

## Large Diameter RO Technology

---

*By Lisa Henthorne, P.E. (CH2M HILL), with C. Bartels (Hydranautics), R. Bergman (CH2M HILL), M. Hallan (FilmTec), P. Knappe (Trisep), J. Lozier (CH2M HILL), P. Metcalfe (Toray Membrane America), M. Peery (FilmTec), I. Shelby (Hydranautics)*

With the continued growth of dense population areas, particularly in coastal regions, there is a greater demand on potable water supplies. As the cost of reverse osmosis (RO) desalination continues to decrease, an increasing number of communities around the world are utilizing RO to augment their existing water supply. Similarly, advanced water reuse is gaining in application as demonstrated by countries as diverse as Singapore and Kuwait, which are applying RO technology in large-scale water reuse facilities. Currently there lacks any significant economy of scale advantages for large-scale RO and NF plants. Until recently, most RO<sup>1</sup> systems have been small to medium size, less than 95,000 m<sup>3</sup>/day. Unlike many other technologies in water treatment which achieve lower per cubic meter treatment costs with increasing plant capacity, savings for RO typically plateau in the 38,000-76,000 m<sup>3</sup>/day range.

The reason for the relatively poor economy of scale for RO is that all systems, small to large, are designed using a common 8-inch by 40-inch spiral wound element. The use of only one element size means that the number of elements and associated equipment must increase proportionally with flow. For example, a standard 189,000 m<sup>3</sup>/day RO train would contain over 8,000 "8 by 40" elements, with a 568,000 m<sup>3</sup>/day brackish water RO plant costing roughly three times that for a 189,000 m<sup>3</sup>/day plant, with little savings for expanded production.

As a result, in 2003, a group of RO membrane manufacturers formed a Consortium to determine whether and to what extent the use of a larger diameter element could improve the economics of RO plants, and subsequently establish what they considered to be the most feasible diameter for a new industry standard large diameter RO element. The Consortium included FilmTec Corporation, Hydranautics, Toray Membrane America, Inc. and Trisep Corporation with involvement by CH2M HILL, together forming the "Consortium Team". The project was funded by the U.S. Bureau of Reclamation and cost-shared by the Consortium Team. The primary function of the Consortium Team was to establish a standard element size that reflected consensus by RO membrane manufacturers, RO/NF system suppliers and end users in order to realize the maximum economic benefits of larger diameter elements.

Concurrently, Koch Membranes developed a large-diameter RO membrane of 18-inches. GrahamTek, a Singaporean-based company, developed a large-diameter RO technology using a unique flow distributor to enhance hydrodynamics within the RO element. This paper will first evaluate the economics and other important issues considered by the large-diameter Consortium.

---

<sup>1</sup> RO used to refer to both RO and NF technologies in the remainder of this article because of their similar physical design features.

## Increasing Element Standard

Working with the Consortium, CH2M HILL, Inc. conducted an economic evaluation (Economic Study) that considered multiple desalting applications and plant capacities. The evaluation was designed to estimate and compare capital, operations and maintenance (O&M) and life-cycle costs of “8 by 40” based RO designs to candidate large diameter element designs considering RO train, system, and overall facility costs. Industry stakeholder feedback and Consortium Team deliberation resulted in the selection of 16- and 20-inch diameters for evaluation in the Economic Study.

The Consortium Team conducted surveys with industry experts, end users, engineering consultants, and system suppliers provided an understanding of the perceived issues and benefits related to large diameter elements. The survey identified primary perceived concerns, including: handling challenges associated with the increased element weight and size; pressure vessel issues (cost, availability, and end-cap weight), particularly for seawater applications; and element efficiency and performance. While perceived benefits included: improved economics, reduced facility footprint, and reduced maintenance/improved reliability based on fewer element product water connections.

