Guidelines for Implementing Seawater and Brackish Water Desalination Facilities

Subject Area: Water Quality

Arsenic Water Technology Partnership

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DISCLAIMER

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FOREWORD

The Water Research Foundation is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the drinking water community.

The Arsenic Water Technology Partnership (AWTP) program is a partnership between Water Research Foundation, Sandia National Laboratories (SNL) and WERC, a Consortium for Environmental Education and Technology Development at New Mexico State University that is funded by DOE and the Water Research Foundation. The goal of the program is to provide drinking water utilities, particularly those serving small and rural communities, with cost-effective solutions for complying with the new 10 ppb arsenic MCL. This goal is being met by accomplishing three tasks: 1) bench-scale research to minimize operating, energy and waste disposal costs; 2) demonstration of technologies in a range of water chemistries, geographic locales, and system sizes; and 3) cost effectiveness evaluations of these technologies and education, training, and technology transfer.

The AWTP program is designed to bring new and innovative technologies developed at the laboratory and bench-scale to full-scale implementation and to provide performance and economic information under actual operating conditions. Technology transfer of research and demonstration results will provide stakeholders with the information necessary to make sound decisions on cost-effective arsenic treatment.

The Foundation participates in the overall management of the program, helps to facilitate the program's oversight committees, and administer the laboratory/bench-scale studies. SNL conducts the pilot-scale demonstrations and WERC oversees the education, training, economic analysis, and outreach activities associated with this program.

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- Zororai Choto, Robert Reiss, and other members of Reiss Environmental, who served as principal authors of appendices B, C, and E.
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EXECUTIVE SUMMARY

OBJECTIVES

To help overcome obstacles associated with desalination (desal) implementation in the United States (US), this project is aimed at providing utilities with practical and informative guidelines and related decision support tools to facilitate better desal planning and implementation. The research products are intended to help water managers gain an understanding of the options and strategies available to address these challenges. The intent is to help utilities identify promising strategies and avoid potential missteps. The hope is that this report and associated materials will help utilities consider a wider range of desal-related options and strategies, and result in more rapid, less costly, and less frustrating implementation of desal projects.

BACKGROUND

With increasing water demands and more limited traditional water supply options in many locations, desal provides an important option for meeting near-term and future water supply needs. In many areas, desal is a logical candidate because it is based on proven technologies, is used extensively around the world, and has costs that are declining and becoming increasingly competitive with other new water supply alternatives.

Desal also can offer several important benefits over more traditional source water alternatives. For example, desal offers communities enhanced reliability as a drought resistant supply. These reliability benefits do not accrue to most other water supply options, such as drawing from surface water sources. Despite its potential advantages, desal remains largely untapped in the US (especially in coastal settings), and is being implemented more slowly than elsewhere in the world. A primary reason for this is that the process of planning and implementing desal as a part of a community's water supply portfolio is a highly complex (and often controversial) undertaking.

A suite of issues—both technical and institutional—create uncertainties, delays, cost escalations, and other complexities that have inhibited desal implementation in the US. These barriers include complex and unsettled regulatory and permitting requirements (e.g., for coastal feedwater intakes, and for inland and coastal brine management); relatively high energy use (and a potentially large carbon footprint); high costs (relative to historic water supplies); and other issues that have made desal implementation a very complex, uncertain, time consuming, and often frustrating endeavor for US utilities.

APPROACH

To meet the objectives of this project, Stratus Consulting has developed "guidelines" intended to facilitate better desal planning and implementation. The term guidelines is open to a wide range of possible interpretations—from informal guidance and suggestions—to highly prescriptive or numeric design specifications. In this report, we lean toward the former interpretation, and offer a range of decision support tools and a compilation of practical experiences and resources to enable utility practitioners and other interested parties to readily locate and glean relevant information.

Our efforts span both technical desal system issues (e.g., intricacies of various membrane, hybrid, and non-membrane process options) as well as the broad suite of "institutional" issues that create many of the critical implementation barriers (e.g., permitting requirements). Our emphasis is directed slightly more toward institutional matters (e.g., regulations and permitting, energy and environmental impacts, economics, and public acceptance) as compared to the technical side, because it is the institutional factors that pose the most significant barriers to broader and more streamlined implementation of desal in the US.

A key component of the guidelines is a computer-based tool called the Desalination Planning Issues Matrix (PIM). The PIM is a user-friendly Excel-based application, with many hyperlinks to Word and other files, and structured to enable easy navigation across a range of core issues and desal process steps. A second resource developed as part of this research is the Desal Decision Framework, designed to provide utilities with a logical, phased approach to desal planning and implementation. To provide real world examples of desal challenges and successes, we have also compiled a series of case studies of desal facilities both in the US and abroad. The case studies are categorized to highlight various technical and institutional issues associated with desal planning and implementation. Finally, in addition to the research and background presented in the report, we have developed a series of appendices on current and emerging issues associated with desal in the US.

The guidelines and resources developed as part of this research are based on primary and secondary research, developed in coordination with leading desal experts and practitioners. Our materials include insights gained through targeted workshops, a survey of water utilities, and key person interviews.

CONCLUSIONS

Despite growing interest in desal, and technological improvements that have dramatically increased the performance of desal processes, there are a number of key challenges and issues associated with desal implementation in the US.

Key Issues Associated With Desal Implementation in the US

Although desal has the potential to provide multiple benefits, a number of key challenges and issues associated with desal implementation remain. These include:

- Environmental impacts associated with surface water intake and concentrate management
- Technical and engineering challenges associated with reverse osmosis (RO) membrane processes
- Development and implementation of effective pilot testing
- Desal's high energy use, and associated greenhouse gas emissions
- Environmental and technical issues associated with co-location of desal facilities with coastal power plants
- The high costs of desal
- Working with regulators, many of whom are unfamiliar with desal

- Incorporating desal into utility planning, management, and culture
- The use of various project delivery methods, including issues associated with the role of private entities in developing and operating desal facilities
- Public acceptance of desal facilities and desalinated water

Trends in Key Factors for Desal Implementation

Technological improvements have dramatically increased the performance of desal processes, helping to reduce total water costs and improve performance. Key factors that continue to influence the feasibility and cost of successfully implementing desal facilities include:

- Technological improvements have dramatically increased the performance of RO membranes, and the increased growth of RO in the desal market is expected to continue.
- Larger desal plants are being constructed to take advantage of economies of scale, helping to further reduce the unit cost of desalinated water.
- For co-located coastal facilities, there has been a growing trend to use separate intake and/or disposal structures to avoid or reduce environmental impacts, permitting challenges, operational challenges, and potential uncertainties and risks associated with using power plant cooling water as desal feedwater.
- Significant energy efficiency in membrane processes have been achieved through optimizing operational parameters, using high-efficient pumps and energy recovery devices, and improvements in system design. More desal plants are using renewable energy or developing environmental restoration strategies to reduce the carbon footprint of desal.
- Technological advances are expected to reduce the cost of desalinated water by 20% in the next five years (Voutchkov 2007a). However, desal costs may increase due to the potential for cost increases in electricity, construction and materials, planning and permitting, and potential costs for carbon emissions and environmental restoration.
- Sub-seabed intakes have been increasingly employed at seawater desal facilities (where feasible) to provide good feedwater quality and reduce environmental impacts relative to open water intakes. The higher quality feedwater has allowed for an increased use of microfiltration or ultrafiltration membranes for desal feedwater pretreatment, which provides reliable water quantity and quality while reducing pretreatment costs.
- There is a significant need for developing environmentally responsible and sustainable methods for concentrate management or disposal, especially in inland settings. Approaches that may help mitigate disposal challenges include the beneficial use of concentrate, and regional and watershed management for concentrate disposal.
- The performance of desal processes may be further improved by hybrid configurations and alternative desal technologies, such as flexibility in operation, higher recoveries, reducing fouling and scaling, and decreasing energy consumption and capital and operating costs.

Agenda for Future Research

There are numerous areas in which future research will benefit the implementation of desal projects. Many identified research needs revolve around hoped for technology and operational improvements, such as might reduce costs, net energy use, environmental impacts (notably for impingement and entrainment at coastal feedwater intakes), and residuals (i.e., brine concentrate). However, there are also several research needs that revolve around facilitating desal planning and implementation processes, such as by streamlining the permitting and associated regulatory processes. These latter research needs include ideas such as convening a national workshop for regulators and other key stakeholders to provide a forum for dialogue, and creating some general uniformity across states. The objective of such permitting-oriented research needs are to help develop a well informed and reasonable set of expectations about which approaches and technologies might be generally viewed as acceptable for desal implementation.

APPLICATIONS

As stated throughout the report, the desal implementation guidelines are intended to provide utilities and other water resource managers a suite of tools and resources that can be used differently, based on individual levels of knowledge and experience with desal. The resources included in this report are targeted toward practitioners with knowledge and experience ranging from a "getting started" level, to a more in-depth experience and familiarity with desal. They are not intended to serve as technical or design standards. In addition to those interested in desal implementation at the utility level, the guidelines will also serve as a useful tool for regulators and for interested members of the public.

CHAPTER 1
INTRODUCTION

BACKGROUND AND OBJECTIVES

In many water-short areas in the United States (US), and in many other parts of the world, water utilities are searching for new water supplies. For many, desalination (desal) is a technically viable option to consider. Desal is a logical candidate because it is based on proven technologies, is used extensively around the world, and has costs that are declining and becoming increasingly competitive with other new water supply alternatives (especially given the scarcity of new supply options in many areas). It can be used to develop potable supplies from coastal waters, and from brackish groundwaters and surface waters in inland settings.

Desal also can offer several important benefits over more traditional source water alternatives. For example, desal offers communities enhanced reliability as a drought resistant supply because its yields are not generally impacted by droughts or other climatic events. It also may be locally controlled, which can be a significant advantage compared to supply options that rely on importing waters from other basins and jurisdictions. Desal also can offset freshwater extractions that may impose environmental or other adverse consequences.

Despite these potential advantages, desal in the US remains largely untapped (especially in coastal areas) and is being implemented more slowly than elsewhere in the world. The primary reason is that the process of planning and implementing desal as a part of a community's water supply portfolio is a highly complex undertaking.

A suite of issues—both technical and institutional—create uncertainties, delays, cost escalations, and other complexities that have inhibited desal implementation in the US. These barriers include complex and unsettled regulatory and permitting requirements (e.g., for coastal feedwater intakes, and for inland brine management); relatively high energy use (and a potentially large carbon footprint) associated with membrane and other desalting technologies; high costs; and other issues that have made desal implementation a very complex, uncertain, time consuming, and often frustrating endeavor for US utilities.

In order to help overcome these obstacles, this project is aimed at providing utilities with practical and informative guidelines and related decision support tools to facilitate better desal planning and implementation. The research products are intended to help water managers gain an understanding of the options and strategies available to address these challenges. The intent is to help utilities identify promising strategies and avoid potential missteps. The hope is that this report and associated materials will help facilitate a better utility desal planning process by helping utilities consider a wider range of desal-related options and strategies, and result in more rapid, less costly, and less frustrating implementation of desal projects.

THE NATURE OF THESE DESAL IMPLEMENTATION "GUIDELINES"

The objective of this research project is to provide "guidelines" to help water utilities and other water professionals better navigate their way through the desal planning and implementation process. The guidelines cover the wide range of implementation challenges, from feedwater acquisition to concentrate disposal, with a focus on the topics listed in Table 1.1.

Table 1.1 Key topics addressed by this research

1. ***Emerging technical and institutional factors*** that may limit the potential to realize some of the advantages of ***co-locating*** desal facilities with coastal power plants [especially in California, where once-through cooling (OTC) is likely to be phased out by regulators].
2. ***Alternative feedwater intake design and operating options*** for standalone coastal desal facilities, such as intake screening options and velocity parameters and their impact on impingement and entrainment (I&E), and the viability and performance (across different settings) of beach wells and other subsurface alternatives to open water intakes.
3. ***Selecting pretreatment processes***, considering source water quality and variability, meshing with the desalting process options, and accounting for finished water quality objectives.
4. ***Product water post-treatment***, blending, and distribution, and associated disinfection byproduct (DBP), microbial, and other public health and compliance issues, aesthetics, and corrosion.
5. ***Energy-related concerns***, including cost impacts, energy efficiency, grid reliability, peak load management, alternative energy, air pollution, greenhouse gas (GHG) emissions, and global warming.
6. ***Concentrate management and disposal*** (especially, but not exclusively, for inland desalting).
7. An assortment of ***public perception and stakeholder issues***, including the role of the private sector in water supply provision, community growth and land use issues, environmental justice concerns, and water supply planning gaps.
8. ***Alternative project delivery options*** and the potential for ***regional collaborations*** in project development.

The term "guidelines" is used in the title and throughout the text of this report. This term is open to a wide range of possible interpretations—from informal guidance and suggestions at one end of the spectrum—to highly prescriptive or numeric design specification at the other. In this report, we lean toward the former interpretation, and offer a range of decision support tools and a compilation of practical experiences and resources to enable utility practitioners and other interested parties to readily locate and glean relevant information. One key component of these guidelines is a computer-based tool called the "Planning Issues Matrix" (PIM), which is described in chapter 7, and provided on a compact disc (CD) that accompanies this report. The PIM is a user-friendly Excel-based application, with many hyperlinks to Word and other files, and structured to enable easy navigation across a range of core issues and desal process steps.

Throughout this report, our efforts span both technical desal system issues (e.g., intricacies of various membrane, hybrid, and nonmembrane process options) as well as the broad suite of "institutional" issues that create many of the critical implementation barriers (e.g., permitting requirements). Our emphasis is directed slightly more toward institutional matters (e.g., regulations and permitting, energy and environmental impacts, economics, and public acceptance) as compared to the technical side, because much is already well understood about desal engineering and related processes. The technology issues can be complex and there is clearly room for improving technology performance and information dissemination; however, it is the institutional factors that pose the most significant barriers to broader and more streamlined implementation of desal in the US.

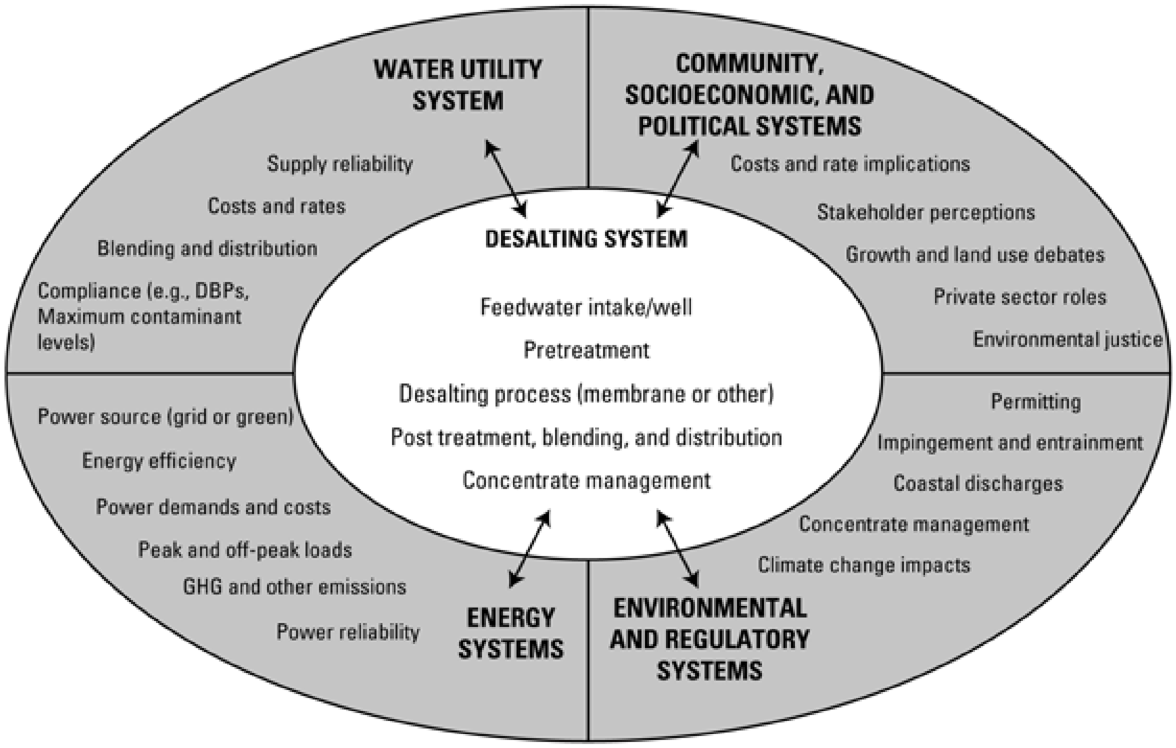


Figure 1.1 A systems perspective on the desal process

One of the key principles behind the development of these desal guidelines is the adoption of a broad systems planning approach, intended to help utilities integrate desal systems into existing technical and institutional systems. As shown in Figure 1.1, desal processes do not operate in isolation from the rest of the utility or the broader community. Desal operations must be integrated—physically and institutionally—into the rest of the utility's systems, the community's social-political systems, regional energy systems, and applicable environmental and related regulatory systems.

As depicted in center of Figure 1.1, desalting processes are themselves an integrated system. This system consists not only of the desalting technology [e.g., reverse osmosis (RO) membranes], but also includes source water intake and pretreatment, that both occur before the desalting technology itself is engaged. After the desalting step, the product water must be chemically treated or blended with other waters as part of the post-treatment process. Finally, concentrated brines removed by the desalting process need to be disposed of in an environmentally suitable manner.

A host of complicating factors arise when considering how the desal system integrates into the broader suite of systems in which it must be placed. For example, the process of obtaining feedwater for a coastal desal facility needs to consider the environmental, regulatory, and other implications of constructing and operating a coastal intake pipe or beach well. Likewise, the power needs of the desalting technology needs to be considered within the context of the region's energy systems (e.g., is there enough power available at the right times, at a reasonable cost, with needed reliability, and without undue environmental or financial impact?). There are also community financial, social, and political systems issues, such as whether the cost of desal will unduly raise water costs and rates, and how this will impact the utility and its customers. By viewing desal from a systems perspective, we can begin to see where and why some of the challenging implementation and planning issues are likely to arise. The following sections provide a summary of the key topics and planning issues addressed as part of the desal implementation guidelines.

KEY TOPICS FOR DESAL IMPLEMENTATION AND PLANNING

As noted above, the following sections highlight some of the key issues and challenges associated with desal in the US.

Environmental Impacts: Surface Water Intake and Concentrate Management

Among several environmental concerns related to desal, two in particular garner significant attention. The first pertains to I&E of aquatic species due the use of open water intakes to draw feedwater. *Impingement* occurs when larger organisms, mostly fish and shellfish, are trapped against intake screens by the force of the water being drawn into the intake. *Entrainment* takes place when small egg and larval stages of organisms are drawn into the intake structure along with the plant feedwater. I&E is generally not an issue for sub-seabed intakes (e.g., beach wells) or facilities co-located with power plants.

In many cases, the adverse effects of I&E can be avoided or minimized through appropriate location selection, operational flexibility, and improved technologies (Xu et al. 2009). Key questions include how well alternative open water feedwater intake design and operating options (e.g., intake screening design and velocity parameters) minimize I&E. There are also key questions about the viability and long-term performance of beach wells and other subsurface alternatives to surface water intakes (i.e., beach wells are not technically feasible in some coastal settings).

The second major environmental concern associated with desal pertains to the management (reuse or disposal) of desal concentrate. Coastal desal plants are often able to safely dispose of desal concentrate (via blending and/or direct discharge into the ocean or estuaries) at relatively modest costs. However, concentrate management is currently one of the most challenging issues associated with desal in an inland setting. Although several disposal methods are available, each method has its own set of environmental challenges, regulatory requirements, and site-specific costs.

Traditional options for brine concentrate disposal at inland facilities include surface water discharge (to freshwater or via a brine line to the ocean), discharge to an existing sewer system, deep well injection, land application, and evaporation ponds. More recently, higher recovery processing, including zero liquid discharge, has received considerable attention in an effort to provide an alternative means of concentrate management. All of these inland options are of limited applicability, depending on concentrate quality and quantity, physical location, hydro-geologic conditions, energy requirements, and numerous regulatory constraints related to potential impacts on the receiving water or soil. As a result, it is becoming more and more challenging to find a technically, environmentally, and financially viable method of dealing with the concentrate from inland facilities.

Membrane Processes

In the US, Australia, and Europe, almost all desal applications utilize RO or nanofiltration (NF) membrane technology. Both RO and NF utilize the principle of RO to accomplish desal. They are essentially the same process with different degrees of salt rejection.

RO is the most versatile technology, and has been demonstrated as the most economically viable option for a wide range of applications and feed water quality. However, there are several technical and engineering challenges related to the implementation of RO processes. Key challenges include:

- Membrane fouling
- Corrosivity of the product water
- Incomplete rejection of trace organic pollutants
- Relatively low recovery rate resulting in high volumes of desal concentrate
- High energy requirements
- High costs

Alternative and emerging technologies are being developed, aimed at improving certain aspects of the performances of existing desal processes (e.g., higher recoveries, reducing fouling, decreasing energy consumption and capital and operating costs). A discussion on emerging desal technologies is included in appendix A, and a discussion of the challenges associated with integrating membrane processes into water treatment plants is provided in appendix B.

Pilot Testing

Development of desal facilities requires accurate and appropriate design and cost information. Every desal facility is designed and constructed based on the consideration of numerous site-specific factors. This requires multiple design decisions relative to the type and configuration of a treatment system. Pilot studies provide the opportunity to evaluate the performance of proposed treatment systems under site-specific conditions. The base objectives are to confirm the ability of the desal system to meet finished water quality goals, operate for sustained periods of time and, in the case of surface water desal, withstand seasonal changes in raw water quality.

Data gathered from pilot studies are fed back into the planning and design process and adjustments made accordingly. The result is a more complete design, more refined cost estimate, and a more accurate understanding of the viability of a proposed project. Pilot studies provide utilities with an excellent opportunity to gain the public's acceptance of the potential design and implementation of a desal facility in their community. The selected treatment systems must be robust enough to ensure sustained operation under all possible conditions that might be encountered. This assessment is most effectively accomplished through field testing as part of a pilot study.

The investment in a pilot study typically represents less than 1% of the total costs of a desal facility. In return, risk is mitigated both in terms of ensuring a sustainable and appropriate design as well as a more true and accurate project cost estimate. Appendix C of this report describes the importance of pilot testing for development of both seawater and brackish groundwater desal systems.

Energy and Greenhouse Gas Emissions

Current desal technologies are very energy intensive and require much more energy than most traditional sources of water supply. This contributes to the high cost of desal compared to most other water supply options.

Energy intensity raises more than just cost concerns. In many regions, there are concerns that the energy demands associated with desal will affect the reliability and sustainability of the overall power grid system (especially as water demands tend to peak at the same times as energy demands, for example, on hot summer days). This is particularly true in areas where grid capacity is already strained by current demands (Stratus Consulting 2006).

There is also concern among some stakeholders regarding GHG emissions—and air pollution emissions in general—associated with the need to expand fossil fuel use to power desal facilities. GHG emissions are linked with global climate change, and other air pollutants pose risks to human health, vegetation, and other resources, and/or impair visibility (Stratus Consulting 2006).

Approaches for decreasing the energy demand of RO processes are critical for sustainable development of desal technologies. Significant energy savings can be achieved through optimizing operational parameters, using high-efficient pumps and energy recovery devices (ERDs), and improvements in system design. Increasing membrane efficiency by reducing membrane fouling can also control the increase in energy demand during long-term operation.

The use of alternative (renewable) energy options for desal facilities is also key to future desal implementation. Renewable energy has been pursued to power the majority of the large-scale desal plants in Australia and at least one in the United Kingdom (UK). Although generally valued by the public, the costs associated with renewable energy to support desal can be significant (and can actually increase overall desal costs).

Co-location With Coastal Power Plants

Until recently, co-locating seawater desal facilities with OTC power plants appeared to be a natural and advantageous linkage. The existing power plant intake and discharge structures provide pre-existing infrastructure, thereby reducing construction permitting costs and delays. Power plant intake water volumes are much larger than needed for the desal facility, so no additional water withdrawals are necessary. Assuming the desal facility operates only when the power plant operates, the environmental and ecological impacts of the facility are minimal since the desal facility uses cooling water already in the power plant and the large discharge volumes provide dilution and mixing for the brine. As a result of these factors, power plant co-location can yield significant permitting and construction cost savings (NRC 2008).

These benefits, however, presume the continued operation of power plants with OTC systems. One of the major concerns associated with co-location stems from opposition to OTC power plants due to environmental impacts. Some believe siting desal facilities with OTC power plants might serve to perpetuate these facilities when they might otherwise be phased out. In addition, if the power plant ultimately is changed to a different cooling system, the investment in the desal facility could either be lost or subject to significant cost increases. Likewise, if the OTC system is eliminated, the intake volume and brine discharge of a (now) standalone desal facility could result in significant environmental impacts.

The feasibility and desirability of co-location in the US has not been fully evaluated. To date, Tampa Bay is the only large-scale, co-located desal project that has been successfully implemented in the US. The Tampa experience has revealed some operational challenges associated with a co-located facility, including periodically over-elevated feedwater temperatures, and occasional unanticipated power plant shutdowns. Much of the published information on co-location has been based on experience in other countries and/or expected results in the US. There are currently several US co-located projects slated for implementation (most of which are in California) that have initiated or completed required planning processes. Based on lessons learned from these processes, we can begin to gauge how the stated advantages of co-location have played out in the US with coastal power plants.

Costs and Economics

In the US, desal has traditionally been cost prohibitive and in most locations, desal is still very expensive relative to the cost of traditional supplies. This raises several issues regarding potential impacts on local water rates and the associated impacts on households and commercial customers in the served communities.

However, recent technological advances have allowed desal to become more efficient and less energy demanding, resulting in lower costs. At the same time, the cost of traditional supply alternatives has become more expensive. As these trends continue, desal may become more economically favorable in some areas.

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. Energy and annualized capital costs account for the largest portion of seawater reverse osmosis (SWRO) costs (36% and 37%, respectively) (NRC 2008). For brackish water reverse osmosis (BWRO), the capital investment required to build the plant typically accounts for more than half of total costs. Compared to SWRO, the energy consumption associated with BWRO is relatively low, accounting for only about 11% of total costs.

