on the attached table at length, particularly the train and plant size. The Liberman paper is required reading for all Consortium members prior to next week's conference call. A significant discussion of the application of this paper to our project ensued. The issue of decoupling of the high-pressure pumps from the train is a critical issue. It was not evident that Liberman considered the energy requirement dictated by operating all the trains within the domain of a single pump at the pressure required by the train with the greatest pumping need. There would need to be close monitoring of operation to ensure equal run time on all trains to minimize this impact. After this discussion, it was clear that the CH2M Hill will need to run their cost analysis for 2-3 different total plant capacities. Additionally, their presence is needed to discuss the specified train capacity and decoupling of the pumps and trains. Lisa will ask Jim to join our November 5, 2003 conference call in order to begin to get his input on these issues. His participation will be dependent on the ability to resolve the negotiation issues mentioned above and the subsequent issuance of a Notice to Proceed to CH2M Hill.

Further discussion followed on some of the remaining study parameters. Estimates for discussion purposes were determined as shown on the attached table. It was determined that the pretreatment standards did not require specification but that CH2M Hill should utilize appropriate pretreatment technologies for the respective applications (BW high flux; BW low flux; and seawater).

Discussion of status of Lisa's contract

Marty will be meeting with the Dow lawyer tomorrow (10/23/03) to iron out the last issues in the contract language. The Confidentiality Agreement appears to be acceptable to the legal staff. If the provided M&E contract language is unsuitable to Dow's lawyer, Lisa offered to switch to a Dow contract to expedite matters. Marty will notify Lisa this week if there appears to be problems that require her intervention.

Lisa is in the process of switching to her new M&E email address, which is Lisa.Henthorne@m-e.com Either email address will work, but the new address is preferred.

Next teleconference meeting. The next conference call is scheduled for October 29, 2003 at 10:00 am CST, 9:00 am MST and 8:00 am PST. All conferencing information is identical to that used this week, and for the follow-on conference calls. Lisa will not send out these instructions each week. If you lose or forget the call-in and conference ID numbers, please let Lisa know and she will resend them to you.

Teleconference Consortium Meeting, November 5, 2003

Attendees: Craig Bartels (Hydranautics), Matthew Hallan (Filmtec), Lisa Henthorne (M&E), Peter Knappe (Trisep), Jim Lozier (CH2M Hill), Peter Metcalfe (Toray), Marty Peery (FilmTec), Irv Shelby (Hydranautics)

Meeting Minutes

Review of anti-trust guidelines and considerations.
Lisa will send guidelines to Jim for his information.

Consortium Agreement Status

Toray presently has the agreement. Hydranautics, FilmTec and Trisep have signed. Toray will forward to FilmTec after signature for distribution. Marty will provide Lisa and Jim with copies for their records.

CH2M Hill Contract Negotiation

Craig and Peter M. provided notification to MWH, Carollo, Hartman and UAI regarding the Consortium negotiation with another A&E firm. UAI has requested feedback on their proposal and Peter M. will provide verbally.

Jim provided a CA and edited budget worksheet. There were a few suggested minor changes in the budget worksheet which Jim will prepare and redistribute. The CH2M Hill CA language will be incorporated into the FilmTec/CH2M contract language. Marty has sent the draft contract to Jim for CH2M's review. Additionally, both Lisa and Jim will be held to the Bureau of Reclamation Assistance Agreement provisions. Marty will upload this information to the CH2M ftp site once Jim provides instruction, as the file size is too large to email from FilmTec. Jim will then forward it to Lisa.

A detailed Scope of Work will be required from CH2M similar to that required from Lisa. Lisa will email hers to Jim for his information regarding the level of detail required. Though Jim is out of the country from November 7-15, he will ensure progress is made within CH2M regarding review of the documents during his absence. The goal is to get a purchase order issued to CH2M prior to the December 2 meeting. If this is not feasible, Jim will ensure his attendance by obtaining necessary internal approvals.

Pre-work for Kick-Off Meeting

Lisa provided feedback to Doug this week regarding preference on obtaining only non-confidential information from Protec. She has not received a reply yet. She has also contacted Kevin Goodge's office and provided the letter requesting information from Codeline and will be talking with him on Nov. 6 when he returns to the office. Jim indicated the critical pieces of information from the vessel manufacturers to be diameter limitation, cost of the vessels, and any handling restrictions.

Regarding obtaining information from other key players in the industry, Jim indicated that CH2M could gather this input during the economic study (Task 2) of the project. Jim indicated that the “ergonomic factor” was of particular importance and that this should be comprehensively discussed at the Kick-Off meeting to ensure its impact is properly considered in the economic study.

The train size was discussed in relation to the Liberman paper. It was determined that the assumptions for the economic study would greatly influence the train size. The team will discuss and determine these assumptions during the Kick-Off meeting and then CH2M will propose the train size based on these discussions.

The plant size was discussed and Jim indicated that CH2M could develop a cost curve for cost versus plant size for the 8-inch case and two large-diameters cases in order to determine at what approximate capacity the large-diameter element becomes most cost-effective. This will be provided by CH2M within the existing budget structure.

Status of Lisa’s Contract

Marty will provide a copy of Lisa’s contract for review to the Consortium members. It is anticipated that a purchase order can be issued by November 10, 2003.

Lisa will provide a contact list for the team ASAP.

Next teleconference meeting The next call is scheduled for Friday, November 21 at 8:00 am PST, 9:00 am MST, and 10:00 am CST. Call-information remains the same for all calls.

Teleconference Consortium Meeting, November 21, 2003

Attendees: Lisa Henthorne (M&E), Peter Knappe (Trisep), Jim Lozier (CH2M Hill), Peter Metcalfe (Toray), Marty Peery (FilmTec), Irv Shelby (Hydranautics)

Meeting Minutes

Review of anti-trust guidelines and considerations.

<u>Consortium Agreement Status</u>

All parties have signed the Consortium Agreement and originals have been sent out to each Consortium member. Marty will send a copy to Lisa and to Jim for their records.

<u>CH2M Hill Contract Negotiation</u>

The Dow lawyers are presently reviewing the comments received by the CH2M staff on the contract language for the Dow/CH2M contract. Their response is expected back to Jim by Monday, November 24, 2003. Jim is in the process of developing the detailed Scope of Work (SOW), and is awaiting input from other CH2M team members. One issue that remains outstanding in the CH2M proposal is their proposed concept of utilizing a constant number of vessels for each train for each of the costing scenarios (8-inch and two large-diameter element scenarios). This concept was discussed by the Consortium and was generally accepted as being less limiting than other options. Unfortunately it will preclude the study from determining an approximate train size at which the large-diameter element becomes cost-effective. Jim will address this issue specifically in the SOW to provide some flexibility in this regard. The Consortium will review this language to ensure it is acceptable to meet the needs of the project.

<u>Pre-work for Kick-Off Meeting</u>

Lisa indicated that both Protec (Doug Eisberg) and Codeline (Kevin Goodge) will individually participate in the upcoming Kick-Off meeting via a teleconference call. The questions generated by the Consortium have been distributed to both parties. Lisa will notify them as to the call-in information and time.

The issue of including metal tubes into our discussion was introduced, particularly for seawater applications. Koch is presently using medal tubes in their large-diameter element application in their refinery in Corpus Christi, Texas. It was decided that the Consortium will wait until after the Kick-Off Meeting and discussions with Protec and Codeline to determine whether metal tubes should be considered and manufacturers consulted.

The Kick-Off Meeting Agenda was evaluated and no comments were introduced.

The logistics of the Kick-Off Meeting were discussed. All parties will be residing at the Quality Suites. Lisa will re-send the logistics information to all parties, as some did not receive them. Lisa will plan on meeting all attendees in the lobby of the hotel about 7:30 am for transportation to the meeting at the Mt. Vernon Country Club. We will need to ensure we wrap up the meeting by 5:00 pm to allow the Dow staff to catch their flight.

Lisa will have a computer and meeting supplies at the meeting site, including a flip chart and tape recorder for documenting the day's discussion. Lisa will utilize the tape recorder to prepare the minutes from the meeting, and will then destroy the tape. Peter Metcalfe will bring an LCD projector to the meeting.

Status of Lisa's Contract

Lisa's contract has been finalized and is in place within Metcalf and Eddy.

Next meeting Kick-Off Meeting in Evergreen, Colorado on Tuesday, December 2, 2003.

Meeting Minutes

Membrane Consortium Kick-Off Meeting, December 2, 2003

Held at the Mt. Vernon Country Club, Boardroom, Golden, CO

Attendees: Craig Bartels (Hydranautics), Matthew Hallan (Filmtec), Lisa Henthorne (M&E), Peter Knappe (TriSep), Jim Lozier (CH2M Hill) Peter Metcalfe (Toray), Marty Peery (Filmtec), Irv Shelby (Hydranautics)

Anti-Trust guidelines

The meeting began with a thorough review, reading and discussion of the anti-trust guidelines and considerations. The guidelines, as discussed, include:

DO:

Adhere to the Agenda
Understand the purpose of the meeting
Protest or speak up if concerned

DON'T

Discuss in fact or appearance:

1. pricing of membrane products or data that bears on pricing or production
2. Industry pricing policies
3. Changes in industry production
4. Bids on contracts or procedures
5. Plans concerning design or production of products
6. Matters relating to suppliers of raw materials
7. Termination of manufacturing of a product

Socially exchange information or discuss any of these matters

Review of project goals and objectives

Project goal: Establish an optimum large diameter element standard agreed upon by the Consortium thereby enabling competitive project bidding, considering manufacturability, system design limitations and capital cost reductions.

Project Objectives

1. Develop the parameters, outline and scope of an objective and comprehensive Economic Study

2. Conduct the Economic Study including capital and life cycle cost analyses of different element diameters in different applications.

3. Develop Consortium consensus regarding optimum parameters

4. Communicate recommended standard and supporting documentation to industry and water treatment community

A lengthy discussed ensued regarding soliciting input from potential users now. As a result of this discussion, the Consortium decided to develop a press release and survey to gain the following information.

Purpose: Communicate to users that this is on-going and get buy-in from users

Timing: Harvest the info in early January to use it in the Economic Study

Input to be requested: Benefits and advantages and disadvantages
Issues they perceive (handling)
Would they consider using large diameter elements?
What info do they need to see (cost, performance)?
What is the potential size of their future plants?
What limitations of applications?

Names: We should provide Lisa with 5-10 names (OEM's End Users, A&E) from each member company by 12/8/03. Lisa will provide first draft of document by 12/8/03. The document can be sent via email to these individuals with a follow-on phone call from each specific Consortium member. The email will include the overview of the project. We should ensure that we include Yuma.

<u>Expected meeting accomplishment</u>
We want to accomplish the following today:
Provide sufficient information for Jim to get started on the Economic Study
Develop the assumptions and design parameters for the Economic Study
Determine a picture of the final products including:
Report to USBR,
Technical papers and presentations
CH2MHill Report
Clear definition of limitations and assumptions

Economic Study Outline

What do we want to achieve with the Economic Study?

Good Baseline (believable, credible, document assumptions,
Relative Assessment (not necessarily absolute costs, relative value of large diameter, generic based on assumptions, recognize site specificity of RO, consider upper bound limits)

What does the Economic Study look like?

Definition of cases
General assumptions and specific assumptions
Design including process flow diagram of the entire plant and lay-outs of the RO building
Cost analysis of the 9 cases including output sheets
The study will also indicate the number of plants the cost model is based up and will include labor costs
Results and conclusions

Discussion of Assumptions, Constraints and Limitation

Assumptions

1. Element Length – 40" (alternate lengths may be available whereas the vessel length is more important)

2. Element Performance – No difference from current 8" performance

3. Fouling Rate – Same, based on same hydraulics

4. Active Area – 400 ft2/370 ft2 SWRO scaled as a function of the square of the diameter

5. Core Tube diameter – scale product water tube diameter with the flow increase to maintain same velocity.

6. Life Cycle costs – 5% discount rate 20 year term with sensitivity case of alternate term,

7. Power costs - $0.06/kwhr for BWRO, $0.04 for SWRO

8. Recovery – 85% for BWRO cases, need to minimize waste, limited by scaling for SWRO – 45%

9. Temperature – 25 C

10. Permeate Pressure – 15 psi to move water to storage

11. Membrane Life – 5 years

Limitations

1. Manufacturabilty
   Leaf length and number of leaves
   Delta P loading on last element
   Element length
   Core tube diameter

   Koch used 2”, unsure why (availability, same linear velocity, mechanics of attaching leaves)

2. Handling and loading
   Need to ensure we address this in the final report
   How are we going to load – will impact footprint

3. Vessel Manufacturability (see attached responses from Pentair and Progressive Composites)

4. Hydraulics

5. Element components

6. ASME code restrictions 20” BWRO, 16” SWRO

<u>Discussion of Economic Study Parameters</u>

The following parameters were determined

Plant Sizes to be evaluated: 25, 50, 100, and 150 Mgd; Base Case is 50 mgd

Assumption Values for Economic Study Parameters
for 8-inch and Large-Diameter Scenarios

Parameter	Brackish – High Flux	Brackish – Low Flux	Seawater
Plant size (Mgd)- Base case	50	50	50
Train size (Mgd)	12.5	10	8.4
Vessels per train	70	90	90
Trains per plant for Base case	4	5	6
Elements per vessel	7	7	7
Feedwater salinity (mg/L)	800	1,500	38,000
Avg. system flux (gfd)	16	10	9
Inlet feed pressure (psi)	400	400	1,000
Specific flux (gfd/psi)	0.2-0.25	0.12-0.13	0.03-0.04
Fouling rate (%)	5	10	5
Brine/permeate ratio	5:1	5:1	5:1
Cleaning frequency	1 per year	3 per year	2 per year
Staging	2:1	2:1	single
8-inch membrane area per element (ft^2)	400	400	370
Diameter A (inches)	16	16	16
Diameter B (inches)*	20	20	12

*To be finalized at a later date via conference call

Additional Outreach Efforts – Press Release for our Consortium, IDA, AWWA, ADA, MTN, etc. Request input from industry personnel (Peter Knappe will set up a web site for their input) Lisa will prepare draft press release for review and comment.

Teleconference Consortium Meeting, December 17, 2003

Attendees: Craig Bartels (Hydranautics), Matt Hallan (FilmTec), Lisa Henthorne (M&E), Peter Knappe (Trisep), Jim Lozier (CH2M Hill), Peter Metcalfe (Toray), Marty Peery (FilmTec), Irv Shelby (Hydranautics)

Meeting Minutes

Review of anti-trust guidelines and considerations.

CH2M Hill Contract Status

The CH2M contract has been finalized and should be signed and mailed to CH2M in the next few days.

Comments on Kick-Off Meeting minutes and vessel manufacturer's Q&A

The minutes and Q&A were accepted as final by the Consortium.

Kick-Off Meeting Post-Work

The Consortium Team discussed the value of obtaining more specific and refined feedback from the vessel manufacturers at the 16" diameter (and eventually the alternative large-diameter). Lisa will send an email to both Kevin Goodge and Doug Eisberg ASAP to obtain this information.

The survey form was discussed at length and improved based on feedback from each attendee. Lisa will make the appropriate changes and provide to each Consortium Team member for their distribution. The distribution list was further refined as well. Lisa will ensure no duplications exist in the list and email it with the assigned contacts to each Consortium Team member. It was noted that the survey should be emailed out from each individual as soon as possible. The deadline for submission of the surveys is January 9, 2004. Each Consortium Team member should be prepared to follow up by phone with their respective contacts early in the week of January 5, 2004 to answer any questions and remind the contact to email or fax their completed surveys to Lisa.

The press release was discussed and further refined. Peter K. suggested that the press release not be distributed until the website was up and running. Peter K. will take responsibility for the website and provide a draft of the contents to the Team for review before it becomes accessible to the public. Each membrane company within the Consortium should email Peter K. their logo at their earliest convenience. Peter K. will provide the draft as soon as possible for review.

Jim and Bob Bergman have not had an opportunity to discuss the project details further, in order to determine if there is additional information needed from the Consortium or issues to be resolved prior to initiation of the Economic Study. Jim is to have a conference call with Bergman in the coming week regarding the project and will email any issues or questions to the Consortium after the call.

1st Quarter Progress Reports

The 1st quarter progress reports are due to Reclamation in January. Lisa will prepare the draft technical progress report and send to each to review by January 9, 2004. Lisa requests that the financial information be provided to her by January 9, 2004 in order that she can prepare the draft financial report to FilmTec for submittal. Please submit labor hours, direct expenses and any other related costs to Lisa. Lisa will prepare a 'blind" submittal to Filmtec which will be a composite cost-share value for the Consortium. This will then be submitted directly from FilmTec to the Bureau of Reclamation.

Next meeting The next teleconference call is scheduled for Wednesday, January 7, 2004 at 8:00 am PST, 9:00 am MST and 10:00 am CST.

Teleconference Consortium Meeting, January 28, 2003

Attendees: Craig Bartels (Hydranautics), Matt Hallan (FilmTec), Lisa Henthorne (M&E), Peter Knappe (Trisep), Bob Bergman (CH2M Hill), Peter Metcalfe (Toray), Marty Peery (FilmTec), Irv Shelby (Hydranautics)

Meeting Minutes

Review of anti-trust guidelines and considerations.

Comments on Minutes from January 7 conference call

The minutes were accepted as final by the Consortium.

Follow-On with Vessel Manufacturers

Survey

The team discussed the overall response from the surveys. It was agreed that the information needed to be condensed down into something more useable and quantitative. Marty agreed to take on this assignment. Additionally, the survey results from the website survey will be compiled in an Access database and Peter K. will provide this periodically to the team. To date there have been 110 hits on the website.

Press Release

Lisa reported that the project press release was made to SEDA, IDA, AMTS, EDS, D&WR Quarterly, AWWA Journal and Water Desalination Report. There were follow-on questions from a number of these entities which Lisa responded to.