As a result of the concern expressed by end users, the Consortium Team investigated handling options, including discussions with engineering and operations staff at the Yuma Desalting Plant regarding equipment and protocols used to load/unload the 12-inch diameter RO elements used at this facility. As occurred at Yuma, the Consortium Team expects the industry change would push the development of the necessary mechanical handling devices to facilitate large diameter element installation, servicing, and removal. Other industries experienced similar product handling challenges and responded with suitable handling equipment development.

### ***Economic Study***

The scope of the Economic Study conducted by the Consortium project involved 45 different cost models based on three water quality applications: 1) Brackish groundwater with high RO flux; 2) Brackish surface water or water reuse with low RO flux; 3) Seawater; and five plant capacities: 47,000 m<sup>3</sup>/day; 95,000 m<sup>3</sup>/day; 189,000 m<sup>3</sup>/day; 379,000 m<sup>3</sup>/day and 568,000 m<sup>3</sup>/day; and three element diameters: 8-, 16-, and 20-inch

CH2M HILL developed comprehensive capital, O&M and life-cycle costs, using each combination of the three elements, and based on an “order of magnitude” engineering estimate and plants built to United States’ standards using standard assumptions (please access the Bureau of Reclamation Report No. 114 at [www.usbr.gov](http://www.usbr.gov) for a full listing of assumptions).

CH2M HILL developed a computerized isometric model of an RO train design using “8 by 40” elements in 3-D, based on an RO train size of 16,000 m<sup>3</sup>/day permeate capacity (12 trains for 189,000 m<sup>3</sup>/day WTP). The 16,000 m<sup>3</sup>/d train capacity was selected based on the approximate optimum number of vessels (90-95) per train as discussed in Faigon and Liberman (IDA, 2003). CH2M HILL also used this vessel number per train for the 16- and 20-inch element design except for the 47,000 m<sup>3</sup>/day and 95,000 m<sup>3</sup>/day cases, where the number of vessels per train was reduced to ensure a minimum of four trains in the RO facility design.

## Results

The Economic Study results demonstrated clear economies of scale with the two larger diameter elements. All costs presented below are in U.S. dollars. Figures 1 illustrates the Economic Study results and show that overall construction 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 47,000 m<sup>3</sup>/day (12.5 mgd) capacity to 27 percent for the 568,000 m<sup>3</sup>/day (150 mgd) plant size. Savings were less significant (7 to 17 percent) for the surface water feed due to the leveling effect of the more extensive microfiltration (MF)/ultrafiltration (UF) pre-treatment, whose costs were considered to be equivalent for the three RO element diameters.