While desal may appear to be costly relative to the costs associated with securing past water supplies, it is important to recognize that the meaningful comparison is to consider desal relative to the full cost of other feasible options for adding more water to the community's future supply portfolio. Further, in addition to financial costs, the external costs and benefits (e.g., environmental impacts and increased reliability) should be included in project planning and analysis of alternative supply options. Finally, it is important to note that reliance on alternative energy sources will play a large role in the future of desal costs. Without alternative energy sources, the cost of desal will remain tied to increases in the cost of traditional energy supplies.

Working With Regulators

Regulators are often placed in a difficult position with respect to desal. Their mission is to ensure that the regulatory and permitting processes suitably protect the environment, public health, and similar broad societal interests. However, desal is a new endeavor for many of them, and a "standards of practice" on which regulators can support their decisions is lacking. Regulators in the US are thus cautious to sign off on desal permits because any conditions that are approved may be seen as setting a precedent. In addition, because of its limited use for municipal applications in the US, desal may be viewed as a novel or unreliable technology by some regulators. Further, the lack of practical desal experience and its uniqueness often manifest as "desal being a square peg jammed into a regulatory system set up with round holes" (Raucher, Strange, and Hallett 2006).

There are (at least) two approaches that can be used as a way of working constructively with regulators in the "round peg-square hole" context of desal facilities and operations (Stratus Consulting 2006):

- First, there needs to be an open, advance dialogue with regulators (perhaps aimed at the higher management levels of key agencies, so that cooperative signals flow down to field staff) that explains the desal issues and needs, and tries to set up a reasonable set of protocols for permit approval.
- Second, research that generates key findings, or establishes desal-suitable testing/monitoring protocols, will help give comfort and reassurance to regulators who find themselves facing permitting issues in desal's unfamiliar territory.

It is interesting to note how different states appear to be addressing the desal issue. An example of different regulatory approaches in three key desal states (i.e., California, Florida, and Texas) is provided in appendix E of this report.

Utility Planning and Management

The evaluation, design, and implementation of a desal project involves a number of opportunities and challenges that must be addressed within the context of existing utility, community, and institutional systems. While the development of a desal project requires a long and involved process, proper planning can facilitate more rapid, less costly, and less frustrating implementation.

To facilitate desal planning and implementation, the project team developed the desal decision framework (framework). The framework divides the desal planning and implementation process into six stages, as follows:

- Getting Started: Visioning and Goal Setting
- Implementation Planning
- Pre-Design
- Design
- Facility Construction
- Implementation

For each stage of the planning and implementation process identified above, the framework identifies key questions to be answered, actions to be taken, and decisions to be made (before moving forward to the next stage). It is important to recognize that the stages build on each other, with each stage laying the foundation for the next. Costs are additive, and increase with each stage. It is therefore valuable to revisit the question, "Is desal a viable option?" at the end of each stage.

Further, given their complex nature and the range of possible options, it is not uncommon for desal projects (especially seawater desal facilities) to be altered during the course of design, planning, public involvement, and permitting. When such modifications are made, different stages of the process may need to be revisited.

In addition to the distinct phases of desal planning implementation, there are a number of processes that need to be conducted throughout the project period (i.e., during each stage of the planning and implementation process). These processes include vision and planning; leadership, clearly defined roles, and decisionmaking; stakeholder involvement; managing organizational change; and knowledge and risk management.

Chapter 11 of this report provides additional detail on the desal planning and implementation framework, including a description of each phase of the process outlined above.

Project Delivery Method

The process of planning, designing, financing, constructing, and operating a desal facility can be accomplished through a number of different approaches (i.e., project delivery methods) involving the water supplier and multiple private service providers (NRC 2008).

Public water providers have traditionally preferred a more utility-driven method of project delivery, referred to as design-bid-build (DBB) (Xu et al. 2009). This method allows for a high degree of involvement and control by the public water provider, because the public water provider oversees design and construction of the desal facility through separate contractual relationships. The public water provider is responsible for obtaining all permits, arranging funding, and will own and operate the plant when construction is complete. The primary disadvantage of this approach is that the public water provider bears responsibility for most of the cost, performance, and risk associated with the project (NRC 2008).

For many public water providers, the financial capacity and ability to perform desal under a DBB model is becoming quite limited. Water providers have therefore shifted toward alternative methods of project delivery that provide a higher level of private entity involvement and control. Alternative delivery methods can offer advantages over the traditional DBB model, including reduced total project costs, shorter time to project completion, and reduced risk for public water suppliers (Voutchkov 2007a, NRC 2008).

Despite these advantages, some members of the public and some public officials have expressed concerns over having private sector entities involved in desal projects. This stems from a deeper philosophical issue about what role (if any) the private sector should play in the provision of water as an essential good and public service (e.g., critical to life, health, safety, and welfare) (Stratus Consulting 2006).

In addition, many public agencies argue that the private model has few advantages over traditional approaches because the public sector has access to the same expertise and technology as the private sector. Many public agencies claim that the risks of water shortages are the same under private and public models, and thus there is no real mitigation of risk.

Despite these concerns, as public entities face growing budgetary constraints, many locally-elected officials are attracted to the perceived benefits of “privatizing” all or some of their water service responsibilities (CCC 2004). Concurrently, a number of domestic and multinational business entities have identified providing water or “water services” as an attractive profitable investment opportunity. In California, among the approximately two dozen desal projects currently proposed along the coast, at least six are proposed as private-held facilities or public/private partnerships, including two (in Huntington Beach and Carlsbad) that would be the largest coastal desal facilities in the US.

Public Acceptance

Affected persons and stakeholders are often able to slow or block implementation of a desal facility if public perception is negative, whether or not a concern is justified in the particular project (NRC 2008). Public concerns about desal vary and include worries related to cleanliness of the source and product water, technical feasibility, environmental effects of process operations and concentrate management, privatization issues, growth-inducement, energy use and carbon footprint, and future affordability of the resource, among others.

Failure to gain public acceptance can derail the most essential and feasible desal project. Local citizens and nongovernmental organizations may influence a regulatory body or local government officials, and these regulators or officials can in turn place impediments in the permitting process. Broad-based public participation in the process—that is, greater than that necessitated by permitting requirements—may help minimize adverse relationships and help the project progress more readily toward successful implementation (NRC 2008 as cited in Burroughs 1999, Roberts 2004, Robinson 2007).

OUTLINE OF THE REPORT AND ASSOCIATED MATERIALS

The report is structured as follows:

- Chapter 2 provides background information on the status of desal, including the steps in the typical process—feedwater supply, pretreatment, desalting processes (with a focus on membranes), blending/distribution and use, and concentrate management. It also discusses the general background on current and planned future use of desal.
- Chapter 3 reviews several relevant trends in desal, to help readers place current desal practices and options in perspective with respect to where it has been and where it may be heading. Trends are presented topically, with a focus on the issues that are most critical to successfully implementing desal projects. An appendix is also provided at the end of this report on emerging desal technologies.
- Chapter 4 describes why desal is an important part of the future water supply portfolio for many communities, due to growing water demands (e.g., population and economic growth) and increasingly constrained supplies (e.g., over-tapped traditional sources, and environmental concerns of extraction, as in the California Bay-Delta), as magnified by recent severe droughts and anticipated climate change.
- Chapter 5 explores key differences between desal and other supply options (as well as similarities worth acknowledging). We then describe the implications and the practical challenges faced for planning and implementing coastal and inland desal.
- Chapter 6 provides a “systems perspective” on desal implementation, to help utilities see how many pieces there are to the puzzle, and how they need to fit together. This describes the desal process steps (feedwater intake, pretreatment, desalting, post treatment and blending, and concentrate management) as the core system, and how the desal process system needs to be integrated into the other relevant systems within which the utility operates (i.e., integration into energy, environmental, utility, and

socio-political systems). This serves to lay the foundation for the organizing structure of the PIM decision support tool (provided on an accompanying CD).

- Chapter 7 offers a "User's Guide" to the PIM, with an introduction on the intended uses and value of the PIM, and a set of easy-to-follow instructions to help users navigate and get value from the tool. Much of the technical content developed in this research effort are embodied in the PIM, rather than in this written report.
- Chapter 8 discusses a wide range of key topics in desal implementation, providing information to supplement the content contained within the PIM. Since the PIM is structured in a compartmentalized manner, it does not always provide the best vehicle for providing users with broader perspectives and comparisons. This chapter provides such overviews, comparisons, and perspectives about the top issues in desal planning and implementation. Each topic is covered briefly in this chapter, with more extensive materials being either in the PIM, or in subsequent report chapters or appendices. Key topics addressed include:
  - Coastal intakes
  - Concentrate management (focusing on inland desalting)
  - Membrane processes
  - Pilot testing
  - Energy issues and options
  - Co-location
  - Costs and economics
  - Permitting and working with regulators
  - Utility planning and management
  - Project delivery
- Chapter 9 provides brief case studies, organized by key topic areas (e.g., coastal intake, concentrate management, alternative energy, regional approaches), to reveal important lessons from desal implementation experiences in the US and elsewhere.
- Chapter 10 addresses the permitting and regulatory challenges associated with most desal projects, describing the number and types of permits required, challenges in acquiring permits, and strategies to help minimize delays and obstacles.
- Chapter 11 provides guidance to utilities for planning and managing the desal implementation process. Topics include the need to exert leadership on a broader level (e.g., regional, watershed), addressing key implementation challenges, and the imperative to better articulate the need for and values of desal as a reliable part of the community/regional water supply portfolio.
- Chapter 12 offers conclusions and recommendations for future research.

Following the main text, references are provided, followed by a series of appendices:

- Appendix A: Emerging and Hybrid Desal Technologies
- Appendix B: Challenges in Integrating Membrane Processes
- Appendix C: Pilot Testing Guidance
- Appendix D: Tools to Enhance Stakeholder Understanding of Desal
- Appendix E: Permitting and Regulatory Requirements, A Three-State Comparison
- Appendix F: Improving the Process for Implementing Seawater Desal: Value and Public Perception Issues

- Appendix G: Desal Costs
- Appendix H: Regional Approaches and Advantages for Implementing Desal Projects

ADDITIONAL RESOURCES

Beyond this research report, there are several other recently published works that provide useful information related to desal and its implementation. Readers interested in obtaining additional perspectives and insights may wish to review the following:

Cotruvo, J.A., N. Voutchkov, J. Fawell, P. Payment, D. Cunliffe, S. Lattemann (eds.). 2010. *Desalination Technology: Health and Environmental Impacts*. CRC Press, Taylor and Francis, K11421, ISBN 9781439828908, ISBN 10: 1439828903, June 2010.

Lattemann, S. 2008. *Desalination Resource and Guidance Manual for Environmental Impact Assessments,* United Nations Environment Programme, Regional Office for West Asia. World Health Organization, Regional Office for the Eastern Mediterranean. Cairo. Available: <www.un.unep.org.bh/Publications/Type 7.asp>.

NRC (National Research Council). 2008. *Desalination: A National Perspective* [Online]. Washington, D.C.: National Academy Press. Available: <http://www.nap.edu/catalog/12184.html>. [cited August 12, 2008].

WHO (World Health Organization). 2007. Desalination for Safe Water Supply: Guidance for the Health and Environmental Aspects. Public Health and the Environment. Applicable to Desalination [Online]. Available: <www.who.int/water_sanitation_health/gdwqrevision/desalination.pdf>. [cited April 13, 2009]. Note that this is essentially the same as the Cotruvo et al. (2010) reference above.

Xu, P., T. Cath, G. Wang, J.E. Drewes, and S. Dolnicar. 2009. *Critical Assessment of Implementing Desalination Technology*. Denver, Colo.: Water Research Foundation.

CHAPTER 2
BACKGROUND AND STATUS OF DESAL

BACKGROUND TO DESAL

Due to continued population growth, economic development, frequently occurring droughts, and other factors, the demand for freshwater has increased significantly. However, freshwater resources are very limited, and these limited sources are further declining due to salinity buildup, contamination, and overdraft. Many municipalities and water utilities have turned to development of alternative water sources such as seawater, brackish inland waters, and highly treated wastewater effluent. Desal has been considered one of the viable solutions to augment fresh water sources and expand and diversify water supply portfolios.

Desal is a process that removes dissolved minerals and soluble organics from water. Two main types of technologies are currently being employed for water desal: thermal-based and membrane-based processes. Thermal technologies are the traditional processes used in early desalting applications in the Middle East and Caribbean, including multi-stage flash (MSF) evaporation, multiple effect distillation (MED), and vapor compression (VC). They employ a distillation process in which feedwater is heated and then evaporated to separate out dissolved minerals (CCC 1993). Thermal technologies are best suited for desal of seawater because energy requirements are high and almost independent of source water salinity. Thermal desal technologies are mostly used in the Middle East and are not widely used in the rest of the world, in large part due to their high energy requirement and lack of centralized water and power planning (Xu et al. 2009).

Membrane-based technologies, including NF, RO, electrodialysis (ED), and electrodialysis reversal (EDR), represent the overwhelming majority of plants outside the Arabian Gulf region. Recently constructed desal facilities (seawater and brackish water) outside the region rely almost exclusively on membrane technologies.

In RO and NF, feedwater is pumped at high pressure through semi-permeable membranes, separating salts from the water (CCC 1993). The feedwater is pretreated to remove particles that would clog the membranes. The quality of the water produced depends on the pressure, the concentration of salts in the feedwater, and the salt permeation constant of the membranes. Product water quality can be improved by adding a second pass of membranes, whereby product water from the first pass is fed to the second pass.

In ED and EDR, dissolved ions are separated through ion permeable membranes under the influence of an electrical potential gradient. An ED/EDR stack consists of a series of anion-exchange membranes and cation-exchange membranes arranged in an alternating mode between anode and cathode. This results in an alternated increasing ion concentration in one compartment (concentrate) and decreasing concentration in the other (diluate). The EDR process is similar to the ED process, except that it also uses periodic reversal of polarity to effectively reduce and minimize scaling and fouling, thus allowing the system to operate at comparatively higher recoveries (Sethi et al. 2009).

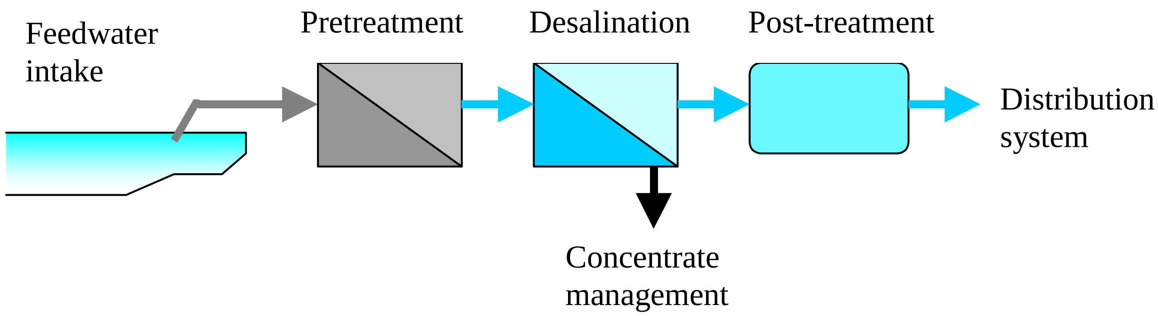


Figure 2.1 Layout of five key elements of a desal system for either brackish water or seawater desal

1. Feedwater intake is the structure that withdraws source water and conveys it to the process system. Feedwater intake can be classified into open intake and subsurface intake.
2. Pretreatment is the process that removes suspended solids, controls biological growth, and prevents scaling during desal.
3. Desal is the process that removes dissolved solids, organic contaminants, and microorganisms from water.
4. Post-treatment involves the addition of chemicals to the product water to prevent corrosion of the distribution system, ensure the compatibility with other water sources, and protect public health (e.g., disinfection, and addition of micro-nutrient minerals).
5. Concentrate management involves treatment, handling, and disposal or reuse of waste residuals from the desal system.

Membrane systems typically have advantages over thermal processes, such as lower energy consumption, lower capital costs, and a smaller physical footprint. Membrane treatment, however, often requires extensive feedwater pretreatment, and is not applicable to very high salinity water [e.g., above seawater level 40,000 mg/L total dissolved solids (TDS)].

Desal processes produce high-quality water by removing most contaminants and impurities from the feedwater. Desalinated water, from either thermal or membrane processes, is highly corrosive due to low concentrations of calcium and carbonate alkalinity. The acidic water has to be properly treated to prevent adverse effects to public heath and the distribution system, and prior to blending with other source water.

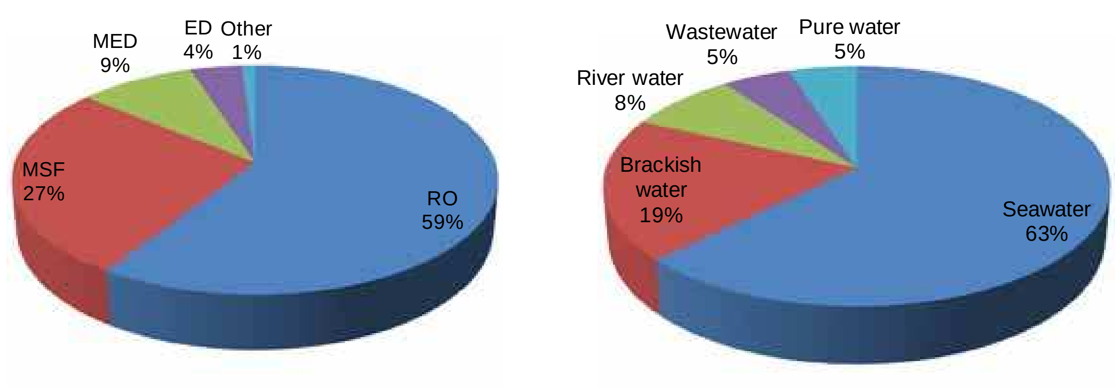
During desal processes, a concentrated salt solution is generated that may also contain some pretreatment and process residuals, and chemical cleaning solutions. The concentrate and residuals require appropriate management to meet regulatory requirements and reduce environmental impact. Concentrate management involves options including waste minimization, treatment, beneficial reuse, and disposal (Mickley 2006, NRC 2008). The five key elements of a desal system are illustrated in Figure 2.1.

STATUS OF DESAL

Desal capacity has risen remarkably over the last few years, indicating that desal technologies have been used to help produce a reliable water supply to address the global water crisis. According to new statistics released by the International Desalination Association (IDA), the amount of global contracted (planned) capacity grew by 43.3% in 2007, increasing from 1.25 bgd (4.75 million m^3/d) in total contracted capacity in 2006 to 1.8 bgd (6.81 m^3/d) in 2007 (IDA 2008a). IDA reported that this growth trend continued in 2008. During the first six months of 2008, newly contracted capacity increased by an additional 39%. As of June 30, 2008, the cumulative contracted capacity of desal plants around the world reached 16.6 bgd (62.75 million m^3/d). Sixty-two percent of the newly contracted capacity is seawater desal, with brackish groundwater and river water desal representing 19% and 8%, respectively (Figure 2.2). Wastewater applications of desal technologies for water reuse is growing quickly, currently representing 5% of total capacity (IDA 2008a).

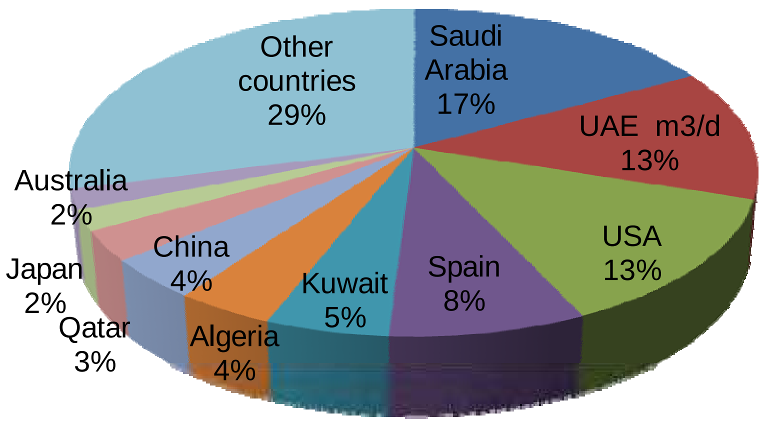
The traditional dominating desal technology, thermal MSF, is continuing to lose its share (27%) to RO (59%) and MED (9%), due to the improvement of membrane technologies and RO's inherent cost advantage (Figure 2.2). The contracted MED capacity has increased 90% since 2004; nearly 0.7 bgd (2.7 million m^3/d) of MED capacity was contracted between the end of 2004 and mid-2008 (IDA 2008a). ED still takes 4% of the contracted desal capacity in comparison with year 2006.

The number of contracted desal plants worldwide increased from 13,080 in 2007 to 13,869 as of June 30, 2008 (IDA 2008a). The top 10 desal countries are listed in Figure 2.3. The Middle East still takes a large share of the desal market; Saudi Arabia and United Arab Emirates are the leading countries in desal, constituting 17% and 13% of the global desal capacities, respectively. In Europe, the major desal plants are in Spain, which has nearly 8% of the global desal capacity. Desal in the UK is also progressing with the first large-scale brackish water desal plant, the Beckton Desalination Plant, under construction and scheduled to open in 2010. The plant is expected to provide 37 mgd (140,000 m^3/d) of drinking water to London.



Source: Adapted from IDA 2008a.

Figure 2.2 Global contracted desal plants by technology and feedwater quality



Source: Adapted from IDA 2008a.

Figure 2.3 Top 10 desal countries

Desal is proving to be one of the keys to Australian water management and the country's total contracted desal capacity has recently increased to 2% of the global total. In Western Australia, the 34 mgd (130,000 m^3/d) seawater desal plant in Perth, which is Australia's first large-scale desal plant, supplies 17% of the city's daily demand. Construction of a second plant for this area has started. At the completion of the second project in late 2011, on average, more than 30% of Western Australia's water supply will come from seawater desal. Along Australia's eastern shore, the 33 mgd (125,000 m^3/d) Gold Coast Desalination Plant has already supplied more than 7 million m^3 of water into the South East Queensland region since production began in February 2009. In New South Wales, the 66 mgd (250,000 m^3/d) desal plant in Sydney is now producing 15% of Sydney's potable water supply. Along Australia's southern coast, plants for the Victoria and Adelaide regions are still in relatively early stages of construction, including the 108 mgd seawater desal plant in Melbourne, and the 72 mgd desal plant in Adelaide.

Desal in the US accounts for 13% of the world's total desal capacity (Figure 2.3). Nearly 96% of US online desal capacity uses RO and other membrane systems, and 100% of the municipal desal capacity uses membrane technologies (Mickley 2006). ED and EDR have been used for wastewater and industrial water treatment but not for drinking water treatment in the US because of no removal of pathogens. More than 2,100 BWRO desal plants operate in the US, and most municipal desal plants are located in Florida, California, and Texas. In Florida, the nation's first large seawater desal facility, the Tampa Bay Seawater Desalination Plant, has been fully operational since December 2007, providing the Tampa Bay region with up to 25 mgd (95,000 m^3/d) of drinking water and alleviating pressure on the over-drafted regional groundwater supply.

California has seen a rapid rise in installed desalting capacity the last decade (Table 2.1). This is primarily due to dramatic improvements in membrane technology and the increasing cost (and decreased availability and reliability) of conventional water supply delivery (CDWR 2009). Currently there are 25 desalting plants operating in California that provide the total capacity of 74 mgd (281,000 m^3/d) for urban use. Currently there are seven new groundwater desalting plants and nine plant expansions in the design and construction phase or the planned and

Table 2.1
Desalting in California for new water supply

Feedwater source	Plants in operation				Plants in design and construction				Plants planned or projected			
	No. of plant	Capacity			No. of plant	Capacity			No. of plant	Capacity		
		AFY	mgd	m^3/d		AFY	mgd	m^3/d		AFY	mgd	m^3/d
Groundwater	19	81,400	73	275,000	4	22,300	20	75,300	3	57,300	51	193,600
Seawater	6	1,700	2	5,700	3	50,800	45	171,700	14	263,600	235	890,700
Total	25	83,100	74	281,000	7	73,100	65	247,000	17	320,900	286	1,084,300
Cumulative					32	156,200	139	527,800	49	477,100	426	1,612,100

Source: CDWR 2009.
Note: mgd = daily average of annual desal capacity (AFY) in terms of million gallons per day.
m^3/d = daily average of annual desal capacity (AFY) in terms of cubic meters per day.

projected phase, for a total of about 80,000 AFY in new capacity (CDWR 2009). There are three seawater desalting plants (Sand City, Ocean View Plaza, and Carlsbad) with a combined capacity of about 51,000 AFY in the design and construction phase as of early 2010. An additional 14 plants with a combined capacity of 264,000 AFY of capacity are in various stages of planning. Several seawater desalting pilot plants have begun operation or are being designed as part of desalting feasibility studies (CDWR 2009). These desal facilities would supply up to 477,000 AFY of potable water by 2025. Voutchkov (2007b) estimated that, if all of the proposed California desal projects are built at their maximum planned capacity, they would supply 1.1% of the total current state water demand of 40,000 mgd and approximately 5.6% of its urban water demand of 8,000 mgd (30.3 million m^3/d).

SUMMARY

The global desal capacity has increased remarkably over the past decade, and desal has provided a reliable water supply to the regions that lack adequate fresh water supplies. The improvement of membrane technologies and the relative cost advantage have made RO a major desal process for new desal facilities and in the areas outside of the Middle East. It is forecast that desal will play an increasing role in expanding regional water supply portfolios around the world.

CHAPTER 3
TRENDS IN KEY FACTORS FOR DESAL IMPLEMENTATION

The world's desal capacity has increased significantly due to technological improvements, reduced treatment costs, and limited conventional water supplies. The most significant trend in desal is the increased growth of the RO market compared to thermal technologies. Technological improvements have dramatically increased the performance of desal processes, helping to reduce total water costs.

This chapter discusses relevant trends for the key factors that continue to influence the feasibility and cost of successfully implementing desal facilities, including co-location, the scale of operation, energy use and sources, costs, intake structures, pretreatment advances, concentrate management, hybrid configurations, and emerging desal technologies.

CO-LOCATION WITH POWER PLANTS

Due to the constraints and pressures for land use, coastal desal plants are often located in areas designated for large-scale infrastructure, such as existing electrical power plants. Seawater desal plants that "co-locate" with coastal power plants may take advantage of existing power plant intake structures, or directly connect the desal plant intake and/or discharge facilities to the discharge outfall of a power plant (CDWR 2003). Co-location has been considered, planned for, or implemented at several large-scale municipal applications in the US. Examples of existing and planned co-located facilities include the Tampa Bay Seawater Desalination Project (in operation), the Carlsbad Seawater Desalination Project, and the Huntington Beach Desalination Project.