CH2M Hill Questions

Bob had a number of questions which he posed to the team. This listing and responses is shown below:

1. Will feed water bypass/blending be considered for the low TDS cases? ***-- No; not in any of the cases.***

2. Will energy recovery be considered for the low TDS cases? ***-- No; only consider for the seawater source water.***

3. What should be the assumed plant operating factor for the operating cost calculations to allow time for maintenance, cleaning, repairs. etc.? ***-- 95%***

4. What site costs should be considered (outside of the membrane building)? ***-- None are required.***

5. The December 2 meeting minutes included the train size for each source water in a table of assumptions. Is that the train size for all membrane elements sizes? ***-- No; just the larger diameter elements (the 8" elements will have the same number of pressure vessels per stage but smaller`train capacity); CH2M HILL should propose an assumed train size for each case after re-review of the Faigon-Liberman IDA paper.***

6. Also in the Dec 2nd assumption table, what is the meaning of the inlet feed pressure? ***-- It is the pressure vessel rating; not the assumed membrane feed pressure for the cost analyses; CH2M HILL is to propose an assumed feed pressure for each case.***

7. Confirm if the design is to assume one feed pump per train of a pumping center concept? ***-- Use the pumping center concept for all cases.***

8. What pressure vessel costs shall be assumed for the 8" vessels and what should be the scale-up factor for the larger sizes? ***-- CH2M HILL shall review the correspondence from the two pressure vessel manufacturers and propose assumed costs and size scale-up factors.***

1st Quarter Progress Reports

The technical and financial progress reports were submitted to the Bureau of Reclamation. Marty reported that the cost sharing amounted to $54,758.35 from the 1st quarter from the Consortium members. This number does not include the $9,146.95 from M&E.

Other

Lisa announced the upcoming IDA workshops on seawater RO pretreatment and invited the Consortium members to participate in the manufacturer's roundtable at this workshop. Lisa will provide follow-on information to the Consortium regarding the topic of discussion for the roundtable.

Next meeting The next teleconference call is scheduled for Tuesday, February 10, 2004 at 8:00 am PST, 9:00 am MST and 10:00 am CST.

Teleconference Consortium Meeting, February 26, 2004

Attendees: Craig Bartels (Hydranautics), Matt Hallan (FilmTec), Lisa Henthorne (M&E), Peter Knappe (Trisep), Bob Bergman (CH2M Hill), Marty Peery (FilmTec), Irv Shelby (Hydranautics), Jim Lozier (CH2M Hill)

Meeting Minutes

Review of anti-trust guidelines and considerations.

Comments on Minutes from January 28 and February 10 conference calls

No one received the minutes which Lisa sent out on February 12. The team did receive the minutes within the package of all meeting minutes which were emailed to Frank Leitz, the Bureau of Reclamation COTR, on early February 26.

Due to email problems, Lisa will request receipt notification when sending important emails to the team.

We will finalize the January 28 and February 10 minutes at the next conference call, in order to allow time for people to review them.

Follow-On with Vessel Manufacturers

Survey

Everyone was very pleased with the work Marty accomplished in summarizing the results from the survey. Marty explained the process he utilized to make the analysis. Of significance in the results was the prominence of the savings in plant footprint afforded by large-diameter elements. CH2M will be including this analysis in their work.

Also of note was the municipalities interest in ensuring procurement of vessels from multiple sources. The team discussed the threshold of newly installed capacity required to meet the 1,000 vessels per year per vessel manufacturer needed to make it financially feasible. This threshold was determined to be approximately 240 mgd per year. We will need to include a thorough analysis of this market evaluation in the Final Report.

Handling of the large-diameter elements was the most significant concern voiced in the survey. Both the elements and endcaps will require special handling equipment. Pushing the elements into place is also a concern of the Consortium. CH2M will initially assume a

10-foot area is required around the ends of the train to maneuver a fork-lift. Irv will prepare a brief analysis of potential handling equipment and the footprint required. CH2M will revise their overall footprint analysis based on Irv's results. It will also be necessary to include this analysis in the Final Report.

CH2M Hill Questions

There was significant discussion regarding the questions and responses provided in the last conference call. A problem developed in utilizing the train size for the large-diameter lay-out and assuming the same number of vessels for the 8-inch case. As a result, the constant vessel number approach will not be utilized but the 8-inch case will utilize 4 mgd train sizes.

Additionally, Bob recommended a change be made in the high flux and low flux brackish water scenarios. The high flux brackish case will be changed to 1,500 mg/L feedwater salinity and 15 gfd average flux. The low flux brackish case will be changed to 800 mg/L feedwater salinity.

A summary of the questions and responses summarized by Bob in follow-on emails are as follows:

1. Please confirm that we may use a single applied pressure for each source water condition (as we assumed in our original proposal) and that the fouling rate shown in the 12/2/03 assumption table does not need to be considered for estimating an increased pressure over time for the power cost analyses. -- ***Yes, it is OK to assume an average applied pressure (one for each of the three cases) for the power cost estimates.***

2. Please confirm that the sea water RO design will be a single pass system and no partial brackish water RO second pass will need to be assumed. -- ***Yes, the seawater case design is single pass.***

3. Can we change the 8" elements train size criteria to be more representative of large plants? The current method of having the same number of pressure vessels as in the large diameter element trains is making the 8" trains to small. -- ***Yes, make the 8" trains approximately 4 mgd each.*** *[It was agreed that CH2M HILL does not have to prepare multiple drawings showing the differences in the 8" and large diameter element trains.]*

4. We recommend that the following changes be made to the 12/2/03 assumption table: (A) brackish water high flux - change feed salinity to 1,500 mg/L, flux to 15 gfd, and recovery to 75% to represent a typical brackish groundwater system that has recovery limited by inorganics; (B) brackish water low flux - change feed salinity to 800 mg/L to represent a lower TDS surface water or reuse application. -- ***These changes are acceptable***

5. Are we to prepare the cost estimate for each of the three cases considering assumed pretreatment, post-treatment, and facility costs so the relative cost difference between 8" and large diameter elements trains can be determined and compared to the difference in total plant costs. -- ***Yes*** *[Also, conventional groundwater pretreatment is to be used for the brackish high flux case and MF/UF pretreatment for the other two cases.]*

Additional Questions

1. What is the basis for the pressure vessel manufacturers comments about cost scale-up? Did they assume end ports, side ports, or multiport styles for each of the three cases? Is the scale-up factor different for the three cases? A multiport design would minimize train manifold piping. Can large enough side ports (or multiports) be installed in the large diameter pressure vessels to be a viable product?

2. There is a very significant difference in the weight of the pressure vessels given to us by the two pressure vessel manufacturers. What is the basis for the weight estimates? Did they assume elements are installed or just empty vessels? Are they dry or "wet" weights? What type of vessel design(s) (end port, side port, or multiport) do the estimates assume?

Next meeting The next teleconference call is scheduled for Thursday, February 26, 2004 at 8:00 am PST, 9:00 am MST and 10:00 am CST.

Teleconference Consortium Meeting, March 17, 2004

Attendees: Craig Bartels (Hydranautics), Matt Hallan (FilmTec), Lisa Henthorne (M&E), Peter Knappe (Trisep), Bob Bergman (CH2M Hill), Marty Peery (FilmTec), Irv Shelby (Hydranautics), Peter Metcalfe (Toray)

Meeting Minutes

Review of anti-trust guidelines and considerations.

Minutes from January 28, February 10 and February 26 conference calls

All minutes accepted as final.

Further Discussion regarding Handling

From discussions with the Yuma staff, particularly Mike Norris, Irv indicated that their 12" end-caps were all placed by hand (no handling device). A plunger mechanism attached to the loading device assists in loading the elements into the vessels at the Yuma Plant.

It was discussed that for the larger diameter elements, more stabilization is required to the vessel platform to compensate for the pushing and pulling of loading elements. For the purpose of Bob's costing activities, it was assumed that two lift mechanisms would be required for loading elements, one of which would be equipped with a plunger.

AWWA Membrane Conference Call for Papers

The recent announcement of the Call for Papers for the 2005 AWWA Membrane Conference was discussed. Everyone agreed we should pursue publication of the project results at this conference. Lisa will prepare a draft abstract for the team to review, using the scope of the project from the proposal as a guide. All Consortium members will be listed as authors.

Economic Analysis

The team reviewed the flow diagrams and drawings, as well as the initial content in the cost estimate pdf files. A discussion was held regarding the need for cartridge filters downstream of the MF/UF systems in the brackish low flux and seawater cases. It was decided that no cartridge filters would be required, but in-line strainers would be used instead for these applications.

Bob indicated the work exchanger was used for cost estimating the energy recovery device. In the next edition of drawings, the flush pumps will be included in the process flow diagrams.

Bob also indicated that in our original assumption table, in the brackish water low flux case, we assumed a 7M vessel with 85% recovery in two stages. This is not physically possible. The team decided to assume a three-stage design for the brackish water low flux application, keeping the recovery at 85%.

Bob indicated there was no "local" factor included in the design. The CH2M Hill cost program utilizes a composite of U.S. facilities, and therefore the results would be applicable to a generic U.S. location.

Because the preliminary results which Bob provided indicated only a slight cost distinction between the large diameter and current 8-inch cases, Bob made it clear that the data was very preliminary at this point. Many of the estimates were placeholders and the bottom line did not reflect the final analysis. Bob also indicated that he predicted the large-diameter improvements would not be as significant as that seen in the Metropolitan Water District (MWD) analysis due to our assumptions. These differences in assumptions include 1) the number of pressure vessels per train; and 2) the centralized versus decentralized pumping/ER approach. The assumptions we are utilizing for this project are more realistic than the MWD assumptions, that is, we are varying the pressure vessel per train between 8" and large diameter cases and utilizing the centralized pumping/ER strategy.

Bob also sought input from the team on changing the TDS assumption to 2,000 for the brackish high flux case, as more representative of groundwater plants in the U.S. The team agreed.

Based on the limited viability of the cost information presented for the 8" and 16" cases, the team agreed to wait to make a decision on the alternate large diameter. Bob indicated the cost information for the 8" and 16" cases would be provided by March 26, 2004. April 8 was scheduled for the next conference call, allowing sufficient time for everyone to review the March 26 results. The goal is to have all the cases completed by the end of April.

<u>Schedule Consensus Meeting</u>

Dates were discussed for the Consensus meeting. May 11 appeared satisfactory. Follow-on emails after the conference call indicated this date would not work. Lisa will determine an acceptable date for everyone, including Frank Leitz, and provide this information prior to the next conference call.

<u>Next meeting</u> The next teleconference call is scheduled for Thursday, April 8, 2004 at 8:00 am PST, 9:00 am MST and 10:00 am CST. Be prepared to discuss the 16-inch case results to be provided by CH2M on March 26.

Teleconference Consortium Meeting, April 8, 2004

Attendees: Craig Bartels (Hydranautics), Matt Hallan (FilmTec), Lisa Henthorne (M&E), Peter Knappe (Trisep), Jim Lozier (CH2M Hill), Christian Colvin (CH2M Hill), Marty Peery (FilmTec), Irv Shelby (Hydranautics), Peter Metcalfe (Toray)

Meeting Minutes

Review of anti-trust guidelines and considerations.

Minutes from March 17, 2004

Minutes accepted as final.

AWWA Membrane Conference Call for Papers

The abstract was approved for submittal to AWWA. Jim Lozier will be the corresponding author, but all team members will be official authors. Jim was concerned regarding the copyright form requirements. Lisa will address the copyright as needed at this stage. Lisa will submit the abstract on behalf of the Consortium.

Economic Analysis

Bob has recently emailed pdf files containing the isometrics and CPES files for the 8-inch and 16-inch diameter cases for the three feedwater applications. Additionally, a summary table was provided which compares the economics for each of the cases. Jim will email the table documenting all the assumptions that were utilized in the analysis. The discussion focused on the summary table. It was noted that the O&M cost differed between the 8-inch and 16-inch cases. Christian indicated that he believed the primary difference was attributed to the lower cleaning cost for the 16-inch case due to reduced piping requirements. The team voiced a desire to have the Total Water Cost (TWC) for each of the cases. There was a concern voiced regarding the accuracy of extrapolation to a 50 Mgd facility. Jim indicated a conservative pricing approach was utilized to compensate for the lack of data relevant to a 50 Mgd facility. CH2M used vendor quotes to provide the needed information in these instances.

The team discussed that in the MWD analysis only RO system cost were considered. This type of analysis demonstrates a larger % change from larger diameter elements. The team asked that both the RO and total plant cost be broken out so that the % change in cost could be evaluated for each. Also, the team asked that the footprint size be included in the summary table for each case.

There was a brief discussion regarding the recent advertisement in the AWWA journal of the 18-inch diameter element.

Discussion then focused on the alternative large-diameter size. From the results provided on the 16-inch, it appears that the larger the diameter, the more significant the savings. The team discussed the relative merits of 20-inch, 12-inch and of a technology leap to a 24-inch diameter design. The 24-inch diameter would push the bounds of existing technology and would be a what-if evaluation.

Because of time considerations, the team adjourned to reconvene next week. CH2M will take the lead to schedule this conference call. Bob will be available during the call to answer specific questions relative to the economic analysis.

<u>Schedule Consensus Meeting</u>

May 25 appears workable. *Note that since this conference call the meeting date has changed to May 27.*

<u>2nd Quarter Progress Reports</u>

Lisa asked that all financial information be provided to her by April 16. Lisa will email a draft 2nd quarter progress report for review by April 16 as well. Jim will provide Lisa with text to address CH2M's progress.

<u>Next meeting</u> The next teleconference call is scheduled for the week of April 12. CH2M to schedule the specific time.

Teleconference Consortium Meeting, April 13, 2004

Attendees: Craig Bartels (Hydranautics), Lisa Henthorne (M&E), Peter Knappe (Trisep), Jim Lozier (CH2M Hill), Bob Bergman (CH2M Hill), Marty Peery (FilmTec), Irv Shelby (Hydranautics), Peter Metcalfe (Toray)

Meeting Minutes

Review of anti-trust guidelines and considerations.

Alternative Diameter

Lisa reiterated the deliverable for the project: a recommendation for the industry for a large-diameter element standard. There was discussion as to the necessity of having to evaluate the specific economics for this standard or whether an interpolated diameter could be recommended. The consensus was that interpolation was acceptable.
If a 24-inch diameter was chosen as the alternative diameter for analysis, it would require significant interpolation between 16-inch and 24-inch.

There was discussion regarding the option of recommending two standards, one for brackish water and one for seawater. It was felt that this was unacceptable as it would require a very large number of very large plants to justify the membrane and vessel manufacturers' increased manufacturing and development costs for multiple large-diameter standards.

Jim reiterated that cost was only part of the equation. Handling considerations, vessel supply and demand were equally important considerations.

Bob indicated that the current economic analysis assumes that element cost is a direct function of membrane area, i.e. 4:1 ratio of cost for 16-inch:8-inch comparison. Should this assumption be utilized for our alternative diameter? The Consortium indicated yes, as they could not enter into discussions regarding element cost within the Consortium.

Jim indicated that if the range of diameters was 8- to 16-inches for the seawater and 8- to 24-inches for the brackish water applications, the accuracy between the analyses would be different. The team preferred to use the same alternative diameter for both seawater and brackish water applications.

The train size was also discussed. We don't want to have less than 4 trains for a plant so that the plant availability is acceptable during train shut-downs. This will require some additional analysis at the 25 Mgd plant size.

After lengthy discussion, the team chose 20-inches as the most suitable alternative diameter, as it was plausible for both brackish and seawater applications and meets the other desired criteria presented above.

Bob will prepare the economic analysis for the 20-inch design and provide it to the team by April 21. CH2M will also begin the analysis of alternative plant capacities of 25, 100 and 100 Mgd (50 Mgd is the capacity used in all analyses to date).

Schedule Consensus Meeting

The meeting date has changed to May 27.
Lisa will provide a draft agenda by April 16 for the team to review.

2nd Quarter Progress Reports

Reminder, please send financial information asap.

Next meeting The next teleconference call is scheduled for April 29, 8:00 am PDT.

Teleconference Consortium Meeting, April 29, 2004

Attendees: Craig Bartels (Hydranautics), Lisa Henthorne (M&E), Peter Knappe (Trisep), Jim Lozier (CH2M Hill), Bob Bergman (CH2M Hill), Marty Peery (FilmTec), Irv Shelby (Hydranautics), Peter Metcalfe (Toray)

Meeting Minutes

Review of anti-trust guidelines and considerations.

Acceptance of minutes from April 8 and 13

Minutes were accepted and Lisa will email them to Frank Leitz and Susan Martella, the COTRs.

Economic Analyses at 50 mgd

Bob led the group through a discussion of the 20-inch scenario cost files indicating there had been some minor errors which had been fixed in the CPES models such as the inlet pressure on the brackish surface water case, and the cleaning cost and number of cleanings. The results indicate there is no significant economic benefit to go from 16-inch to 20-inch diameter.

Bob has also done a side-by-side comparison to the MWD study comparing the 8- and 16-inch diameter elements. He indicates that by going to a centralized pumping and energy recovery and the same number of pressure vessels per train, we have eliminated some of the economic benefit as seen in the MWD study. Additionally, with our cost assumptions of a straight 4:1 ratio for membranes and vessel cost for 16-inch compared to the 8-inch scenario, we do not gain any economy-of-scale benefits. Our cost savings is primarily in piping and instrumentation.

Alternative Capacities

The team discussed the challenge of evaluating the 25 mgd case for the alternate capacity evaluation. Presently we anticipate developing cost curves at 25, 50, 100 and 150 mgd. The challenge at 25 mgd is the requirement to not fall below 4 trains. This will require additional work on the cost models to include the modifications to utilize a minimum of 4 trains. Bob will develop an estimate of how much additional time is required for CH2M to develop the 25 mgd cost estimates.