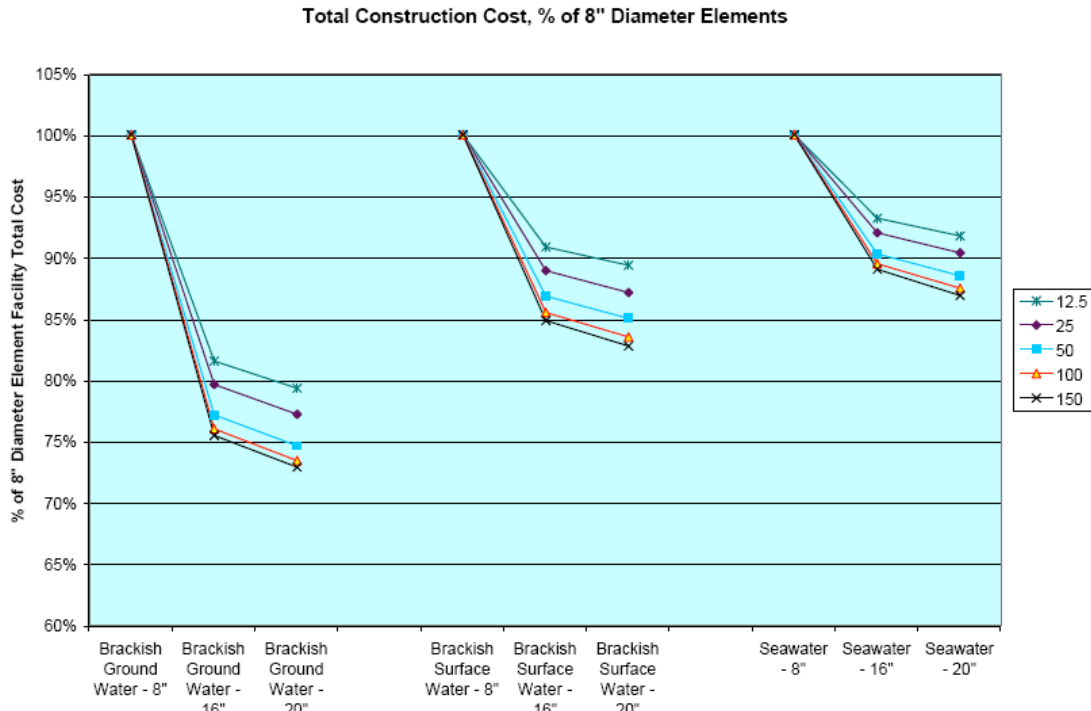
The most significant portion of the RO plant construction cost positively impacted by the increased diameter elements occurs in the RO train. These savings are primarily from savings in piping, manifolding, fittings and footprint. For the brackish groundwater cases, installed RO train cost was reduced \$29 per m<sup>3</sup>/day when 16-inch elements are used in an 189,000 m<sup>3</sup>/day (50 mgd) plant, a 50-percent savings. The largest plants could realize a 24-percent train cost saving. In addition, some O&M savings associated with larger-diameter designs come from reductions in repair and maintenance, as fewer elements, pressure vessels, and RO skid components translate into lower repair and maintenance costs.

Figure 2 illustrates unit life cycle costs (total treated water costs). Realized life-cycle cost savings from large diameter element use are less dramatic than for construction costs due to the levelling impact of the similar O&M costs for the RO plant using all diameter elements. 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 189,000 m<sup>3</sup>/day (50 mgd) 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.

