KEY POINT: Annualized capital costs and energy costs are the two largest components of annual costs for seawater RO desal.

SUMMARY OF ISSUES

- The costs associated with brackish water and seawater desal are a function of numerous variables and are highly site-specific. Individual project costs can vary significantly depending on a number factors, including source water quality, plant size, the cost and availability of power, project financing terms, permitting requirements, and others.

- Given the site-specific nature of desal project design, the costs of different projects can be difficult to compare. In addition, reviews of published data on costs can be confusing because costs are rarely reported consistently and some cost parameters are often not reported at all. For example, some authors report the cost of desalinated water delivered to customers, while others present the cost of produced water prior to distribution (Cooley et. al. 2006).

- To further complicate matters, the underlying assumptions associated with different cost estimates often remain unstated (Miller, 2003). Few authors clearly state key variables included including the year and type of estimate (actual operating experience, bid, or engineer’s estimate), interest rate, amortization period, energy cost, salinity of the source water, and the presence or absence of subsidies. All of these factors can significantly affect overall project costs.

Despite these limitations, there is a wealth of information available on the nature of desal costs and on the ways in which these costs are determined. The following provides an overview of published cost estimates and summarizes the key factors influencing desal project costs.

Reported costs for SWRO facilities

The costs associated with SWRO desal have generally been reported within a range of $1.90 to $3.50 per thousand gallons (kga) ($0.50 to $0.70/m³) of water produced (Miller 2003, Dore 2005). Miller (2003) reports that it has generally become accepted that SWRO can be carried out in the U.S. for less than $2.00/kga ($0.50/m³). The Pacific Institute (2006), however, reports that in California, the cost of desalinated water production ranges from $3.00 to $3.50/kga (roughly $0.79 to $0.92/m³) for large, efficient plants, and can be as high as $8.35/kga ($2.21/m³) for
plants of smaller capacity. This wide range of estimates exemplifies the site-specific nature of desal projects, and likely, a variation in reporting assumptions and methods.

Cost information reported by the California Department of Water Resources (CDWR) (2003) encompasses most of the estimates reported above, ranging from $1.52/kgal to more than $5.70/kgal ($0.4 to $1.5/m³), depending on the size of the desal facility. Table 1 shows the unit costs of seawater desal, by plant size, as reported by CDWR (2003).

<table>
<thead>
<tr>
<th>Plant size</th>
<th>$/kgal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large plants (&gt;10 MGD)</td>
<td>$1.52 – 3.80</td>
</tr>
<tr>
<td>Medium plants (1-10 MGD)</td>
<td>$3.80 – 5.70</td>
</tr>
<tr>
<td>Small plants (&lt;1 MGD)</td>
<td>Over $5.70</td>
</tr>
</tbody>
</table>

The Pacific Institute (2006) attempted to standardize reported costs of produced water from SWRO seawater desal plants around the world. Table 2 shows the results of this analysis in U.S. dollars per kgal. The costs shown below exclude distribution costs and are not adjusted for inflation from the year of the reported cost since inflation varies from country to country. Even without this adjustment, it is apparent that costs vary widely (Cooley et. al. 2006).
Table 2. Summary of Reported First-Year Cost of Produced Water for RO Plants