However, environmental concerns with OTC power plant systems may make it difficult to obtain permits for some proposed co-located facilities (Pankratz Undated, Luster 2009). Experience with co-located facilities has also revealed several operational challenges arising from complexities associated with matching desal activities with the operation of the power plant, and challenges posed by the power plant cooling water quality and/or temperature to the pretreatment and desal system. Thus, large desal plants may determine it is preferable to not use power plant cooling water as feedwater and instead develop dedicated desal feedwater intake facilities. For example, the Perth Seawater Desalination Plant (Australia) and the Ashkelon SWRO Desalination Plant (Israel) are co-located with power plants, but have separated intake structures (Xu et al. 2009). The Tampa Bay desal facility was designed to use cooling water from a co-located OTC power plant, but has found it often necessary to draw feedwater from its own dedicated feedwater intake due to temperature or other operational issues with the cooling waters from the power plant (Christine Owen, Tampa Bay Water, personal communication, June 20, 2009).

SCALE OF OPERATION

According to the 2008–2009 Desalination Yearbook, desal plants are being built on a new massive scale (IDA 2008b). For example, the Fujairah Plant in the United Arab Emirates, the largest seawater desal hybrid plant in the world, produces 120 mgd (454,000 m^3/d) of water, of which 62.5% is from five MSF units coupled with the power plant and 37.5% (45 mgd or

170,500 m^3/d) from SWRO (Sanza, Bonnélyea, and Cremerb 2007). There are five other plants with capacities in excess of 132 mgd (500,000 m^3/d) now under construction in the Middle East region. The largest of these is the 232 mgd (880,000 m^3/d) Shoaiba 3 unit in Saudi Arabia, using MSF technology (IDA 2008b). In April 2009, the 211 mgd (800,000 m^3/d) Jubail II desal plant started providing desalinated water to the eastern cities of the region (D&WR 2009). This plant employs MED technology on a larger scale than ever used previously; it has 27 units (each with a capacity of 7.8 mgd, or 29,630 m^3/d), and uses waste heat from the power station.

While not approaching the same magnitude as thermal technologies in the Middle East, large-scale SWRO desal facilities are also being planned or have been constructed. For example, the 87.2 mgd (330,000 m^3/d) Ashkelon SWRO Desalination Plant has been in operation since November 2005. The recently approved Carlsbad Seawater Desalination Project in California will be the largest desal plant in the Western Hemisphere, providing 50 mgd (189.3 m^3/day) of high-quality drinking water to San Diego region. The capacities of desal facilities in Australia vary from 34 mgd (130,000 m^3/d) at the Perth Seawater Desalination Plant to 66 mgd (250,000 m^3/d) at the SWRO plant being completed in Sydney.

The benefit of larger capacity desal plants is that the design complexity and operation is not significantly different than that of a smaller plant (Pankratz Undated, NWC 2008). There is no theoretical or design size limit for RO systems because of its inherent modularity. In addition, economies-of-scale contribute to a considerable reduction in the cost of water production. The number of components per unit of water produced in larger scale plants can be significantly reduced. Larger systems are able to obtain higher yields and lower energy/operating costs of the systems by using larger capacity components, more efficient pumps, and ERDs.

ENERGY USE AND SOURCES

Energy Demand

The need to reduce energy consumption (and address GHG emissions associated with climate change), is putting pressure on the desal industry, in particular seawater desal. Currently, the energy consumption of SWRO alone varies between 8 and 13 kWh/kgal (2.1 and 3.5 kWh/m^3) (Veerapaneni et al. 2007, NWC 2008, Xu et al. 2009). Additional energy [typically greater than 13 kWh/kgal (3.5 kWh/m^3)] is required for other desal process components, including intake, pretreatment, distribution, and overall plant operations (Xu et al. 2009). The energy use of current generation SWRO systems is about 20% of the energy used in the first generation RO desal plants. This is mainly due to improvements in membrane efficiency, system design, and highly efficient ERDs. However, the actual energy consumption of RO is still significantly higher than the thermodynamic minimum energy required to overcome the membrane's osmotic pressure. For seawater containing 35 g/L TDS, the osmotic pressure is calculated as 2.85 kWh/kgal (0.75 kWh/m^3) at 25°C (NWC 2008).

Significant energy efficiency can be achieved through a number of options such as optimizing operational parameters, using highly efficient pump and ERDs, and improvement in system design. For example, the centralized and membrane cascade design has significantly reduced the energy demand of the Ashkelon SWRO plant. This membrane system design uses a multistage process, with inter-stage booster pumps and ERDs. It achieves high product water quality while minimizing membrane fouling potential, which in turn, is significant to energy saving by maintaining operating pressure and reducing cleaning frequency (Gorenflo et al. 2007).

Options for reducing the energy requirements may also include the development of new generation membrane materials for RO systems, and alternative desal processes such as forward osmosis (FO) and membrane distillation (MD). Appendix A describes the emerging desal technologies.

Energy Sources and Reducing the Carbon Footprint of Desal

In addition to developing high energy-efficient membranes and ERDs, using alternative energy sources (e.g., wind, solar, biofuel, hydroelectric) has been an important step towards reducing the carbon footprint of desal. For example, the Beckton desal plant in London will use biodiesel to meet desal energy demand and ease environmental concerns about the plant's high-energy consumption (BBC News 2007). In Australia, renewable energy has been developed to power the majority of the proposed large-scale desal plants, such as the Kwinana SWRO plant in Perth and the Kurnell SWRO desal plant in Sydney, both using wind energy to power the plants (Xu et al. 2009). In California, Poseidon Resources Corporation committed the Carlsbad desal facility to be the first major California infrastructure project to go carbon neutral (Poseidon 2007). The carbon neutral plan is proposed to reduce net GHG emissions through a series of offset projects as well as renewable energy credit (REC) purchases (and also by reflecting energy savings by offsetting energy-intensive imported water supplies).

Typically, renewable energy is relatively expensive and may add to the already expensive desal technology. This dilemma may need to be solved with a policy providing incentives to use renewable energy sources at desal plants.

ECONOMICS OF DESAL

Cost of Desal

Desal technologies are becoming more efficient, less energy demanding, and less expensive. This has helped to reduce the cost of desalinated water to levels that are comparable, and in some instances competitive, with other alternatives for acquiring and delivering new potable water supplies (CDWR 2009). In addition to improvements in technology, several factors-including construction of large capacity plants and enhanced competition due to alternative project delivery methods—have also helped to reduce costs in recent years.

Figure 3.1 illustrates the overall trend of water costs reduction from large SWRO plants over the past two decades. These costs include total capital costs and operation and maintenance (O&M) costs. However, they have not been adjusted to account for inflation and many of the assumptions involved in estimating these costs (e.g., plant size, interest rate) are not reported. Therefore, the costs reported in Figure 3.1 are intended to show a general trend. The actual decline in costs may not be as large as shown here. See appendix G for more detail.

Table 3.1 lists the range in total unit water cost that can be expected from plants desalting brackish groundwater, wastewater, and seawater (CDWR 2009). It should be noted that there is no detailed cost breakdown to indicate what key costs are included or omitted in the reported estimates in Table 3.1.

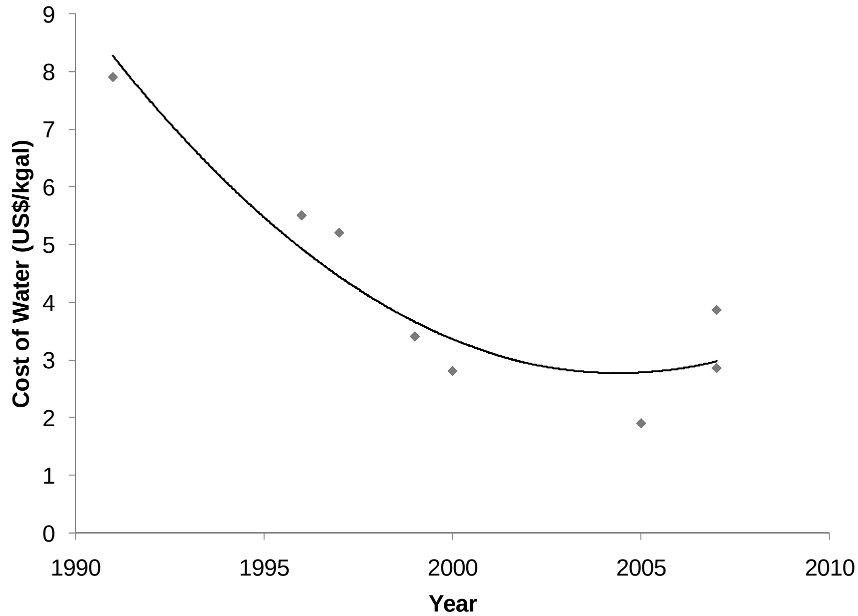


Figure 3.1 Historic trend of water costs from large seawater RO plants

Table 3.1
Total unit water costs of desal

Type of desalting plant	Water costs		
	US$ per AF	US$/kgal	US$/$m^3$
Brackish groundwater	500–900	1.53–2.76	0.41–0.73
Wastewater	500–2,000	1.53–6.14	0.41–1.62
Seawater	900–2,500	2.76–7.67	0.73–2.03

Source: CDWR 2009.
Note: These costs (in US dollars, US$) are based on the expected lifetime of the plant (20–30 years). The year dollars in which the costs are portrayed is not reported.

When planning desal projects, it is important that cost estimates take into account the full costs of implementation including costs associated with intake, pretreatment, the desalting system, post-treatment, concentrate and waste management, and desal product water blending and delivery systems. Cost estimates should include initial capital costs (equipment, construction, financing costs, and other one-time costs needed to build the complete desal treatment facilities), as well as annual O&M costs (including energy, labor, chemicals, etc., for all the process steps). Project capital cost estimates should include costs for environmental studies and mitigation, public meetings, legal support, and other activities necessary to get through the planning and permitting process.

The unit cost of desal are very site specific and can be affected by several factors such as cost of electricity, type of intake (e.g., co-locating and using existing intake and cooling water), type of outfall (e.g., using existing outfalls), and basis for annualizing costs (i.e., facility life or amortization period, and interest rate). Appendix G provides more detail on desal project costs and key cost factors.

Several future improvements to membrane technology are forecast, such as development of membranes with high salt and pathogen rejection and productivity; reduced fouling potential; improved membrane resistance to oxidants; elevated temperature and compaction; improved chemical cleaning; integration of membrane pretreatment; advanced energy recovery; high-efficiency pumps; and development of cost-effective methods for concentrate management (including beneficial use and disposal). These technology advances are expected to reduce the cost of desalinated water by 20% in the next five years and by up to 50% by year 2020 (Voutchkov 2007a).

However, several factors may serve to increase the costs of desal in the future, including potential increases in: the cost of electricity, construction, and materials; costs associated with planning and permitting desal projects; costs of concentrate management and intake systems; process costs; and potential costs for carbon (GHG) emissions. In addition, environmental mitigation costs are likely to increase, especially in sensitive coastal settings like California and where I&E might be an issue, and special screens or intake facilities and/or extensive monitoring may be required. For many desal plants currently in the planning phases, costs associated with environmental mitigation activities are proving to be quite substantial.

Impact of Electricity Cost

The energy cost in the form of electrical power represents in large part the operating cost of an RO desal facility. The energy consumption may contribute up to 11% of the total water cost of a BWRO facility (Miller 2003), and 38% of a SWRO facility (CDWR 2009). The O&M costs for RO processes are very sensitive to increases in the price of electricity. This is particularly true for SWRO desal facilities (Figure 3.2). For example, for a typical brackish water and seawater desal facility, a tripling of the cost of electricity from $0.05/kWh (US$) to $0.15/kWh (US$) could result in increases in the total water cost of 22% and 76%, respectively (as seen in Figure 3.2). For a BWRO facility with a total water production cost of $1.53/kgal, this would result in an increase of $0.34/kgal to $1.87/kgal. For an example SWRO facility with a total water production cost of $2.76/kgal, costs would increase to $4.86/kgal (Table 3.1 and Figure 3.2). Thus, it is very important that water utilities investing in desal develop effective strategies to manage the impact of increased electricity costs on the cost of producing and supplying water by desal.

Impact of Offsetting Carbon Emissions

It is possible that offsetting the carbon emissions associated with desal will become an important part of managing potential increases in the cost of water as a result of the introduction of a price on carbon emissions. The amount of carbon emitted by a desal facility will depend on the source of energy used to generate electricity, the amount of chemicals used in the process, and the economic life of consumable items such as the membranes. The largest component of the carbon emission for desal is power. Consequently, water utilities in Perth, Sydney, and Melbourne have committed to buying RECs to offset the GHG emissions. According to a report published by Australian Government National Water Commission (NWC 2008), a desal facility with a power consumption of 17.4 kWh/kgal (4.6 kWh/m^3) that sources electricity produced by black coal will emit between 17.8 and 22.7 kg of carbon dioxide equivalents (CO_2-eq) per kgal

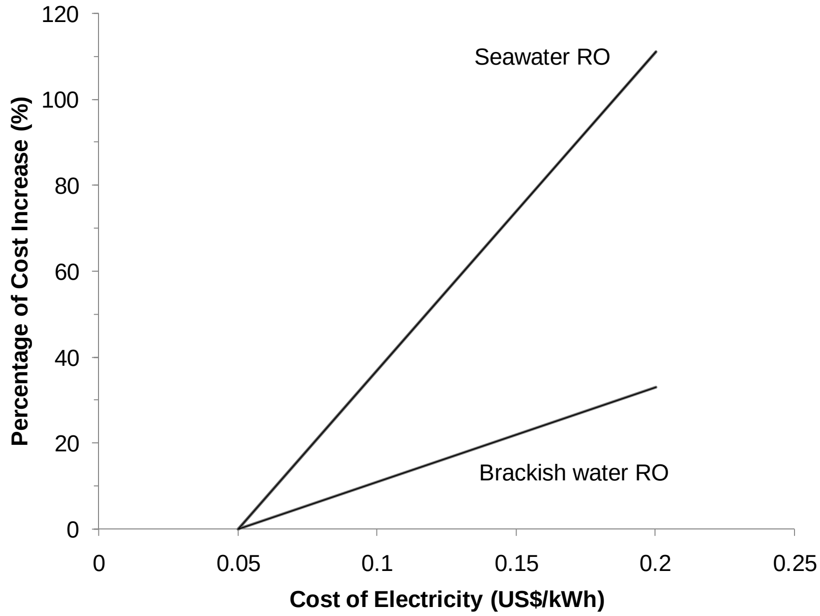


Figure 3.2 Sensitivity of desalinated water costs to increase in cost of electricity. It is assumed that the energy consumption may contribute up to 11% of the total water cost of a BWRO facility (Miller 2003), and 38% of a SWRO facility (CWDR 2009). The total water costs are assumed $1.53/kgal and $2.76/kgal for BWRO and SWRO facilities, respectively, at an electricity price of $0.05/kWh (CWDR 2009).

(4.7 to 6.0 kg CO_2/m^3), depending on the location of the plant. The introduction of an emissions trading scheme where carbon is priced at $50 (in Australian $, AU$) per ton of CO_2 will add approximately 16% to the O&M cost of the facility (NWC 2008).

According to the California Department of Water Resources (CDWR 2009), the average energy consumption of RO desal treatment is currently estimated at about 5.5 kWh/kgal (1.5 kWh/m^3) for brackish water and about 12.3 kWh/kgal (3.2 kWh/m^3) for seawater desal. Using a conservative estimate of GHG emissions of 0.4 kg CO_2/kWh (assuming electricity is generated from natural gas, this number climbs up to 0.9 kg CO_2/kWh for electricity generated from coal), the GHG emissions associated with operating a RO desal plant are estimated to be 2.2 kg CO_2/kgal (0.6 kWh/m^3) of desalinated brackish water and 4.9 kg CO_2/kgal (1.3 kWh/m^3) of desalinated seawater.

A sensitivity analysis of the price of carbon offsets on the increase in desalinated water cost is illustrated in Figure 3.3. Assuming a carbon offset cost of US$10 per metric ton of carbon emitted from desal, water production cost will increase by $0.02/kgal for brackish water, and $0.05/kgal for seawater desal. Investment in carbon offsets over the 30-year life of a 10 mgd desal plant would thus be estimated to cost approximately $2.5 million and $5.4 million for brackish water and seawater desal, respectively.

Besides the purchase of RECs, other measures to help reduce the carbon footprint of desal plants include gaining energy efficiencies through ERDs, high efficiency pumps, variable frequency drives, low-energy with improved salt rejection membranes, and the onsite use of renewable energy sources.

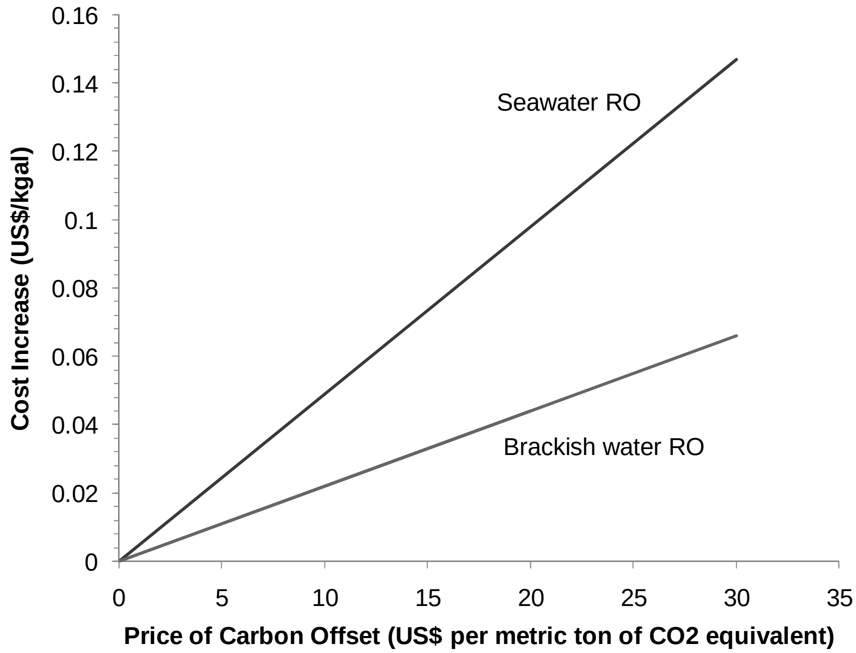


Figure 3.3 Sensitivity of desalinated water costs to cost of carbon offset

COASTAL INTAKE STRUCTURES AND ENVIRONMENTAL CONSIDERATIONS

Feedwater intake is a key technical component in a desal plant, especially for seawater desalting. It plays a major role in controlling the quantity and the quality of the water transferred to the pretreatment and desal process. Intake structures can cause adverse environmental effects on aquatic organisms through I&E and on benthic organisms by digging intake tunnels. A significant trend in coastal intake systems is the pursuit of measures that minimize environmental impacts through using subsurface (i.e., below seabed) intake structures, and proper design, siting, and operation (e.g., intake velocity) of an intake facility.

Since the early 1970s, seawater intakes used for electric power plant cooling water intakes have been required to employ the best available technology (BAT) to minimize adverse environmental impact under section 316(b) of the US Environmental Protection Agency's (USEPA's) Clean Water Act (CWA). The 316(b) requirements for new sources were amended in December 2001 and new rules for existing power plant intakes were proposed in February 2002. California State regulatory agencies have indicated that the siting of a new or existing open water seawater intake for a desal facility will require a current assessment of I&E impacts as part of the environmental review and permitting process. Desal intake structures may be required to be designed to meet the BAT to minimize impacts on marine life.

Environmental impacts associated with open intake systems can be reduced through appropriate siting of the intake, installation of variable speed drives, employing advanced screening technologies and behavior barriers, and using low intake velocities. Co-location with an existing power plant and use of cooling water as feedwater can avoid additive environmental impacts as long as the power plant is operating. Off-site mitigation and restoration may be required to offset unavoidable adverse impacts from the intake operation, and might include supporting a fish hatchery, habitat restoration, and land acquisition to create conservation areas.

In recent years, subsurface intakes have been increasingly employed or pilot tested. Subsurface intakes use sand as a natural slow filter to minimize ecological impacts associated with I&E, and yield a highly filtered, better quality feed water compared to open water intakes. Subsurface intakes are also protected from shock loading in the open ocean from red tides, oil spills, and algae growths. Subsurface intake facilities can thus reduce pretreatment requirements. The level of reduced pretreatment depends on the design of the subsurface intake system.

The largest seawater desal plant with a seabed intake system currently in operation is the 13.2 mgd (50,000 m^3/d) Fukuoka District RO facility in Japan (Matsumoto et al. 2001). Recently the Municipal Water Management District of Orange County (MWDOC) completed a two-phased study on a slant well technology for the proposed 15 mgd (56,775 m^3/d) Dana Point desal plant (MWDOC 2007). The Long Beach Water District (LBWD) is experimenting with the Under Ocean Floor Seawater Intake and Discharge Demonstration System designed by LBWD and the US Bureau of Reclamation (USBR) (LBWD 2009c).

PRETREATMENT ADVANCES

Desal membranes are highly susceptible to particulate fouling by suspended solids, adsorption of organic substances, inorganic scaling of sparingly soluble salts, and biofouling. Efficient pretreatment is vital and the most critical aspect in the success of desal process.

In recent years, the use of membrane pretreatment (microfiltration, MF, or ultrafiltration, UF) has emerged as an alternative to conventional pretreatment to seawater desal, including coagulation, media filtration, and cartridge filtration. Membrane pretreatment provides a consistent quality of permeate and a smaller footprint. As a result, there is currently a trend toward low pressure membranes for sea water pretreatment (Pankratz Undated, Stedman 2009), in particular where subsurface intakes are employed. For example, the Fukuoka District RO facility in Japan uses UF prior to RO membranes to treat seawater withdrawn from a seabed infiltration gallery. In North America, the primary water quality issues for open intakes that have been encountered are algal blooms and biogrowth, which challenge the design and operation of both conventional and membrane pretreatment. Current research and development (R&D) emphasis is being placed on pretreatment system selection and optimization, and novel physical, chemical, or biological processes to improve pretreatment.

CONCENTRATE MANAGEMENT

Concentrate management may present a number of environmental concerns that require careful consideration. The concentrate from a desal process typically is two to five times higher in salinity than the surrounding water (assuming 50–80% recovery). This waste stream may contain antiscalants, cleaning chemicals, coagulants, and pretreatment filter backwash. It may also contain concentrated amounts of other compounds removed from source waters by the membrane process, including arsenic and other contaminants posing toxicity concerns for the environment and human health. The concentrate may also have relatively high temperatures if cooling water is used as source water. Therefore, concentrate from membrane desalting systems can cause significant impact to the receiving environment if it is not handled correctly.

Concentrate management and the associated environmental concerns represent the greatest challenge to successful and widespread implementation of inland desal. Disposal options at many inland locations are very limited and may be environmentally and/or cost prohibitive. The low product water recovery leads to not only substantial loss of valuable water resource but also affects permitting of brackish water desal facilities because raw water withdrawal volumes and concentrate disposal are the key parameters assessed during permitting.

Substantial research efforts have been taken to increase desal water recovery and minimize concentrate volume, although the downside with increased recovery efficiency is that salts and other membrane-removed contaminants (e.g., arsenic) become more concentrated and thus more difficult to manage safely. Approaches that may help mitigate the disposal challenges include beneficial use of concentrate, and regional and watershed management approaches that may facilitate economies of scale or other advantages for concentrate disposal.

Direct beneficial use of concentrate is an attractive option for the sites where concentrate can find an environmental friendly application, such as wetland restoration and irrigation. Regional concentrate management includes regional collection, treatment, centralized disposal (e.g., co-discharge desal concentrate with wastewater effluent), or beneficial uses of concentrate from a number of desal plants. A regional approach may take advantage of site-specific beneficial conditions for disposal and of the economies of scale of constructing larger concentrate disposal facilities. Another advantage of regional management is the use of concentrate from brackish water desal plants as source water to seawater desal plants, such as the case in Eilat, Israel (Ravizky and Nadav 2007). The use of brackish water concentrate in this manner will reduce the feedwater plant salinity, when blended with ocean water for the feed source. This will decrease the seawater desal plant's energy and treatment costs and potentially increase recovery, while also avoiding the brackish desal concentrate disposal issues.

An emerging desal trend is to further treat concentrate in order to increase recovery, thereby minimizing concentrate volume. However, this can complicate the disposal challenge. Concentrate volume reduction eliminates the use of most conventional disposal options, as follows:

- It effectively eliminates discharge to surface waters, to the sewer, and to land as it makes the concentrate more incompatible (salinity-wise and individual constituent-wise) with the receiving water (surface water or groundwater).
- Higher salinity brine has a reduced evaporation rate and results in evaporation ponds filling up with solids more rapidly. The net effect may be that the total evaporation pond area is reduced relative to lower salinity concentrate disposal by evaporation ponds.
- Deep well injection of high recovery brines where one or more salts are close to saturation has its own challenges and unknowns. Because of this and because of higher levels of total suspended solids (TSS), some form of treatment (filtering in many cases) may be required prior to injection.
- Processing all the way to mixed solids (zero-liquid discharge, or ZLD) is efficient in terms of maximizing the use of the water resource, but does not provide a concentrate management solution. The high level of solids produced (including additional solids produced by processes such as lime softening that allow high recovery processing) results in high landfill costs with the amount of solids, in many cases, requires dedicated monofills to be constructed.

HYBRID THERMAL/MEMBRANE CONFIGURATIONS

Innovations of hybrid systems, where thermal and membrane processes are combined with a power generation plant, are a significant developing trend in the desal market, in particular in the Middle East. The design of hybrid desal system integrates the use of thermal and membrane processes to maximize flexibility by using two different forms of energy for desal. The design also takes advantage of waste heat for the thermal process and higher feed temperatures for the membrane process. The hybrid system is mainly focused on reducing the costs, increasing the efficiency, and improving flexibility in operation. For example, the first hybrid plant, the Fujairah plant in the United Arab Emirates, produces 120 mgd (454,000 m^3/d) of water, 62.5% from five MSF units coupled with the power plant and 37.5% from SWRO. The hybrid system helps to sustain the electricity demand when there is a mismatch between the water and electricity demand (Sanza, Bonnélyea, and Cremerb 2007). Other large hybrid plants are found in Saudi Arabia (Hamed 2005). Research in the hybrid area has largely involved modeling studies to identify optimal arrangements (Helal et al. 2004; Cardona, Piacentino, and Marchese 2007).