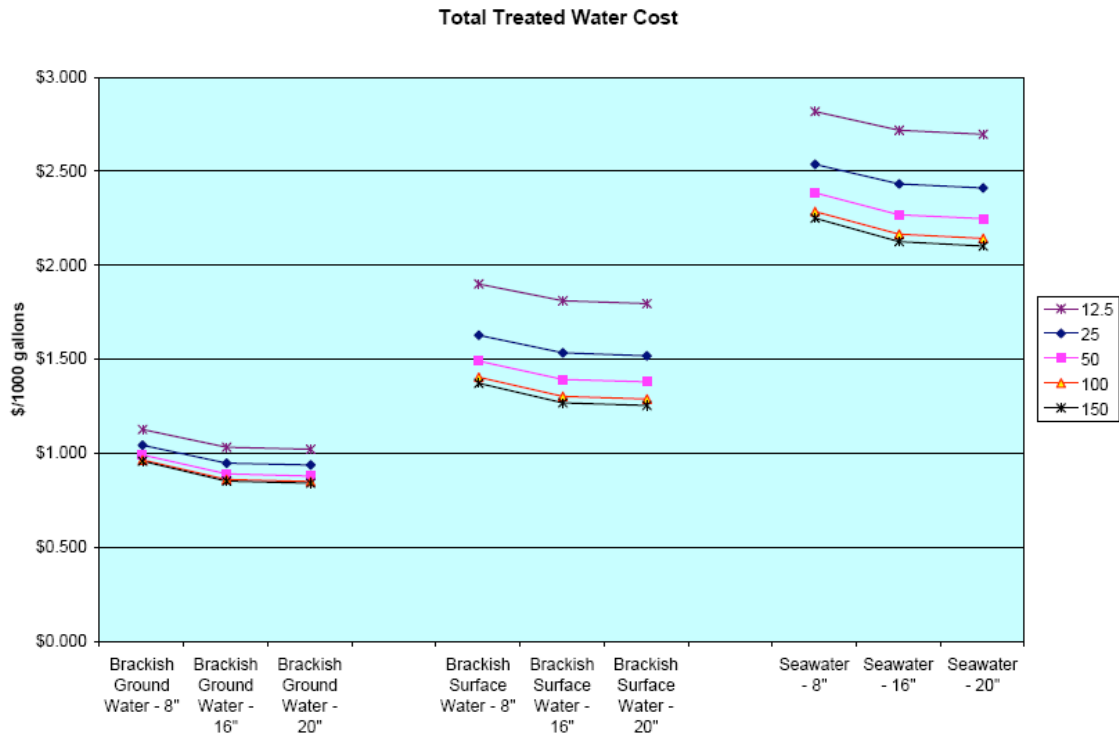
## Conclusions

Several factors must be considered when evaluating a new large diameter element standard that substantially increases the membrane active area and increases water production:

- Market application, size, growth rate, and forecasts
- Balanced risk management across the industry value chain
- Justifiable economic savings



**FIGURE 1. COMPARATIVE CONSTRUCTION COSTS OF 8, 16, AND 20 INCH RO DESALINATION FACILITIES FOR VARIOUS WATER APPLICATIONS SHOWN AS PERCENTAGE OF COST RELATIVE TO THE 8 INCH COST**



**FIGURE 2 TOTAL WATER COST OF 8-, 16- AND 20-INCH DESALINATION FACILITIES FOR VARIOUS WATER APPLICATIONS**

## **Market**

Estimated market demand for large diameter elements over the foreseeable future is significant, albeit not extensive. Investment grade economics justifying research and development expenses and re-tooling costs incurred by element and pressure vessel manufacturers for a larger diameter standard are more readily obtained when aggregate nanofiltration, brackish water, and seawater markets are serviced by a single diameter element design.

## **Risks**

Understandably, any sizeable increase in element diameter will necessitate the development and utilization of mechanical handling equipment. However, the vessel/element handling equipment development was not identified as a limiting factor over the evaluated element diameter range (16 – 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 increase with increasing diameter. Minimizing industry concerns associated with this cost and risk, as well as concerns of handling, quality, and multiple sourcing requires balancing the extent of system cost savings derived from larger element diameters with these concerns.

## **Outcome**

Limitations regarding manufacturability of large diameter vessels that incorporate state-of-the-art features, such as flow through ports and ASME Section 10 certification, strongly influenced the element diameter selected by the Consortium as their recommended standard. To minimize vessel development costs the same large-diameter standard should be adopted for all feedwater water quality applications: brackish groundwater, brackish surface water (including reclaimed 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 83 bar, creates significant engineering challenges in vessel design at very large diameters, particularly when retaining modern vessel design features such as through-porting.

As a result, the Consortium balanced the inherent cost benefits of larger diameter elements with the associated risks, which indicated the majority of the cost savings occur in the transition from 8-inch to 16-inch diameter. Combined with the recognition of risk and the limitations and recommendations from the vessel manufacturers, a large diameter standard consensus of 15.90 +/- 0.01 inches (nominal 16 inches) emerged as viable and readily attainable.

Several RO manufacturers are presently in the prototype-testing phase of 16-inch diameter RO elements for both brackish and seawater applications. These same manufacturers indicate the large-diameter products will be commercially available in early 2007. Koch Membrane Systems continues to market its 18-inch brackish and seawater systems, the MegaMagnum. GrahamTek has standardized their large-diameter technology on 16-inch and is presently supplying their first large-scale commercial seawater RO plant using this technology in Singapore, in a 10,000 m<sup>3</sup>/day facility.

Large-diameter RO technology is clearly the wave of the future for medium-to-large-sized facilities and the industry will quickly gravitate towards this technology as the initial commercial plants successfully come on-line during the 2007 period.