<table>
<thead>
<tr>
<th>Facility/Loc.</th>
<th>US$/kgal (first year)</th>
<th>US$/m3 (first year)</th>
<th>Operational?</th>
<th>Year</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashkelon, Israel</td>
<td>2.03</td>
<td>0.54</td>
<td>Yes</td>
<td>2002</td>
<td>EDS (2004), Segal (2004), Zhou &amp; Tol (2005)</td>
</tr>
<tr>
<td>Ashkelon, Israel</td>
<td>2.00</td>
<td>0.53</td>
<td>Yes</td>
<td>2003</td>
<td>NAS (2004)</td>
</tr>
<tr>
<td>Ashkelon, Israel</td>
<td>2.10</td>
<td>0.55</td>
<td>Yes</td>
<td>2004</td>
<td>Wilf &amp; Bartels (2005)</td>
</tr>
<tr>
<td>Ashkelon, Israel</td>
<td>2.34</td>
<td>0.62</td>
<td>Yes</td>
<td>2005</td>
<td>Red Herring (2005), Semiat (2006)</td>
</tr>
<tr>
<td>Bahamas</td>
<td>5.60</td>
<td>1.48</td>
<td>Yes</td>
<td>2003</td>
<td>NAS (2004)</td>
</tr>
<tr>
<td>Carlsbad, CA (Poseidon)</td>
<td>2.90</td>
<td>0.77</td>
<td>No</td>
<td>2005</td>
<td>San Diego Daily Transcript (2005)</td>
</tr>
<tr>
<td>Dhekelia, Cyprus</td>
<td>5.40</td>
<td>1.43</td>
<td>Yes</td>
<td>2003</td>
<td>NAS (2004)</td>
</tr>
<tr>
<td>Eilat, Israel</td>
<td>2.80</td>
<td>0.74</td>
<td>Yes</td>
<td>1997?</td>
<td>Wilf &amp; Bartels (2005)</td>
</tr>
<tr>
<td>Hamma, Algiers</td>
<td>3.19</td>
<td>0.84</td>
<td>No</td>
<td>2003</td>
<td>EDS (2004), Segal (2004)</td>
</tr>
<tr>
<td>Larnaca, Cyprus</td>
<td>2.84</td>
<td>0.75</td>
<td>Yes</td>
<td>2000</td>
<td>Segal (2004)</td>
</tr>
<tr>
<td>Larnaca, Cyprus</td>
<td>3.20</td>
<td>0.85</td>
<td>Yes</td>
<td>2003</td>
<td>NAS (2004)</td>
</tr>
<tr>
<td>Larnaca, Cyprus</td>
<td>3.23</td>
<td>0.85</td>
<td>Yes</td>
<td>2001?</td>
<td>Wilf &amp; Bartels (2005)</td>
</tr>
<tr>
<td>Moss Landing, CA</td>
<td>4.75&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1.28&lt;sup&gt;1&lt;/sup&gt;</td>
<td>No</td>
<td>2005</td>
<td>MPWMD (2005b)</td>
</tr>
<tr>
<td>Moss Landing, CA</td>
<td>3.63</td>
<td>0.96</td>
<td>No</td>
<td>2005</td>
<td>MPWMD (2005b)</td>
</tr>
<tr>
<td>Perth, Australia</td>
<td>3.49</td>
<td>0.92</td>
<td>No</td>
<td>2005</td>
<td>Water Technology (2006)</td>
</tr>
<tr>
<td>Singapore</td>
<td>1.75</td>
<td>0.46</td>
<td>Yes</td>
<td>2002</td>
<td>Segal (2004)</td>
</tr>
<tr>
<td>Singapore</td>
<td>1.70</td>
<td>0.45</td>
<td>Yes</td>
<td>2003</td>
<td>NAS (2004)</td>
</tr>
<tr>
<td>Sydney, Australia</td>
<td>4.21&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1.11&lt;sup&gt;2&lt;/sup&gt;</td>
<td>No</td>
<td></td>
<td>Not reported</td>
</tr>
<tr>
<td>Tampa Bay, FL</td>
<td>1.75 to 2.18</td>
<td>0.46 - 0.58</td>
<td>No</td>
<td>1999</td>
<td>Semiat (2000)</td>
</tr>
<tr>
<td>Tampa Bay, FL</td>
<td>2.10</td>
<td>0.55</td>
<td>No</td>
<td>2003</td>
<td>Segal (2004)</td>
</tr>
<tr>
<td>Tampa Bay, FL</td>
<td>2.18</td>
<td>0.58</td>
<td>No</td>
<td>2003?</td>
<td>Wilf &amp; Bartels (2005)</td>
</tr>
<tr>
<td>Trinidad</td>
<td>2.49</td>
<td>0.66</td>
<td>No</td>
<td>?</td>
<td>Arroyo (2004)</td>
</tr>
<tr>
<td>Trinidad</td>
<td>2.77</td>
<td>0.73</td>
<td>Yes</td>
<td>?</td>
<td>Segal (2004)</td>
</tr>
<tr>
<td>Trinidad</td>
<td>2.80</td>
<td>0.74</td>
<td>Yes</td>
<td>2003</td>
<td>NAS (2004)</td>
</tr>
</tbody>
</table>