Another hybrid system involves the pre-treatment of MSF and SWRO feed by NF to remove hardness ions (Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^-), which causes scale formation on membrane and heat transfer surfaces (Al-Sofi et al. 1998, Hassan et al. 1998, Hamed 2005). The NF pretreatment brings significant benefit to MSF, as it allows higher top brine temperatures in the MSF, reduces the need for antiscalants and acids, and increases product recovery from 35% to over 70%. The SWRO permeate produced from the NF-SWRO arrangement has very low TDS, making the requirement for a second-pass RO treatment unnecessary (Hassan et al. 1998).

ALTERNATIVE DESAL TECHNOLOGIES

Alternative and emerging technologies are being developed to improve certain performance aspects of existing desal processes, such as higher recoveries, reduced fouling, and decreased energy consumption and capital and operating costs. These new technologies can be classified into three categories: thermal (i.e., Dewvaporation™, MD), physical (i.e., FO), and electrical-chemical (i.e., capacitive deionization, CDI). The potential for these new technologies to supplement or replace existing technologies represents the new frontier of desal technology.

New hybrid configurations are also being investigated to improve water recovery and control membrane fouling/scaling. These include:

- Physical-chemical or biological treatment of primary RO concentrates, followed by secondary RO or EDR
- Seeded slurry processes to remove scaling compounds in a controlled fashion
- Electromagnetic field (EMF) for scaling control of RO membranes
- Membrane filtration enhanced by vibratory shear enhanced process (VSEP)
- RO/ED or RO/EDR

More details regarding the alternative and emerging desal technologies are provided in appendix A.

SUMMARY

The advances in desal technologies have significantly increased system performance, decreased energy demand, and reduced water production costs. The major trends of desal technologies are summarized below.

1. Technological improvements have dramatically increased the performance of RO membranes, and the increased growth of RO in desal market is expected to continue.
2. Larger desal plants are being constructed to take advantage of economies-of-scale, which reduces the unit cost of desalinated water.
3. There has been a growing trend that co-located desal plants may use separate intake and/or disposal structures to avoid environmental impacts, permitting challenges, operational challenges, and potential uncertainties and risks associated with using power plant cooling water as desal feedwater.
4. Significant energy efficiency in membrane processes have been achieved through optimizing operational parameters, using high-efficient pumps and ERDs, and improvements in system design. More desal plants are using renewable energy or developing environmental restoration strategies to reduce the carbon footprint of desal.
5. The technological advances are expected to reduce the cost of desalinated water by 20% in the next five years. However, desal costs may increase due to the potential for cost increases in electricity, construction and materials, planning and permitting, and potential costs for carbon emissions and environmental restoration.
6. Subsurface intakes have been increasingly employed to provide a good feedwater quality and reduce environmental impacts. This also results in the trend of using membrane pretreatment.
7. There is a significant need for developing environmentally responsible and sustainable methods for concentrate management or disposal. The approaches that may help mitigate the disposal challenges include beneficial use of concentrate, and regional and watershed management for concentrate disposal.
8. The performance of desal processes may be further improved by hybrid configurations and alternative desal technologies, such as flexibility in operation, higher recoveries, reducing fouling and scaling, and decreasing energy consumption and capital and operating costs.

CHAPTER 4
DESAL'S ROLE AS A VALUABLE PART OF FUTURE WATER SUPPLY PORTFOLIOS

As the previous chapters indicate, there is increasing interest in, and widening application of desal approaches for providing potable water supplies to communities in North America, Australia, and the European Union (EU). There are numerous logical reasons for the growing interest in desal, and yet many utilities are finding it difficult to move forward with desal implementation (or are only able to successfully move forward when a water shortage reaches crisis proportions, as in many parts of Australia over the past decade).

This chapter summarizes the key rationales for making desal a water supply option that many communities may wish to consider as part of their water supply portfolio. The objective is to help utilities better understand and articulate why they may wish to consider desal. Chapter 5 will cover several related issues that have additional practical implications for proceeding with desal implementation.

GROWING WATER SUPPLY SCARCITY

Due to a variety of important factors and realities, many parts of North America, Australia, the EU, and other parts of the globe are facing increasing water supply shortfalls relative to demands. The factors that are most relevant are often location-specific, but many water-short areas face a similar mix of challenges. These challenges are emerging not only in traditionally arid regions, but also in areas that until recently were considered relatively water rich (such as the southeastern US). These challenges typically include some combination of the following emerging realities:

Current sources of supply cannot be readily expanded. In many areas, currently relied upon surface and groundwater supplies have been tapped to their maximum, or perhaps even tapped at levels now recognized as unsustainable. Accordingly, many communities find themselves facing limits on their ability to extract additional waters from the array of supply options that have been available to them in the past.

Current sources of supply no longer reliably provide the same yields as in the past. Many water sources are no longer providing water yields at levels relied on in the past. This reduction in reliable yields may be due to a number of factors, including increased extraction by other water users, climate variability, and climate change. For example, prolonged and severe droughts through much of Australia and the western US have significantly reduced the amount of water available from existing supply options, and may be part of a long-term trend (i.e., being representative of likely future climate realities, or perhaps evidence of existing climate change impacts). Increased evaporation and other factors associated with climate change are also likely to reduce the volume of water that can be stored in reservoirs. There also is increased recognition that some water supply sources face potential risks from natural events that would impose significant supply disruptions (e.g., the potential for seismic events that would severely limit or cut off use and/or delivery of water from California's Bay-Delta system to its many existing users throughout the state).

In addition to reduced quantity associated with existing supplies, the quality of existing supplies continues to be an issue in many areas. In the future, extreme water quality problems may necessitate the use of RO to “purify” some traditional drinking water supplies. This would substantially increase the costs associated with accessing these sources.

Institutionally-imposed limits on extraction and use of existing or potential new supplies. Environmental and other considerations are playing an increasing role in limiting current and future extractions from several surface and groundwater sources that have been (or that in the future might have been) tapped as potable supplies. Court rulings, driven in large measure by ecosystem impacts, have significantly reduced allowable extractions from many important water supply sources, including the Bay-Delta in California, and the Edwards Aquifer in Texas.

Barriers to expanded water reuse. Advanced treatment techniques, coupled with growing practical experience by utilities and the communities they serve, are making the reclamation and reuse of highly treated wastewater effluent a viable option for supplementing traditional potable water supplies. Water reuse can augment potable supplies by either serving water demands otherwise met through the potable supply (e.g., nonpotable reuse for landscape irrigation), and/or by being integrated into the potable supply (e.g., indirect potable reuse, such as through reservoir augmentation or aquifer recharge). However, there remain many barriers to expanded water reuse in some communities, including occasional public reluctance, regulatory constraints and requirements, cost, energy use, and water rights issues.

INCREASING WATER DEMANDS

A discussion of water supply scarcity needs to consider demand-side issues alongside factors that limit the quantity of water availability. Some relevant demand-side factors that often lead to consideration of desal follow.

Population and economic growth. While there are stakeholders in many areas that have a strong preference to limit future growth in their communities, global and national populations are expected to increase. Therefore, population growth remains likely in most regions and needs to be accommodated. Water utilities do not generally have input into regional growth plans, and instead are expected to do their best to meet the anticipated changes in future population levels and economic activity. More people and more economic activity tend to imply more total water demand, assuming that good conservation practices make existing and future water uses reasonably efficient.

Limited opportunities for additional water conservation. Reducing water losses and promoting efficient use of water in businesses and homes are hallmarks of well managed water utilities. In many communities—especially in areas that have already encountered water shortages—considerable efforts have already been implemented to reduce per capita water consumption, industrial water use, and water losses. Additional opportunities often exist to squeeze out additional water savings, however they generally entail high costs and/or impose considerable restrictions on traditional community values and lifestyle choices. For example, restrictions on residential outdoor water use (e.g., bans on car washing or lawn and garden watering) are relied upon by utilities in challenging drought periods, but these restrictions are not generally considered necessary or acceptable during normal water supply years.

In addition, significant reductions in indoor water consumption can create considerable problems for wastewater collection and treatment systems. Wastewater systems have been designed based on specific levels of flows and dilutions, and significant reductions in wastewater discharges from homes and businesses can lead to collector system failures and challenges to treatment process performance. Reduced wastewater flows also diminish water reuse opportunities. These are additional reasons why water conservation is rarely viable as the primary solution to matching future water supplies with future demands.

Climate change-related increases in water demands. Climate change has a likely potential for increasing water demands for municipal water as well as competing water use sectors (e.g., agriculture, energy production). Hotter temperatures, especially in summer, coupled with projected changes in seasonal precipitation patterns (with drier summers and possibly increased winter precipitation projected in many regions), are expected to increase water demands related to outdoor use (agricultural, urban, and residential irrigation). Power demands are also likely to increase, especially in hotter summer periods, which will increase demand from the water-intensive energy sector. Higher river and lake water temperatures (and lower dissolved oxygen levels) will also require more instream flows to support key fisheries and other ecosystem functions.

In sum, fewer water supply options are likely to be available, and yields from traditional sources are likely to be less reliable than in the past. Concurrently, we anticipate increased demand for water across sectors and water uses. Desal is a logical and often necessary option to consider in such a water supply planning context, in most areas.

BENEFICIAL VALUES THAT DESAL CAN PROVIDE TO COMMUNITIES

With increasing water demands and more limited traditional water supply options, it is clear that desal provides an important option for meeting near-term and future water supply needs. Indeed, all future water supply options need to be given serious consideration in many communities.

Desal, however, has several drawbacks, both perceived and real. These drawbacks are described elsewhere in this report (e.g., high cost, high energy use, potential adverse environmental impacts associated with feedwater intakes and concentrate management), and water supply planners need to recognize and address these issues. At the same time, desal offers several important beneficial values that are not always applicable with other water supply alternatives. It is important that utilities, and the communities they serve, recognize these often unique and important benefits as they weigh the pros and cons of adding desal to their water supply portfolio.

Desal offers reliability of water supply yield. One of the potentially important benefits of desal projects is that the yields from such 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 reliability benefits go unrecognized by the water agency, policymaker, or average citizen, then desal options may remain undervalued and, perhaps, underutilized. However, these 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.

The term “reliability” as used here refers to the ability of a water supply option to produce a given yield (e.g., in mgd or AFY) on a reasonably stable, continuous basis, whenever the utility wishes to tap and operate that given source. In other words, a reliable water supply option is one that produces a predicable and reasonably stable target yield, without much variability or uncertainty about how much water will be produced over a given timeframe.

Portfolio theory, as originally developed for application in financial markets, provides some useful insights into how water supply planners might develop and manage the portfolio of water sources available to them. Portfolio theory is based on the concept that people want to manage their mix of financial holdings in a way that minimizes their overall risk—they want to maximize their anticipated returns subject to preferences about how much risk they bear.

In the 1950s, Harry Markowitz developed a modern portfolio theory, showing how diversified asset allocations—involving an optimal mix of holdings in stocks, bonds, and other financial instruments—could reduce the overall risk borne by a portfolio. In essence, portfolio theory is a statistics-based formalized embodiment of the old maxim about not placing all of one's eggs in one basket. The central premise, long recognized and applied by financial managers, is to jointly maximize expected returns (water yields) while also reducing the overall variance in portfolio yield. This can be accomplished by minimizing the covariance in yield risks across the assets held in a portfolio (Markowitz 1952).

This basic premise of portfolio theory also applies to water resource planning. Each water supply option can be viewed as an asset that is subject to some sources and degree of risk (where risk refers to variability or uncertainty about the water yield, cost, or both). There may well be a premium value that a risk-averse community would be willing to pay to better manage its water risks, either by providing some insurance and/or by providing some variance-balancing water portfolio diversification. The portfolio approach, as applied to water supply planning, introduces the unique risk/benefit profiles of different water supplies to the analysis, thus allowing an assessment of increased (or at least equal-to-existing) supply reliability at the least cost, rather than merely least-cost total supply irrespective of reliability and community values.

A more in-depth discussion of portfolio theory is provided in Wolff (2007) and Kasower et al. (2008), which also offers some simple empirical illustrations of how much added value may be derived from having a water supply with a yield variability that is uncorrelated (or negatively correlated) with that variability of other source water options in the community's water supply portfolio. This added value can also be used to develop a "constant reliability-adjusted cost" per unit of water delivered, which can then be used to develop a reliability-adjusted cost-effectiveness comparison of water supply options including desal (Wolff 2007, Kasower et al. 2008).

There also is a body of research—now being updated with funding from the WateReuse Foundation—which aims to more directly value reliability by surveying households about their willingness to pay (WTP) to reduce the likelihood (or frequency and severity) of local water shortages and related water use restrictions. Results from the earlier studies suggest reliability values for households may range up to $4,000 per AF or higher (e.g., Carson and Mitchell 1987; CUWA 1994; Howe and Smith 1994; Griffin and Mjelde 2000; Raucher et al. 2005; Raucher, Henderson, and Rice 2006).

Desal typically provides a locally controlled source of water. Local control can be a valuable attribute, especially in regions that rely exclusively or predominantly on imported supplies. In such a context, desal is likely to provide water supply reliability benefits for both periodic risks such as droughts, as well as infrequent but catastrophic events such as earthquakes. Drought protection may arise because the additional local supplies diversify the water supply portfolio and adds a drought-resistant supply to the mix, plus the added local source provides additional total capacity. Catastrophic risks are likely to be reduced because when the imported supply is cut off or severely curtailed because of a seismic or other event (e.g., impacting the amount of water reaching the region, or cutting off a major feed line from the source or wholesale agency to its wholesale and retail customers), then the local source remains available (and may be the only water available for local basic needs).

Additional values may come from the level of operational control a community exercises over the desal water supply and the degree of value that the community places on their own "local control." Some imported surface water sources (e.g., waters transported long distances, such as through California's State Water Project (SWP) or the Federal Central Valley Project) have complex contractual, regulatory, and operational characteristics associated with them. On the other hand, water supplies derived from local desalinated sources, using locally controlled treatment facilities, may exhibit little or no institutional, contractual, or operational complexities outside the community that the project serves. These potentially valuable benefits may induce a community to choose a water supply that has a higher unit cost than alternative supplies, but exhibits increased community values associated with better water portfolio risk management.

Desal may be cost competitive relative to the true marginal cost of alternative new supply options. While desal may appear to be costly relative to the out-of-pocket expense utilities and their customers have incurred to secure their past water supplies (e.g., desal costs approaching $1,000 per AF, and perhaps much higher in some instances; see chapter 8 and appendix G), it is important to recognize that the meaningful comparison is to consider desal relative to the full cost of other feasible options for adding more water to the community's portfolio. Because new water supply options are often very limited in many locations (per the discussion above), it may often be the case that there are few if any alternatives to desal, and the viable alternatives are themselves likely to be expensive if all the applicable costs are fully taken into account. In addition, it is likely that even traditional water sources will require more advanced treatment (such as RO) in the future, to address growing concerns over endocrine disrupting compounds (EDCs) and other contaminants being detected at lower concentrations in source waters.

Desal can be implemented in an environmentally sensitive manner, and can even generate important ecosystem benefits. Depending on the setting in which a utility operates, there may be actual or perceived environmental impact issues that could derail or delay desal implementation (especially as related to concentrate management at inland locations, and coastal zone impacts from intakes and discharges from seawater facilities). It will generally be prudent for water utilities to consider environmentally preferred, green approaches from the outset, rather than face potential issues with stakeholders, public officials, and/or regulators. For example, considering alternatives to open water intakes in coastal zones may cost more to implement, but they are likely to increase the likelihood of a desal facility receiving regulator and public support (and may ultimately save the utility money associated with permitting and delays).

Also, where actual or perceived environmental impacts cannot be fully mitigated through facility design or operating regimes, utilities should consider near-site habitat restoration options that offset potential adverse impacts (e.g., provide good fish nursery habitat for species that may be impinged or entrained). Habitat creation, enhancement, or restoration can provide many ecologic and recreational benefits to the concerned parties, and thereby relieve some of the pressure from desal opponents.

Finally, where the use of desal enables extraction pressures to be eased from traditional surface or groundwater sources, there are opportunities for desal to offer net environmental improvements. Water rights realities may limit the opportunities to ensure that desal production will continue to offset extractions from ecologically-sensitive water sources (e.g., if a utility foregoes its right to extract water from a river, another party may make claim to those waters and extract them). However, freshwater offsets that result in ecologic gains is a potential value that is worth taking into consideration if the desal offset can be assured over a reasonable timeframe.

Desal can be implemented in a reasonably energy-efficient manner (relative to viable alternatives for new supply sources), and can have a modest carbon footprint by promoting renewable energy. While desal is becoming more energy-efficient through energy recovery systems, improved membrane design, and other advances, desal remains energy intensive relative to most current alternatives. However, other *new* water supply alternatives are themselves often quite energy intensive, such as when the alternatives includes long-distance imports (due to pumping and related infrastructure requirements), or when the viable alternative draws on a low-quality source that requires the use of membrane and other energy-intensive processes to comply with applicable drinking water standards. Therefore, it is important to ensure that energy use scenarios for desal are properly cast in a comparative context wherein the energy demands of the viable alternatives are fully accounted for.

Desal also has become a vehicle to promote more extensive and rapid deployment of solar, wind, and other forms of alternative energy. This is evident in Australia, where wind and solar power are being developed to provide enough green energy to power (or offset fossil fuel power use) at the Perth and Sydney desal facilities. While opponents may point out that absent desal the renewable energy could be used for other purposes, it is unclear that the renewable energy projects would have been pursued at the same scale and pace if the desal facilities had not provided the impetus. And, in general, it appears to be good practice to “separate tomorrow’s water from yesterday’s energy.”

Desal often can be highly beneficial as part of a comprehensive, integrated regional water resource management strategy. Since desal is often cast as an option for providing a potable supply to a community or region, it is natural to evaluate it in that context alone. However, our case study research indicates how the true value of desal may often be more important when viewed from the perspective of broader regional water resource management challenges (see chapter 9 and appendix H). This may be especially true for inland desalting such as tapping brackish groundwater.

Many regions face a multitude of water resource management problems, in addition to the need to provide a safe and reliable potable supply. For example, salinity-related groundwater quality problems often are evident in many areas, either due to past land use practices (e.g., the Chino Basin in California), or due to freshwater extractions increasing the rate at which adjacent brackish waters encroach upon existing freshwater wellfields (e.g., El Paso, Texas). In these instances, brackish water desal not only provides part of their respective regions’ potable supply, but it also helps manage the groundwater quality challenges. In the Chino Basin, the hydraulic control and groundwater quality improvements enabled by the brackish water desal program were essential for gaining regulatory acceptance of a highly valuable water reuse program (including aquifer recharge) and an aquifer water storage program. Thus, desal is not a substitute for reuse; instead, desal enabled the water reuse and groundwater storage programs to proceed, such that those benefits can be attributed in part to the region’s desal investment.

Likewise, desal-generated water is typically of such high quality that it provides benefits for other water supply options. For example, desal water can be blended with lower quality sources to yield a suitable quality for potable uses (thereby saving some of the drinking water treatment costs and energy use that would have been associated with making the low-quality source potable). Likewise, desal water can enhance a water reuse program by providing low TDS waters to a source that typically faces its own salinity issues.

CONCLUSIONS

There are many factors that are causing desal to be seriously considered as a water supply option in many communities. These factors reflect the increasing scarcity of traditional water supply options in many locations, coupled with inevitable increases in water demands.

Despite the frequent lack of many alternatives, desal is challenging to implement for a variety of reasons, as described elsewhere in this report. Given these challenges, it is important to also recognize some of the highly valuable attributes that desal can offer a utility and the community it serves. In this chapter, we have aimed to provide a description of the beneficial values that desal can furnish, as well as implementation-facilitating approaches to consider.

Ultimately, a key aspect of bringing desal into a water supply portfolio is to ensure that the discussion is framed by the relevant baseline. This means that the need for additional water needs to be cast with a look toward the future (i.e., articulating what the community would face in terms of water shortages and implications, in 20 to 30 years, if no new water supply is added), rather than in the context of what residents and businesses face today. Then, as a critical second step, desal needs to be compared to its viable alternatives for adding new water to the community in the future (rather than compared to historic options and costs that are not relevant for future water supply enhancement).

CHAPTER 5
DESAL PERCEPTIONS AND REALITIES: IMPLICATIONS FOR IMPLEMENTATION

Desal is often viewed by many key stakeholders—including regulators, customers, and public officials—as being fundamentally different from other water supply options. In many ways, these differences are real, and in other ways the differences are more a matter of perception than reality. Regardless, both real and perceived differences between desal and other water supply options (as well as overlooked similarities) often have significant implications for whether a utility can successfully navigate its way through the challenging desal planning and implementation process. Accordingly, this chapter describes some of the real and perceived differences and similarities, and discusses their implications for implementation.

DESAL MAY BE PERCEIVED AS A NEW AND UNPROVEN TECHNOLOGY

Discussion

As described in chapters 2 and 3, desal has been successfully implemented in many locations world-wide for several decades. Both thermal and membrane desalting processes are well established and well understood by many water professionals. Hence, desal is neither new nor unproven.

Nonetheless, in North America and many other parts of the world, desal has yet to be implemented on a large scale, which makes it appear to be novel and possibly unproven. For example, it has only been in recent years that the first major utility desalting facilities have been made fully operational in the US. These include the 25 mgd seawater desal facility supplying Tampa Bay Water (TBW, Florida), and the 27.5 mgd groundwater desalting facility operated by El Paso Water Utilities (EPWU, Texas). Thus, large-scale, water utility desal is relatively novel in the US (although many smaller scale desalters have been operational for many years).

Complicating the US situation is the fact that the TBW seawater desalting facility had a troubled history, having faced many delays and technical problems in its development and initial operating history. These problems—which arose mostly due to a series of unusual and unfortunate circumstances associated with bankruptcies and technical errors by the series of private sector entities initially contracted to design, build, and operate the facility—have helped create a public misperception that seawater desal is inherently fraught with technical problems. The problems at TBW's facility were significant and unfortunate, and several may have been avoided with alternative contracting and project delivery strategies (see the case study summary in chapter 9). Although the problems were not inherent to the seawater desalting process and have been largely rectified, there may remain a perception in many public circles that large-scale utility desal is not ready for prime time, and will inevitably be fraught with technical challenges, extensive delays (due to either technical or permitting problems, or both), and cost overruns.

Suggested Implementation Strategy

It may be beneficial for utilities with desal aspirations to anticipate some public skepticism and wariness (or even opposition) on the basis of perceptions that desal will be troublesome to plan and implement, and difficult and unreliable to operate. One strategy to address this is to prepare materials that help communicate the successful track record for desal, perhaps focusing on the growing adoption of large-scale membrane systems throughout Australia and the EU, as well as elsewhere in North America. These materials should be aimed at utility customers, local public officials, regulators, and other stakeholders, and may include approaches such as public education displays, Web site materials, and so forth. See appendix D for additional guidelines and examples for public outreach and communication.

In addition, careful pilot testing is essential, and can provide one mechanism—if communicated effectively—to address potential public skepticism and concern (and may also be critical in gaining regulatory acceptance). Guidelines for pilot testing are provided in appendix C.

MEMBRANE PROCESSES AND INTEGRITY MAY BE PERCEIVED AS NOVEL AND UNRELIABLE

Discussion

In addition to some potential misperceptions about the novelty and reliability of desal in general, the use of membrane processes is also viewed in many areas as new, challenging, and potentially unreliable. Even though membranes have been deployed successfully for many years in some locations (such as California and Florida), the use of membrane technologies remains relatively novel in many other states and regions (e.g., the eastern and midwestern US). For example, interviews conducted by the research team with over a dozen state drinking water regulators revealed a considerable unfamiliarity with membranes in many areas and, hence, significant concern about how they could ensure that utilities in their states would make suitable membrane selection choices, integrate the membranes suitable within their treatment trains, and properly operate membrane systems. In addition, some regulators may fear that granting permits or approvals for desal facilities may set a precedent for desal permitting elsewhere.

State regulator concern over membranes extended beyond the RO and NF systems typically used for desalting, and include the more porous MF and UF membranes that water utilities are starting to consider for other purposes, including compliance with federal surface water treatment requirements for microbial control (the “Long Term 2” rule). Chief concerns articulated by regulators include quality assurance related to membrane integrity and performance, operational considerations, whether local utility personnel (and their consulting engineers) have the know-how to properly select, install, integrate, operate, and trouble-shoot membrane systems, and the lack of expertise in the state regulatory program to help recognize and resolve problems.

For the Sand City desal plant in California, regulator unfamiliarity with desal led to a more lengthy permitting process than is typical for a standard treatment plant. Specifically, before the California Department of Public Health (CDPH) felt comfortable granting a drinking water permit that would allow the California American Water Company (Cal AM) to begin operating the plant, they required several conditions, additional protections, and assurances. Cal AM and project partners worked with CDPH over the course of seven months to develop a detailed O&M manual and to meet requirements (e.g., through biweekly phone calls, site visits, and meetings). CDPH granted the permit in March 2010. Once operating, the Sand City plant will serve as a case study for other facilities in California. Monitoring results at the site will hopefully help to expedite the permitting process for future plants.

Suggested Implementation Strategy

Regulator concerns with membrane processes are not unfounded in regions where experience with and expertise in membrane applications are limited. As detailed in appendix B, it is not a simple matter to integrate membrane processes into existing water utility systems (i.e., adding membranes is not a simple "plug and play" procedure). Guidance on these issues, as included in appendix B, as well as federal guidance on membrane processes, will hopefully resolve some of these issues.

A utility in a state with limited membrane experience should anticipate some hesitancy and concern from applicable regulators, and we recommend that they take pre-emptive efforts to communicate with regulators to help identify and address their concerns (e.g., by revealing how membrane implementation, integrity, and operation are addressed in states and utilities where these processes are more familiar).

In addition, carefully designed and executed pilot testing is essential. Pilot testing guidance is provided in appendix C. Pilot testing is essential for the utility's ability to gain experience and knowledge about membrane options, selection, and operation. It also is essential for gaining regulatory acceptance.