There was continued interest in evaluating a 10 mgd case in order to ensure the users understand where the economics for large-diameter elements become beneficial.

CH2M Hill will develop a spreadsheet indicating the work they have done beyond their original scope and what additional work may be required.

Consensus Meeting

The draft agenda has been provided to the team. Discussion of the agenda will wait until the economic analyses results have been more fully discussed. There is a concern that we may not be sufficiently completed with the economic analyses to hold our meeting on May 27. We will discuss further on the next conference call.

2nd Quarter Progress Reports

Progress reports were submitted. In-kind cost-sharing is $58,488 through the second quarter.

Next meeting The next teleconference call is scheduled for May 5, 8:00 am PDT.

Teleconference Consortium Meeting, May 5, 2004

Attendees: Craig Bartels (Hydranautics), Lisa Henthorne (M&E), Peter Knappe (Trisep), Bob Bergman (CH2M Hill), Marty Peery (FilmTec), Irv Shelby (Hydranautics), Peter Metcalfe (Toray)

Meeting Minutes

Review of anti-trust guidelines and considerations.

Economic Analyses - Comparison to MWD Results

The discussion focused on the comparison of the 8- and 16-inch results for a 50 mgd plant to the MWD study results for a 185 mgd plant. The comparison utilizes the brackish groundwater for comparison as being most representative to the MWD scenario. Bob presented the assumptions he has used, particularly in developing the overall RO skid cost. The biggest assumption was the utilization of a detailed lay-out for the seawater scenario which was then ratioed in cost for the brackish groundwater and surface water cases. Bob indicates that as a result of our discussion, he has probably not provided sufficient benefit to the large-diameter cases for this ratio, and he will revise the cost estimates accordingly. Additionally, from our discussion, Bob will re-evaluate the footprint and equipment cost, the labor rate and number of staff. He will provide these revisions by May 14.

CH2M Hill Scope Expansion

The additional cost required by CH2M to prepare the 25 mgd case has not been prepared yet. Lisa will discuss with Jim asap the need to provide a spreadsheet of all tasks that have been or may be done which are beyond their existing scope, with the associated cost estimates. These include the 25 mgd capacity cost, a detailed layout and cost for the brackish groundwater and surface water cases, and a detailed layout and cost for the 20-inch seawater skid.

Consensus Meeting

It was determined that the meeting should be postponed until the week of June 7. Lisa will determine the availability of Frank Leitz and Susan Martella, and the meeting location.

Next meeting The next teleconference call is scheduled for May 17, 8:00 am PDT.

Teleconference Consortium Meeting, May 17, 2004

Attendees: Craig Bartels (Hydranautics), Lisa Henthorne (M&E), Peter Knappe (Trisep), Jim Lozier (CH2M Hill) Bob Bergman (CH2M Hill), Marty Peery (FilmTec), Irv Shelby (Hydranautics)

Meeting Minutes

Review of anti-trust guidelines and considerations.

CH2M Hill Scope Expansion

Jim and Bob walked the group through the spreadsheet of their scope expansion and related cost. They had held a brief conference call with Marty and Lisa immediately prior to the team conference call. Items 1-3 were tasks that have already been completed including the additional CPES modeling cost not originally anticipated, preparing the comparison table to the MWD study, and conducting the CPES model modifications required for the 25 mgd capacity evaluation. Items 4-6 include detailed cost estimates for the 20-inch seawater case, and detailed costing for the groundwater and surface water cases, respectively. Peter K. had to leave the conference call during this discussion. The remaining Consortium members recommended that the CH2M scope be modified to include Tasks 1-4. After evaluation of the alternate capacity cost curves, an additional task may be added to evaluate 10 mgd.

These recommendations will be made to those Consortium members not on the conference call to gain their concurrence before this action can be implemented. Funds to cover this additional scope will come from the remaining $6,400 in the Reclamation funds and the contribution of $5,000 from Lisa from her scope for non-labor items which have not been required.

Economic Analyses

Bob presented the changes in the cost estimates based on applying the new assumptions developed during the May 5 conference call regarding the RO skid cost using the same ratio for the brackish water as that determined from the detailed lay-out and costing for the seawater cases. Additional changes which were made include building cost adjustments, and an increase in the labor cost and number of staff. Additionally Bob fixed an error related to the energy recovery savings on the O&M costs. These changes have made a significant impact to the cost savings. The cost now compare closely to those seen in the MWD study. A 24% savings is realized in capital cost for 16-inch over 8-inch elements. An 11% savings is seen in life cycle cost.

Consensus Meeting

June 8 is the revised meeting date. Peter K. has a conflict but will determine if he can reschedule to accommodate the June 8 date (Note: Subsequent to the call Peter K. has notified Lisa that June 8 will work). Lisa will check to ensure the meeting location is available and notify the team asap.

Next meeting The next teleconference call is scheduled for May 25, 8:00 am PDT.

Consensus Meeting
Mt Vernon Country Club
June 8, 2004

Attendees: Marty Peery, Frank Leitz, Peter Metcalfe, Jim Lozier, Irv Shelby, Craig Bartels, Peter Knappe, Matt Halen, Lisa Henthorne

Review of Anti Trust Guidelines

Review Project Goal and Objectives

> Establish an optimum large diameter element standard agreed upon by the consortium enabling competitive project bidding, considering manufacturability, system design limitation and cost reductions.

USBR Requirements: Presentation to USBR in Denver, and Final Report (draft Sept 1).

Limiting Factors

a. Vessel Limitations

b. Handling

- Review of Koch sealing design. No Ucup seal. Able to load/unload from one side. Precludes the need for space on one side of the skid. Other side needs at least 6 feet.
- Follow-up with users to see how they react to handling issues? Jim and Lisa may talk to MWD or Scottsdale.
- Handling is “doable”. Mechanical assist is required. Should have references on this in our report. Various designs are possible (such as the Koch patented design) and the equipment to handle may vary. Leasing is option for small plants. Practical issue, not economic.

c. Market demand for pressure vessels

- 1000-1500 vessels per year to justify the new product according to manufacturers.
- Market PowerPoint by Lisa. 2 plants at 85 mgd and 7 plants planned at about 33 mgd. 40-45 new RO plants with capacity > 25 mgd in next 6 years. 10 of these over 50 mgd. 540 vessels for 50 mgd seawater and 460 vessels for 50 mgd BW. 15-20 NF plants of 15-20 mgd each in next 6 years. Marginal number of vessels to be needed for planned projects. Some additional demand may come from plants < 25 mgd.

d. Impact of these Factors on Standard

Discussion with Vessel Suppliers

Targeted Survey Results

Advantages – Reduced footprint, lower capital/TWC, fewer connections
Disadvantages – Handling (this needs to be carefully dealt with in the report, since it is a major concern in industry), element efficiency/quality
Magnitude of Savings –
Info needed – full scale demo, cost saving values, engineering data
Size of Future Plants – 20% over 50 mgd
Level of Demonstration – comprehensive full scale demo

Web Survey (Limited response)

Desire impact – 70% want a major advantage
Desired Benefit: Handling 50%
Savings – 80% want a 20% savings
Size of plants mostly in 5-25 mgd size

Overview of Economic Analysis Findings

Review of Assumptions
Design Parameters

- Concern that 15% 3-year fouling factor chosen for Surf Water/Reuse application is not sufficient in practice. As it only affects the operating cost, we will not make changes. Cleaning frequency for reuse probably overstated.

PFD for all three cases

Isometric Drawings

- All plants assume through port design with 4 vessels on both sides. This may not be possible immediately for seawater. If used conventional side port design for SWRO, 5-6 more manifolds for SWRO and foot print will be larger. Can justify based on consistency in our approach and the fact that first BWRO plants will allow for confidence for eventual SWRO. Report should highlight the design considerations that have been included.

Building and Layout Facilities

- Generic designs, any size plant. Meant to show the relative proportions for 8" element designs, and items included in the building. 5 million gallon storage tanks.

Cost Summary

- RO Cost Savings 8 vs 16 – 28% for GW to 14% for SW
- Savings from 16 vs 20 is only 3-4%.
- Facility Cost Savings 8 vs 16 – 18% for GW to 8% for SW
- O&M Cost Savings 8 vs 16 – 3% for SW to 1% for SW
- Life Cycle Savings 8 vs 16 – 9% for GW to 4% for SW
- Detailed designs done for seawater 50 mgd, 8", 16" and 20".
- NEED table to summarize skid cost for 8, 16, 20 and show this cost as a ratio of skid cost/mgd. Similar to MWD table which breaks out the skid table.
- CONSIDER skid design and cost for element <16" to see the relative benefit. Would this smaller diameter be easier to develop.
- Footprint savings are very important. NEED to show RO skid savings and RO building savings for all three cases of feed water.
- Conclusions
  - Max reduction in RO Facility costs occurs from 8 to 16
  - Cap cost reductions seen for ST are dampened for SBW and SW by pretreatment costs
  - Comparable O&M costs for all diameters reduces life cycle costs compared with capital costs
  - Cost reduction benefits of large diameter elements will occur at plant capacities less than considered in this anlaysis (<25mgd)

MWD vs Current Study

- RO facility cap cost reduction 24 vs 31%
- Total facility 24 vs 26
- O&M reduction 1 vs 3%

- Total water cost reduction 11 vs 12%
- Generally good agreement.

Discussion of Standards

Impact of Multiple Standards

- Tooling of ATD, test equipment, public perception, vessel mfr., volume discounts
- Impact of Koch 18" – Little advantage of following their lead since they have not established significant precedence in the industry, nor is there demonstrated additional value for 18"

Consensus Building

PK - handling concerns favor smaller diameter. 20 seems to big. Market for element >16 not sufficient. Look at stnd size vessel stainless steel.
MP – associated risks w/ 18 vs 16 are significant
PM – handling will be an issue for any large diameter. Could we get vessel mfrers more involved in the final decision making, they have big impact. Our conclusions are based on solid analysis.
CB – 16 is an optimum between economic gain and minimize risk.
MH – Don't state 16 is optimum, but rather a manageable risk. Koch has not supported their conclusions. No factual reason to follow Koch lead.
IS – ASME certified vessel for SW is a must, and 16 fits with this.
JL – Need solid documentation from Vessel mfr regarding 16 makes the most sense (safety, development cost).

Consensus Building Summary

- Decide on a recommended 16.000" diameter now, valid based on current info
- Poll other vessel mfr to see if they have information that is contrary to this decision. Seawater case only. Need to show they have done design work.
- Reevaluate our decision after final input from vessel mfr. Need some fact-based input from vessel mfr to change decision.
- Core tube Diameter should be scaled PW tube diameter with the flow increase to maintain same velocity.
- Lower capacity evaluation – extrapolate curves down to lower flow, reduce number of skids, but we will need explanation why the savings is subjective and will depend on customer's operation objectives. Too many scenarios for us to adequately address them with detailed analysis. CONSIDER limited analysis of 2 train, 12.5 mgd plant savings. Cost estimate from CH2MHILL to do this.

Final Report (Font Times New Roman 12 pt)

- Title Page
- Executive Summary (LISA)
- Summary of Conclusions and Recommendations
- Table of Contents
- Background (CRAIG, PETER M)

  1. Approach

  - Administrative (MARTY, PETER K)

    1. Agreement,
    2. parties involved,
    3. antitrust considerations,
    4. project objectives

  - Strategy
    1. Survey, (MARTY), web survey (PETER K)
    2. Assumptions - (CRAIG & PETER M, MATT)
    3. Pumping Center Concept
    4. Limitations –
       a. Handling (IRV, JIM),
       b. Vessels (PETER K, MATT)
       c. Market – (LISA)

  2. Economic Study (JIM and BOB, MARTY and PETER K)
     - Engineering design
     - Isometrics
     - MWD Comparison
     - Results
  3. Consensus/Conclusions (MATT & IRV, all to review)
     - Limiting Factors
     - Risk vs Benefits
  4. References (ALL PREPARE, LISA review)
  5. Appendix (Meeting Minutes)

Additional Assignments

- Marty – formatting info from contract by 6/11
- Lisa – prepare template and comprehensive outline 6/15
- CH2MHILL to provide CPES on CD or PDF
- Lisa check on $ for additional CH2MHill work on 2 train 12.5 mgd case
- Abstract for IDA 6/18

Due Dates for Final Report –

- Drafts by July 9 to Lisa and Reviewer
- Review of Drafts complete by July 16 and send to author (turn on Track Changes)
- Finalize Sections and send to LISA by Aug 1.
- LISA Compile/fine tune report by Aug 21
- Review Final Report – feedback to Consortium at Phone conf by Aug 27
- Send to Reclamation by Sept 1

Next Meeting – Conference Call, Wednesday, June 24 at 8:00 am PDT.

Teleconference Consortium Meeting, June 24, 2004

Attendees: Lisa Henthorne (M&E), Peter Knappe (Trisep), Jim Lozier (CH2M Hill) Peter Metcalfe (Toray), Irv Shelby (Hydranautics)

Meeting Minutes

Review of anti-trust guidelines and considerations.

CH2M Hill Scope Expansion

Jim has requested the Consortium members review his email of 6/21/04 with the revised budget estimate. He will work to finalize as soon as Marty returns so that Bob can complete the additional tasks.

Additional Input from Vessel Manufacturers

IDA Abstract

Lisa has not submitted yet but will prior to our next conference call.

Final Report

There were no questions on the final report. Lisa reiterated that July 9 is the due date for the draft write-ups to the reviewers.

Next meeting The next teleconference call is scheduled for July 7, 2004, 8:00 am PDT.

Teleconference Consortium Meeting, July 7, 2004

Attendees: Lisa Henthorne (M&E), Craig Bartels (Hydranautics), Bob Bergman (CH2M Hill), Peter Knappe (Trisep), Jim Lozier (CH2M Hill), Marty Peery (FilmTec), Irv Shelby (Hydranautics)

Review of anti-trust guidelines and considerations.

<u>Meeting Minutes</u>

Minutes of June 24, 2004 conference call accepted.

<u>CH2M Hill Scope Expansion</u>

Marty in the process of revising the SOW to include Items 1-6 and then it will be reissued to CH2M Hill.

<u>Additional Input from Vessel Manufacturers</u>

<u>IDA Abstract</u>

Lisa submitted the project abstract to IDA on July 6, 2004. There was one problem in that the system would only accept eight names, and our team has nine members. Lisa will discuss with Jim how best to handle this for the paper submittal.

<u>Final Report</u>

Everyone will submit their sections as Final to Lisa by July 9. CH2M Hill will lag on the Economic Study portion until their contract amendment gets in place.

<u>Quarterly Progress Report</u>

Lisa reminded all that the financial and technical progress reports were due by the end of July to Reclamation. Please provide the cost-sharing financial info and review of the draft 3rd quarter report that Lisa has provided.

Lisa's Move

Lisa will be joining CH2M Hill and will be subcontracted from Metcalf and Eddy to complete her SOW for the project. She will be eventually based in Dubai.

Next meeting The next teleconference call is scheduled for July 15, 2004, 8:00 am PDT.

Teleconference Consortium Meeting, July 15, 2004

Attendees: Lisa Henthorne (M&E), Craig Bartels (Hydranautics), Matt Hallan (Filmtec), Peter Knappe (Trisep), Peter Metcalfe (Toray), Marty Peery (FilmTec), Irv Shelby (Hydranautics)

Anti-Trust Guidelines

Review of anti-trust guidelines and considerations.

Additional Input from Vessel Manufacturers

Final Report

Update on all section reports. All sections completed except the Executive Summary (Lisa), Vessel Limitations (Peter K.), and the Economic Study (Jim and Bob). Bob is working on the Economic Study and hopes to have a draft to us by the first of August.

The Appendices were discussed. They are as follows:

Appendix A: Consortium Agreement – ok to include
Appendix B: Anti-trust Guidelines – ok to include
Appendix C: Minutes from Meetings and Teleconferences – ok to include
Appendix D: Written Survey Response Compilation – ok to include
Appendix E: Web Survey Response Compilation – ok to include
Appendix F: Pressure Vessel Input – use questions only
Appendix G: CPES output – put on CD ROM only

Quarterly Progress Report

Some financial cost-sharing information is still outstanding. Please ensure it is provided asap. The technical 3rd quarter progress report was approved by all for submittal to Reclamation.

Next meeting The next teleconference call is scheduled for August 3, 2004, 8:00 am PDT.

Teleconference Consortium Meeting, August 3, 2004

Attendees: Lisa Henthorne (M&E), Craig Bartels (Hydranautics), Bob Bergman (CH2M Hill), Matt Hallan (Filmtec), Peter Knappe (Trisep), Marty Peery (FilmTec), Irv Shelby (Hydranautics)

Anti-Trust Guidelines

Review of anti-trust guidelines and considerations.

Additional Input from Vessel Manufacturers

Final Report

Bob provided an update on the progress of the Economic Study. He hopes to have something for our review by the next conference call. Lisa will begin the compilation of the full final report. The schedule provides until August 21 for this completion.

Irv wanted to ensure that Lisa had received the pictures of the handling devices. Lisa will check.

3rd Quarter Progress Report

Both the technical and financial progress reports were submitted to Reclamation in late July. The total cost-share as of June 30 (3rd quarter) was $105,772. We have already reached our minimum cost share of $100,000.

Final Presentation to Reclamation

Marty asked about scheduling the final presentation. It was assumed that Lisa and Jim would make the presentation and all members are free to attend. Lisa will send an email to Frank Leitz determining his desire for scheduling of this presentation.

Next meeting The next teleconference call is scheduled for August 11, 2004, 8:30 am PDT.