<sup>1</sup> May include conveyance costs from the desal facility to the existing distribution mains.  
<sup>2</sup> May include some or all distribution costs.
SWRO Cost Components

Based on an evaluation of reported costs for existing plants, the National Research Council (NRC), Committee on Advancing Desalination Technology, provides a breakdown of annual costs for SWRO desal plants (NRC 2008). Figure 1 shows the typical breakdown of annual costs for a 50 million gallon per day (MGD) SWRO plant that uses conventional pretreatment. For this scenario, energy costs are assumed constant at $0.07/kWh. Membrane life is assumed to be 5 years; the nominal interest rate is 5 percent; and the depreciation period is 25 years. Annualized capital costs include both principal and interest payments.

![Figure 1. Annual cost breakdown in a 50 million gallon/day seawater RO plant with conventional pretreatment](source)

Source: NAS 2008

Miller (2003) shows a slightly different distribution of seawater RO costs, with energy and capital (or fixed costs) amounting to 44% and 37% of total annual costs, respectively. This is likely due to differences in underlying assumptions regarding plant size, the price of energy and materials, interest rates, and other factors.

The distribution of costs shown in Figure 1 does not include concentrate management costs, which can range widely, based on the alternatives available, the volume and salinity of the concentrate, and other site-specific factors. For most seawater RO applications, concentrate management does not account for a significant portion of total costs. However, as described in subsequent sections, concentrate management costs can significantly increase the total costs of
desal at inland facilities (e.g. from 50 to 200 percent above the desal process costs (NRC 2008 from Mickley 2007).

**Key variables influencing overall desal project costs**

A number of key variables can significantly influence desal costs, including:

- **Source Water Quality.** The annual costs of membrane desal plants are very sensitive to the salinity and temperature of the source water. In general, desal costs increase as the salinity (TDS concentration) of the source water increases, and as the temperature of the source water decreases. Site-specific water quality factors such as turbidity, temperature, boat traffic, oil contamination, nearby outfalls, tides, and the influence of runoff, can also increase desal costs due to additional pretreatment and/or post-treatment requirements.

- **Plant size.** Desal facilities demonstrate significant economies of scale. NRC (2008) reports that the cost per unit of water produced in small plants can be 50% to 100% higher than in large plants. Savings associated with plant size are large as one moves from small (< 5.0 MGD) to medium-sized (10-20 MGD) plants, but are not as important as one moves from medium to large (> 25 MGD) plants (Voutchcov 2005).

- **Pretreatment.** The magnitude of pretreatment costs depends mostly on source water quality (turbidity/total suspended solids and membrane fouling compounds) and the type of pretreatment technology used. CDWR notes that in many instances, pretreatment is the biggest performance and operating cost variable for desal and that the capital and operating costs of pretreatment can account for more than 50% of the overall cost of the RO system (CDWR 2003).

- **Cost and availability of power.** Power requirements (and associated costs) are directly related to source water salinity and the associated osmotic pressure that has to be overcome to produce freshwater. Brackish water desal facilities therefore typically have much lower energy requirements compared to seawater facilities. For SWRO, efforts to reduce energy costs (as well as reductions in the total capital costs of the system) offer the greatest potential for significant reduction in the total costs of desal (NRC 2008).