DESAL'S UNIQUE FEATURES MAY NOT BE PERCEIVED OR ACCOMMODATED BY SOME REGULATORS

Discussion

Even in states where membrane processes are familiar, there are other aspects of desal facilities that are significantly different from the activities and technologies that relevant regulators normally address. For example, concentrate discharge entails gaining permits from regulators who typically focus on industrial and municipal effluent rather than desalting brines. These regulators are accustomed to issuing and enforcing the National Pollutant Discharge Elimination System (NPDES) permits for surface water discharges under the CWA, or Underground Injection Control (UIC) permits for deepwell injection under the Safe Drinking Water Act (SDWA). The waste streams they typically regulate are freshwaters that have been contaminated by conventional and toxic pollutants that arise in municipal wastewater and industrial effluent. Their procedures and experiences are not aligned with the realities of managing waste streams that are highly saline (rather than fresh) and that generally contain little, if any, of the traditional wastewater constituents of concern.

In this context, desal can be a square peg in a regulatory scheme that is set up with round holes. This can create several potential problems, such as when desal concentrate needs to be managed in coastal environments and it is not a discharge that relevant regulators have typically confronted.

For example, one California utility seeking to set up a small desal pilot facility struggled to obtain a permit to discharge the small volume of pilot plant brine concentrates, even though it would be heavily diluted with high volume freshwater effluent from the municipal wastewater facility that was discharging to a large brackish water bay. In this case, the wastewater discharge regulator had procedures for testing the toxicity of industrial and municipal effluent that relied on using freshwater species, because the typical regulated facilities discharge fresh water. This effluent toxicity testing regime was perfectly suitable for the typical discharger, but not at all relevant to a desalter discharging brines (Bob Castle, Marin County Water District, personal communication, 2006).

Ultimately, the issue was resolved and the pilot plant was allowed to operate and discharge. However, it is indicative of how regulatory schemes that are designed to manage other types of activities may be ill-suited for permitting desal facilities. The novelty of desal in the US thus creates challenges for regulators and permit seekers, because procedures and protocols appropriate for desal have not always been developed, and existing regulatory approaches may be irrelevant for desal considerations.

Suggested Implementation Strategy

Utilities should start by recognizing all the regulators from whom they will require permits, and then identifying which ones may be thrust into unfamiliar regulatory terrain by desal. A dialogue with those regulators, early in the process, should be pursued to help both parties recognize the issues and concerns that the other is facing. Providing the regulators with relevant and reliable information is likely to help with the process, such as drawing from the materials in appendix E, which offers a summary and comparison of permitting requirements in three states where inland and/or coastal desal activities have been addressed (Florida, Texas, and California).

DESAL MAY BE PERCEIVED AS AN UNNECESSARY, UNLIMITED, GROWTH-PROMOTING SUPPLY

Discussion

As discussed in chapter 4, for many utilities exploring desal as a future water supply option, the main driver is increasing water scarcity. As utilities plan ahead to consider anticipated growth, or respond to ongoing water supply challenges relative to existing demands, many recognize that there may be few (if any) alternatives to desal for meeting the near-term and/or longer-term water supply needs of their communities. Desal is also relatively attractive to many utilities because it is drought resistant (i.e., it provides relatively reliable yield, regardless of climate) and typically would be locally controlled (i.e., not subject to institutional or physical disruptions of supplies imported from outside the area).

Potential opposition to desal from customers, public officials, regulators, and other stakeholders often stems from perceptions about water scarcity, and perceptions about the alternatives to desal that some might believe are available to their communities. For example, regulators and stakeholders tend to be more receptive to desal when they are convinced that (1) there truly is a need for more water in the community, and (2) all other practical alternatives to desal—including aggressive conservation measures and water reuse—have been implemented (or at least considered and rejected on a suitable basis).

Within this context, desal also can stir up opposition from no-growth advocates. This opposition may have less to do with desal per se than with an interest in curtailing future population growth in the community. Slow growth and no-growth advocates may see any opportunities to limit future water availability as desirable, because they believe this will effectively limit future increases in regional population. Thus, desal would be opposed alongside any other alternative to expand the future water supply. However, desal carries an added burden because it may be seen as a relatively unlimited future supply (especially seawater desal, since the oceans are so vast) compared to other possible alternatives.

Suggested Implementation Strategy

As described in chapter 11, appendix F, and elsewhere in this report, it is imperative that utilities develop a sound and compelling case for (1) why more water is needed for the community (including factors such as current water supply limitations and reliability issues, climate change that make future water supply and demands more problematic, and the inevitability and scale of projected growth); (2) why desal is one of the top options to consider (stressing the reliability features and other beneficial values that desal can provide the community); and (3) why most (if not all) other alternatives are either infeasible or less desirable (e.g., conservation is already aggressively implemented, as evident by key metrics such as water use per capita compared to state or regional benchmarks). Having a clear and compelling rationale for why more water is needed, and why desal is a good option, is often a necessary ingredient for gaining traction with regulators, customers, public officials, and other relevant stakeholders.

DESAL MAY BE PERCEIVED AS ENERGY-INTENSIVE AND IMPOSING A LARGE CARBON FOOTPRINT

Discussion

As detailed throughout this report, desal is a relatively energy-intensive water supply option. This raises legitimate concerns in many circles, including those who worry about current and future energy availability, the reliability of the power generation and transmission system, and national security issues linked to energy consumption and imported fuels. It also raises concerns because of the GHG emissions (i.e., carbon footprint) associated with energy use.

Suggested Implementation Strategy

Utilities considering desal should directly address (1) how they intend to efficiently manage the energy demands of their desal facilities (e.g., through energy recovery, high efficiency systems, peak load management), and (2) how they intend to reduce their use of fossil fuels and their carbon footprint by implementing energy conservation throughout the utility, and/or by using (or helping to develop) alternative energy supplies (e.g., the use of wind or solar power). These materials should be credible, accessible, and effectively communicative to the general public, regulators, public officials, and other stakeholders.

In addition, it is important to compare energy use for desal with energy requirements for any other alternative to desal (e.g., importation, advanced treatment of alternative low-quality sources). In many areas, any reasonably feasible alternative to desal has the potential to have a large energy demand and carbon footprint of its own.

DESAL MAY BE PERCEIVED AS ENVIRONMENTALLY UNFRIENDLY

Discussion

As discussed in chapter 4 (and elsewhere in this report), desal can have several actual or perceived adverse environmental consequences. In addition to the energy-related concerns over the carbon footprint, there are potential environmentally sensitive issues related to concentrate management for any mid- or large-scale desalting operations in inland settings, and in many coastal discharge settings as well (although opportunities often exist to significantly dilute the salt concentration of brines at coastal outfalls with freshwater discharges from wastewater or other facilities). Another primary environmental concern pertains to feedwater intake in coastal areas, and the associated I&E of marine species. Other potential coastal zone impacts and ecosystem disruptions may also be of concern, such as where new intakes or outfalls need to be constructed, or where desal facilities may contribute to reduced beach and coastal zone access and impaired visual aesthetics.

Suggested Implementation Strategy

It is important for utilities to recognize and acknowledge potential adverse environmental consequences from their planned desal activities. Concurrently, utilities typically will have greater success with stakeholders and regulators if they start, from the outset, by exploring those design and operational options that can minimize environmental impacts (e.g., investigating the feasibility and performance of beach wells in lieu of open water coastal intakes). Chapter 8, and key portions of the PIM, provide additional details.

It also will be useful to make useful comparisons of desal to other water supply alternatives. For example, freshwater extraction from rivers, streams, and reservoirs also use open intakes and, thus, adversely impact aquatic species. In this regard, surface water desal is not much different from tapping fresh surface water supplies (other than which ecosystem is impacted, coastal marine waters versus inland freshwaters). Freshwater extractions can also impose ecologic harms by reducing instream flows. Likewise, other (non-desal) treatment regimes typically generate residuals that require prudent management to avoid adverse environmental consequences. Thus, utilities need to place desal into a proper comparative context relative to the other options available for water supply acquisition, treatment, and distribution.

Finally, utilities may often gain greater desal acceptance if they consider offering environmental offsets for any inevitable ecosystems risks that desal might impose. Environmental offsets and enhancement opportunities may consist of activities such as providing local habitat restoration of the type and scale that would offset potential adverse impacts by the facility. Another option entails buying and setting aside conservation easements for areas that are environmentally valuable and/or provide ecosystem-based recreational and aesthetic benefits to the community (e.g., coastal marshes or other such preserves where nature viewing, hiking, boating, or other such activities can be enjoyed and where important habitat and ecosystems functions can be provided).

DESAL MAY BE PERCEIVED AS VERY EXPENSIVE

Discussion

Desal is typically quite expensive, compared to historic costs incurred by utilities and their customers for past and existing water supply options. This reality is described in previous chapters as well as in chapter 8 and appendix G.

Suggested Implementation Strategy

There are several aspects to addressing the concern over costs. It will be important to be realistic about what the actual costs of desal will be for the community, but it is equally important to place those cost levels within the proper comparative context.

First, describe what will happen if desal is not pursued. This is the critical step of defining the proper baseline against which to evaluate desal. What are the other feasible options available to the community or region? Be sure to compare desal to the costs of the other *new* water supply sources that are viable (i.e., the marginal cost of adding water to the community via other options), rather than comparing the expense of desal to the cost of past or current supplies that can no longer be expanded or tapped. And, if an option (or, more typically, the baseline) is to not add any new water (via desal or any other option), then what are the costs to the community in terms of the likelihood and impacts of potential water shortfalls in the future?

Second, consider how desal might be developed on a broad regional basis, rather than within the context of a single community or utility within the region. Regional collaborations offer many potential advantages for desal implementation, as documented in case studies described in chapter 9 and appendix H.

Third, consider the role that desal may play—and thus the added benefits it might generate—if it is considered and deployed within the context of a broad, integrated regional water resource management perspective. Case studies in chapter 9 and appendix H reveal how desal deployed and evaluated in such a context may generate considerable benefits beyond water supply enhancement (such as by providing groundwater remediation and protection).

CONCLUSIONS

Implementing desal is no small matter. In North America, a relative lack of experience with large-scale utility desal projects can hamper desal implementation efforts at several levels, including wariness on the part of the public and regulators. It also places desal into regulatory systems that were often designed for very different types of activities and impacts. Desal also has some drawbacks that raise legitimate concerns in some circles, such as its cost, potential environmental impact, and energy use.

Nonetheless, desal may often be a very prudent option for many water utilities and the communities they serve. It is important that utilities place desal within the proper comparative context, so that decisionmakers within the utility and the community can evaluate their options on the relevant basis (e.g., desal compared to the other options for providing new water to the community). It also may be valuable to consider desal within a larger context than a water supply option. Desal can provide additional benefits to the community, especially if considered in a regional context where it may be deployed in a manner that helps address a suite of water resource management challenges.

CHAPTER 6
INTEGRATED SYSTEMS PLANNING PERSPECTIVE ON DESAL IMPLEMENTATION

As noted throughout this report, the primary objective of this research project is to develop a series of decision support tools (i.e., a useful and accessible compilation of practical experiences, resources, and guidelines) to help water utilities and other water professionals better navigate their way through the desal planning and implementation process.

One of the key principles guiding this work is the adoption of a broad systems planning approach intended to help utilities integrate desal systems into existing technical and institutional systems. As shown in Figure 6.1, desal processes do not operate in isolation from the rest of the utility or the broader community. Desal operations must be integrated—physically and institutionally—into the rest of the utility's systems, the community's social-political systems, regional energy systems, and applicable environmental and related regulatory systems.

Accordingly, the guidelines and resources developed as part of this research span both the technical issues associated with desal system (e.g., intricacies of various membrane, hybrid, and nonmembrane process options) as well as the broad suite of "institutional" issues that create many of the critical implementation barriers. This research emphasizes the institutional matters (e.g., regulations and permitting, energy and environmental impacts) rather than the technical aspects, because much is already well understood about desal engineering. Further, institutional factors pose the greatest challenge to broader and more streamlined implementation of desal in the US.

The following sections provide an overview of the desal systems planning perspective upon which this research is based, and a summary of the key issues and challenges associated with desal implementation in the US. The technical and institutional issues identified below are explored in more detail throughout this report and the accompanying Desal PIM. At the end of this chapter, we provide an introduction to the structure of the PIM in order to direct readers to relevant issues associated with each of the desal process components.

INTEGRATED SYSTEMS PLANNING PERSPECTIVE

First, as depicted in the center of Figure 6.1, desalting processes are themselves an integrated system. This system consists not only of the desalting technology (e.g., RO membranes), but also includes source water intake and pretreatment (to help protect and improve the operating efficiency of the membranes), that both occur before the desalting technology itself is engaged. After the desalting step, the product water must be chemically treated or blended with other waters as part of the "post-treatment" process (to avoid excessive corrosivity, and to yield aesthetically acceptable and safe, regulatory compliant drinking water). Finally, concentrated brines removed by the desalting process need to be properly managed (e.g., disposed of in an environmentally suitable manner). There are complex institutional, environmental, and energy-related issues associated with each of these critical components of the desalting process, even if viewed in isolation from the other systems.

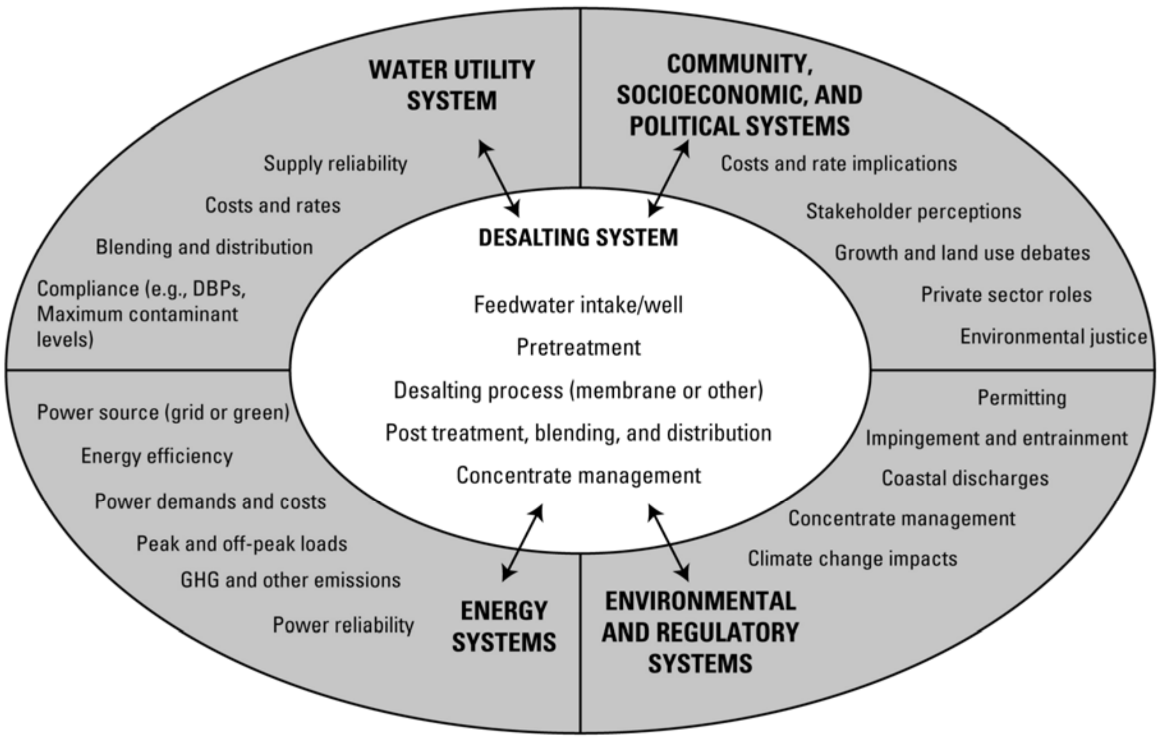


Figure 6.1 A systems perspective on the desal process

Second, a host of complicating factors arise when considering how the desal system integrates into the broader suite of systems in which it must be placed. For example, the process of obtaining feedwater for a coastal desal facility needs to consider the environmental, regulatory, and other implications of constructing and operating a coastal intake pipe or beach well. Likewise, the power needs of the desalting technology needs to be considered within the context of the region's energy systems (e.g., is there enough power available at the right times, at a reasonable cost, with needed reliability, and without undue environmental or financial impact?). There are also community financial, social, and political systems issues, such as whether the cost of desal will unduly raise water costs and rates, and how will this impact the utility and its customers from an economic and environmental justice perspective. By viewing desal from a systems perspective, we can begin to see where and why some of the challenging implementation and planning issues are likely to arise.

KEY ISSUES FOR DESAL IMPLEMENTATION AND PLANNING

The following sections highlight some of the key issues and challenges associated with desal in the US. The information reported below is largely based on current research, but includes insights gained through a targeted workshop and survey of water utilities that are interested in or have begun to implement desal as part of their water supply portfolio. As noted above, most of the issues and challenges identified below are more "institutional" in nature, rather than related to technical issues associated with the different components of the desal process.

Energy and GHG Emissions

Current desal technologies are very energy intensive and require much more energy than most traditional sources of water supply (the key exception is in Southern California, where imported water pumped from the northern part of the state requires more energy than local seawater desal). This contributes to the high cost of desal compared to most other water supply options.

Energy intensity raises more than just cost concerns. In many regions, there are concerns that the energy demands associated with desal will affect the reliability and sustainability of the overall power grid system (especially as water demands tend to peak at the same times as energy demands, for example, on hot summer days). This is particularly true in areas where grid capacity is already strained by current demands (as in California). Thus, the concern is that the broader application of desal could push the electrical transmission grid, and the region's power generating capacity, into heightened vulnerability to blackouts and other failures (Stratus Consulting 2006).

There is also concern among some stakeholders regarding GHG emissions—and air pollution emissions in general—associated with the need to expand fossil fuel use to power desal facilities. GHG emissions are linked with global climate change, and other air pollutants pose risks to human health, vegetation, and other resources, and/or impair visibility. The link between the energy needs for desal and increased air pollutant emissions and global warming creates another basis for concern about (and for some people, opposition to) desal (Stratus Consulting 2006).

One avenue to address this concern is to explore alternative (renewable) energy options for desal facilities (and/or for water agencies in general). Renewable energy has been pursued to power the majority of the large-scale desal plants in Australia and at least one in the UK. Although generally valued by the public, the costs associated with renewable energy to support desal can be significant (and can actually increase overall desal costs). Exploitation of renewable energy and development of desal plants typically require intensive capital investments. There are also limitations related to the temporal and spatial dependency of renewable resources (including associated high land requirements) (Mathioulakis, Belessiotis, and Delyannis 2007).

Environment

Among several environmental concerns related to desal (including the energy-related environmental concerns noted above), two in particular garner significant attention. The first pertains to I&E of aquatic species due the use of open water intakes to draw feedwater. *Impingement* occurs when larger organisms, mostly fish and shellfish, are trapped against intake screens by the force of the water being drawn into the intake. *Entrainment* takes place when small egg and larval stages of organisms are drawn into the intake structure, along with the cooling water, and into the plant's cooling system. In general, the magnitude of I&E increases as the volume of intake flow and the intake velocity increase. I&E is generally not an issue for subsurface intakes (e.g., beach wells) or facilities co-located with power plants.

In many cases, the adverse effects of I&E can be avoided or minimized through appropriate location selection, operational flexibility, and improved technologies (Xu et al. 2009). Key questions include how well alternative feedwater intake design and operating options, such as intake screening options and velocity parameters, minimize I&E. There are also key questions about the viability and long-term performance (across different settings) of beach wells and other subsurface alternatives to open water intakes.

The second major environmental concern associated with desal pertains to the management (reuse or disposal) of desal concentrate, the byproduct of the membrane process. Coastal desal plants are often able to safely dispose of desal concentrate (via direct discharge into the ocean or estuaries) at relatively modest costs. Where coastal facilities can blend their concentrate with high volume freshwater discharges from wastewater treatment plants (WWTPs), or with the discharge of cooling water from OTC power plants, the saline concentrations are likely to be reasonably close to the ambient levels in receiving seawaters.

However, concentrate management is currently one of the most challenging issues associated with desal in an inland setting. Typically few disposal methods are available at a given location as each method has its own set of site-specific limitations and costs, regulatory requirements, and environmental challenges.

Current options for concentrate disposal at inland facilities include surface water discharge (whether to an inland water or via brine lines that carry the concentrate to a coastal location), discharge to an existing sewer system, deep well injection (pumping the wastes into deep, unusable, and hydrologically isolated aquifer systems), land application (irrigation) and evaporation ponds (which are often not viable due to the land area required and the concerns associated with wind-blown dispersal of hazardous salt compounds or potential leaching leading to groundwater contamination).

All of these inland options are of limited applicability, depending on concentrate quality and quantity, physical location (e.g., close enough to the coast for a brine line), hydro-geologic conditions (e.g., proximity to a suitable deep well injection site), and numerous regulatory constraints related to potential impacts on the receiving water or soil. As a result, it is becoming more and more challenging to find a technically, environmentally, and financially viable method of dealing with the concentrate from inland facilities.

Recent interest in high recovery processing, including ZLD, has shown that these approaches used in other industries are prohibitively expensive for municipal settings. Innovations to reduce costs associated with high recovery processing are being sought.

Public Health

In general, there are no direct public health concerns associated with desalinated water. RO membranes are highly effective at removing contaminants, should any be present in the source waters. However, there can be public health and associated regulatory compliance issues that arise when the desalted water is blended with other utility waters in the post-treatment and distributional phases of the desalting systems process. These concerns include the potential for desal to alter the level and/or mix of DBPs produced when potable waters are disinfected with chlorine or other disinfectants. Several DBPs are regulated in drinking water by the USEPA and related state agencies. The presence of low levels of bromide in desalted seawater may, for example, lead to the formation of more brominated DBPs, and these could imply higher health risks in tap water than a community faces currently.

Working With Regulators

The types and complexity of permits required for a desal plant vary depending on the project location and other site-specific factors, such as the type of desal technology and the method of concentrate management employed. The implementation of a desal project typically requires multiple permits from numerous federal, state, and local agencies. In general, the regulatory programs and associated permitting processes revolve, and can be broadly classified, around the three streams involved in the process (Stratus Consulting 2006):

- **Source water** (or feedwater stream) permits address the location and means of obtaining the source water used by the desal facility
- **Potable water** (or finished water stream) permits address the use of the finished water produced by the desal facility
- **Waste** (concentrate and other associated waste stream) permits address the treatment or discharge of the waste streams, including concentrate, chemical wastes from cleaning processes, and any other waste associated with the operation of the facility

The number of permits and approvals that are required for desal (and the associated number of government entities to be engaged) may seem daunting. However, it is not the number of permits required that poses the greatest potential obstacle to implementing a desal project. The greatest challenge may arise from the manner in which the permit applications are evaluated.

Regulators are often placed in a difficult position with respect to desal. Their mission is to ensure that the regulatory and permitting processes suitably protect the environment, public health, and similar broad societal interests. However, desal is a new endeavor for many of them, and a “standards of practice” on which regulators can support their decisions is lacking.

Interviews with regulators and the utility professionals who interact with them indicate that this lack of practical desal experience and its uniqueness often manifest as “desal being a square peg jammed into a regulatory system set up with round holes” (Raucher, Strange, and Hallett 2006). A past example was the mandate to use *freshwater* species for effluent toxicity testing in a coastal pilot plant’s concentrate outfall, because use of these species was the standard practice for issuing NPDES permits to the many other classes of dischargers that the agency regulated in its jurisdiction.

In the survey sent to utility representatives as part of this project, respondents indicated that working with state and federal permit writers posed one of the greatest challenges for desal implementation (more so than local permit writers). In addition, representatives of both inland and coastal desal facilities ranked “revised federal and state permits” as a top strategy for moving desal implementation forward.

There are (at least) two approaches that can be used concurrently as a way of working constructively with regulators in the “round peg-square hole” context of desal facilities and operations (Stratus Consulting 2006):

- First, there needs to be an open, advance dialogue with regulators (perhaps aimed at the higher management levels of key agencies, so that cooperative signals flow down to field staff) that explains the desal issues and needs, and tries to set up a reasonable set of protocols for permit approval

- Second, research that generates key findings, or establishes desal-suitable testing/monitoring protocols, will help give comfort and reassurance to regulators that find themselves facing permitting issues in desal's unfamiliar territory

Findings from the workshop held in September 2008 as part of this research confirmed the importance of this issue/challenge. During the workshop, water utility representatives articulated the need to work more closely with regulators and public officials in order to help streamline the permitting process. A key recommendation of the group was to work with key policymakers (in top state and federal executive and legislative positions) to explain the challenges associated with getting desal facilities permitted and operating. This would motivate them to participate in looking for ways to harmonize and streamline the permitting process across agencies and levels of government.

Finally, it is interesting to note how different states appear to be addressing the desal issue. In Texas, the state's Commission on Environmental Quality and the Texas Water Development Board have taken a fairly open and supportive view of desal, and the latter agency's Web site offers useful guidance for water agencies considering desal options. In contrast, State of California agencies have a varied and generally more skeptical view of desal (Stratus Consulting 2006). An example of different regulatory approaches in three key desal states is provided in appendix E of this report.

Costs and Benefits

Desal water is expensive relative to the cost of most existing supplies. This raises several issues regarding potential impacts on local water rates and the associated impacts on households and commercial customers in the served communities. However, recent technological advances have allowed desal to become more efficient, less energy demanding, and less expensive. Cost efficiency may be further improved as desal is combined with nonpotable reuse. As the cost of desal continues to decrease, the cost of traditional supply alternatives has become more expensive. As these trends continue, desal will become more favorable in some areas.

In addition to the financial costs associated with desal, economic costs must also 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 can be 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 that allow them to be estimated, either directly or indirectly, with considerable accuracy.

In addition to financial and economic costs, the unique benefits of desal must also be taken into account. One of the potentially important benefits of desal projects is that the yields from such 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. Desal can also bring some unrecognized regional benefits such as maintaining or restoring stream flows, or freeing up other existing regional resources for other users.

The reliability and environmental benefits of desal do not accrue to most other water supply options, such as drawing from surface water sources. When these reliability benefits go unrecognized by the water agency, policymaker, or average citizen, then desal options may remain undervalued and, perhaps, underutilized. These desal-specific benefits of providing reliable yields during drought periods can be hard to quantify because they extend beyond readily observable financial costs and utility revenues. However, similar to external costs, there are numerous techniques available that can help to directly or indirectly estimate the value of these benefits. A full accounting of the benefits of desal should be included in project planning and analysis of alternative supply options.