January 14, 2004

To: Frank Leitz and Susan Martella, GCAOTR

From: Membrane Consortium Members
FilmTec Corporation
Hydranautics
Toray Membrane America
Trisep Corporation
Lisa Henthorne, Metcalf and Eddy, Project Facilitator
Jim Lozier, CH2M Hill, Economic Study Project Manager

Subject: 1st Quarterly Report, Period 10/1/03-12/31/03
Industry Consortium Analysis of Large Reverse Osmosis/Nanofiltration Element Diameters: Designed for Manufacturability, System Capital Reduction and Industry Acceptance
Agreement Number 03-FC-81-0916

The purpose of this project is to develop an industry standard for large diameter RO and NF membrane elements. By establishing a standard that has been agreed upon by several membrane element suppliers, the end users will be able to realize the maximum economic benefits of the larger diameter elements through use of competitive bidding. The standard will be determined based on a thorough economic analysis. The economic analysis will be augmented with knowledge from key players within the industry to consider ancillary issues such as manufacturability, handling considerations, vessel constraints and industry acceptance.

Accomplishments during this reporting period

The project was initiated in early October, 2003. A formal Consortium Agreement was established between the membrane suppliers participating in the project, which provides the guidelines and framework by which the companies will work together on this project. The Agreement's sole purpose is the conduct of this project. Anti-trust guidelines were established which are strictly adhered to during all Consortium discussions (in person, teleconferencing or via email). Meeting minutes are formally documented for all Consortium conference calls and meetings, and are available to the GCAOTR staff.

During this reporting period, the Consortium requested qualifications for the role of Project Facilitator. After evaluation of the qualification submittals by the Consortium members, Lisa Henthorne of Aqua Resources International was offered the position. During this interim period between submittal and offer, Ms. Henthorne became an employee of Metcalf and Eddy, Inc. As a result, she was subcontracted through Metcalf and Eddy by FilmTec Corporation for the Project Facilitator position.

The Consortium also entertained qualifications from A&E firms to conduct the Economic Study for the project. After evaluation of the A&E proposals, CH2M Hill was determined to be best qualified. A subcontract was executed between FilmTec Corporation and CH2M Hill for this work and Jim Lozier of CH2M Hill is responsible for the Economic Study on behalf of the project.

During this period the Consortium held weekly or biweekly conference calls and held its Kick-Off meeting on December 2, 2003. During the Kick-Off meeting both membrane vessel manufacturers Pentair Codeline and Progressive Composites provided independent input to the Consortium relative to manufacturability, constraints and costs for large-diameter vessels. A follow-up questionnaire has been provided to them based on a specific large-diameter parameter.

The technical work during this period has been focused on developing the framework and assumptions for the Economic Study. Table 1 lists the assumptive values determined for the different feedwater applications (brackish high flux, brackish low flux and seawater) to be evaluated in the Economic Study. The initial large-diameter parameter to be evaluated will be 16-inches. An additional large diameter will be evaluated for each feedwater application but these specific diameters will be determined after initial results are reported for the 16-inch diameter.

CH2M HILL will conduct the economic Study using their Cost Parametric Estimating System model. The model will use the information and assumptions shown in Table 1. Additional design assumptions agreed to during the Project Kickoff meeting include: (1) MF/UF pretreatment, with or without direct coagulant feed, as pretreatment for seawater and low flux brackish water cases, (2) centralized RO high pressure pumping and energy recovery systems and (3) RO control blocks or trains containing multiple stages. The results of the economic analysis for the initial 16-inch diameter element case (along with the bench mark 8-inch diameter element case) will be presented to the Consortium for review prior to the selection of a second large diameter and subsequent economic modeling.

In order to gain industry input to the project and to gather industry acceptance, a formal survey was developed and circulated to approximately 50 individuals primarily in the utilities and A&E firms. Additionally, a website is being developed (www.bigmembranes.com) which will house project information. This website will also have the capability to survey visitors.

Accomplishments expected during this upcoming reporting period

The primary accomplishment during the upcoming period will be execution of the Economic Study by CH2M Hill. The schedule is for completion of this study by March, 2004. Their progress will be monitored via bi-weekly Consortium conference calls and one to two project meetings with Jim Lozier.

Additional accomplishments expected during this period include analysis of the formal survey results and completion of the website. A press release will also be distributed announcing the website and project. The vessel manufacturers will submit their completed questionnaire relative to a 16-inch diameter element during this period. Their input will be provided to CH2M Hill for their inclusion into the Economic Study.

Difficulties or potential problems

None. The project is on-schedule and on-budget.

Table 1.
Assumption Values for Economic Study Parameters
for 8-inch and Large-Diameter Scenarios

Parameter	Brackish – High Flux	Brackish – Low Flux	Seawater
Plant size (Mgd)- Base case	50	50	50
Train size (Mgd)	12.5	10	8.4
Vessels per train	70	90	90
Trains per plant for Base case	4	5	6
Elements per vessel	7	7	7
Feedwater salinity (mg/L)	800	1,500	38,000
Avg. system flux (gfd)	16	10	9
Inlet feed pressure (psi)	400	400	1,000
Specific flux (gfd/psi)	0.2-0.25	0.12-0.13	0.03-0.04
Fouling rate (%)	5	10	5
Brine/permeate ratio	5:1	5:1	5:1
Cleaning frequency	1 per year	3 per year	2 per year
Staging	2:1	2:1	single
8-inch membrane area per element (ft^2)	400	400	370
Diameter A (inches)	16	16	16
Diameter B (inches)*	20	20	12

*To be finalized at a later date via conference call

April 19, 2004

To: Frank Leitz and Susan Martella, GCAOTR

From: Membrane Consortium Members
FilmTec Corporation
Hydranautics
Toray Membrane America
Trisep Corporation
Lisa Henthorne, Metcalf and Eddy, Project Facilitator
Jim Lozier, CH2M Hill, Economic Study Project Manager

Subject: 2nd Quarterly Report, Period 1/1/04 - 3/31/04
Industry Consortium Analysis of Large Reverse Osmosis/Nanofiltration Element Diameters: Designed for Manufacturability, System Capital Reduction and Industry Acceptance
Agreement Number 03-FC-81-0916

The purpose of this project is to develop an industry standard for large diameter RO and NF membrane elements. By establishing a standard that has been agreed upon by several membrane element suppliers, the end users will be able to realize the maximum economic benefits of the larger diameter elements through use of competitive bidding. The standard will be determined based on a thorough economic analysis. The economic analysis will be augmented with knowledge from key players within the industry to consider ancillary issues such as manufacturability, handling considerations, vessel constraints and industry acceptance. The Economic Study is being conducted by CH2M Hill, led by Jim Lozier. The project is being facilitated by Lisa Henthorne, Metcalf and Eddy.

Accomplishments during this reporting period

Biweekly conference calls have been held throughout this reporting period involving all Consortium members, the CH2M Hill staff and the project facilitator (the Team). To insure that anti-trust guidelines are strictly adhered to during all discussions, a formal agenda is developed for each biweekly conference call. Additionally, formal minutes are provided to the Team following each call for approval and finalization. The GCAOTR is provided with these minutes after each conference call.

During this reporting period, the industry survey results were compiled from survey forms which were emailed to approximately 50 utility and A&E personnel. The survey results are provided as Attachment A. Additionally, a website was developed (www.bigmembranes.com) which provides project information and enables us to collect on-line survey results. Press releases regarding the project were provided to the International Desalination Association, the American Membrane Technology

Association, the European Desalination Association, the Water Desalination Report, the AWWA Journal, and the Desalination and Water Reuse Quarterly. The majority of these organizations have published a write-up about the project in their publications.

Further discussions were held with the vessel manufacturers during this reporting period to ensure the Team's understanding of limitations associated with manufacturing large-diameter vessels for both brackish and seawater applications.

Handling issues associated with large-diameter elements and end-caps were also evaluated during this reporting period. The Team has been in contact with staff at the Yuma Desalting Plant to gain their knowledge and advisement in this area.

The primary effort during this reporting period has been accomplished by the CH2M Hill team in the conduct of the Economic Study. The CH2M Hill staff has participated in the bi-weekly conference calls to ensure communication between their efforts and to keep the Team apprised of their progress. Specifically, their accomplishments during this period are provided below.

The economic study includes cost estimating for RO desalting system using standard (8" diameter by 40" long) element and two different diameter (by 40" long) large elements. During this reporting period, activities focused on developing cost estimates and associated information for RO systems and overall water treatment facilities using the standard diameter element and a 16" diameter element for each of the three desalting alternatives (brackish groundwater, brackish surface water/wastewater reclamation and seawater) selected for study. Specific deliverables produced in this context and provided to the Consortium for review and discussion included:

- Process flow diagrams, showing pretreatment, pumping, RO trains, energy recovery, post treatment and finished water storage and distribution systems

- Two-view isometric drawings for RO skids illustrating vessel/array, feed/permeate/concentrate piping and associated valving

- Representative layouts for major equipment systems within the RO building

- Detailed construction, O&M and lifecycle cost estimates for full water treatment facilities (pretreatment, pumping, RO trains, energy recovery, post treatment and finished water storage) using CH2M HILL proprietary CPES costing model

- Table summarizing construction, O&M, life cycle and total unit water costs for each alternative showing comparative cost savings in both RO system and total facility between 8" and 16" diameter element designs.

Accomplishments expected during this upcoming reporting period

CH2M Hill will develop cost estimates (and associated materials) for RO designs using a second large diameter element (expected to be 20”) to complete the Economic Study.. The Team will assemble in late May for a Consensus meeting to evaluate all the findings-to-date and determine the large-diameter standard.

Difficulties or potential problems

The Economic Study is slightly behind schedule but it is not expected to impact the overall project schedule or budget.

July 14, 2004

To: Frank Leitz and Susan Martella, GCAOTR

From: Membrane Consortium Members
FilmTec Corporation
Hydranautics
Toray Membrane America
Trisep Corporation
Lisa Henthorne, Metcalf and Eddy, Project Facilitator
Jim Lozier, CH2M Hill, Economic Study Project Manager

Subject: 3rd Quarterly Report, Period 4/1/04 - 6/31/04
Industry Consortium Analysis of Large Reverse Osmosis/Nanofiltration Element Diameters: Designed for Manufacturability, System Capital Reduction and Industry Acceptance
Agreement Number 03-FC-81-0916

The purpose of this project is to develop an industry standard for large diameter RO and NF membrane elements. By establishing a standard that has been agreed upon by several membrane element suppliers, the end users will be able to realize the maximum economic benefits of the larger diameter elements through use of competitive bidding. The standard will be determined based on a thorough economic analysis. The economic analysis will be augmented with knowledge from key players within the industry to consider ancillary issues such as manufacturability, handling considerations, vessel constraints and industry acceptance. The Economic Study is being conducted by CH2M Hill, led by Jim Lozier. The project is being facilitated by Lisa Henthorne, Metcalf and Eddy.

Accomplishments during this reporting period

Biweekly conference calls have been held throughout this reporting period involving all Consortium members, the CH2M Hill staff and the project facilitator (the Team). To insure that anti-trust guidelines are strictly adhered to during all discussions, a formal agenda is developed for each biweekly conference call. Additionally, formal minutes are provided to the Team following each call for approval and finalization. The GCAOTR is provided with these minutes after each conference call.

There have been two primary efforts during this reporting period: 1) completion and fine-tuning the Economic Study by CH2M Hill; and 2) a Consensus-building Meeting to discuss and recommend the large-diameter standard based on all the findings of the project.

The CH2M Hill staff has participated in the bi-weekly conference calls to ensure communication between their efforts and to keep the Team apprised of their progress. Specifically, their accomplishments during this period are provided below.

Following up on CH2M Hill's progress last period in which they developed cost models for 8" and 16" diameter elements for each of the three desalting scenarios (brackish groundwater, brackish surface water/wastewater reclamation and seawater) for 50 mgd plant capacities, this period CH2M Hill developed cost models for a 20" diameter element. The Team discussed at length which alternate large-diameter should be evaluated by CH2M Hill in the completion of the Economic Study. After deliberation and discussion, the 20" diameter was chosen by the team to be the best choice for analysis. Specific deliverables produced in this context and provided to the Consortium for review and discussion included:

- Two-view isometric drawings for RO skids illustrating vessel/array, feed/permeate/concentrate piping and associated valving

- Representative layouts for major equipment systems within the RO building

- Detailed construction, O&M and lifecycle cost estimates for full water treatment facilities (pretreatment, pumping, RO trains, energy recovery, post treatment and finished water storage) using CH2M Hill proprietary CPES costing model

- Table summarizing construction, O&M, life cycle and total unit water costs for each alternative showing comparative cost savings in both RO system and total facility between 8", 16" and 20" diameter element designs.

Additionally, CH2M Hill developed cost curves at plant capacities of 25, 50, 100 and 150 mgd in order to understand the impact of the large-diameter element savings across a range of plant capacities. To assist the Team in fully understanding the assumptions and results of the Economic Study, CH2M Hill provided a comprehensive comparison of the results of the Metropolitan Water District large-diameter economic analysis to the results of our Economic Study.

On June 8, 2004, the Team held its Consensus Meeting to evaluate and discuss all of the information gathered and developed for the project, in order to recommend a standard large-diameter. Mr. Frank Leitz, the project GCAOTR, also attended the meeting. The meeting included discussion of the limiting factors such as vessel manufacturability, handling, and the market for large-diameter vessels and elements. A short teleconference was held with Progressive Composites to reiterate issues relative to vessel design and manufacturability (Pentair was unavailable for the call). The survey results were reviewed, followed by a presentation of the Economic Study.

After considerable discussion, the Consensus Meeting outcome was that the 16” diameter offered the most cost savings at the least risk. Additional follow-up with the vessel manufacturers will be undertaken to confirm the Team’s understanding of risks associated with the vessel diameter which impacts the element diameter standard. Assignments for the preparation of the Final Report were made at the conclusion of the Consensus Meeting.

During this reporting period, abstracts were submitted to the Call for Papers for the AWWA Membrane Conference, to be held in March, 2005 in Phoenix, Arizona, and for the IDA Conference to be held in September, 2005 in Singapore.

Accomplishments expected during this upcoming reporting period

CH2M Hill will complete the Economic Study with development of cost data for plant capacities of 12.5 mgd. The focus of the work this period will be on preparation and review of the individual components of the final report, and assembly of the entire report for submittal to the Bureau of Reclamation in early September, 2004.

Difficulties or potential problems

As of July 8, 2004, Lisa Henthorne will become an employee of CH2M Hill. Metcalf and Eddy has recommended that Lisa complete this work via a subcontract to CH2M Hill. This will have to be put into place in July, 2004 so that Lisa can coordinate the assembly of the final report in August. Lisa will ensure this mechanism is put into place. Metcalf and Eddy will remain as the named Project Facilitator in the Final Report.

Appendix D – Results of the Written Survey

Large Diameter Element
Consortium Industry Survey Data

Question 1: Please briefly describe the most significant advantages you perceive with the application of large-diameter elements

Responses:		
	Reduced Footprint	17
	Lower Capital	13
	Fewer Conections	10
	Lower Total Cost of Water	5
	Lower Operating Costs	3
	Improved flow distribution	1
	Requires automation to fabricate elements	1
	Fewer elements to handle	1
	Fewer trains	1
	Possibility of larger feed spacers	1
	Larger feed, brine, and permeate ports	1
	Enables plants >100 MGD	1

Large Diameter Element
Consortium Industry Survey Data

Question 2: Please briefly describe the most significant disadvantages or challenges you perceive with the application of large-diameter RO elements.

Responses:		
	Handling/Weight	19
	Element Efficiency/Quality	12
	PV issues (supply, cost, weight, etc.)	8
	Element Life/Cost of Replacements	6
	Cleaning/Fouling	4
	Membrane Supply/Standardization	4
	Piping Hydraulics	4

dP Forces	3
Lower operational flexibility	2
Low tolerance for risk	2
Impact of failures on train	1
Lower recovery	1
Increased capital cost of piping, PVs, valves,	1
Small market size for larger OD elements	1

Large Diameter Element Consortium
Industry Survey Data

Question 3: What magnitude of savings would be required of large-diameter elements for you to consider using them?

Responses:	Lower overall costs (generic)	9
	25% Capital cost and same lifecycle costs	3
	>20% lower overall capital costs	1
	20% lower RO system capital costs	1
	15-20% lower membrane costs	2
	>10% total water cost	2
	15-20% total water cost	1

Large Diameter Element Consortium
Industry Survey Data

Question 4: What type of information would you most want from this investigation to help you determine the suitability of large-diameter lements for your next project?

Responses:	Comprehensive Full Scale Demonstration	19
	Cost Savings (Capital, Life-cycle, O&M, Footprint)	8
	Engineering Design Data and Software	8

Industry Standard Diameter	7
Element/PV Cost	6
Address Handling Concerns	4
Comprehensive Pilot Plant Demonstration	2
Optimum OD for >100 MGD plants	1
Sufficient warranties	1
Results of industry survey	1
Supply of PVs	1
NSF certification of elements and PV	1

Large Diameter Element Consortium Industry Survey Data

Question 5: What is the potential size of your future plants?

Responses:		
	<5 MGD	2
	5-20 MGD	8
	20-50 MGD	8
	>50 MGD	6

Large Diameter Element Consortium Industry Survey Data

Question 6: What level of demonstration would be needed before you would be willing to purchase or specify large-diameter elements for your next project?

Responses:		
	Comprehensive Full Scale Demonstration	19
	Industry Standarization and Supply	6
	Pilot Test Demonstration	3
	Warranties	2

Appendix E – Results of the Electronic Survey

(1) Do you think that large diameter elements, elements with a diameter greater than 8-inch, will have
(64%) major advantages
(18%) minor advantages
(14%) don't know
(4%) no advantages over standard 8-inch diameter elements?