- **Membrane life.** One of the major operating issues for SWRO facilities is the shortened membrane life that can result from membrane fouling and the need for accelerated cleaning cycles. A decrease in membrane life from 5 to 3 years can increase annual costs by over 3%. Catastrophic, irreversible membrane fouling leading to a membrane life of less than 1 year can increase annual costs by over 25% (NRC 2008). In addition, fouling requires increases in operating pressures if the membrane is to remain effective, and increases of 25% are not uncommon (NRC 2008). An increase in operating pressure of this magnitude can increase annual costs by over 8% per kgal (NRC 2008).
Cost of money. With any capital investment, interest costs are invariably one of the larger components of total project cost. Thus, the ability to secure relatively favorable rates of interest has a strong bearing on both the financial and the economic feasibility of any project.

Project delivery and financing method. The project delivery method (i.e. level of private involvement) can have a significant effect on desal costs. Voutchcov (2007) reports that although desal projects have been delivered under a number of different methods and financial arrangements, most cost reduction breakthroughs have been achieved under a “design-build-own-operate-transfer” (DBOOT) or “build-own-operate-transfer “ (BOOT) method of project delivery. A more detailed discussion of different types of project delivery methods is included in section 8.10 of this report.

Permitting and related implementation costs. Because SWRO projects are relatively new to many permitting agencies, the time and effort required for permitting are typically more extensive than those for conventional water and wastewater treatment plants. In the U.S., the permitting of large SWRO desal projects typically requires long and costly environmental and engineering studies and can be influenced by environmental opposition. Permitting is often considered one of the primary (and most expensive) risks associated with desal project implementation (Voutchcov 2007).

Target product water quality. Product water quality has a measurable effect on plant configuration, design and costs. Typically, the higher the required product water quality (e.g. potable vs. non-potable) the higher the desalinated water costs due to additional pretreatment and post treatment requirements (Voutchcov 2007). Costs associated with meeting different water quality standards vary based on the costs of various consumables (e.g. chemicals, power) used for product water quality polishing as well as the technology or combination of technologies used to meet the product water quality target.

Concentrate disposal. As noted elsewhere in this report, concentrate management can account for a very large portion of desal at inland facilities. In general, surface water discharge and disposal to sewer (when feasible) are typically the least expensive disposal options. Depending on site-specific conditions and the size of the plant, deep well injection, evaporation ponds and spray irrigation can also be viable options. Due to high capital costs and energy use, ZLD has historically been prohibitively expensive for municipal desal plants in the U.S. (Mickley 2005).

Relative costs

When evaluating water supply alternatives, it is important to understand that benefits and costs should be evaluated in a relative rather than an absolute fashion. When the focus is on costs, for example, the absolute cost of the facility or project in question has little meaning unless it is
compared with the costs of alternatives for accomplishing the same purposes (e.g. demand side management, traditional supply options) (NRC 2008).

**BENEFITS & COSTS**

**Benefits**

In addition to costs, it is important to take into account the unique benefits provided by desal. For example, one of the potentially important benefits of desal is that the yields from desal facilities are independent of drought and other weather-related factors that can significantly impact the year-to-year (or season-to-season) availability of water from traditional water supply sources. This means that there are potentially large beneficial values associated with the yield-reliability of desal with respect to cyclical drought periods and potential climate change.

These reliability benefits do not accrue to most other water supply options, such as drawing from surface water sources. When these benefits go unrecognized by the water agency, policymaker, or average citizen, desal options may remain undervalued and, perhaps, underutilized. However, the desal-specific benefits of providing reliable yields during drought periods are hard to quantify and monetize because they extend beyond readily observable financial costs and utility revenues.

There is a body of research—now being updated by Stratus Consulting with funding from the WateReuse Foundation—which aims to more directly value reliability by surveying households about their willingness to pay (WTP) to increase water supply reliability within their community (i.e. reduce the likelihood of local water shortages and related water use restrictions). These values can be integrated into a Triple Bottom Line analysis of desal facilities (that takes into account the financial, social and environmental costs and benefits of desal).