The costs of desal production (thus not including concentrate management) have decreased considerably in recent years to a combination of factors, including more efficient membrane and membrane systems, use of ERDs, longer membrane life, and increased competition between original equipment manufacturers (OEMs). The costs of concentrate management, however, have not decreased and are likely to increase as concentrate management options are limited, are more heavily regulated, plant size (and thus concentrate volumes) are increasing, and the conventional options are not amenable to significant cost reduction.

Co-location With Coastal Power Plants

From the perspective of some, locating seawater desal facilities with OTC power plants is a natural linkage. The existing power plant intake and discharge structures provide pre-existing infrastructure. Power plant intake water volumes are much larger than needed for the desal facility, so no additional water withdrawals are necessary. Assuming the desal facility operates only when the power plant operates, the environmental and ecological impact of the facility is minimal since the desal facility uses cooling water already in the power plant and the large discharge volumes provide dilution and mixing for the brine. As a result of these factors, power plant co-location can yield significant permitting and construction cost savings (NRC 2008).

These benefits, however, presume the continued operation of power plants with OTC systems. One of the major concerns associated with co-location stems from opposition to OTC power plants due to environmental impacts. Some believe siting desal facilities with OTC power plants might serve to perpetuate these facilities when they might otherwise be phased out. In addition, if the power plant ultimately is changed to a different cooling system, the investment in the desal facility could either be lost or subject to significant increases. Likewise, if the OTC system is eliminated, the intake volume and brine discharge of a (now) standalone desal facility could result in significant environmental impacts.

The feasibility of co-location in the US has not been fully evaluated. To date Tampa Bay is the only co-located desal project that has been successfully implemented in the US. Thus, much of the published information on co-location has been based on experience in other countries and/or expected results. There are currently several US co-located projects slated for implementation (most of which are in California) that have initiated or completed required planning processes. Based on lessons learned from these processes, we can begin to gauge how the stated advantages of co-location have played out in the US.

Ownership

Desal projects in the US are often promoted by private sector entities that have access to capital and a willingness to invest in a potentially risky, but potentially rewarding, venture. This sometimes raises philosophical issues about what role (if any) the private sector should play in the provision of water as an essential good and public service (e.g., critical to life, health, safety, and welfare).

The idea of privatization certainly raises issues that can be contentious. For example, who owns the water delivered by a private company once it is delivered to the customer, recovered, and treated by the wastewater system? Water rights disputes over recycled water are already occurring, even without the private-ownership factor.

However, as public entities face growing budgetary constraints, many locally-elected officials are attracted to the perceived benefits of "privatizing" all or some of their water service responsibilities (CCC 2004). Concurrently, a number of domestic and multinational business entities have identified providing water or "water services" as an attractive profitable investment opportunity. In California, among the approximately two dozen desal projects currently proposed along the coast, at least six are proposed as private-held facilities or public/private partnerships, including two (in Huntington Beach and Carlsbad) that would be the largest coastal desal facilities in the US. As a private commodity, desal may be developed, managed, and marketed as a for-profit product subject to market forces and practices. Thus, one concern is that the full range of public interest values might not be fully considered during planning, design, and operation (CCC 2004).

Further, many public agencies argue that the private model has few advantages over traditional approaches because the public sector has access to the same expertise and technology as the private sector. Public agencies can also obtain lower cost financing and may have greater access to development subsidies, both of which help keep water rates low. Finally, many public agencies claim that the risks of water shortages are the same under private and public models, and thus there is no real mitigation of risk (Xu et al. 2009).

Similar to the opposition in some circles to private sector desal provision, there is a related concern over foreign ownership of desal facilities. This too stems from philosophical beliefs about control over water as an essential good. While contracts can be drawn that assure protections for both parties to an agreement—regardless of owner type or point of origin—the aversion to foreign ownership may impede some desal projects where the merchant vendor, or the investor-owned utility, has foreign ties.

Public Acceptance

Affected persons and stakeholders are often able to slow or block implementation of a desal facility if public perception is negative, whether or not a concern is justified in the particular project (NRC 2008). Public concerns about desal vary and include worries related to cleanliness of the source and product water, technical feasibility, environmental effects of process operations and concentrate management, privatization issues, growth-inducement, and future affordability of the resource, among others.

Failure to gain public acceptance can derail the most essential and feasible desal project. Local citizens and nongovernmental organizations may influence a regulatory body or local government officials, and these regulators or officials can in turn place impediments in the permitting process. Broad-based public participation in the process—that is, greater than that necessitated by permitting requirements—may help minimize adverse relationships and help the project progress more readily toward successful implementation (NRC 2008 as cited in Burroughs 1999, Roberts 2004, Robinson 2007).

In the informal survey sent out as part of this project in early 2008, representatives from coastal desal facilities identified advocacy groups (including environmental groups, anti-growth, or other nongovernmental organizations) as their biggest challenge related to decisionmakers and stakeholders. During the workshop held in September 2008, participants articulated the need to reach out and work [individually, and through organizations like the Water Research Foundation, American Water Works Association (AWWA), and Association of Metropolitan Water Agencies (AMWA)] with elected officials at the state, local, and federal levels (e.g., governors, State and Federal legislators, mayors and city council members), as well as with advocacy groups and customers. Their specific recommendations reflect this theme, indicating a need by the water supply community to better articulate and justify the need for (and value of) adding desal to the water supply portfolio for a specific utility, and/or for a specific region or state.

In addition, workshop participants stressed the need to evaluate desal in a comparative context in order to garner public support. A comparative evaluation helps the public to understand how desal stacks up to alternative water supply options across a broad array of relevant impacts, including costs (when all factors are duly considered for desal and its alternatives), reliability, and regulatory/permitting requirements.

More information on public perceptions of desal associated with environmental issues, growth inducement, necessity of supply, and others has been integrated into the PIM. Additionally, strategies for working with stakeholders are discussed in appendix D: Tools to Enhance Stakeholder Understanding of Desal.

Brief Introduction to the Desal PIM

Many of the topics identified above are appropriately characterized as "cross-cutting" issues, meaning they have implications for overall project implementation rather than a specific component of the desal process. However, as noted above, the desal process is in itself an integrated system made up of several different process components (e.g., intake, pretreatment, membrane processes, post-treatment, and concentrate management). For each component of the desal process, there are a number of unique planning considerations that must be taken into account (e.g., environmental, technical, financial, and energy-related issues).

Given the complex nature of desal systems, the project team developed the Desal PIM. The PIM is intended to complement this report, and accompanying resources, by providing a more compartmentalized view of desal planning issues. In short, the PIM provides an integrated systems planning perspective associated with each component of the desal process.

The PIM is an Excel-based, interactive guide that presents issues in a structured and easy-to-follow format. The guide presents key issues broken down by six topics, based on the sequence of processes associated with a desal facility:

- Feedwater intake
- Pre-treatment
- Desalting process
- Post-treatment and distribution

- Water use
- Concentrate management

For each aspect of the desal process identified above, the PIM provides a matrix of key points for both inland and coastal desal facilities (12 matrices in total). The rows of the matrix are defined by processes associated with the relevant desal process component. For example, the matrix related to feedwater intake for coastal facilities includes a row for each type of intake option: standalone intakes, intakes co-located with a power plant, and subsurface intakes.

The columns of each matrix are defined by four key issues relevant to each desal process component: environment and public health, technical (e.g., engineering), financial and economic, and energy and GHG-related issues. The intersection of the rows and columns contain key points related to the relevant topic area. Users can click on each key point for further information. For example, for the coastal feedwater intake matrix, the intersection of the row related to standalone intakes at coastal facilities and the column related to environmental issues would provide information on issues related to I&E of aquatic species.

In addition to the 12 matrices, the PIM also contains a planning and analysis section that is presented in a nonmatrix format. This section of the PIM provides links to planning resources, including a desal decisionmaking process tool and case studies of desal facilities in the US and abroad.

Chapter 7 of this report provides a more detailed explanation of the PIM, including specific instructions for accessing and using the PIM.

CHAPTER 7
GUIDE TO NAVIGATING THE DESAL PLANNING ISSUES MATRIX

OVERVIEW

The Desalination PIM is an Excel-based, interactive guide to the broad range of issues and complexities associated with planning a desal facility. The content of the PIM draws upon the depth and expertise of the project team and professionals from various backgrounds (e.g., engineers, environmental scientists, academics, economists, and regional planners) that have specific experience with planning and/or evaluating desal facilities.

The PIM is more than just a list of potential issues related to desal. It is an organized guide that presents issues in a structured and easy-to-follow format. The guide presents key issues broken down by six logical and relevant topics, based on the sequence of processes associated with a desal facility:

- Feedwater source
- Pre-treatment
- Desalting process
- Post-treatment and distribution
- Water use
- Concentrate management

For each aspect of the desal process, the PIM presents information at a getting-started level, as well as at a level of more detail for practitioners and water managers more familiar with the desal process. The guide highlights key points for each of the six topic areas and provides resources (e.g., hyperlinks to Internet resources whenever possible and appropriate) for further reading.

Figure 7.1 shows the Overview page of the PIM. By clicking on one of the key topic areas (grey buttons), the user is directed to more detailed information, including a matrix of key points associated with the relevant topic. As shown in Figure 7.1, in addition to the six topic areas identified above, the PIM also contains a planning and analysis section that is presented in a nonmatrix format. This section of the PIM provides links to planning resources, including a desal decisionmaking process tool and case studies of desal facilities in the US and abroad.

It is important to note that because the PIM is organized based on the different components of the desal process, the matrices for most components do not provide an overview of many of the broader, cross-cutting issues associated with desal planning (e.g., public-private partnerships and public involvement). Many of these issues are addressed in the Planning & Analysis section of the PIM. However, as noted in chapter 6, the PIM is intended to complement this report, and accompanying resources, which focus more on these crosscutting issues. Together, these two resources are intended to serve as a comprehensive resource for these different aspects of desal planning and implementation.

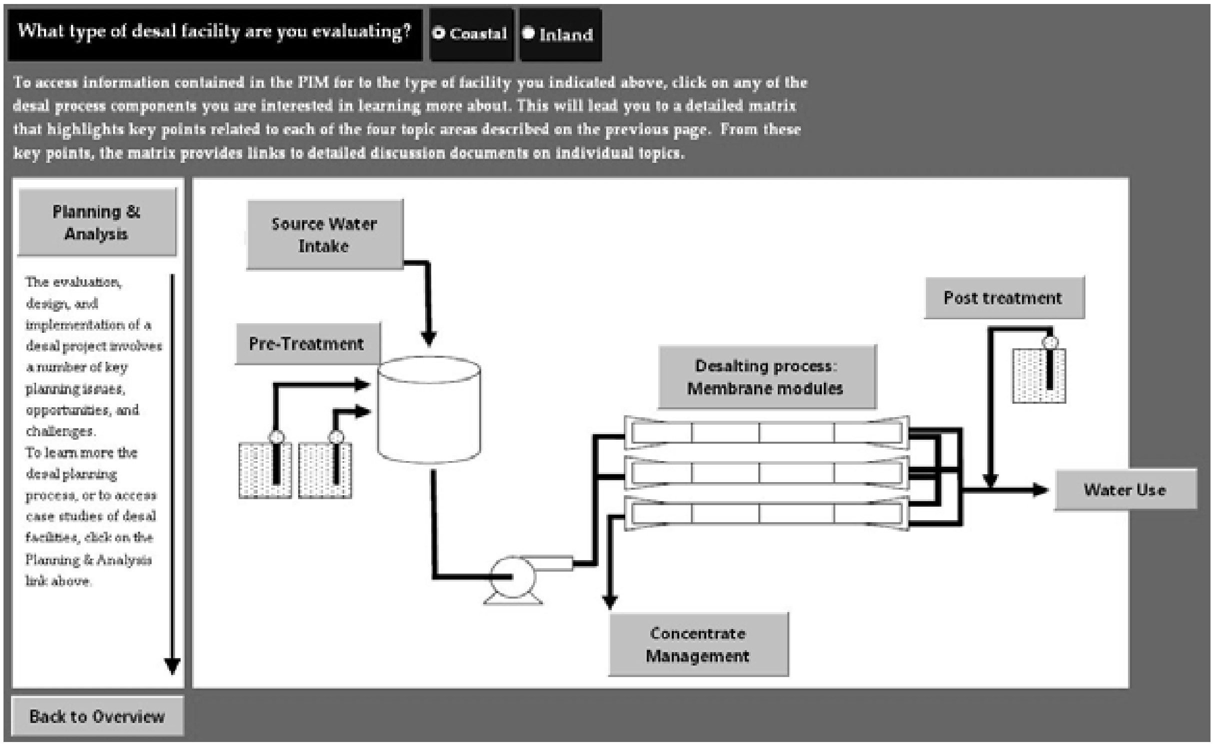


Figure 7.1 The Overview page gives the user the opportunity to evaluate either a coastal or inland facility and provides a brief summary of each of the six topics for which the PIM contains a detailed matrix

HOW TO "USE" THE PIM

As noted above, the PIM contains a matrix of key points for each of the six desal process components, for both inland and coastal facilities (i.e., there are 12 matrices total). Given the crosscutting issues and complexities associated with desal planning and analysis, key points and information for this topic area are organized in a nonmatrix format, providing resources and links to further information.

When first opening the PIM, users are directed to an introductory page, which provides background and general instructions for navigating the PIM. From the introductory page, users are led to the "Overview" page, as shown in Figure 7.1. On the Overview page, users will first need to indicate whether they are interested in inland or coastal desal. The users can then select which topic (or desal process component) they would like to read more about by clicking on the corresponding gray button. When the user clicks on a specific topic area, they are directed to the matrix for that topic area. Figure 7.2 illustrates the completed matrix for the topic "Concentrate Discharge and Management" that is specific to inland facilities.

<< Water Use | Back to Overview | Planning >>

INLAND FACILITY

Concentrate Discharge and Management

		Environmental & Public Health Risks/Regulations (environmental impacts, permitting, mitigation)	Engineering (technology and performance)	Energy & Greenhouse Gas Issues (power needs and carbon footprint)	Economics, Finance, & Social Issues (benefits and costs, rates, PUC issues, TBL)
Surface Water Discharge	Discharge to ocean via "brine line"	Potential adverse impacts to receiving water quality and aquatic organisms	Often only feasible for coastal brackish water desalination plants where access to ocean is easy	*Draft being developed by Pei Xu, Colorado School of Mines*	When available, surface water discharge can be the simplest and most economical option for concentrate disposal.
	Freshwater discharge	Potential adverse impacts to receiving water quality and aquatic organisms	Surface water discharge is a common, relatively low-energy, low-technology solution		
Sewer Discharge		Potential for minor water quality degradation downstream of WWTP	Can be most convenient option if there is existing sewer service		WWTP fees can make this method cost prohibitive.
Injection Wells		Permitting can be complex due to environmental and geologic concerns	Applicability is dependent on local geology		Economies of scale makes this method more feasible for larger capacity plants
Evaporation Ponds		Potential adverse impacts to adjacent waterways, soils, groundwater and/or wildlife	Large surface area requirements as determined by evaporation rate and concentrate flow		Costs are typically excessive for all but the smallest plants
Irrigation/Land Applicatiion		Potential adverse effects from surface runoff, salt accumulation and groundwater quality degradation	Potential adverse impacts on local groundwater aquifers, surface water, vegetation and soils.		Key cost variables include concentrate volume and salinity
Zero Liquid Discharge		Final brine disposal can have adverse environmental effects	ZLD has not yet been implemented for municipal desalination	Implementation of ZLD has been limited by substantial energy requirements	ZLD is usually cost prohibiitive for municipal desal plants

Figure 7.2 The user can click on any cell within the matrix—the hyperlink will lead the user to a Word document with additional information

As shown in Figure 7.2, each matrix presents key points for a particular topic, organized into four main categories (these are the columns of the matrix):

- Environmental & Public Health Risks/Regulations
- Engineering
- Energy & Greenhouse Gas Issues
- Economics, Finance, & Social Issues

Each component of the desal process has different elements that are important. For example, for the topic "Inland Concentrate Management," the important elements are the different technologies currently being implemented and researched. There is therefore a separate row for seven different types of concentrate management strategies, including freshwater discharge, ocean discharge via a brine line, sewer discharge, evaporation ponds, irrigation/land application, and zero liquid discharge.

The intersection of the PIM rows and columns contain the key points. For example, in Figure 7.2, the key point associated the category "Environmental & Public Health Risks/Regulations" and the element "Surface Water Discharge—Freshwater discharge," is *"Potential adverse impacts to receiving water quality and aquatic organisms."* Each key point is a hyperlink. Clicking on a key point will lead the user to a portable document format (PDF) document that contains more detailed information (e.g., summary of key issues, strategies, key uncertainties, costs and benefits, and suggested reference materials). There are buttons that make it easy to navigate back and forth between topics.

It is important to note that the discussion documents linked to the key points in the matrix not only discuss issues associated with the particular key point, but cover additional topics related to the intersection of the relevant row and column. For example, the document related to the key point "Environmental & Public Health Risks/Regulations" and "Surface Water Discharge—Freshwater discharge" not only covers issues and strategies associated with the "*potential adverse impacts to receiving water quality and aquatic organisms,"* but also discusses other potential environmental or public health impacts (e.g., environmental impact of pipeline construction on land).

CHAPTER 8
KEY TOPICS IN DESAL IMPLEMENTATION

As described in chapter 7, the environmental, technical, financial, social, and energy-related issues associated with different components of the desal process (e.g., feedwater intake, pretreatment, concentrate management) are covered in great detail in the PIM. However, because the PIM is structured in this compartmentalized manner, it does not provide some of the broader perspectives and comparisons associated with the overall desal process. This chapter is intended to provide such perspectives, in relation to the key issues associated with desal planning and implementation:

- Coastal feedwater intakes
- Inland concentrate management
- Membrane processes
- Pilot testing
- Energy use
- Co-location
- Costs and economics
- Permitting and working with regulators
- Utility planning and management
- Project delivery method

Each issue is covered briefly here, with more extensive information available in the PIM, or in subsequent report chapters and appendices.

COASTAL FEEDWATER INTAKES

Source water intake design can affect feedwater quality and can have significant environmental implications (e.g., in terms of I&E) at a given site. The following provides an overview of source water intake technologies, highlighting the issues associated with each approach.

Inland Source Water Intake

Brackish water desal facilities can utilize feedwater from surface water sources or wells. Inland desal plants use intake technology that is no different from traditional water treatment plants dependent on surface water or groundwater, and this technology is well developed. There are important issues, however, associated with sustainable brackish groundwater withdrawals for inland systems. These issues are addressed in the inland source water intake section of the PIM.

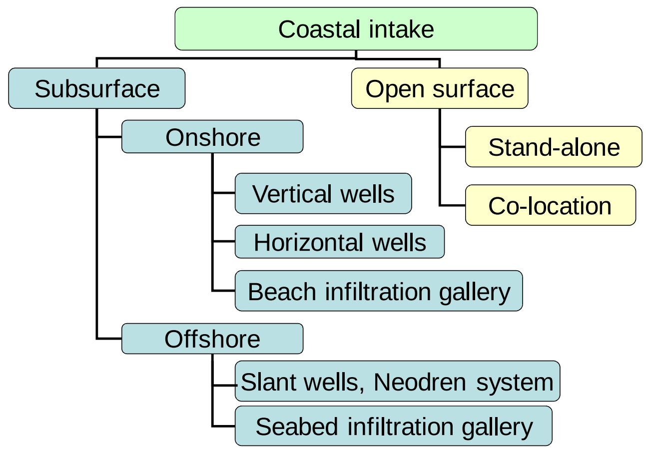


Figure 8.1 Type of feedwater intakes used at coastal facilities

Coastal Source Water Intake

Seawater intakes can be broadly categorized as either (1) open surface water intakes, where water is withdrawn from above the seabed (i.e., through a standalone facility or co-location with a power plant intake), or (2) subsurface intakes, where water is collected via onshore or offshore wells and infiltration galleries. Figure 8.1 shows the different types of feedwater intakes used at coastal facilities.

Standalone Surface Water Intake

Currently large seawater desal plants almost exclusively use open (surface water) intake structures. Conventional surface water intakes withdraw water directly from the surface of the ocean or sea through offshore intakes, pumps, screens, and pipelines; or from below the surface, through submerged intakes. Surface water intakes provide reliable water quantity, but often yield inferior water quality compared to subsurface intakes, and more complex pretreatment is typically required.

I&E of aquatic organisms is a major permitting issue for standalone intake facilities. *Impingement* occurs when larger organisms, mostly fish and shellfish, are trapped against intake screens by the force of the water being drawn into the intake. *Entrainment* takes place when small egg and larval stages of organisms are drawn into the intake structure, along with the cooling water, and into the plant's cooling system. In general, the magnitude of I&E increases as the volume of intake flow and the intake velocity increase. In many cases, the adverse effects of I&E can be minimized through appropriate location selection, operational flexibility, improved screening technologies, and habitat restoration.

The cost of a new surface water intake typically accounts for 5 to 20% of total expenditures for plant construction. Costs will vary, depending on the type of technology used, the distance of the intake from shore, and the intake flow rate. The costs of intakes can increase significantly if advanced screening technologies are employed to control I&E. Costs associated with environmental permitting can also be significant.

Surface Water Intake Co-located With a Power Plant

Seawater desal plants often co-locate with power plants to take advantage of existing power plant intake structures and/or to use the plant cooling water as feedwater. This approach can yield significant benefits, compared to standalone facilities, including:

- Substantial construction cost savings due to the use of existing power plant intake structures
- Minimal or no impact on I&E due to the use of power plant cooling water as the desal feed water
- Energy savings because less pressure is required to move the feed water through the RO membranes due to the higher feedwater temperature
- Environmental benefits associated with the dilution of desal concentrate before it is discharged to the ocean, due to blending with the power plant cooling water

Although there are several stated advantages to co-location, the feasibility of this approach has not been fully evaluated in the US. To date, Tampa Bay is the only co-located facility that has been implemented in the US. There are currently several co-located projects slated for implementation (most of which are in California), that have initiated or completed required planning processes. Based on lessons learned from these processes, we can begin to gauge how the stated advantages of co-location have played out in the US. For example, potential disadvantages and uncertainties associated with this approach include:

- Difficulties matching the operation of desal plant with that of power plant due to different O&M schemes.
- Desal facilities may encounter serious biofouling, corrosion, and other unforeseen problems caused by using OTC water as source water. A thorough understanding of source water quality variability, long-term pilot testing, adequate and robust pretreatment, flexible process design, and sufficient pretreatment capacity, are critical to ensure adequate design and maintain sustainable operation of a desal facility.
- By operating on property that is owned and managed by a power company, the desal facility may face complications (e.g., space and access restrictions) and added expense in design and/or operation.
- Many of the coastal power plants that rely on OTC were sited decades ago, before the adverse environmental impacts of their intake structures were understood, and before current environmental legislation and regulations were in place. As a result, some existing OTC power plants are located in areas where their intakes create considerable environmental damage. Thus, the potential source water impacts of co-located facilities still need to be considered.
- Specific consideration should be given to potential changes in power plant operations, such as the phasing out of OTC systems. For example, the California Coastal Commission (CCC) has signaled that by 2020, OTC will no longer be permitted at

power plants along the California coast. Existing power plants in California are therefore beginning to modify their operations to discontinue OTC.
- The association with coastal power plants, which are unpopular in many locations (e.g., because they are unsightly and impair beach access), can draw criticism and added permitting delays.

Subsurface (Sub-seabed) Intakes

Subsurface intake facilities extract seawater from the sand below the beach, or below the seabed near the shore. Coastal subsurface intakes include:

- Onshore subsurface intakes, including vertical wells, horizontal wells, and beach infiltration gallery
- Offshore subsurface intakes, including horizontal directionally drilled (also called slant-drilled) wells, and seabed infiltration galleries

By taking advantage of the natural filtration provided by sediments, subsurface intakes can yield better quality feed water than open seawater intakes, including reduced suspended solids, turbidity, natural organic matter, pathogens. Subsurface intakes commonly achieve lower silt density index (SDI) in the feedwater. The natural filtration also serves to minimize ecological impacts associated with I&E.

Because of the higher quality feed water, subsurface seawater intakes can reduce the pretreatment required for membrane-based desal systems, thereby lowering associated operations and maintenance costs. Subsurface intake systems have been proven economically justifiable for SWRO desal plants with a capacity of up to 13 mgd (49,000 m^3/d) (CDWR 2003).

The construction of subsurface intakes, in particular beach wells, requires appropriate geological conditions including permeable sand formation with adequate transmissivity and depth (Voutchkov 2005). Shallow beaches that contain a substantial amount of mud/alluvial deposits do not provide favorable conditions for beach well operations.

In addition, a significant area is required to generate water from subsurface intakes. It is estimated that for a 10 mgd plant, 4.2 acres of beach shore may be needed for horizontal beach wells, infiltration galleries or seabed infiltration galleries, as opposed to 2 acres for open surface water intakes (Voutchkov 2005).

The construction costs of subsurface intakes are very site-specific and this method is typically only feasible for smaller desal plants. The costs associated with different types of intakes are detailed in appendix F of this report.

Although subsurface intakes generally yield better water quality compared to surface water intakes, the water quality from a subsurface intake system can be affected by adjacent groundwater aquifers, such as presence of higher concentrations of iron and manganese, which can complicate pretreatment. It is not always evident whether a subsurface intake will perform reliably (e.g., produce sufficient yields without clogging) over the expected life of the desal facility. A thorough assessment should be conducted, especially in warm tropical or semi-tropical waters, to address the issue of potential carbonate scaling of the formation above/around the intake. Further, the knowledge and experience in designing subsurface intake facilities is far less than for surface water supply systems. This may result in poorly designed (and even failure of) some intake systems.

Currently there are several seawater desal projects testing subsurface intake structures such as the slant well technology at the MWDOC, and the Under Ocean Floor Seawater Intake and Discharge Demonstration System at the LBWD. These projects will provide valuable experiences in designing and implementing ocean subsurface intakes in the US.