(2) Which issue would most concern you if you had to purchase a large diameter element:
(45%) Handling
(27%) Element performance over time
(23%) Availability from multiple manufacturers
(4%) Lack of an installed base

(3) I would consider using a large diameter element if it produced a savings on the total water cost of:
(48%) 20%
(33%) >20%
(19%) 10%
(0%) Would not consider at any cost savings

(4) I am an:
(23%) End User
(27%) OEM
(23%) A&E
(27%) Other

(5) If you are an end user, please describe the size of system you work with:
(52%) Not Applicable
(24%) > 5 MGD and < 20 MGD (3,200 m3/hr)
(24%) > 20 MGD (3,200 m3/hr)
(0%) < 5 MGD (790 m3/hr)

(6) I would consider using large diameter elements for new projects if the plant size was:
(50%) > 20 MGD (3,200 m3/hr)
(30%) > 5 MGD and < 20 MGD (3,200 m3/hr)
(20%) < 5 MGD (790 m3/hr)
(0%) Would not consider using them.

Appendix F – Vessel Manufacturer's Questionnaire

Brackish Water Vessels

(1) Using the current technology, what is the maximum diameter that could be produced with a maximum feed pressure of 400 psi?

(2) What would be the weight of the end cap?

(3) What do you estimate would be the relative cost of this diameter to an 8-inch diameter tube? (Use the square of the diameters to normalize the production capacity, i.e., a 16-inch diameter tube would produce 4 times the amount of permeate so a cost 4 times an 8-inch vessel would have a relative cost of 1.0.)

(4) Would you be willing to develop such a tube for the market?

(5) Rate the risk of catastrophic failure on a scale of 1-10, with 10 being the most risk. (Assume the current 8-inch tube has a risk of 1)

(6) Could the design be made to ASME Section 10?

(7) Rate the risk of mechanical failure that would require replacement on a scale of 1-10, with 10 being the most risk. (Assume the current 8-inch tube has a risk of 1)

(8) What is the development time required to produce this tube for the market?

(9) Would you anticipate any restrictions on your production capacity with this new diameter? (That is, if large plants were made with this new diameter, could they be produced in sufficient numbers and in a sufficient time to meet demand.)

(10) Would the tube require any special support from the frame?

(11) What would be the weight of the pressure tube assembly?

(12) Could it be produced to 7M lengths?

(13) Would there be any constraints in producing side-ported vessels?

(14) Would vessel elongation be greater than for 8-inch vessels at a similar pressure rating?

(15) Would the end cap restraining method be similar to or different from that used with 8-inch vessels?

(16) Would end cap removal be more difficult than for an 8-inch vessel? If so, would removal require a special tool?

Seawater Pressure Vessels

(17) Using the current technology, what is the maximum diameter that could be produced with a maximum feed pressure of 1,000 psi? of 1,200 psi?

(18) What would be the weight of the end cap?

(19) What do you estimate would be the relative cost of this diameter to an 8-inch diameter tube? (Use the square of the diameters to normalize the production capacity, i.e., a 16-inch diameter tube would produce 4 times the amount of permeate so a cost 4 times an 8-inch vessel would have a relative cost of 1.0.)

(20) Would you be willing to develop such a tube for the market?

(21) Rate the risk of catastrophic failure on a scale of 1-10, with 10 being the most risk. (Assume the current 8-inch tube has a risk of 1)

(22) Could the design be made to ASME Section 10?

(23) Rate the risk of mechanical failure that would require replacement on a scale of 1-10, with 10 being the most risk. (Assume the current 8-inch tube has a risk of 1)

(24) What is the development time required to produce this tube for the market?

(25) Would you anticipate any restrictions on your production capacity with this new diameter? (That is, if large plants were made with this new diameter, could they be produced in sufficient numbers and in a sufficient time to meet demand.)

(26) Would the tube require any special support from the frame?

(27) What would be the weight of the pressure tube assembly?

(28) Could it be produced to 7M lengths?

(29) Would the endcap restraining method be similar to or different from that used with 8-inch vessels?

(30) Would endcap removal be more difficult than for an 8-inch vessel? If so, would removal require a special tool?

(31) What volume of Sales would be needed to make this product price roughly (within 10%) scalable with 8-inch vessels? For example, if you sold 50 or 100 or 1000, would the latter figure be needed to get to prices that scale with the 8-inch vessels.

(32) For tube diameters up to the maximum diameter you specify, are there any restrictions as to the actual tube i/d which can/ should be considered (i.e., should they be in inch increments only? Half inch?)

6-16-04

Questions for Pressure Tube Suppliers

The large element membrane consortium has made a tentative decision, based in some part on the response from the pressure tube suppliers, on a 16-inch diameter. We would like to have some input in writing from you, to support this decision. Your responses could be used in the final report, which is a public document.

(1) If we assume that we do not want to sacrifice any features available on current vessels (i.e. multi ports, AMSE rating, etc.), do you perceive that there is substantially more risk involved in producing an 18-inch versus a 16-inch 1,000 psi rated pressure tube? What about a 1,200 psi rated pressure tube? Please give some details to support your response.

Response to question 1 from Pressure Tube Supplier A

> "The answer to both questions is yes. The problem here is the fact that the end load of an 18-inch vessel is substantially more than that of a 16-inch. This is all a result of the bearing plate surface area. "
>
> "When evaluating the required strength of an FRP housing to handle 1000 or 1200 PSI at a safety factor of 6 times, it is clear that new technology must be created. 16-inch by itself is a challenge but 18-inch is so much more of an obstacle that we are not sure that a cost effective solution can be obtained."

(2) We are currently suggesting that the new diameter be 16.000-inch. Can you give us some input about the tolerances and whether or not 16.000-inch is a good choice.

Response to question 2 from Pressure Tube Supplier A

“We have spoken about this issue at length and have the following information. Mandrels that have a diameter to yield 16.000 products must be made from 16.5-inch tubing. This is possible but will depend on material availability. “

“If the diameter can be decreased to a product diameter of 15.75 to 15.90, steel pipe can be used to make the mandrels. “

“The difference here is that steel pipe will be much more cost effective than tubing for making the mandrels to wind the vessels. While this may add to the expensive in starting production, is should not affect the fabrication of the vessel over time. The cost to produce the two different diameters is so close that we do not see a significant variation in product cost.”

Appendix G – 8-inch, 16-inch, and 20-inch Diameter RO Element Bill of Materials and CPES Models

Table G-1.—Assumed Seawater RO Train Costs (50 mgd Plant Capacity)

	Installed Cost ($/gpd)		
	8-inch	**16-inch**	**20-inch**
Feed Headers	0.013	0.009	0.006
Feed Manifolds & Vessel Connectors	0.126	0.016	0.013
Cleaning Feed	0.005	0.005	0.004
Pressure Vessels	0.129	0.130	0.129
RO Membrane Elements	0.226	0.227	0.226
Concentrate Manifolds & Vessel Connectors	0.032	0.016	0.013
Concentrate Header	0.021	0.019	0.013
Cleaning Concentrate Return	0.004	0.002	0.002
Permeate Connectors & Manifolds	0.008	0.005	0.003
Permeate Header	0.010	0.010	0.008
Permeate-to-Waste	0.004	0.003	0.003
Cleaning Permeate Return	0.0003	0.0002	0.0002
Instrumentation & Panels	0.021	0.010	0.007
RO Skid (painted weldment)	0.011	0.010	0.012
Sample Panel & Valves	0.001	0.0003	0.0002
Total	0.609	0.462	0.440

Notes:
1. Train permeate capacity: 8-inch – 4.17 mgd; 16-inch – 8.33 mgd; 20-inch – 12.5 mgd
2. Installation costs assumed to be 20 percent of the uninstalled costs

Table G-2.—BOM for 8-inch Seawater Case

08/09/2004 3:53 PM

8" Seawater Skid

ESTIMATE SUMMARY

PROJECT : R O TRAIN OPTIONS
FACILITY : 8" SEAWATER TRAIN
FILE NAME: R O TRAIN OPTIONS.XLS
MARK-UPS:

	MATL	LABOR	EQUIP.	INSTL or S/C
OVERHEAD =				
PROFIT =				
MOB/BOND/INS. =				
CONTINGENCY =				

ESTIMATOR: D JONES
PROJ. MANAGER:
PROJ. NO.:
ESTIMATE NO. : 2004047
REV. NO. : 1
DATE: 3/23/04 (Rev 6-21-04 Bergman)

NO.	DESCRIPTION	QTY	UNIT	MATERIALS		LABOR			CONST. EQUIP.		INSTL or S/C		TOTAL	SUBTOTALS
				UNIT $	AMOUNT	MH	RATE	AMOUNT	UNIT $	AMOUNT	UNIT $	AMOUNT		
	Feed Header													
	20" Pipe Spool													
	4 ft long 6XN	2	EA	$5,887.20	$11,774		$883.08	$1,766					**$13,541**	
	1 ft long 6XN	2	EA	$4,000.80	$8,002		$600.12	$1,200					**$9,202**	
	16" Pipe Spool													
	7 ft long 6XN	1	EA	$6,202.08	$6,202		$930.31	$930					**$7,132**	
	20" 90 Elbow 6XN	2	EA	$2,135.72	$4,271		$427.14	$854					**$5,126**	
	20" Butterfly valve 6XN	1	EA	$10,800.00	$10,800		$2,160.00	$2,160					**$12,960**	
	20"x16" Tee 6XN	1	EA	$2,976.00	$2,976		$595.20	$595					**$3,571**	
	16" Tee 6XN	1	EA	$2,380.80	$2,381		$476.16	$476					**$2,857**	
	20x16 Reducer 6XN	1	EA	$660.00	$660		$132.00	$132					**$792**	$55,181
	Feed Manifold													
	16" pipe 13 ft long with 24 ea 3" side outlets w/vics 6XN	2	EA	$17,720.48	$35,441	84.00	$2,658.07	$446,556					**$481,997**	
	Pressure vessel 3" connectors with vics 6XN (should have been $71.25)	79	EA	$465.60	$36,782		$69.84	$5,517					**$42,300**	$524,297
	CF (Cleaning Feed)													
	12" Pipe Spool													
	5 ft long 6XN	1	EA	$3,098.40	$3,098		$464.76	$465					**$3,563**	
	1 ft long 6XN	2	EA	$1,512.48	$3,025		$226.87	$454					**$3,479**	
	12" 90 Elbow 6XN	2	EA	$2,311.20	$4,622		$462.24	$924					**$5,547**	
	12" Butterfly Valve 6XN	1	EA	$6,120.00	$6,120		$1,224.00	$1,224					**$7,344**	$19,933
	Pressure Vessels	179	EA	$2,500.00	$447,500		$500.00	$89,500					**$537,000**	$537,000
	Membrane Elements	1253	EA	$625.00	$783,125		$125.00	$156,625					**$939,750**	$939,750
	Concentrate Manifold													
	10" pipe 13 ft long with 24 ea 3" side outlets 6XN	2	EA	$15,430.40	$30,861		$2,314.56	$4,629					**$35,490**	
	Pressure vessel 3" connectors with vics 6XN (should have been $71.25)	179	EA	$465.60	$83,342		$69.84	$12,501					**$95,844**	$131,334
	Concentrate Header													
	12"x10" 90 Elbow 6XN	1	EA	$2,311.20	$2,311		$462.24	$462					**$2,773**	
	12" Pipe Spool													
	8 ft long 6XN	1	EA	$4,287.84	$4,288		$643.18	$643					**$4,931**	
	14x12 Reducer 6XN	1	EA	$462.00	$462		$69.30	$69					**$531**	

Bills-of Materials 50 mgd 8-16-20 seawater - 8-9-04.xls

ESTIMATE SUMMARY

PROJECT : R O TRAIN OPTIONS
FACILITY : 8" SEAWATER TRAIN
FILE NAME: R O TRAIN OPTIONS.XLS
MARK-UPS:

	MATL	LABOR	EQUIP.	INSTL or S/C
OVERHEAD =				
PROFIT =				
MOB/BOND/INS. =				
CONTINGENCY =				

ESTIMATOR: D JONES
PROJ. MANAGER:
PROJ. NO.:
ESTIMATE NO. : 2004047
REV. NO. : 1
DATE: 3/23/04 (Rev 6-21-04 Bergman)

NO.	DESCRIPTION	QTY	UNIT	MATERIALS		LABOR			CONST. EQUIP.		INSTL or S/C		TOTAL	SUBTOTALS
				UNIT $	AMOUNT	MH	RATE	AMOUNT	UNIT $	AMOUNT	UNIT $	AMOUNT		
	14" Pipe Spool													
	5 ft long 6XN	1	EA	$3,284.40	$3,284		$492.66	$493					$3,777	
	6 ft long 6XN	1	EA	$3,680.88	$3,681		$552.13	$552					$4,233	
	4 ft long 6XN	1	EA	$2,887.92	$2,888		$433.19	$433					$3,321	
	2 ft long 6XN	1	EA	$2,094.96	$2,095		$314.24	$314					$2,409	
	1 ft long 6XN	3	EA	$1,698.48	$5,095		$254.77	$764					$5,860	
	14x10 Tee 6XN	1	EA	$2,083.20	$2,083		$416.64	$417					$2,500	
	14"x12" 90 Elbow 6XN	1	EA	$1,495.20	$1,495		$299.04	$299					$1,794	
	14" Anti-cavitation Globe Valve	1	EA	$45,161.76	$45,162		$6,774.26	$6,774					$51,936	
	14" Tee 6XN	1	EA	$2,083.20	$2,083		$416.64	$417					$2,500	$86,566
	<u>CCR (Cleaning Concentrate Return)</u>													
	12" Butterfly Valve 6XN	1	EA	$6,120.00	$6,120		$918.00	$918					$7,038	
	12" Pipe Spool													
	4 ft long 316SS	4	EA	$1,769.30	$7,077		$265.40	$1,062					$8,139	
	1 ft long 6XN	1	EA	$1,512.48	$1,512		$226.87	$227					$1,739	
	1 ft long 316SS	1	EA	$895.70	$896		$134.36	$134					$1,030	$17,946
	<u>Permeate Connectors</u>													
	1.25" J-Bends w/2 vics PVC (should have been $38.30)	179	EA	$25.00	$4,475		$3.75	$671					$5,146	$5,146
	<u>Permeate Manifold</u>													
	6" Pipe Spool 14.5 ft long w/24 ea 1.25" side outlets with vic 304 SST	8	EA	$2,993.75	$23,950		$449.06	$3,593					$27,543	$27,543
	<u>Permeate Header</u>													
	10x6 90 Elbow 304 SST	1	EA	$682.13	$682		$136.43	$136					$819	
	10" pipe spools													
	2 ft long 304 SST	1	EA	$1,402.90	$1,403		$210.44	$210					$1,613	
	1 ft long 304 SST	2	EA	$1,219.45	$2,439		$182.92	$366					$2,805	
	10x6 Tee 304 SST	4	EA	$989.75	$3,959		$197.95	$792					$4,751	
	14x6 Tee 304 SST	4	EA	$867.59	$3,470		$173.52	$694					$4,164	
	14x10 Reducer 304 SST	1	EA	$191.63	$192		$38.33	$38					$230	
	14" Pipe Spool													
	1 ft long 304 SST	4	EA	$1,106.00	$4,424		$165.90	$664					$5,088	
	2 ft long 304 SST	1	EA	$1,367.33	$1,367		$205.10	$205					$1,572	
	5 ft long 304 SST	1	EA	$2,151.33	$2,151		$322.70	$323					$2,474	
	6 ft long 304 SST	4	EA	$2,412.67	$9,651		$361.90	$1,448					$11,098	
	14" 90 Elbow 304 SST	2	EA	$622.92	$1,246		$124.58	$249					$1,495	
	14" 90 Elbow w/6" side outlet 304 SST	1	EA	$1,044.14	$1,044		$208.83	$209					$1,253	
	14" Tee 304 SST	1	EA	$867.59	$868		$130.14	$130					$998	
	14" Butterfly Valve 304 SST	1	EA	$2,975.00	$2,975		$446.25	$446					$3,421	$41,781

ESTIMATE SUMMARY

PROJECT : R O TRAIN OPTIONS
FACILITY : 8" SEAWATER TRAIN
FILE NAME: R O TRAIN OPTIONS.XLS
MARK-UPS:

	MATL	LABOR	EQUIP.	INSTL or S/C
OVERHEAD =				
PROFIT =				
MOB/BOND/INS. =				
CONTINGENCY =				

ESTIMATOR: D JONES
PROJ. MANAGER:
PROJ. NO.:
ESTIMATE NO. : 2004047
REV. NO. : 1
DATE: 3/23/04 (Rev 6-21-04 Bergman)