**Costs**

The costs described in the preceding sections are all appropriately characterized as financial costs. However, the economic costs of desal also need to be considered. Economic costs include the external costs that are borne by the public at large. In the case of desal facilities, the most significant category of external costs are environmental costs, which can take several forms and are often difficult to put into monetary terms. For example, the environmental costs of surface water concentrate discharges are virtually never monetized and in many instances are not even well understood from a biological perspective. Examples of other external costs that might be associated with desal facilities include the loss of environmental amenity values along the coast.
because the facilities may be unsightly or interfere with lines of sight. The cost of air pollution stemming from energy generation necessary for desal would be yet another example. Although such costs are rarely monetized, there are numerous techniques which allow them to be estimated, either directly or indirectly, with considerable accuracy.

Many external costs can be attenuated or mitigated if they are accounted for in project design and operations. Federal and state water quality and marine protection legislation normally require that the water providers consider environmental costs and take appropriate steps to minimize or mitigate them. This can require either additional capital facilities or changes in operating routines or both. The costs of these facilities and operations will appear as financial costs.

External costs are, however, rarely treated in an economically optimal fashion in the planning of desal facilities. Most environmental quality legislation does not require a precise balancing of the costs and benefits of facilities and operations that protect environmental quality; thus, the financial costs may be equal to, less than, or greater than the true environmental costs. Often external costs are completely ignored and, where they must be considered because of laws and regulations, there is little attention to whether the external costs that are ultimately borne are optimal.

**KEY UNCERTAINTIES**

**Future desal costs**

Desal capital and operating costs have decreased primarily due to technological improvements (membrane technologies, pretreatment and energy recovery), economies of scale associated with larger plants, and improved project management and experience. Improvements in RO technology have yielded the greatest progress in cost reduction. Salt rejection, the measure of the ability to remove salt from feed water, can be as high as 99.7% today, up from 98.5% a decade ago (Cooley et. al. 2006). In addition, the output of product from a unit of membranes has risen from 16 to 22 kgal per day (60 to 84 m³/d) (Cooley et. al. 2006 from Glueckstern 1999).

Other factors that have contributed to desal cost reductions include increased plant life due to improved building materials and the use of more mature technologies, lower financing costs due to reduced project risk factors, lower labor requirements due to increased process automation, lower membrane replacement costs, and less chemicals needed as a result of alternative and effective pretreatment of the feed water. As described below, additional improvements may allow costs to fall somewhat further.
The Pacific Institute (2006) maintains that despite hopeful projections from desal proponents, the long-term objectives of reducing costs 50% by 2020 (e.g. USBR and SNL 2003) are daunting and may not be achievable via incremental improvements (Cooley et. al. 2006). Radical new technologies or breakthroughs in both materials and energy costs may be necessary to achieve this goal. The Pacific Institute reports that while these are possible, they are certainly not easy and are unlikely to occur in the short term.

Indeed, a counter-trend in reported costs is emerging, and some experts think that membrane costs are unlikely to fall much further in the near term (Cooley et. al. 2006 from AWWA 2006). All of the newer cost estimates are notably higher than similar plants bid just a few years ago. The director general of the majority owner of the consortium operating the Ashkelon plant stated last year that more recent tenders for plants in Israel and elsewhere were in the range of $3.10 to $3.90/kgal ($0.82 to $1.03/m³) due to increases in the cost of raw materials (e.g., steel) and energy and rising interest rates (Cooley et. al. 2006 from Jerusalem Post 2005). Cost estimates at Moss Landing, California and Sydney, Australia are even higher, exceeding $4.00/kgal ($1.06/m³) in two of three reported estimates. Higher capital and energy costs appear to have created an upward trend in overall desal cost in recent years (Cooley et. al. 2006 from Water Desalination Report 2006).

The Unique Benefits Provided by Desal

Additional (and site-specific) work is required to more fully assess the benefits that desal can provide a community, where it is added to the local or regional water supply portfolio.

ADDITIONAL RESOURCES


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