Regulations and Permitting

A standalone desal plant in coastal waters will need to develop a surface water intake structure, beach wells, or use horizontal directional drilling (HDD) to develop under-sea well intakes some distance from the shore. This is likely to entail several permits and approvals, including:

- A CWA section 404 permit for the intake pipe (one is also needed for any new discharge pipe). This is administered by the US Army Corps of Engineers (USACOE), but typically requires buy-in and approval from other agencies, such as the US National Oceanic and Atmospheric Administration (NOAA) and/or relevant state or regional bodies that have jurisdiction over fisheries and other coastal resources and impacts.
- The Rivers and Harbors Act permit for the intake pipe (again, a separate permit also will be required for a discharge pipe). This too is administered by the USACOE, and again they will typically not issue such a permit unless other agencies (e.g., NOAA) are consulted and sign off.
- In some states, a permit will be required from the state coastal authority (e.g., the CCC).

With co-located facilities, there is no need for a new water intake pipe or any increase in the volume of coastal waters taken in. This eliminates the need for permitting of *new* intakes, and avoids any associated coastal ecosystem disruption from placing such new intake pipes into the coastal environment. As noted above, there is generally no added I&E of aquatic species, beyond what is already occurring. This also serves to minimize permitting requirements**.** However, because of the potential phasing out the OTC system in California, the permitting of new co-located facilities may require studies to evaluate the impacts of the co-located plant if it were to operate as a standalone facility.

Open ocean intakes usually experience more difficult regulatory reviews because of the primary concerns on I&E, and resulting in longer permitting time as compared to subsurface intakes. Table 8.1 compares the regulatory considerations and time required for permitting two different types of desal intakes in California (Luster 2009). These examples illustrate the importance of coordinating with regulatory agencies and addressing environmental concerns.

Table 8.1
Regulator perspective on two contrasting desal intake permit reviews

City of Sand City	Poseidon Huntington Beach
Uses beach wells	Uses open water intake
Standalone facility	Co-located with power plant
Limited water production to approved Sand City limits	Unknown basis for water production
Addressed Coastal Act issues promptly	Not responsive to key information requests
Public agency transparency	Private company w/less transparency
Result: 3 months from application to approval; facility up and running	Result: over 3 years; application still incomplete

Source: Adapted from Luster 2009.

INLAND CONCENTRATE MANAGEMENT

Concentrate management is currently one of the most challenging issues associated with desal implementation, especially for inland facilities. Due to a number of factors, it is becoming more and more challenging to find a technically, environmentally, and financially viable method of dealing with desal concentrate (Mickley 2006). These factors include:

- Growing size of plants, which limits disposal options
- Increased number of plants in a region such that the cumulative effect on receiving waters is becoming a limiting factor
- Increased regulation of discharges, which makes disposal more difficult and slows the permitting process
- Increased public concern with environmental issues, which plays a role in the permitting process
- Increased siting of desal plants in semi-arid regions where conventional disposal options are limited

Traditional options for inland concentrate management include surface water discharge, disposal to sewer, deep well injection, evaporation ponds, and land application. Together these five options account for over 98% of the concentrate disposal situations for municipal desal plants in the US (Mickley 2006). Rarely are more than one or two options available at a given site as each method has its own set of site requirements, site-specific costs, regulatory requirements, and environmental challenges. The following sections provide an overview of each traditional disposal method, outlining the challenges associated with each approach. More recently, higher recovery processing including ZLD, has received considerable attention in an effort to provide an alternative means of concentrate management. This approach and the development of other alternative options for concentrate management are also discussed.

Ocean Surface Water Discharge

Surface water discharge to the ocean can be a low-technology, and in some cases, an inexpensive disposal option for inland facilities. If designed appropriately, discharge of inland concentrate to the ocean can have very low environmental impacts compared to other disposal options. The feasibility of this method depends on the distance of the desal plant to the ocean outfall, the conveyance cost of transporting concentrate, and the cost of building new ocean outfalls.

California has several brine lines that convey concentrate from multiple desal plants (and in some cases other wastewaters) directly to the ocean. Gravity flow for long or all stretches of the brine line decreases capital and operating costs.

The primary environmental concern with ocean discharge from inland facilities is compatibility of the concentrate with the receiving water. Concentrate from brackish water desal plants may have salinities that are similar to or lower than seawater (depending on source water salinity and recovery efficiency). However, concentrate from brackish groundwater desal may also contain trace elements, such as arsenic or selenium, in elevated concentrations compared to seawater. Like seawater desal concentrate, inland concentrate can also include desal process chemicals used for pretreatment, cleaning, corrosion prevention, and membrane anti-fouling. Concentrate streams containing trace elements or certain process chemicals can cause significant impact to the receiving environment if not handled correctly (NRC 2008).

Additionally, when concentrates originating from groundwater are discharged to seawater, major ion toxicity [as determined in whole effluent toxicity (WET) tests] can result (NRC 2008 as cited in Mickley 2001). This toxicity occurs when certain ions are present in very different concentrations (higher or lower) relative to the seawater adjusted to the same salinity. Toxicity due to this “imbalance” of ions relative to seawater has been seen in mysid shrimp with respect to high calcium or fluoride or low potassium (NRC 2008). Major ion toxicity has also occurred with other WET test organisms. Many concentrates originating from groundwater would have major ion toxicity as determined from whole effluent toxicity tests if mysid shrimp were used as a test organism. However, most states (other than Florida) either do not require WET tests or do not use the very sensitive mysid shrimp in WET tests (Mickley 2001).

In most cases, dilution by only a factor of 4 to 6 is sufficient to eliminate the concentrate’s impact on the environment (Mickley 2001). Disposal can become an issue if the concentrate contains elements that have toxic effects on aquatic organisms or on wildlife that feed on aquatic organisms (NRC 2004).

Concentrate from brackish groundwater can also be very corrosive. To avoid environmental degradation of receiving waters at the outfall of a brine line, pipelines transporting brackish water concentrate must be fitted with special protective liners. This requirement substantially increases capital costs of this method and depending on the length of the pipeline, may render the use of this method infeasible in some locations.

Freshwater Discharge

Desal concentrate is sometimes discharged to rivers and other inland surface water bodies in accordance with local, state, and national water quality regulations (Mickley 2006). Depending on the source water composition, the potential for trace elements and major ion toxicity, as discussed above, are a concern when concentrate from brackish groundwater is discharged into freshwater ecosystems (NRC 2008).

Impacts of discharge of brackish water to surface water can be greater in freshwater than in estuaries or the marine environment, where higher levels of salt are a natural component of the ecosystem. Some freshwater organisms are only able to tolerate low levels of dissolved solids. As salinity levels increase in rivers, streams, and lakes, a shift to more salinity-tolerant species can be expected. High levels of salinity may also affect the growth of certain types of aquatic vegetation (NRC 2008).

In addition, since saltwater is denser than freshwater, relatively saline concentrate can sink and form a layer at the bottom of receiving rivers and streams. The resulting layer can have negative implications for benthic communities. Water containing high salt concentrations may also create brackish layers in receiving lakes which can lead to decreased dissolved oxygen levels and associated impacts (Mickley 2006).

An increasing challenge for surface water disposal at inland facilities involves limiting the continued degradation of waterways caused by discharge of higher salinity effluents (Mickley 2004). A new discharge may impact permit limits for existing dischargers, and over time, new discharges may become severely limited, if not prohibited (CWQCC 2006).

Sewer Discharge

Discharge of concentrate to an existing sewer system is one of the most widely used concentrate disposal practices for brackish water desal plants (Mickley 2006). This method is easy to implement (where available) and is employed by approximately 31% of municipal desal facilities in the US (Mickley 2006).

The feasibility of this disposal method is limited by the hydraulic capacity of the wastewater collection system and by the treatment capacity of the WWTP receiving the discharge (NRC 2008). Large-volume discharges are typically not practical or suitable.

Sewer discharge is relatively low in cost and energy use but has the potential for adverse environmental impacts due to elevated concentrations of salt or trace elements in the treated effluent. In addition, the potential for major ion toxicity for aquatic organisms can be a concern. However, this is usually minor due to the low relative volume of concentrate to the total WWTP effluent volume (NRC 2008).

Changes in the concentration or composition of ions can cause chronic stress affecting important functions of an organism such as growth and reproduction. Sudden changes in ion concentration or composition can result in death (SETAC 2004). However, in general, the mixing of concentrate and sewer water tends to lessen the occurrence of major ion toxicity and decrease the concentration of bacteria in the effluent (i.e., it dilutes the “bad” characteristics of both the concentrate and the sewer water). A desal facility is not required to obtain an NPDES permit to discharge desal concentrate to a WWTP. However, disposal to sewer requires a permit (or permission) from the local sanitation agency to ensure that potential adverse impacts on wastewater treatment processes, if any, are within acceptable limits. The permit may impose discharge limits in order to protect sewer lines and treatment plant infrastructure, wastewater treatment processes (mainly biological), and final effluent and biosolid quality.

In addition, the WWTP may charge the desal facility a connection fee. Sewer connection fees usually are related to the available capacity of the sewer facilities and the effect of the concentrate discharge on the operational costs of the WWTP. These fees vary significantly form one location to another, and can be quite large and prohibitive (Mickley 2004).

Deep Well Injection

Deep-well injection is a mature technology that involves the injection of liquid wastes into porous subsurface rock formations. Deep-well injection is used at about 12% of municipal desal facilities in the US (Mickley 2006). It is typically employed at larger desal plants because the costs for developing deep well injection wells are not largely reduced for smaller flows. The high initial costs lead to an economy of scale when spread out over larger flows.

The primary environmental concern associated with deep-well injection is potential concentrate leakage from the injection well and/or the underground aquifer. If the injection well is not properly constructed, and/or the aquifer is not adequately separated from nearby aquifers (including water supply aquifers), the nearby aquifers may be contaminated by the injected concentrate (Xu et al. 2009).

Desal concentrate is considered an “industrial waste” under the CWA. As a result, it must be injected via a Class I well per UIC regulations. This regulatory framework restricts the number of compliant well sites and requires more conservative well construction, which increases the cost associated with this method of concentrate management.

Site selection for deep well injection is dependent upon geologic and hydrogeologic conditions, and only certain areas are suitable for construction of Class I wells. Suitable underground strata capable of receiving the waste (considering capacity as well as permeability characteristics) must be present and separated from any underground sources of drinking water (USDWs) by impermeable strata. Further, it is essential that the well not be located in areas subject to earthquakes or in regions containing recoverable mineral resources such as ores, oil, coal, or gas. Most favorable locations are generally in the midcontinental, Gulf Coast, and Great Lakes regions of the country.

Deep well injection is not permitted in every state, but those that do allow it, including California, Florida, Texas, and New Mexico, require permits, monitoring wells, and completions in deep contained aquifers. Deep well injection has been widely used for disposal of desal concentrate in Florida, and more recently in El Paso, Texas, which have some of the best geologic formations to support deep well injection (Mickley 2006, Hutchison W. 2007). Deep-well injection is less common elsewhere in the US due to combined regulatory and practical (i.e., cost) considerations.

Texas has been active in exploring disposal of concentrate to other class wells and presently municipal desal concentrate in Texas may be disposed of to Class II (oil and gas) wells to maintain pressure and to Class V wells as long as the TDS is less than that of the receiving water and concentrate meets primary standards. These possibilities, along with further efforts underway to redefine injection requirements, may lead to cost reductions for deep well injection of concentrate.

Land Application

Approximately 2% of municipal desal plants in the US use land application in the form of percolation ponds, spray irrigation, or leach fields (Mickley 2006). The feasibility of land application depends on the availability and cost of land, irrigation needs, water quality, tolerance of target vegetation to salinity, percolation rates, and the ability to meet ground water quality standards.

This method of concentrate disposal is not practical for the large volume and highly saline concentrate from seawater desal facilities and is therefore typically only considered for brackish water applications. Even for these applications, a TDS greater than 5,000 mg/L in the concentrate can typically preclude spray irrigation, or require addition of dilution water (Mickley 2006, NRC 2008).

Key environmental concerns associated with land application or irrigation include the influence of concentrate on soil and vegetation, potential contamination of groundwater, and runoff to surface water (NRC 2008). Currently, in arid and semi-arid environments (generally west of the 100 Meridian in the US), land application is not a sustainable method for disposal because it is likely to exacerbate an already a large worldwide problem of soil salinization (NRC 1993).

An NPDES permit may be required for spray irrigation if the potential exists for runoff to reach a receiving water. To avoid this requirement, the facility must prove beyond reasonable doubt that no runoff can possibly travel to a receiving water, or it must provide secondary containment. However, proving that runoff will never reach a receiving water is generally more costly and time consuming than obtaining a permit.

Spray irrigation can provide a beneficial reuse of water when membrane concentrates are applied to vegetation, such as irrigation of lawns, parks, or golf courses. However, the use of spray irrigation is possible only if the concentrate meets groundwater compatibility limits and a level acceptable for crops/vegetation irrigation. Feasibility depends on the type of the crops/vegetation and on the soil uptake rates. Any blending with a fresh water source to reduce its salinity may increase cost. Further, because irrigation demands are seasonal, a second or backup disposal or storage method is necessary for year-round operation (Malmrose et al. 2004).

Evaporation Ponds

Evaporation ponds are a low-technology but high-cost approach to concentrate management, where the concentrate is pumped into a shallow lined pond and allowed to evaporate naturally using solar energy. Approximately 2% of municipal desal plants (including both inland and coastal facilities) in the US use evaporation ponds for concentrate disposal (Mickley 2006).

Although evaporation ponds are straightforward and require little maintenance, there are a number of disadvantages that often preclude their use as a means of concentrate management (Mickley 2006):

- Regulations typically require that expensive natural (e.g., clay) or synthetic liners be used to prevent the saline concentrate from percolating into the water table. This requirement substantially increases the costs of this disposal option.
- Seepage from poorly constructed evaporation ponds can contaminate underlying potable water aquifers.
- There is a potential for wind to dislodge and spread the dried materials, particularly if the concentrate contained hazardous materials.
- There is very little economy of scale in conjunction with evaporation ponds, virtually eliminating any possible unit cost savings associated with using this strategy for concentrate management at larger facilities. With little economy of scale (due to

substantial land requirements), evaporation ponds are generally only feasible for small volume concentrates. The largest municipal plant discharging to evaporation ponds has a capacity of 1.5 mgd. All the others have capacities of less than 0.4 mgd (Mickley 2004).

- The most significant issue associated with evaporation ponds is the substantial land requirement.

Various groups have been investigating approaches to enhance net evaporation through methods such as spraying of water into the air and evaporating water from porous vertical surfaces. Some of the methods are commercial and in general hold promise to significantly reduce evaporation pond area requirements and to reduce capital cost. While operating costs are increased due to the various enhance evaporation means, the net result is a decrease in annualized costs.

Evaporation ponds hold the potential of providing wildlife habitat; however, elevated levels of salinity and trace elements in the discharge water may have negative impacts on breeding and migrating birds, as was seen with the effects of selenium at the Kesterson National Wildlife Reserve (Hoffman, Ohlendorf, and Aldrich 1988; NRC 1989; Hannam, Oring, and Herzog 2003). Furthermore, while maintenance needs can be relatively minor, the need for active erosion control and wildlife management should be considered in all cases (NRC 2008).

Evaporation ponds can be a viable option in relatively warm, dry climates with high evaporation rates, level terrain, and low land costs (Mickley 2006). Under suitable climatic conditions, evaporation ponds enable operation of desal plants under ZLD conditions, where no liquid waste leaves the plant boundary (NRC 2008).

ZLD and High Recovery Processing

ZLD is subcategory of high recovery processing where no liquid by-product leaves the plant boundary. Due to its only recent consideration in municipal desal, ZLD and more generally high recovery processing is considered a concentrate management option rather than a processing option. From its earliest use at power plant sites, ZLD processing included either evaporation ponds as a final processing step or processing of the brine to produce mixed solids suitable for landfill.

While original ZLD systems included only thermal evaporative equipment for volume reduction, later systems included a membrane volume reducing step prior to the thermal step, and in some cases the system did not include any thermal step.

High recovery systems can be ZLD systems when no liquid crosses the plant boundary. As with ZLD, high recovery systems can be comprised of either membrane or thermal steps or a combination of the two. Final brine can be processed all the way to mixed solids, discharged to evaporation ponds, or deep well injected. The higher salinity brines are typically incompatible with receiving waters—whether surface water, sewer water, or groundwater.

High recovery processing, including ZLD, is usually the least cost effective method of concentrate disposal, due its high capital, energy, and chemical costs. Although this method has found practical application in industrial facilities, it has not yet been used for disposal of concentrate from a municipal desal plant (Mickley 2006).

In addition to the high energy requirements associated with high recovery processing, particularly when thermal processes are used, disposal of the final product is of environmental concern. If the salts are disposed of in a landfill, there may be future environmental impacts to groundwater near the disposal site.

Costs aside, there are some advantages to ZLD, including (Mickley 2006):

- It may avoid a lengthy and tedious permitting process
- It may gain quick community acceptance
- It can be located virtually anywhere
- It represents a positive extreme in recycling, by efficiently using the water

Before widespread implementation of high recovery processing, including ZLD, can occur, improvements are needed that reduce capital costs and/or energy usage. ZLD is being considered for some water supply applications in inland regions where the concentrate flows are small and other methods of concentrate management are not feasible (e.g., the desal facility at the Deuel Vocational Institution in Tracy, Calif., incorporates a brine concentrator).

Alternative Disposal Options

A recent Water Research Foundation-sponsored report (Xu et al. 2009) identified several areas of research to help address the increasing challenges of concentrate management, including:

- Beneficial use of concentrate
- Regional concentrate management
- Watershed concentrate management

As detailed by Xu et al. (2009), the following sections describe the identified research areas.

Direct beneficial use of concentrate is an attractive option for sites where an environmental friendly application can be found. The use of concentrate as a means to restore wetlands is one such example. Wetland restoration is site-specific and suitable for conditions where the concentrate quality is compatible with the native flora and fauna of the saltwater marsh or wetland.

Salt recovery may also have the potential for beneficial use. Desal concentrate is often viewed as an undesirable residual that requires disposal. If the chemical components in the concentrate can be solidified and used as a future resource, the overall recovery of the system will be greatly enhanced and the concentrate stream minimized.

A positive attribute of salt solidification is the recovery of salts and potential for revenue generation through resale. The sale of products from the facilities might provide revenues that could offset costs involved in installing and running the full-scale facilities. The economics and marketing of products, however, need further investigation (Jordahl 2006, Mickley 2008, 2009).

Regional concentrate management includes regional collection, treatment, centralized disposal, or beneficial uses of concentrate from a number of desal plants. Regional management may take advantage of site-specific beneficial conditions for disposal and of the economies of scale of constructing larger concentrate disposal facilities. Another advantage of regional management is the use of concentrate from brackish water desal plants as source water to seawater desal plants, which is currently being employed in Eilat, Israel (Ravizky and Nadav 2007). The use of concentrate from the brackish water plants can reduce the salinity of the source water, even when blended with ocean water for the feed source. This can decrease the seawater desal plant's energy and treatment costs and potentially increase recovery, while avoiding the brackish desal concentrate disposal issues.

Watershed management may provide an option to manage concentrate disposal at a desired watershed scale. Watershed management can be used to ensure that concentrate discharges are protective of beneficial uses of receiving waters for agriculture, environmental uses, and drinking water. Watershed management could be structured in a manner that would support a system for pollutant trading. Receiving water quality requirements could be imposed at the point of use rather than for the entire watershed. The effective protection level could be based upon preserving existing ambient water quality to protect aquatic life uses, agricultural, or drinking water supply uses. It might also be possible to specify effluent limitations, waste load allocations, and/or treatment requirements in a control regulation focused on a specific water body (CWQCC 2006).

MEMBRANE PROCESSES

In practice, there are several different desal processes, of which there are two distinct categories: thermal processes and membrane processes. Thermal processes use heat and pressure to separate pure water vapor from dissolved and suspended solids. Thermal processes consume a large amount of energy, and are seldom used in public water supply applications in the US, as they are generally not cost-effective.

In the US, Australia, and Europe, almost all desal applications utilize RO or NF membrane technology. Both RO and NF utilize the principle of RO to accomplish desal. They are essentially the same process with different degrees of salt rejection. In RO and NF, water passes through the membrane while its constituents are rejected. Thus, they are both considered "barrier technologies" for the purpose of removing pathogenic microorganisms.

RO is used to reject most of the contaminants in water, including TDS, organics, and pathogens. NF membranes are designed to selectively provide a high degree of rejection for compounds such as multivalent ions or organic contaminants, while rejecting monovalent ions less efficiently. Because this characteristic property reduces overall rejection, NF membranes can be operated at lower feed pressures, and thus have lower energy requirements.

RO is the most versatile technology, and has been demonstrated as the most economically viable option for a wide range of applications and feed water quality. NF is commonly used for specialty applications in which the more robust salt rejection properties of RO are unnecessary.

Although membrane technologies have been demonstrated as the most economically viable option in the US. There are several technical and engineering challenges related to the implementation of these processes. Key challenges include:

- Membrane fouling
- Corrosivity of the product water
- Incomplete rejection of trace organic pollutants

- Relatively low recovery rate resulting in high volumes of desal concentrate
- High energy requirements
- High costs

Membrane fouling is considered a major obstacle for efficient membrane operation. Fouling can result in reduced permeate flux, increased energy consumption, reduced permeate quality, shortened membrane life, and increased O&M costs. The most direct and effective way to protect against fouling is with effective pretreatment to remove suspended/colloidal matter and dissolved organic matter. Strategies to prevent and control membrane fouling are discussed in PIM cell discussion: Pretreatment/Engineering, Minimizing Membrane Fouling.

Because the RO process is very efficient at rejecting dissolved solids, the resulting permeate has very low levels of alkalinity and calcium, two parameters that are critical to maintaining chemical stability (i.e., preventing pipeline corrosion) in the distribution system. The addition of acid in the pretreatment process also contributes to the dissolution of the existing protective scale on the piping. Therefore, effective post-treatment of membrane permeate is required to reduce the corrosive character of the product water.

RO and NF membranes have observed incomplete rejection of certain trace organic pollutants with molecule size smaller than the membrane molecular weight cutoff, such as DBPs, during full- and pilot-scale high-pressure membrane applications. The removal of these compounds is of great importance where a high product water quality is desired.

Another limitation of RO is the relatively low recovery rate for seawater (up to about 60%) and brackish water (typically between 50 to 85%) desal, which results in large volumes of concentrate. Maximum recovery is limited by mechanical pressure limitations of the materials in the membrane element for seawater desal, and membrane fouling and scaling potential for brackish water desal.

As detailed below, the energy requirements associated with membrane processes account for a substantial portion of the total cost to produce desalinated water. Thus, small changes in the cost of energy and/or power consumption have the potential to significantly influence the cost of desal. Reduction in energy demand and use of ERDs is now a key component of membrane desal processes.

As detailed elsewhere in this report, desal water is expensive relative to the cost of most existing supplies. This raises several issues regarding potential impacts on local water rates and the associated impacts on households and commercial customers in the served communities.

Alternative and emerging technologies are being developed; aiming at improving certain aspects of the performances of existing desal processes (e.g., higher recoveries, reducing fouling, decreasing energy consumption and capital and operating costs). A discussion on emerging desal technologies is included in appendix A.

PILOT TESTING

The design of desal facilities is typically more involved than the design of standard water treatment facilities due to the complexity of the systems involved. Membrane facility design hinges heavily on the site-specific characteristics of the source water used. As such, these installations are not “plug-and-play” designs, and require experienced and knowledgeable engineering to ensure proper design and cost information. Pilot studies provide the opportunity to evaluate the performance of proposed treatment systems under site-specific conditions.

The base objective of pilot testing is to confirm the ability of the desal system to meet finished water quality goals, operate for sustained periods of time and, in the case of surface water desal, withstand seasonal changes in raw water quality. Data gathered from pilot studies are fed back into the planning and design process and adjustments are made accordingly. The result is a more complete design, more refined cost estimates, and a more accurate understanding of the viability and potential challenges of the proposed full-scale project. In some states, a pilot study is required in order to obtain a construction permit for an RO desal facility.

This section briefly summarizes the importance of pilot testing for development of both seawater and brackish groundwater desal systems including key logistics and considerations for pilot study implementation. Detailed discussions are provided in appendix C.

Key Factors to Consider for Project Managers

Prior to investing in a pilot study, desal facility project managers should consider key aspects of the study that could have an impact on the viability of the project results and costs, including finished water quality goals, pilot set-up, pilot test duration, and regulatory requirements.

- **Finished water quality goals.** Establishing finished water quality goals is one of the first steps of developing a desal project. Water quality goals are based on regulated primary drinking water standards as well as on specific conditions of the water system. For a specific source, established water quality goals will be the basis for selecting the configuration of a desal system.
- **Pilot set-up.** Depending on the source water quality and the size of the full-scale plant, a utility may consider pilot testing multiple treatment trains. Utilities may also choose to test different RO membrane elements. It is important to note that the choice of how many pilot trains to use in a pilot study, the RO elements sizes, and the number of RO membranes tested can significantly impact the cost of the pilot study. However, the more extensive a pilot study is, the better the risk mitigation it can provide. Decisionmakers must balance the cost considerations associated with a pilot study with the risk mitigation.
- **Pilot test size.** To provide representative and scalable data, pilot equipment configuration should represent production sized unit processes. For example, the use of a single element pilot unit would not provide representative data for the full scale process.
- **Pilot test duration.** For a seawater desal facility, pilot testing over the course of a 12-month period is typically performed to capture seasonal effects on the source water. For a brackish groundwater desal facility, water quality relatively constant, and thus pilot testing can be conducted for three to six months. Pilot testing may also be performed multiple times through the course of a project.
- **Regulatory requirements.** Some State regulatory agencies may require a pilot study to demonstrate the feasibility of seawater and brackish water treatment. In such

States, it is the responsibility of the utility conducting the pilot study to comply with all regulatory requirements which may apply.

What a Pilot Study Provides

There are several factors a utility must consider in planning a desal pilot study to ensure its success in providing meaningful results for the full-scale facility design. A pilot study provides information to support the planning efforts in the following areas:

- **Intake/well siting.** The choice of what method of raw water supply will be used depends on several factors such as water quality, co-location with a power plant, permit implications, environmental considerations, and costs. The pilot study is one of the tools that will validate the decisionmaking.
- **Pretreatment design.** Pretreatment system designs can vary considerably and directly affect plant production sustainability. Inadequate pretreatment will result in poor performance of the pretreatment system itself and the RO membrane system, therefore leading to an increase in O&M costs. A pilot study can be used as a tool to help utilities select the proper pretreatment system, pretreatment design criteria, and refine the capital and operational costs of the fullscale plant. Pretreatment requirements for groundwater are minimal compared to those for surface water.
- **Desal design.** Draft design criteria are typically "proof-tested" at pilot scale to validate the design concept. There are numerous resources available to utilities to aid in the desal design process.
- **Post-treatment design.** Finished water quality regulations are becoming more stringent. Pilot studies are useful in determining potential water quality issues (e.g., due to blending of finished waters from different sources).
- **Permitting.** A pilot study provides the opportunity to define the fate and transport of chemical constituents through the treatment process train. Pilot studies are useful in determining compliance of the desal system with permitting requirements and regulations.
- **Public outreach.** An effective way to provide information regarding the proposed desal project is to allow the public to tour the pilot system.
- **Costs/funding.** The ability to more accurately assess total project costs is one of the most important benefits resulting from a pilot study.