NO.	DESCRIPTION	QTY	UNIT	MATERIALS		LABOR			CONST. EQUIP.		INSTL or S/C		TOTAL	SUBTOTALS
				UNIT $	AMOUNT	MH	RATE	AMOUNT	UNIT $	AMOUNT	UNIT $	AMOUNT		
	Permeate-To-Waste													
	14" Pipe Spool													
	1 ft long 304SST	1	EA	$1,106.00	$1,106		$165.90	$166					$1,272	
	4 ft long 304SST	1	EA	$1,890.00	$1,890		$283.50	$284					$2,174	
	14" Butterfly Valve 6 XN	1	EA	$7,140.00	$7,140		$1,071.00	$1,071					$8,211	
	14" Butterfly Valve 304SST	1	EA	$2,975.00	$2,975		$446.25	$446					$3,421	$15,078
	CPR (Cleaning Permeate Return)													
	6" Butterfly Valve PVC	1	EA	$387.60	$388		$58.17	$58					$446	
	6" Pipe Spool													
	6 ft long PVC	3	EA	$93.00	$279		$13.95	$42					$321	
	3 ft long PVC	1	EA	$69.00	$69		$10.35	$10					$79	
	6" 90 Elbow PVC	3	EA	$57.50	$173		$11.50	$35					$207	$1,053
	Instrumentation													
	14" Mag Meter - concentrate 6XN	1	EA	$33,600.00	$33,600		$5,040.00	$5,040					$38,640	
	14" Mag Meter - permeate 304SST	1	EA	$22,400.00	$22,400		$3,360.00	$3,360					$25,760	
	PITs with diaphragm seals 316SST	2	EA	$2,100.00	$4,200		$525.00	$1,050					$5,250	
	PITs 316SST	1	EA	$1,700.00	$1,700		$425.00	$425					$2,125	
	Conductivity Meters	2	EA	$1,800.00	$3,600		$450.00	$900					$4,500	
	Instrument Rack	1	EA	$2,000.00	$2,000		$300.00	$300					$2,300	
	Instrument Panel	1	EA	$5,000.00	$5,000		$750.00	$750					$5,750	
	I/O Panel	1	EA	$2,000.00	$2,000		$300.00	$300					$2,300	$86,625
	Painted Carbon Steel Skid	1	EA	$43,200.00	$43,200		$4,320.00	$4,320					$47,520	$47,520
	Sample Panel													
	Sample Panel	1	EA	$2,000.00	$2,000		$200.00	$200					$2,200	$2,200
	Sample Valves													
	Feed													
	Concentrate 6XN	1	EA											
	Permeate Manifolds 316 SST	8	EA											
	Permeate Total 316 SST	1	EA											
	Permeate per Pressure Vessel 316 SST	179	EA											
A	**SUBTOTAL**				$1,769,532			$769,419					$2,538,952	2,538,952
B	**OVERHEAD & PROFIT**	(A*ohd)+((A+ohd)*p)												
C	**MOB / BOND / INSUR.**	(% of A)												
D	**CONTINGENCY**	(% of A)												
E	**TOTAL ESTIMATED CONSTRUCTION COST**				$1,769,532			$769,419					$2,539,000	

Table G-3.—BOM for 16-inch Seawater Case

ESTIMATE SUMMARY
PROJECT : R O TRAIN OPTIONS
FACILITY : 16" SEAWATER TRAIN
FILE NAME: R O TRAIN OPTIONS.XLS

ESTIMATOR: D JONES
PROJ. MANAGER:
PROJ. NO.:
ESTIMATE NO. : 2004047
REV. NO. : 1
DATE: 3/23/04 (Rev 6-21-04 Bergman)

MARK-UPS:	MATL	LABOR	EQUIP.	INSTL or S/C
OVERHEAD =				
PROFIT =				
MOB/BOND/INS. =				
CONTINGENCY =				

NO.	DESCRIPTION	QTY	UNIT	MATERIALS		LABOR			CONST. EQUIP.		INSTL or S/C		TOTAL	SUBTOTALS
				UNIT $	AMOUNT	MH	RATE	AMOUNT	UNIT $	AMOUNT	UNIT $	AMOUNT		
	<u>Feed Header</u>													
	24" Pipe Spool													
	1 ft long 6XN	2	EA	$4,803.36	$9,607		$720.50	$1,441		$0		$0	$11,048	
	3 ft long 6XN	1	EA	$6,317.28	$6,317		$947.59	$948		$0		$0	$7,266	
	6 ft long 6XN	1	EA	$8,588.16	$8,588		$1,288.22	$1,288		$0		$0	$9,876	
	20" Pipe Spool													
	13 ft long 6XN	1	EA	$14,918.40	$14,918		$2,237.76	$2,238		$0		$0	$17,158	
	24" 90 Elbow 6XN	2	EA	$2,563.20	$5,126		$512.64	$1,025		$0		$0	$6,152	
	24" Butterfly valve 6XN	1	EA	$12,240.00	$12,240		$2,448.00	$2,448		$0		$0	$14,688	
	24"x20" Tee 6XN	1	EA	$3,571.20	$3,571		$714.24	$714		$0		$0	$4,286	
	20" Tee 6XN	1	EA	$2,976.00	$2,976		$595.20	$595		$0		$0	$3,571	
	24x20 Reducer 6XN	1	EA	$792.00	$792		$158.40	$158		$0		$0	$950	$74,992
	<u>Feed Manifold</u>													
	20" pipe 15 ft long with 12 ea 6" side outlets w/vics 6XN	2	EA	$15,076.80	$30,154		$2,261.52	$4,523		$0		$0	$34,677	
	Pressure vessel 3" (should have been 6" $142.50) connectors with vics 6XN	90	EA	$931.20	$83,808		$139.68	$12,571		$0		$0	$96,379	$131,056
	<u>CF (Cleaning Feed)</u>													
	20" Pipe Spool													
	1 ft long 6XN	2	EA	$7,372.80	$14,746		$1,105.92	$2,212		$0		$0	$16,957	
	3 ft long 6XN	1	EA	$8,630.40	$8,630		$1,294.56	$1,295		$0		$0	$9,925	
	20" 90 Elbow 6XN	2	EA	$2,135.72	$4,271		$320.36	$641		$0		$0	$4,912	
	20" Butterfly Valve 6XN	1	EA	$10,800.00	$10,800		$1,620.00	$1,620		$0		$0	$12,420	$44,215
	Pressure Vessels	90	EA	$10,000.00	$900,000		$2,000.00	$180,000		$0		$0	$1,080,000	$1,080,000
	Membrane Elements	630	EA	$2,500.00	$1,575,000		$500.00	$315,000		$0		$0	$1,890,000	$1,890,000
	<u>Concentrate Manifold</u>													
	20" (should be 12") pipe 15 ft long with 12 ea 6" side outlets 6XN	2	EA	$15,076.80	$30,154		$2,261.52	$4,523		$0		$0	$34,677	
	Pressure vessel 3" (should be 6" $142.50) connectors with vics 6XN	90	EA	$931.20	$83,808		$139.68	$12,571		$0		$0	$96,379	$131,056
	<u>Concentrate Header</u>													
	20" (should be 12") 90 Elbow 6XN	1	EA	$2,135.72	$2,136		$320.36	$320		$0		$0	$2,456	
	20" (should be 12") Pipe Spool													
	13 ft long 6XN	1	EA	$14,918.40	$14,918		$2,237.76	$2,238		$0		$0	$17,158	
	24x20 (should be 20x12) Reducer 6XN	1	EA	$792.00	$792		$158.40	$158		$0		$0	$950	

Bills-of Materials 50 mgd 8-16-20 seawater - 8-9-04.xls

ESTIMATE SUMMARY
PROJECT : R O TRAIN OPTIONS
FACILITY : 16" SEAWATER TRAIN
FILE NAME: R O TRAIN OPTIONS.XLS
MARK-UPS:

	MATL	LABOR	EQUIP.	INSTL or S/C
OVERHEAD =				
PROFIT =				
MOB/BOND/INS. =				
CONTINGENCY =				

ESTIMATOR: D JONES
PROJ. MANAGER:
PROJ. NO.:
ESTIMATE NO. : 2004047
REV. NO. : 1
DATE: 3/23/04 (Rev 6-21-04 Bergman)

NO.	DESCRIPTION	QTY	UNIT	MATERIALS		LABOR			CONST. EQUIP.		INSTL or S/C		TOTAL	SUBTOTALS
				UNIT $	AMOUNT	MH	RATE	AMOUNT	UNIT $	AMOUNT	UNIT $	AMOUNT		
	24" Pipe Spool													
	10 ft long 6XN	1	EA	$11,616.00	$11,616		$1,742.40	$1,742		$0		$0	$13,358	
	6 ft long 6XN	1	EA	$8,588.16	$8,588		$1,288.22	$1,288		$0		$0	$9,876	
	4 ft long 6XN	2	EA	$7,074.24	$14,148		$1,061.14	$2,122		$0		$0	$16,271	
	1 ft long 6XN	3	EA	$4,803.36	$14,410		$720.50	$2,162		$0		$0	$16,572	
	24x20 (should be 24x12) Tee 6XN	1	EA	$2,976.00	$2,976		$595.20	$595		$0		$0	$3,571	
	24"x20" (should be 24x12) 90 Elbow 6	1	EA	$2,563.20	$2,563		$512.64	$513		$0		$0	$3,076	
	24" Anti-cavitation Globe Valve	1	EA	$64,516.80	$64,517		$9,677.52	$9,678		$0		$0	$74,194	
	24" Tee 6XN	1	EA	$2,976.00	$2,976		$595.20	$595		$0		$0	$3,571	$161,052
	CCR (Cleaning Concentrate Return)													
	20" Butterfly Valve 6XN	1	EA	$10,800.00	$10,800		$1,620.00	$1,620		$0		$0	$12,420	
	20" Pipe Spool													
	4 ft long 316SS	1	EA	$2,482.98	$2,483		$372.45	$372		$0		$0	$2,856	
	1 ft long 316SS	1	EA	$1,376.37	$1,376		$206.46	$206		$0		$0	$1,583	$16,858
	Permeate Connectors													
	2.5" J-Bends w/2 vics PVC	90	EA	$38.30	$3,447		$5.75	$517		$0		$0	$3,964	$3,964
	Permeate Manifold													
	6" Pipe Spool 14.5 ft long w/24 ea 2.5" side outlets with vic 304 SST	1	EA	$2,993.75	$2,994		$449.06	$449		$0		$0	$3,443	
	8" Pipe Spool 14.5 ft long w/24 ea 2.5" side outlets with vic 304 SST	7	EA	$3,832.43	$26,827		$574.86	$4,024		$0		$0	$30,851	$34,294
	Permeate Header													
	12x6 90 Elbow 304 SST	1	EA	$963.00	$963		$144.45	$144		$0		$0	$1,107	
	12" pipe spools													
	2 ft long 304 SST	3	EA	$690.00	$2,070		$103.50	$311		$0		$0	$2,381	
	1 ft long 304 SST	1	EA	$467.00	$467		$70.05	$70		$0		$0	$537	
	12x8 Tee 304 SST	3	EA	$1,257.00	$3,771		$251.40	$754		$0		$0	$4,526	
	20x8 Tee 304 SST	4	EA	$2,095.00	$8,380		$419.00	$1,676		$0		$0	$10,056	
	20x12 Reducer 304 SST	1	EA	$401.67	$402		$80.33	$80		$0		$0	$482	
	20" Pipe Spool													
	1 ft long 304 SST	2	EA	$3,092.96	$6,186		$463.94	$928		$0		$0	$7,114	
	2 ft long 304 SST	2	EA	$3,375.92	$6,752		$506.39	$1,013		$0		$0	$7,765	
	3 ft long 304 SST	1	EA	$3,658.88	$3,659		$548.83	$549		$0		$0	$4,208	
	6 ft long 304 SST	2	EA	$4,507.76	$9,016		$676.16	$1,352		$0		$0	$10,368	
	8 ft long 304 SST	1	EA	$5,073.68	$5,074		$761.05	$761		$0		$0	$5,835	
	9 ft long 304 SST	1	EA	$5,356.64	$5,357		$803.50	$803		$0		$0	$6,160	
	10 ft long 304 SST	1	EA	$5,639.60	$5,640		$845.94	$846		$0		$0	$6,486	
	20" 90 Elbow 304 SST	3	EA	$889.88	$2,670		$177.98	$534		$0		$0	$3,204	
	20" 90 Elbow w/6" side outlet 304 SST	1	EA	$1,085.88	$1,086		$217.18	$217		$0		$0	$1,303	
	20" Tee 304 SST	1	EA	$1,239.42	$1,239		$185.91	$186		$0		$0	$1,425	
	20" Butterfly Valve 304 SST	2	EA	$4,250.00	$8,500		$637.50	$1,275		$0		$0	$9,775	
	24" x 20" Reducer 304 SST	1	EA	$275.00	$275		$41.25	$41		$0		$0	$316	$83,046

Bills-of Materials 50 mgd 8-16-20 seawater - 8-9-04.xls

ESTIMATE SUMMARY
PROJECT : R O TRAIN OPTIONS
FACILITY : 16" SEAWATER TRAIN
FILE NAME: R O TRAIN OPTIONS.XLS

ESTIMATOR: D JONES
PROJ. MANAGER:
PROJ. NO.:
ESTIMATE NO. : 2004047
REV. NO. : 1
DATE: 3/23/04 (Rev 6-21-04 Bergman)

MARK-UPS:	MATL	LABOR	EQUIP.	INSTL or S/C
OVERHEAD =				
PROFIT =				
MOB/BOND/INS. =				
CONTINGENCY =				

NO.	DESCRIPTION	QTY	UNIT	MATERIALS		LABOR			CONST. EQUIP.		INSTL or S/C		TOTAL	SUBTOTALS
				UNIT $	AMOUNT	MH	RATE	AMOUNT	UNIT $	AMOUNT	UNIT $	AMOUNT		
	Permeate-To-Waste													
	20" Pipe Spool													
	1 ft long 304SST	2	EA	$3,941.84	$7,884		$591.28	$1,183		$0		$0	$9,068	
	20" Butterfly Valve 6 XN	1	EA	$10,200.00	$10,200		$2,040.00	$2,040		$0		$0	$12,240	
	20" Butterfly Valve 304SST	1	EA	$4,250.00	$4,250		$637.50	$638		$0		$0	$4,888	$26,194
	CPR (Cleaning Permeate Return)													
	8" Butterfly Valve PVC	1	EA	$517.07	$517		$77.56	$78		$0		$0	$596	
	8" Pipe Spool													
	6 ft long PVC	2	EA	$233.20	$466		$34.98	$70		$0		$0	$536	
	3 ft long PVC	2	EA	$195.10	$390		$29.27	$59		$0		$0	$449	
	8" 90 Elbow PVC	3	EA	$89.00	$267		$17.80	$53		$0		$0	$320	$1,900
	Instrumentation													
	24" Mag Meter - concentrate 6XN	1	EA	$33,600.00	$33,600		$5,040.00	$5,040		$0		$0	$38,640	
	20" Mag Meter - permeate 304SST	1	EA	$22,400.00	$22,400		$3,360.00	$3,360		$0		$0	$25,760	
	PITs with diaphragm seals 316SST	2	EA	$2,100.00	$4,200		$525.00	$1,050		$0		$0	$5,250	
	PITs 316SST	1	EA	$1,700.00	$1,700		$425.00	$425		$0		$0	$2,125	
	Conductivity Meters	2	EA	$1,800.00	$3,600		$450.00	$900		$0		$0	$4,500	
	Instrument Rack	1	EA	$2,000.00	$2,000		$300.00	$300		$0		$0	$2,300	
	Instrument Panel	1	EA	$5,000.00	$5,000		$750.00	$750		$0		$0	$5,750	
	I/O Panel	1	EA	$2,000.00	$2,000		$300.00	$300		$0		$0	$2,300	$86,625
	Painted Carbon Steel Skid	1	EA	$72,000.00	$72,000		$7,200.0	$7,200		$0		$0	$79,200	$79,200
	Sample Panel													
	Sample Panel	1	EA	$2,000.00	$2,000		$200.00	$200		$0		$0	$2,200	$2,200
	Sample Valves													
	Feed 6XN	1	EA											
	Concentrate 6XN	1	EA											
	Permeate Manifolds 316 SST	8	EA											
	Permeate Total 316 SST	1	EA											
	Permeate per Pressure Vessel 316 SST	90	EA											
A	**SUBTOTAL**				$3,237,054			$609,597		$0		$0	$3,846,651	$3,846,651
B	**OVERHEAD & PROFIT**	(A*ohd)+((A+ohd)*p)												
C	**MOB / BOND / INSUR.**	(% of A)												
D	**CONTINGENCY**	(% of A)												
E	**TOTAL ESTIMATED CONSTRUCTION COST**				$3,237,054			$609,597		$0		$0	$3,846,700	$3,846,700

Bills-of Materials 50 mgd 8-16-20 seawater - 8-9-04.xls

Table G-4.—BOM for 20-inch Seawater Case

ESTIMATE SUMMARY
PROJECT : R O TRAIN OPTIONS
FACILITY : 20" SEAWATER TRAIN
FILE NAME: R O TRAIN OPTIONS.XLS

ESTIMATOR: D JONES
PROJ. MANAGER:
PROJ. NO.:
ESTIMATE NO. : 2004047
REV. NO. : 1
DATE: 3/23/04 (Rev 6-21-04 Bergman)

MARK-UPS:	MATL	LABOR	EQUIP.	INSTL or S/C
OVERHEAD =				
PROFIT =				
MOB/BOND/INS. =				
CONTINGENCY =				

NO.	DESCRIPTION	QTY	UNIT	MATERIALS		LABOR			CONST. EQUIP.		INSTL or S/C		TOTAL	SUBTOTALS
				UNIT $	AMOUNT	MH	RATE	AMOUNT	UNIT $	AMOUNT	UNIT $	AMOUNT		
	<u>Feed Header</u>													
	24" Pipe Spool													
	1 ft long 6XN	2	EA	$4,803.36	$9,607		$720.50	$1,441		$0		$0	$11,048	
	3 ft long 6XN	1	EA	$6,317.28	$6,317		$947.59	$948		$0		$0	$7,266	
	7 ft long 6XN	1	EA	$8,588.16	$8,588		$1,288.22	$1,288		$0		$0	$9,876	$28,189
	24" Pipe Spool													
	16 ft long 6XN	1	EA	$16,157.76	$16,158		$2,423.66	$2,424		$0		$0	$18,681	
	24" 90 Elbow 6XN	2	EA	$2,563.20	$5,126		$512.64	$1,025		$0		$0	$6,152	
	24" Butterfly valve 6XN	1	EA	$12,240.00	$12,240		$2,448.00	$2,448		$0		$0	$14,688	
	24"x20" Tee 6XN	1	EA	$3,571.20	$3,571		$714.24	$714		$0		$0	$4,285	
	20" Tee 6XN	1	EA	$2,976.00	$2,976		$595.20	$595		$0		$0	$3,571	
	24x20 Reducer 6XN	1	EA	$792.00	$792		$158.40	$158		$0		$0	$950	$48,228
	<u>Feed Manifold</u>													
	20" pipe 17 ft long with 12 ea 8" side outlets w/vics 6XN	2	EA	$16,334.40	$32,669		$2,450.16	$4,900		$0		$0	$37,569	
	Pressure vessel 8" connectors with vics 6XN (should be $252.50)	86	EA	$1,241.60	$106,778		$186.24	$16,017		$0		$0	$122,794	$160,363
	<u>CF (Cleaning Feed)</u>													
	24" Pipe Spool													
	1 ft long 6XN	2	EA	$8,849.76	$17,700		$1,327.46	$2,655		$0		$0	$20,354	
	3 ft long 6XN	1	EA	$10,363.68	$10,364		$1,554.55	$1,555		$0		$0	$11,918	
	24" 90 Elbow 6XN	2	EA	$2,562.86	$5,126		$384.43	$769		$0		$0	$5,895	
	24" Butterfly Valve 6XN	1	EA	$12,960.00	$12,960		$1,944.00	$1,944		$0		$0	$14,904	$53,071
	Pressure Vessels	86	EA	$15,625.00	$1,343,750		$3,125.00	$268,750		$0		$0	$1,612,500	$1,612,500
	Membrane Elements	602	EA	$3,906.25	$2,351,563		$781.25	$470,313		$0		$0	$2,821,875	$2,821,875
	<u>Concentrate Manifold</u>													
	20" (should be 16") pipe 17 ft long with 12 ea 8" side outlets 6XN	2	EA	$16,334.40	$32,669		$2,450.16	$4,900		$0		$0	$37,569	
	Pressure vessel 8" connectors with vics 6XN (should be $252.50)	86	EA	$1,241.60	$106,778		$186.24	$16,017		$0		$0	$122,794	$160,363
	<u>Concentrate Header</u>													
	20" (should be 16") 90 Elbow 6XN	1	EA	$2,135.72	$2,136		$320.36	$320		$0		$0	$2,456	
	20" (Should be 16") Pipe Spool													
	13 ft long 6XN	1	EA	$14,918.40	$14,918		$2,237.76	$2,238		$0		$0	$17,156	
	24x20 (should be 20x16) Reducer 6XN	1	EA	$792.00	$792		$158.40	$158		$0		$0	$950	

Bills-of Materials 50 mgd 8-16-20 seawater - 8-9-04.xls

ESTIMATE SUMMARY

PROJECT : R O TRAIN OPTIONS
FACILITY : 20" SEAWATER TRAIN
FILE NAME: R O TRAIN OPTIONS.XLS
MARK-UPS:

	MATL	LABOR	EQUIP.	INSTL or S/C
OVERHEAD =				
PROFIT =				
MOB/BOND/INS. =				
CONTINGENCY =				

ESTIMATOR: D JONES
PROJ. MANAGER:
PROJ. NO.:
ESTIMATE NO. : 2004047
REV. NO. : 1
DATE: 3/23/04 (Rev 6-21-04 Bergman)

NO.	DESCRIPTION	QTY	UNIT	MATERIALS		LABOR			CONST. EQUIP.		INSTL or S/C		TOTAL	SUBTOTALS
				UNIT $	AMOUNT	MH	RATE	AMOUNT	UNIT $	AMOUNT	UNIT $	AMOUNT		
	24" Pipe Spool													
	10 ft long 6XN	1	EA	$11,616.00	$11,616		$1,742.40	$1,742		$0		$0	$13,358	
	6 ft long 6XN	1	EA	$8,588.16	$8,588		$1,288.22	$1,288		$0		$0	$9,876	
	4 ft long 6XN	2	EA	$7,074.24	$14,148		$1,061.14	$2,122		$0		$0	$16,271	
	1 ft long 6XN	3	EA	$4,803.35	$14,410		$720.50	$2,162		$0		$0	$16,572	
	24x20 (should be 24x16) Tee 6XN	1	EA	$2,976.00	$2,976		$595.20	$595		$0		$0	$3,571	
	24"x20" (should be 24x16) 90 Elbow 6	1	EA	$2,563.20	$2,563		$512.64	$513		$0		$0	$3,076	
	24" Anti-cavitation Globe Valve	1	EA	$64,516.80	$64,517		$9,677.52	$9,678		$0		$0	$74,194	
	24" Tee 6XN	1	EA	$2,976.00	$2,976		$595.20	$595		$0		$0	$3,571	$161,052
	<u>CCR (Cleaning Concentrate Return)</u>													
	24" Butterfly Valve 6XN	1	EA	$12,960.00	$12,960		$1,944.00	$1,944		$0		$0	$14,904	
	24" Pipe Spool													
	4 ft long 316SS	1	EA	$2,985.21	$2,985		$447.78	$448		$0		$0	$3,433	
	1 ft long 316SS	1	EA	$1,653.05	$1,653		$247.96	$248		$0		$0	$1,901	$20,238
	<u>Permeate Connectors</u>													
	3.5" J-Bends w/2 vics PVC	86	EA	$66.00	$5,676		$9.90	$851		$0		$0	$6,527	$6,527
	<u>Permeate Manifold</u>													
	6" Pipe Spool 17.5 ft long w/24 ea 3.5" side outlets with vic 304 SST	1	EA	$3,115.85	$3,116		$467.38	$467		$0		$0	$3,583	
	8" Pipe Spool 17.5 ft long w/24 ea 3.5" side outlets with vic 304 SST	7	EA	$4,128.05	$28,896		$619.21	$4,334		$0		$0	$33,231	$36,814
	<u>Permeate Header</u>													
	16x6 90 Elbow 304 SST	1	EA	$1,284.00	$1,284		$192.60	$193		$0		$0	$1,477	
	16" pipe spools													
	2 ft long 304 SST	3	EA	$920.00	$2,760		$138.00	$414		$0		$0	$3,174	
	1 ft long 304 SST	1	EA	$622.67	$623		$93.40	$93		$0		$0	$716	
	16x8 Tee 304 SST	3	EA	$1,676.00	$5,028		$335.20	$1,006		$0		$0	$6,034	
	24x8 Tee 304 SST	4	EA	$2,514.00	$10,056		$502.80	$2,011		$0		$0	$12,067	
	24x16 Reducer 304 SST	1	EA	$482.00	$482		$96.40	$96		$0		$0	$578	
	24" Pipe Spool													
	1 ft long 304 SST	2	EA	$3,712.63	$7,425		$556.89	$1,114		$0		$0	$8,539	
	2 ft long 304 SST	2	EA	$4,734.53	$9,469		$710.18	$1,420		$0		$0	$10,889	
	3 ft long 304 SST	1	EA	$4,393.90	$4,394		$659.08	$659		$0		$0	$5,053	
	6 ft long 304 SST	2	EA	$5,415.79	$10,832		$812.37	$1,625		$0		$0	$12,456	
	8 ft long 304 SST	1	EA	$6,097.05	$6,097		$914.56	$915		$0		$0	$7,012	
	9 ft long 304 SST	1	EA	$6,437.69	$6,438		$965.65	$966		$0		$0	$7,403	
	16 ft long 304 SST	1	EA	$8,822.11	$8,822		$1,323.32	$1,323		$0		$0	$10,146	
	24" 90 Elbow 304 SST	3	EA	$1,067.86	$3,204		$213.57	$641		$0		$0	$3,844	
	24" 90 Elbow w/8" side outlet 304 SST	1	EA	$1,263.86	$1,264		$252.77	$253		$0		$0	$1,617	
	24" Tee 304 SST	1	EA	$1,487.30	$1,487		$223.10	$223		$0		$0	$1,710	
	24" Butterfly Valve 304 SST	2	EA	$5,100.00	$10,200		$765.00	$1,530		$0		$0	$11,730	$104,345

ESTIMATE SUMMARY

PROJECT : R O TRAIN OPTIONS
FACILITY : 20" SEAWATER TRAIN
FILE NAME: R O TRAIN OPTIONS.XLS

ESTIMATOR: D JONES
PROJ. MANAGER:
PROJ. NO.:
ESTIMATE NO. : 2004047
REV. NO. : 1
DATE: 3/23/04 (Rev 6-21-04 Bergman)

MARK-UPS:	MATL	LABOR	EQUIP.	INSTL or S/C
OVERHEAD =				
PROFIT =				
MOB/BOND/INS. =				
CONTINGENCY =				

NO.	DESCRIPTION	QTY	UNIT	MATERIALS		LABOR			CONST. EQUIP.		INSTL or S/C		TOTAL	SUBTOTALS
				UNIT $	AMOUNT	MH	RATE	AMOUNT	UNIT $	AMOUNT	UNIT $	AMOUNT		
	Permeate-To-Waste													
	24" Pipe Spool													
	1 ft long 304SST	2	EA	$4,734.53	$9,469		$710.18	$1,420		$0		$0	$10,889	
	24" Butterfly Valve 6 XN	1	EA	$12,240.00	$12,240		$2,448.00	$2,448		$0		$0	$14,688	
	24" Butterfly Valve 304SST	1	EA	$5,100.00	$5,100		$765.00	$765		$0		$0	$5,866	$31,442
	CPR (Cleaning Permeate Return)													
	8" Butterfly Valve PVC	1	EA	$517.07	$517		$77.56	$78		$0		$0	$695	
	8" Pipe Spool													
	6 ft long PVC	2	EA	$233.20	$466		$34.98	$70		$0		$0	$636	
	3 ft long PVC	2	EA	$195.10	$390		$29.27	$59		$0		$0	$449	
	8" 90 Elbow PVC	3	EA	$89.00	$267		$17.80	$53		$0		$0	$320	$1,900
	Instrumentation													
	24" Mag Meter - concentrate 6XN	1	EA	$33,600.00	$33,600		$5,040.00	$5,040		$0		$0	$38,640	
	24" Mag Meter - permeate 304SST	1	EA	$26,880.00	$26,880		$4,032.00	$4,032		$0		$0	$30,912	
	PITs with diaphragm seals 316SST	2	EA	$2,100.00	$4,200		$525.00	$1,050		$0		$0	$5,250	
	PITs 316SST	1	EA	$1,700.00	$1,700		$425.00	$425		$0		$0	$2,125	
	Conductivity Meters	2	EA	$1,800.00	$3,600		$450.00	$900		$0		$0	$4,500	
	Instrument Rack	1	EA	$2,000.00	$2,000		$300.00	$300		$0		$0	$2,300	
	Instrument Panel	1	EA	$5,000.00	$5,000		$750.00	$750		$0		$0	$5,750	
	I/O Panel	1	EA	$2,000.00	$2,000		$300.00	$300		$0		$0	$2,300	$91,777
	Painted Carbon Steel Skid	1	EA	$140,400.00	$140,400		$14,040.0	$14,040		$0		$0	$154,440	$154,440
	Sample Panel													
	Sample Panel	1	EA	$2,000.00	$2,000		$200.00	$200		$0		$0	$2,200	$2,200
	Sample Valves													
	Feed 6XN	1	EA											
	Concentrate 6XN	1	EA											
	Permeate Manifolds 316 SST	8	EA											
	Permeate Total 316 SST	1	EA											
	Permeate per Pressure Vessel 316 SST	86	EA											
A	SUBTOTAL				$4,620,351			$874,976		$0		$0	$5,496,327	$5,495,327
B	OVERHEAD & PROFIT	(A*ohd)+((A+ohd)*p)			$0			$0		$0		$0	$0	
C	MOB / BOND / INSUR.	(% of A)			$0			$0		$0		$0	$0	
D	CONTINGENCY	(% of A)			$0			$0		$0		$0	$0	
E	TOTAL ESTIMATED CONSTRUCTION COST				$4,620,351			$874,976		$0		$0	$5,496,300	

Table G-5.—CPES Cost Summary for 12.5 mgd Plant Capacities

CH2M HILL CPES COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
12.5 mgd (Note 1)									
RO Facility Before Adders, $ Million (Note 2)	$8.00	$5.74	$5.47	$9.90	$7.67	$7.30	$18.13	$15.69	$15.17
$/gpd	$0.640	$0.459	$0.438	$0.792	$0.613	$0.584	$1.450	$1.255	$1.214
% of 8" dia cost	**100.0%**	**71.8%**	**68.4%**	**100.0%**	**77.4%**	**73.8%**	**100.0%**	**86.6%**	**83.7%**
RO Facility After Some Adders, $ Million (Note 3)	$11.6	$8.36	$7.96	$14.41	$11.16	$10.63	$26.39	$22.83	$22.08
RO Facility$/gpd	**$0.932**	**$0.669**	**$0.637**	**$1.153**	**$0.892**	**$0.850**	**$2.111**	**$1.827**	**$1.767**
% increase from $ before adders	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%
% of 8" dia cost	**100.0%**	**71.8%**	**68.4%**	**100.0%**	**77.4%**	**73.8%**	**100.0%**	**86.6%**	**83.7%**
RO Facility After All Adders, $ Million (Note 4)	$14.91	$10.70	$10.19	$18.45	$14.28	$13.60	$33.77	$29.23	$28.27
$/gpd	$1.193	$0.856	$0.816	$1.476	$1.142	$1.088	$2.702	$2.338	$2.261
% increase from $ before some adders	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%
% of 8" dia cost	**100.0%**	**71.8%**	**68.4%**	**100.0%**	**77.4%**	**73.8%**	**100.0%**	**86.6%**	**83.7%**
Total Plant Construction, $ Million	$22.79	$18.58	$18.08	$45.44	$41.27	$40.60	$66.70	$62.15	$61.19
Total Construction $/gpd	**$1.824**	**$1.487**	**$1.446**	**$3.636**	**$3.302**	**$3.248**	**$5.336**	**$4.972**	**$4.896**
% of 8" dia cost	**100.0%**	**81.5%**	**79.3%**	**100.0%**	**90.8%**	**89.3%**	**100.0%**	**93.2%**	**91.7%**
Annual O&M Costs $ Million/Yr	$3.03	$2.96	$2.95	$4.56	$4.51	$4.50	$6.83	$6.77	$6.75
Annual O&M Costs $/1000 gallons	**$0.699**	**$0.682**	**$0.680**	**$1.053**	**$1.041**	**$1.038**	**$1.576**	**$1.561**	**$1.557**
% of 8" dia cost	**100.0%**	**97.7%**	**97.4%**	**100.0%**	**98.9%**	**98.6%**	**100.0%**	**99.0%**	**98.8%**
Life Cycle Cost, $ Million	$60.53	$55.44	$54.83	$102.29	$97.48	$96.65	$151.84	$146.47	$145.28
% of 8" dia cost	**100.0%**	**91.6%**	**90.6%**	**100.0%**	**95.3%**	**94.5%**	**100.0%**	**96.5%**	**95.7%**
Amortized Capital, $ Million/yr (Note 5)	$1.83	$1.49	$1.45	$3.65	$3.31	$3.26	$5.35	$4.99	$4.91
Amortized Capital, $/1000 gallons	$0.422	$0.344	$0.335	$0.841	$0.764	$0.752	$1.235	$1.151	$1.133
Total Annual Treated Water Cost $/yr	$4.86	$4.45	$4.40	$8.21	$7.82	$7.76	$12.18	$11.75	$11.66
Total Treated Water Cost $/1000 gallons	**$1.121**	**$1.026**	**$1.016**	**$1.894**	**$1.805**	**$1.789**	**$2.811**	**$2.712**	**$2.690**
Total Treated Water Cost $/acre-foot	**$365**	**$334**	**$331**	**$617**	**$588**	**$583**	**$916**	**$884**	**$876**
Total Treated Water Cost $/m3	**$0.296**	**$0.271**	**$0.268**	**$0.500**	**$0.476**	**$0.472**	**$0.742**	**$0.716**	**$0.710**
% of 8" dia cost	**100.0%**	**91.6%**	**90.6%**	**100.0%**	**95.3%**	**94.5%**	**100.0%**	**96.5%**	**95.7%**

1. Annual production at 95% plant factor = 4,334,375 Kgal/yr
2. Additional proj costs (sitework, yard piping, yard elect, plant computer), Contractor markups (OH, profit, Mob/Bonds/Insur/Contingency), *Escalation (to midpoint of construction), Location adjustment factor, and "Red' Flags"*
3. With adders except standard additional project costs (sitework, yard piping, yard elect, plant computer)
4. Adders included: Additional proj costs (sitework, yard piping, yard elect, plant computer), Contractor markups (OH, profit, Mob/Bonds/Insur/Contingency), *Escalation (to midpoint of construction), Location adjustment factor, and "Red' Flags"*
5. Amortization at 5% for 20 years

Table G-6.—CPES Cost Summary for 25 mgd Plant Capacities

CH2M HILL CPES COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
25 mgd (Note 1)									
RO Facility Before Adders, $ Million (Note 2)	$16.29	$11.73	$11.18	$18.91	$14.38	$13.65	$35.48	$30.44	$29.41
$/gpd	$0.652	$0.469	$0.447	$0.756	$0.575	$0.546	$1.419	$1.218	$1.177
% of 8" dia cost	100.0%	72.0%	68.6%	100.0%	76.0%	72.2%	100.0%	86.8%	82.9%
RO Facility After Some Adders, $ Million (Note 3)	$23.7	$17.07	$16.28	$27.52	$20.93	$19.86	$51.63	$44.30	$42.80
RO Facility$/gpd	**$0.948**	**$0.683**	**$0.651**	**$1.101**	**$0.837**	**$0.796**	**$2.065**	**$1.772**	**$1.712**
% increase from $ before adders	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%
% of 8" dia cost	100.0%	72.0%	68.6%	100.0%	76.0%	72.2%	100.0%	86.8%	82.9%
RO Facility After All Adders, $ Million (Note 4)	$30.35	$21.84	$20.83	$35.22	$26.79	$25.42	$66.09	$56.71	$54.79
$/gpd	$1.214	$0.874	$0.833	$1.409	$1.071	$1.017	$2.644	$2.268	$2.192
% increase from $ before some adders	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%
% of 8" dia cost	100.0%	72.0%	68.6%	100.0%	76.0%	72.2%	100.0%	86.8%	82.9%
Total Plant Construction, $ Million	$41.73	$33.22	$32.21	$76.03	$67.59	$66.23	$117.20	$107.82	$105.90
Total Construction $/gpd	**$1.669**	**$1.329**	**$1.288**	**$3.041**	**$2.704**	**$2.649**	**$4.688**	**$4.313**	**$4.236**
% of 8" dia cost	100.0%	79.6%	77.2%	100.0%	88.9%	87.1%	100.0%	92.0%	90.4%
Annual O&M Costs $ Million/Yr	$5.64	$5.49	$5.49	$7.95	$7.82	$7.79	$12.53	$12.38	$12.34
Annual O&M Costs $/1000 gallons	**$0.650**	**$0.633**	**$0.633**	**$0.917**	**$0.902**	**$0.899**	**$1.445**	**$1.428**	**$1.424**
% of 8" dia cost	100.0%	97.4%	97.3%	100.0%	98.4%	98.1%	100.0%	98.8%	98.6%
Life Cycle Cost, $ Million	$111.98	$101.63	$100.60	$175.09	$165.04	$163.37	$273.36	$262.11	$259.74
% of 8" dia cost	100.0%	90.8%	89.8%	100.0%	94.3%	93.3%	100.0%	95.9%	95.0%
Amortized Capital, $ Million/yr (Note 5)	$3.35	$2.67	$2.58	$6.10	$5.42	$5.31	$9.40	$8.65	$8.50
Amortized Capital, $/1000 gallons	$0.386	$0.307	$0.298	$0.704	$0.626	$0.613	$1.085	$0.998	$0.980
Total Annual Treated Water Cost $/yr	$8.99	$8.16	$8.07	$14.05	$13.24	$13.11	$21.94	$21.03	$20.84
Total Treated Water Cost $/1000 gallons	**$1.037**	**$0.941**	**$0.931**	**$1.621**	**$1.528**	**$1.512**	**$2.530**	**$2.426**	**$2.404**
Total Treated Water Cost $/acre-foot	**$338**	**$307**	**$303**	**$528**	**$498**	**$493**	**$824**	**$791**	**$783**
Total Treated Water Cost $/m3	**$0.274**	**$0.248**	**$0.246**	**$0.428**	**$0.403**	**$0.399**	**$0.668**	**$0.640**	**$0.635**
% of 8" dia cost	100.0%	90.8%	89.8%	100.0%	94.3%	93.3%	100.0%	95.9%	95.0%

1. Annual production at 95% plant factor = 8,668,750 Kgal/yr
2. Additional proj costs (sitework, yard piping, yard elect, plant computer), Contractor markups (OH, profit, Mob/Bonds/Insur/Contingency), *Escalation (to midpoint of construction)*, *Location adjustment factor, and "Red' Flags"*
3. With adders except standard additional project costs (sitework, yard piping, yard elect, plant computer)
4. Adders included: Additional proj costs (sitework, yard piping, yard elect, plant computer), Contractor markups (OH, profit, Mob/Bonds/Insur/Contingency), *Escalation (to midpoint of construction)*, *Location adjustment factor, and "Red' Flags"*
5. Amortization at 5% for 20 years

Table G-7.—CPES Cost Summary for 50 mgd Plant Capacities

CH2M HILL CPES COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
50 mgd (Note 1)									
RO Facility Before Adders, $ Million (Note 2)	$32.43	$22.77	$21.71	$37.84	$28.17	$26.84	$70.94	$59.63	$57.55
$/gpd	$0.649	$0.455	$0.434	$0.757	$0.563	$0.537	$1.419	$1.193	$1.151
% of 8" dia cost	**100.0%**	**70.2%**	**66.8%**	**100.0%**	**74.5%**	**70.8%**	**100.0%**	**84.1%**	**81.1%**
RO Facility After Some Adders, $ Million (Note 3)	$47.2	$33.14	$31.59	$55.07	$41.00	$39.05	$103.24	$86.78	$83.75
RO Facility$/gpd	**$0.944**	**$0.663**	**$0.632**	**$1.101**	**$0.820**	**$0.781**	**$2.065**	**$1.736**	**$1.676**
% increase from $ before adders	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%
% of 8" dia cost	**100.0%**	**70.2%**	**66.8%**	**100.0%**	**74.5%**	**70.8%**	**100.0%**	**84.1%**	**81.1%**
RO Facility After All Adders, $ Million (Note 4)	$60.41	$42.42	$40.43	$70.49	$52.48	$49.99	$132.15	$111.08	$107.20
$/gpd	$1.208	$0.848	$0.809	$1.410	$1.050	$1.000	$2.643	$2.222	$2.144
% increase from $ before some adders	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%
% of 8" dia cost	**100.0%**	**70.2%**	**66.8%**	**100.0%**	**74.5%**	**70.8%**	**100.0%**	**84.1%**	**81.1%**
Total Plant Construction, $ Million	$78.68	$60.69	$58.71	$136.68	$118.67	$116.18	$216.62	$195.56	$191.68
Total Construction $/gpd	**$1.574**	**$1.214**	**$1.174**	**$2.734**	**$2.373**	**$2.324**	**$4.332**	**$3.911**	**$3.834**
% of 8" dia cost	**100.0%**	**77.1%**	**74.6%**	**100.0%**	**86.8%**	**85.0%**	**100.0%**	**90.3%**	**88.5%**
Annual O&M Costs $ Million/Yr	$10.75	$10.45	$10.42	$14.75	$14.51	$14.50	$23.86	$23.52	$23.48
Annual O&M Costs $/1000 gallons	**$0.620**	**$0.603**	**$0.601**	**$0.851**	**$0.837**	**$0.836**	**$1.376**	**$1.357**	**$1.354**
% of 8" dia cost	**100.0%**	**97.2%**	**96.8%**	**100.0%**	**98.3%**	**98.3%**	**100.0%**	**98.6%**	**98.4%**
Life Cycle Cost, $ Million	$212.71	$190.93	$188.53	$320.56	$299.46	$296.85	$513.96	$488.66	$484.23
% of 8" dia cost	**100.0%**	**89.8%**	**88.6%**	**100.0%**	**93.4%**	**92.6%**	**100.0%**	**95.1%**	**94.2%**
Amortized Capital, $ Million/yr (Note 5)	$6.31	$4.87	$4.71	$10.97	$9.52	$9.32	$17.38	$15.69	$15.38
Amortized Capital, $/1000 gallons	$0.364	$0.281	$0.272	$0.633	$0.549	$0.538	$1.003	$0.905	$0.887
Total Annual Treated Water Cost $/yr	$17.07	$15.32	$15.13	$25.72	$24.03	$23.82	$41.24	$39.21	$38.86
Total Treated Water Cost $/1000 gallons	**$0.984**	**$0.884**	**$0.873**	**$1.484**	**$1.386**	**$1.374**	**$2.379**	**$2.262**	**$2.241**
Total Treated Water Cost $/acre-foot	**$321**	**$288**	**$284**	**$483**	**$452**	**$448**	**$776**	**$737**	**$730**
Total Treated Water Cost $/m3	**$0.260**	**$0.233**	**$0.230**	**$0.392**	**$0.366**	**$0.363**	**$0.628**	**$0.597**	**$0.592**
% of 8" dia cost	**100.0%**	**89.8%**	**88.6%**	**100.0%**	**93.4%**	**92.6%**	**100.0%**	**95.1%**	**94.2%**

1. Annual production at 95% plant factor = 17,337,500 Kgal/yr
2. Additional proj costs (sitework, yard piping, yard elect, plant computer), Contractor markups (OH, profit, Mob/Bonds/Insur/Contingency), *Escalation (to midpoint of construction), Location adjustment factor, and "Red' Flags"*
3. With adders except standard additional project costs (sitework, yard piping, yard elect, plant computer)
4. Adders included: Additional proj costs (sitework, yard piping, yard elect, plant computer), Contractor markups (OH, profit, Mob/Bonds/Insur/Contingency), *Escalation (to midpoint of construction), Location adjustment factor, and "Red' Flags"*
5. Amortization at 5% for 20 years

Table G-8.—CPES Cost Summary for 100 mgd Plant Capacities

CH2M HILL CPES COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
100 mgd (Note 1)									
RO Facility Before Adders, $ Million (Note 2)	$65.64	$45.78	$43.65	$76.50	$56.72	$53.99	$142.45	$119.24	$114.82
$/gpd	$0.656	$0.458	$0.437	$0.765	$0.567	$0.540	$1.425	$1.192	$1.148
% of 8" dia cost	**100.0%**	**69.8%**	**66.6%**	**100.0%**	**74.1%**	**70.6%**	**100.0%**	**83.7%**	**80.6%**
RO Facility After Some Adders, $ Million (Note 3)	$95.5	$66.63	$63.53	$111.34	$82.54	$78.57	$207.31	$173.53	$167.10
RO Facility$/gpd	**$0.955**	**$0.666**	**$0.636**	**$1.113**	**$0.825**	**$0.786**	**$2.073**	**$1.736**	**$1.671**
% increase from $ before adders	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%
% of 8" dia cost	**100.0%**	**69.8%**	**66.6%**	**100.0%**	**74.1%**	**70.6%**	**100.0%**	**83.7%**	**80.6%**
RO Facility After All Adders, $ Million (Note 4)	$122.27	$85.29	$81.31	$142.51	$105.65	$100.57	$265.36	$222.12	$213.89
$/gpd	$1.223	$0.853	$0.813	$1.425	$1.057	$1.006	$2.654	$2.221	$2.139
% increase from $ before some adders	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%
% of 8" dia cost	**100.0%**	**69.8%**	**66.6%**	**100.0%**	**74.1%**	**70.6%**	**100.0%**	**83.7%**	**80.6%**
Total Plant Construction, $ Million	$154.04	$117.06	$113.09	$254.07	$217.21	$212.12	$410.66	$367.43	$359.20
Total Construction $/gpd	**$1.540**	**$1.171**	**$1.131**	**$2.641**	**$2.172**	**$2.121**	**$4.107**	**$3.674**	**$3.692**
% of 8" dia cost	**100.0%**	**76.0%**	**73.4%**	**100.0%**	**85.5%**	**83.6%**	**100.0%**	**89.6%**	**87.6%**
Annual O&M Costs $ Million/Yr	$20.86	$20.22	$20.15	$28.08	$27.50	$27.45	$46.08	$45.36	$45.24
Annual O&M Costs $/1000 gallons	**$0.602**	**$0.583**	**$0.581**	**$0.810**	**$0.793**	**$0.792**	**$1.329**	**$1.308**	**$1.306**
% of 8" dia cost	**100.0%**	**96.9%**	**96.6%**	**100.0%**	**97.9%**	**97.8%**	**100.0%**	**98.4%**	**98.2%**
Life Cycle Cost, $ Million	$414.05	$369.06	$364.26	$603.97	$559.93	$554.25	$984.94	$932.65	$922.94
% of 8" dia cost	**100.0%**	**89.1%**	**88.0%**	**100.0%**	**92.7%**	**91.8%**	**100.0%**	**94.7%**	**93.7%**
Amortized Capital, $ Million/yr (Note 5)	$12.36	$9.39	$9.07	$20.39	$17.43	$17.02	$32.95	$29.48	$28.82
Amortized Capital, $/1000 gallons	$0.356	$0.271	$0.262	$0.588	$0.503	$0.491	$0.950	$0.850	$0.831
Total Annual Treated Water Cost $/yr	$33.22	$29.61	$29.23	$48.46	$44.93	$44.47	$79.03	$74.84	$74.06
Total Treated Water Cost $/1000 gallons	**$0.958**	**$0.854**	**$0.843**	**$1.398**	**$1.296**	**$1.283**	**$2.279**	**$2.158**	**$2.136**
Total Treated Water Cost $/acre-foot	**$312**	**$278**	**$276**	**$456**	**$422**	**$418**	**$743**	**$703**	**$696**
Total Treated Water Cost $/m3	**$0.253**	**$0.226**	**$0.222**	**$0.369**	**$0.342**	**$0.339**	**$0.602**	**$0.570**	**$0.564**
% of 8" dia cost	**100.0%**	**89.1%**	**88.0%**	**100.0%**	**92.7%**	**91.8%**	**100.0%**	**94.7%**	**93.7%**

1. Annual production at 95% plant factor = 34,675,000 Kgal/yr
2. Additional proj costs (sitework, yard piping, yard elect, plant computer), Contractor markups (OH, profit, Mob/Bonds/Insur/Contingency), *Escalation (to midpoint of construction), Location adjustment factor, and "Red' Flags"*
3. With adders except standard additional project costs (sitework, yard piping, yard elect, plant computer)
4. Adders included: Additional proj costs (sitework, yard piping, yard elect, plant computer), Contractor markups (OH, profit, Mob/Bonds/Insur/Contingency), *Escalation (to midpoint of construction), Location adjustment factor, and "Red' Flags"*
5. Amortization at 5% for 20 years

Table G-9.—CPES Cost Summary for 150 mgd Plant Capacities

CH2M HILL CPES COST SUMMARY	Brackish Ground Water 8"	Brackish Ground Water 16"	Brackish Ground Water 20"	Brackish Surface Water 8"	Brackish Surface Water 16"	Brackish Surface Water 20"	Seawater 8"	Seawater 16"	Seawater 20"
150 mgd (Note 1)									
RO Facility Before Adders, $ Million (Note 2)	$99.10	$68.84	$65.64	$115.55	$85.47	$81.35	$215.83	$180.18	$173.27
$/gpd	$0.661	$0.459	$0.438	$0.770	$0.570	$0.542	$1.439	$1.201	$1.155
% of 8" dia cost	100.0%	69.5%	66.2%	100.0%	74.0%	70.4%	100.0%	83.6%	80.3%
RO Facility After Some Adders, $ Million (Note 3)	$144.2	$100.19	$95.53	$168.16	$124.38	$118.38	$314.10	$262.22	$252.16
RO Facility$/gpd	**$0.961**	**$0.668**	**$0.637**	**$1.121**	**$0.829**	**$0.789**	**$2.094**	**$1.748**	**$1.681**
% increase from $ before adders	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%	45.5%
% of 8" dia cost	100.0%	69.5%	66.2%	100.0%	74.0%	70.4%	100.0%	83.6%	80.3%
RO Facility After All Adders, $ Million (Note 4)	$184.60	$128.24	$122.28	$215.24	$159.21	$151.53	$402.05	$335.64	$322.76
$/gpd	$1.231	$0.855	$0.815	$1.435	$1.061	$1.010	$2.680	$2.238	$2.152
% increase from $ before some adders	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%
% of 8" dia cost	100.0%	69.5%	66.2%	100.0%	74.0%	70.4%	100.0%	83.6%	80.3%
Total Plant Construction, $ Million	$229.77	$173.41	$167.46	$369.55	$313.52	$305.84	$604.41	$538.00	$525.12
Total Construction $/gpd	**$1.532**	**$1.156**	**$1.116**	**$2.464**	**$2.090**	**$2.039**	**$4.029**	**$3.587**	**$3.501**
% of 8" dia cost	100.0%	75.5%	72.9%	100.0%	84.8%	82.8%	100.0%	89.0%	86.9%
Annual O&M Costs $ Million/Yr	$31.04	$30.06	$29.96	$41.38	$40.47	$40.39	$68.18	$67.06	$66.85
Annual O&M Costs $/1000 gallons	**$0.597**	**$0.578**	**$0.576**	**$0.796**	**$0.778**	**$0.776**	**$1.311**	**$1.289**	**$1.285**
% of 8" dia cost	100.0%	96.8%	96.5%	100.0%	97.8%	97.6%	100.0%	98.3%	98.0%
Life Cycle Cost, $ Million	$616.66	$547.99	$540.79	$885.28	$817.88	$809.15	$1,454.15	$1,373.66	$1,358.28
% of 8" dia cost	100.0%	88.9%	87.7%	100.0%	92.4%	91.4%	100.0%	94.5%	93.4%
Amortized Capital, $ Million/yr (Note 5)	$18.44	$13.92	$13.44	$29.65	$25.16	$24.54	$48.50	$43.17	$42.14
Amortized Capital, $/1000 gallons	$0.354	$0.268	$0.258	$0.570	$0.484	$0.472	$0.932	$0.830	$0.810
Total Annual Treated Water Cost $/yr	$49.48	$43.97	$43.39	$71.04	$65.63	$64.93	$116.68	$110.23	$108.99
Total Treated Water Cost $/1000 gallons	**$0.951**	**$0.845**	**$0.834**	**$1.366**	**$1.262**	**$1.248**	**$2.243**	**$2.119**	**$2.095**
Total Treated Water Cost $/acre-foot	**$310**	**$275**	**$272**	**$445**	**$411**	**$407**	**$731**	**$691**	**$683**
Total Treated Water Cost $/m3	**$0.251**	**$0.223**	**$0.220**	**$0.360**	**$0.333**	**$0.329**	**$0.592**	**$0.559**	**$0.553**
% of 8" dia cost	100.0%	88.9%	87.7%	100.0%	92.4%	91.4%	100.0%	94.5%	93.4%

1. Annual production at 95% plant factor = 52,012,500 Kgal/yr
2. Additional proj costs (sitework, yard piping, yard elect, plant computer), Contractor markups (OH, profit, Mob/Bonds/Insur/Contingency), *Escalation (to midpoint of construction), Location adjustment factor, and "Red' Flags"*
3. With adders except standard additional project costs (sitework, yard piping, yard elect, plant computer)
4. Adders included: Additional proj costs (sitework, yard piping, yard elect, plant computer), Contractor markups (OH, profit, Mob/Bonds/Insur/Contingency), *Escalation (to midpoint of construction), Location adjustment factor, and "Red' Flags"*
5. Amortization at 5% for 20 years