Key Pilot Logistics and Operational Considerations

Development of a design concept should be based on historical water data collection, source water sampling and the defined water quality goals for the desal facility. Based on the design concept, logistics and operational considerations associated with implementation of the pilot study must be taken into account. These include:

- What, when, and how testing should be performed to meet the project goals as well as to comply with regulatory requirements
- What water quality parameters to test for

- What operational parameters to monitor and how often
- Operational procedures such as the start-up/shutdown and cleaning procedures

Pilot Study Costs

Pilot study costs can vary widely depending upon the degree to which other upfront planning activities have been completed. However, for surface water desal, based on the assumption that intake selection and development of the design concept are complete, the cost for a one-year study typically ranges from $600,000 to $1.5 million. For groundwater desal, the cost for three to six month study typically ranges from $100,000 to $250,000.

Expenditures associated with a pilot study typically represent less than 1% of the total project costs.

Conclusions

A pilot study is a representation of the project vision and serves as a key planning tool to fill in details related to finance, design, permitting, and public outreach. With a well thought out scope, the specific information obtained through pilot testing can be leveraged to answer questions in almost all areas of project planning and can move a project to the next level of completion. Only data obtained from a pilot study is directly scalable to the full size facility

Regardless of the point in the planning process, a pilot study should be performed per state requirements. The timing of implementation, the scope of the study, and the value obtained from the pilot study can vary from project to project.

Public involvement and outreach is an important element of any pilot study, as it provides an opportunity for the utility to educate the public and address any existing concerns.

ENERGY USE

Desal is an energy intensive process. Energy issues are critical to desal implementation in several ways, including costs, reliability, environmental impacts (including climate change), and stakeholder acceptance. Because the energy demand of desal treatment processes is mainly a function of the feed water salinity, energy is more of a concern for seawater desal than for brackish water desal. Approaches for decreasing the energy demand of RO processes and the use of renewable energy are critical for sustainable development of desal technologies.

The RO process typically uses 80% of the total power demand of a seawater desal plant (MWDOC 2007). Energy requirements of membrane processes are dependent on a number of plant and site-specific factors including feed water quality (salinity and temperature), membrane permeability and resistance, recovery, and other operating parameters (Veerapaneni et al. 2007). Significant energy savings can be achieved through optimizing operational parameters, using high efficient pumps and ERDs, and improvements in system design. Increasing membrane efficiency by reducing membrane fouling can also control the increase in energy demand during long-term operation.

The development of highly efficient ERDs has greatly improved the energy efficiency of SWRO systems. In general, ERDs can recover 75 to 98% of the input energy in the concentrate stream of a SWRO plant (Stover and Cameron 2007). A number of ERDs have been developed.

These ERD systems can be divided into two general categories: centrifugal and pressure exchange devices. The pros and cons of different types of ERDs are discussed in the PIM document related to Energy Issues for Coastal Membrane Processes.

Options for reducing the energy requirements may also include the development of new generation membrane materials for RO systems, and alternative desal processes such as FO and MD. Appendix A describes the emerging desal technologies.

Concentrate disposal at inland facilities is facing increasingly difficult challenges due to limited concentrate disposal options, and more stringent discharge regulations and permitting processes. Energy demands will potentially increase due to further need for treatment of concentrate and reduction of concentrate volume. The typical energy demand of surface discharge, sewer discharge, evaporation pond, and land application is lower than deep well injection. As discussed earlier, high recovery processing, including ZLD, is energy intensive due to the use of secondary membrane processes and/or evaporating and possibly crystallizing processes.

Given the high energy demand and use of fossil fuels for power generation, the high carbon footprint of desal as compared to conventional water treatment may render desal unfavorable due to concerns related to GHG emissions and climate change. However, it is important to emphasize that conventional treatment methods are unable to create a usable water supply without a fresh water source. In addition, it is necessary to consider the energy demand associated with the transportation of water from fresh water sources. As such, in some regions, energy consumption for seawater desal may be comparable to that for water importation.

Regardless, incorporation of renewable energy sources, such as wind and solar energy, may allow desal plants to operate in a carbon neutral mode and be more environmentally friendly. Currently wind energy holds the most potential as a renewable energy source for desal and has been used for large plants in Australia. More recently, the Beckton desal plant in London claimed the use of biodiesel to meet desal energy demand and ease environmental concerns related to the high energy consumption of the desal plant.

Grid reliability and risks are an important factor to be included in project planning and design. For desal plants powered by conventional generation and transmission systems, one concern is the reliability of the grid to provide power on a continuous basis. Co-location with a power plant may introduce additional susceptibility to power failure or spikes due to lack of buffer from transmission grid systems. Power failures or voltage fluctuations can pose challenges to membrane and other desal processes, impacting the ability generate product water in needed quantities or qualities. This risk may be especially acute as peak water demands often coincide with periods of peak energy demand. Different options of power supply should be evaluated including onsite generation, connection to electrical grids, back-up service, and other potential energy sources. Water agencies need to manage their power costs and integrate desal into the community's power systems by striving to use less power during peak electricity demand periods.

CO-LOCATION

Co-location refers to a desal facility sharing some infrastructure and/or siting with another entity**.** The most common form of co-location considered or deployed for desal facilities—especially in coastal locations—has been with coastal power plants. Below, a discussion is provided of the many potential advantages, and disadvantages, of co-location with power plants. First, however, a brief discussion is provided of other forms of co-location.

Co-location With Wastewater Discharge Facilities

Beyond power plants, there are other types of desal facility co-location that may be feasible and beneficial. For example, for inland utilities, the use of a regional brine line for concentrate disposal can be a critical aspect of what makes the desalting operation viable from an economic and regulatory perspective. Brine lines are often shared across various entities, rather than owed and operated exclusively by the desalting utility.

For example, the Chino Basin desalters operated by the Inland Empire Utilities Agency (IEUA) and its partners (described in a case study in chapter 9, and appendix H) discharge concentrate to the Santa Ana Regional Interceptor (SARI), which is available for use to several entities in the region to carry saline and other wastewaters to the coast for final handling (blending/dilution with freshwater effluent from coastal municipal wastewater treatment facilities, and discharge through an ocean outfall).

SARI is a brine-carrying pipeline owned and managed by the Santa Ana Watershed Project Authority (SAWPA), designed to convey up to 30 mgd of treated but nonreclaimable wastewater from the upper Santa Ana basin to the Pacific Ocean. Use of the brine line is allocated across the four SARI member agencies (IEUA, and the San Bernardino Valley, Eastern, and Western Municipal Water Districts), and the line carries wastewater effluent as well as desalting concentrates. IEUA has an allocation of 7.8 mgd of SARI pipeline capacity, including discharge from its wastewater and water reuse operations as well as brines from the Chino Basin Desalter Authority (CDA) desalters.

The availability of the SARI brine line provides significant advantage for the Chino Basin inland desalting operations. First, absent the brine line, it is not clear if or how the concentrates from the desalters could be managed in a manner that satisfied regulatory authorities. Thus, inland desalting may not have been institutionally feasible absent the co-location with SARI.

Second, the brine line offers a relatively low cost concentrate management option to IEUA and its Chino Basin partners. In return for use of the brine line, IEUA has paid an up-front share of its capital costs. The combined cost of SARI capacity acquisition for the desalters was $14.25 million for the Chino 1 and 2 desalted water production of 15,400 AF/yr (Parker 2007). Thus, the capital expense of accessing the SARI line is about $925 per AF per year, over the lifetime of the line. Annualizing the capital outlay (assuming a 5% nominal rate of interest and a 30-year repayment period), the SARI-related brine concentrate management capital costs amount to the equivalent of about $928,000 per year, or about $60 per AF of desalted potable water produced.

An additional $974,000 per year is necessary for SARI-related administrative, volumetric and other operating fees (CDA 2006). Allocated over the total desal production of 24,600 AFY, this amounts to about $40 per AF. Thus, the combined cost of SARI line capacity capital charges and related annual operating expenses amounts to about $100 per AF ($60 + $40). This is a relatively low cost brine management expense for an inland desalting program, compared to what the expense would be absent a brine line disposal option.

In coastal settings, similar co-location opportunities with coastal wastewater treatment and discharge facilities can be highly beneficial for desalters. The availability of existing coastal outfalls removes the expense—and permitting delays and uncertainties—associated with developing a standalone outfall for concentrate discharge. In addition, blending desal brines with municipal WWTP effluent creates considerable in-line dilution before ocean discharge, thereby reducing the potential adverse impact on marine ecosystems from the discharge of either freshwater effluent or brine concentrates.

Co-location With Power Generation Facilities

There are several important potential advantages with power plant co-location for a desal facility. However, there are also considerable disadvantages that are becoming more apparent as more desalters gain experience with the process. Many of the advantages and disadvantages are covered elsewhere in this report, such as in the feedwater intake discussion provided earlier in this chapter, and in case studies provided in chapter 9. Below, a brief overview is offered.

In typical power plant co-located approaches, the desal plant takes a portion of the power plant's OTC water, which creates several technical and regulatory advantages, including:

- There is no need for a new water intake system or any appreciable increase in the volume of coastal waters taken in. This eliminates the need for permitting of new intakes, and avoids any associated coastal ecosystem disruption from placing such new intake systems into the coastal environment.
- This approach also implies that there is no added I&E of aquatic species, beyond what is already occurring due to the pre-existing power plant operations. This means that the desal facility's use of coastal waters is unlikely to cause any ecosystem impacts beyond the baseline of what is already associated with the power plant (except in occasional instances when the desalting operation needs to take in feedwater while the power plant is not operating, such as during maintenance periods).
- The higher temperature attained by the OTC water makes the desal membrane process more efficient, saving energy and perhaps other costly inputs.

In addition, in coastal settings with desal co-located with power plants, the brine concentrates would typically be discharged with the cooling water return flows from the power plant. This provides considerable benefit as well:

- Use of the existing power plant ocean outfall eliminates the need to develop a costly and difficult-to-permit standalone coastal discharge outfall. This saves considerable expense and eliminates the uncertainty and potentially lengthy delays associated with the permitting process in the coastal zone.
- Dilution of the brine wastes in the discharge line (i.e., before the point of discharge into coastal waters), and may even serve to slightly cool the thermal power plant discharge. Presumably, the discharge to a dynamic marine setting (i.e., subject to currents, waves, and tidal influences) would be promptly and highly dispersed and diluted in the ocean setting.

While co-location of desal with coastal power plants offers several advantages, there are also some problems that may arise because coastal power plants are often the target of strong opposition by many parties. Concerns with coastal power plants tend to focus on ecosystem impacts (e.g., I&E from the use of OTC processes), potential thermal impacts, aesthetic concerns, barriers to beach access, and other issues. In some locations (especially in California), there is strong sentiment in some circles that coastal power plants should be phased out.

Co-locating desal facilities with power plants thus creates guilt by association. Power plant opponents worry that co-locating desal plants with power plants along the coast will make it harder to phase the power plants out of existence. In fact, the California Lands Commission, which has jurisdiction over the state's inter-tidal lands, made a policy statement in February 2006 that it would prohibit the renewal of any permits for OTC water systems at power plants after 2020.

In addition to the stigma associated with some coastal power plants in some areas, there are other limitations and drawbacks to desal co-locations with power plants. For example, co-location does not eliminate all regulatory concerns and permit issues associated with feedwater intake or concentrate discharge. Even though co-location will typically provide considerable in-pipe dilution of brines, regulators still express concern over the discharge because it may contain anti-scaling or other cleaning agents and other compounds used in the desal process.

State primacy or federal regulators will generally impose federal CWA NPDES permits on desal facility discharges (even when the wastewater is released through a power plant discharge line, with its own permit). Key issues will tend to be levels of local mixing, dispersion, and dilution, and the potential presence of any special status species. Presumably, reasonable pilot testing and periodic monitoring should identify if any impacts of concern may arise. However, a potential hurdle for desal facilities may arise where concentration-based limits (or bio-monitoring) are set and measured at challenging compliance locations that do not reflect coastal conditions (e.g., inside the discharge pipe).

Finally, growing experience gained by water utilities and desal project developers have revealed several issues that can arise when building and/or operating a desal facility that is co-located with a power plant. In general, the issues that arise stem from the fact that the power plant will tend to operate as it sees fit, and this can create significant challenges to the co-located desal facility.

For example, the Carlsbad facility that is nearing completion in southern California is co-located with the Encina power plant that recently decided to abandon its OTC system and, thus, will no longer provide feedwater to the desal operation. In addition, the change in cooling and other power plant processes means that the power company is now planning to use more of the limited on-site space for its modified facilities, leaving less space (and perhaps altering the location) for the desal plant facilities.

Likewise, at the co-located TBW desalting facility, the power plant managers have not always communicated effectively or performed according to plan in terms of shutdowns and other operational changes that can directly impact the desalting operation. Among the challenges that have confronted TBW at the co-located desal facility are space and site access issues, inadequate notice of production cutbacks that cut-off feedwater, and elevated feedwater temperatures that can damage membranes. As a consequence, TBW has had to develop its own independent feedwater intake system, which it uses when the power plant is not operating or when OTC feedwater water is too hot for the membrane processes.

COSTS AND ECONOMICS

In the US, desal has traditionally been cost prohibitive and in most locations, desal is still very expensive relative to the cost of traditional supplies. However, recent technological advances have allowed desal to become more efficient and less energy demanding, resulting in lower costs. At the same time, the cost of traditional supply alternatives has become more expensive. As these trends continue, desal may become more favorable in some areas.

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, Gleick, and Wolff 2006).In many cases, distribution lines can be a significant percentage of total costs. For example, the desal plant in Sydney, Australia, has a total cost of $1.9 billion. This includes $0.7 billion for the distribution line between the coastal plant and a suitable connection point to the Sydney distribution system.

To further complicate matters, the underlying assumptions associated with different cost estimates often remain unstated (Miller 2003). Few authors clearly state key variables including the year and type of estimate (actual operating experience, bid, or engineer's estimate), the size of the plant, interest rate, amortization period, energy cost, salinity of the source water, and the presence or absence of subsidies. Some international plant cost estimates may have currency exchange rate hedging elements that influence costs as well. 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. This section provides an overview of published cost estimates and summarizes the key factors influencing desal project costs. Additional information on the costs of desal, including specific project costs and cost factors associated with each component of the desal process, are included in appendix G.

SWRO Desal

The costs associated with SWRO have generally been reported within a range of $1.90 to $3.50 per kgal ($0.50 to $0.70/m^3) of water produced (Miller 2003, Dore 2005). Miller (2003) reports that it has generally become accepted that SWRO can be carried out in the US for less than $2.00/kgal ($0.50/m^3). Cooley, Gleick, and Wolff (2006), however, report that in California, the cost of desalinated water production ranges from $3.00 to $3.50/kgal (roughly $0.79 to $0.92/m^3) for large, efficient plants, and can be as high as $8.35/kgal ($2.21/m^3) for smaller capacity plants. This wide range of estimates exemplifies the site-specific nature of desal projects, and likely, a variation in reporting assumptions and methods.

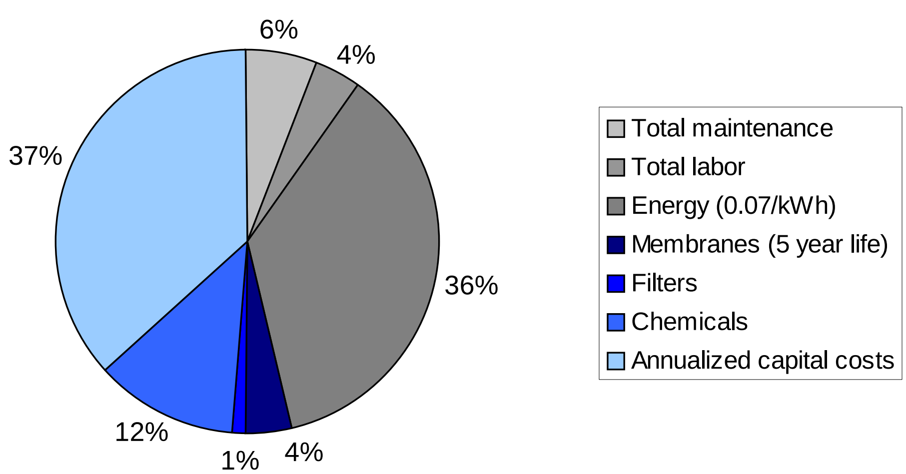
Based on an evaluation of reported costs for existing plants, the National Research Council (NRC) Committee on Advancing Desalination Technology provides a breakdown of annual costs for SWRO desal plants (NRC 2008). Figure 8.2 shows the typical breakdown of annual costs for a 50 mgd SWRO plant that uses conventional pretreatment. For this scenario, energy costs are assumed constant at $0.07/kWh. Membrane life is assumed to be five years, the nominal interest rate is 5%, and the depreciation period is 25 years. Annualized capital costs include both principal and interest payments.

The distribution of costs shown in Figure 8.2 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, concentrate management costs can significantly increase the total costs of desal at inland facilities (e.g., from 50 to 200% above the desal process costs (NRC 2008 as cited in Mickley 2007).

BWRO Desal

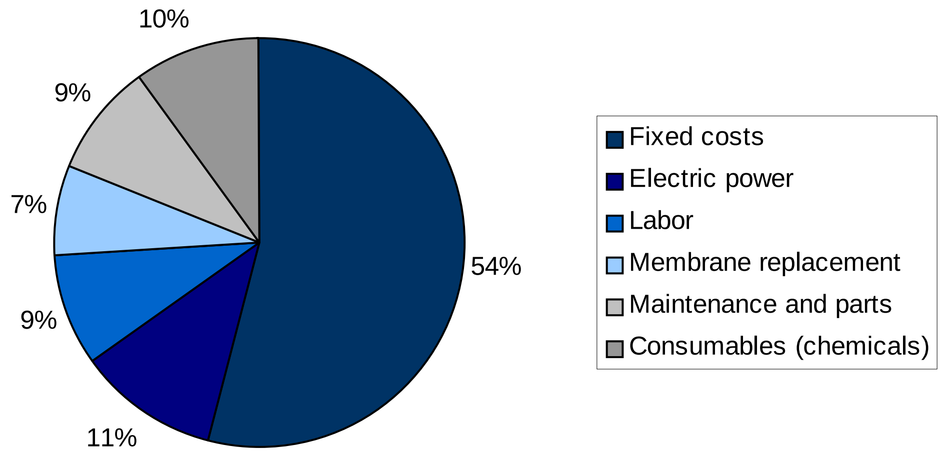
Due to lower levels of salinity compared to seawater, brackish water requires substantially less energy to desalinate. The unit costs of brackish water desal are therefore generally much lower than the costs associated with SWRO. In addition, compared to seawater sources, brackish water aquifers are often located relatively close to consumers; dramatically reducing treated water distribution costs. Many brackish groundwater sources also have a low level of suspended solids and require far less pretreatment than seawater sources (Pankratz Undated).

CDWR (2003) reports that the costs of brackish water desal range between \$0.40 and \$3.80/kgal (\$0.10 and \$1.00/m^3). Others report a tighter range, with costs between \$0.76 and \$1.33/kgal (\$0.20 and \$0.35/m^3) (Miller 2003, Dore 2005, AMTA 2007).



Source: NRC 2008.

Figure 8.2 Annual cost breakdown in a 50 million gpd SWRO plant with conventional pretreatment



Source: Adapted from Miller 2003.

Figure 8.3 Annual cost breakdown of a typical BWRO plant with conventional pretreatment

Figure 8.3 shows the contribution of various factors to the overall cost of BWRO desal as reported by Miller (2003). The capital investment required to build the plant typically accounts for more than half of total costs. The remaining portion is split among various operating costs. Compared to SWRO, the energy consumption associated with BWRO is relatively low, accounting for only about 11% of total costs. The consumables category, which includes various chemicals that are used to pre- and post-treat the water, accounts for 10% overall. Maintaining the plant, including replacing the membranes approximately every three years, makes up about 16% of total costs.

One conclusion that can be drawn from Figure 8.3 is that apart from fixed costs, improvements in any one aspect of plant operation will only result in an incremental improvement in the overall cost of BWRO (Miller 2003).

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 (Voutchkov 2007a).

- **Pretreatment.** The magnitude of pretreatment costs depends mostly on source water quality (turbidity/TSS and membrane fouling compounds) and the type of pretreatment technology used. The 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 five to three years can increase annual costs by over 3%. Catastrophic, irreversible membrane fouling leading to a membrane life of less than one 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. Voutchkov (2007a) 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 below.
- **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 WWTPs. In the US, 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 (Voutchkov 2007a).

- **Target product water quality.** Product water quality has a measureable 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 (Voutchkov 2007a). 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, high recovery processing, including ZLD, has historically been prohibitively expensive for municipal desal plants in the US (Mickley 2005).

PERMITTING AND WORKING WITH REGULATORS

This section provides a brief overview of regulatory and permitting issues, and offers a general common sense strategy for working effectively with regulators and permitting agencies to increase the odds of a successful permitting process and reduce the likelihood of delays and roadblocks. The discussion provided here also is aimed at helping utilities work more effectively with stakeholders and public officials who often use the regulatory and permitting process as the mechanism for expressing their concerns and raising impediments to implementation.

Other portions of this report, and the accompanying PIM, provide considerably more detail on the issues touched on here. In particular, chapters 5 and 10 (as well as chapters 4, 11, and others) and appendices B through F contain information that practitioners may find useful as they identify and address their regulatory and permitting challenges. Accordingly, this section is relatively brief and provides a broad perspective (since more detailed discussion is provided elsewhere in this report).

This information is based on discussions with several key state regulators, and leading utility and private vendor practitioners who have been working their way through the desal permitting process. These guidelines also apply to how a utility should communicate with its customers, local public officials, and other key stakeholders, as their concerns typically spill over into the permitting process, and vice-versa.

Demonstrate Your Clear Need for an Additional Water Supply

Provide a clear demand forecast aligned with established local and regional plans and expectations for population growth, changes in jurisdictional boundaries, and so forth. A desal project that is clearly linked to meeting existing needs or documented anticipated future needs, as consistent with municipal or other official planning documents (and within the current jurisdictional and service area boundaries), is more likely to be seen as truly necessary by regulators and stakeholders. In contrast, a proposed project that appears to be meeting ill-defined future needs (e.g., undocumented population growth or service area expansion) may be seen as speculative and potentially unnecessary.

Cite how climate change and climate variability may impact your future water supply and demand situation, as relevant. Also raise other issues that will (or are likely to) constrain your current water supply sources (or your other future supply options), such as increasingly restrictive limits on the amount of water that can be imported into your service area due to court rulings, environmental constraints, or other reasons (including dwindling import supplies and storage).

Demonstrate That Desal is Your Most Suitable Water Supply Option

Once the need for a supplemental future water supply is well demonstrated, expect to justify why other water supply options are less well suited than desal to meet those needs. Explain why other options will not address the problem adequately. In particular, be prepared to convince regulators and stakeholders that more aggressive demand side options—especially conservation and unaccounted for water controls (e.g., leak detection and control)—and alternative supply side options (including water reuse) are already being (or are planned to be) tapped to their reasonable maximum. Show that desal is being pursued because all other viable alternatives cannot meet the documented needs of the community or region.

Also, emphasize why you think desal is a good choice. Stress the benefits that desal provides (and which the other alternatives might not), such as drought-insensitive yield reliability, local control, and so forth.

Where relevant, show how your proposed desal project is integrated as a key component of a broad, regional water resource management strategy. In many instances, desal not only provides a potable water supply, but also addresses other regional water resource challenges (e.g., local groundwater contamination, seawater intrusion). In these instances, desal may provide a broad array of valuable environmental and social benefits, as well as a water source, and these are likely to be appreciated by regulators and stakeholders. Case studies of such broader, regional values are provided in the case studies in chapter 9 and appendix H.

Demonstrate That Your Desal Project is as Environmentally Sound and Carbon Friendly as Feasible for Your Circumstances

Considerable reluctance (or outright opposition) to desal projects often stem from environmental and energy concerns. Therefore, explore environmentally suitable feedwater intake and concentrate management approaches from the outset, rather than waiting until public and regulatory pressure forces your agency to explore some of the more benign alternatives. Be proactive rather than reactive.

For example, a coastal facility should be prepared to either adopt a feedwater intake approach that will minimize I&E (e.g., beach wells or other alternatives to open water intakes), or demonstrate that these alternatives are not technically viable in their specific coastal setting. If surface water intakes are the only viable feedwater option, then the utility should propose to deploy an open intake design and operating protocol (e.g., intake volumes, velocity, and timing) that will minimize I&E. Pilot testing is likely to be an integral part of this process (see appendix C).

In addition, consider how your agency can provide offsetting environmental restoration projects to enhance to ecologic, recreation, and/or other values that the desal operation may impact at your facility location. For example, committing to help restore or enhance a coastal marsh in the area will help compensate for any potential impacts the feedwater intake and/or concentrate discharge may have on local marine ecosystems.

On the energy use and GHG emissions side, adopt the same proactive strategy. Plan to deploy energy efficient and energy recovery methods to the highest degree practical for your situation. Consider and tap alternative energy supply options (e.g., solar or wind) to power your facility or to offset your use of traditional grid-supplied power. Be prepared to offer convincing evidence to regulators and stakeholders that your project will end up as energy efficient and carbon neutral as reasonably feasible.

Demonstrate Your Willingness and Ability to Address Regulator and Stakeholder Concerns

Respond directly to questions, data requests, and so forth from regulators and stakeholders. The more evasive and slower your utility is to respond to questions and data requests, the longer the delays you are creating for yourself.

Prompt and responsive actions create a positive impression on regulators and stakeholders, and tend to promote a more trusting, frank, and accepting attitude in the dialogue. Pilot testing and other well documented field evidence (from your utility, or from well documented experience gained by others) will likely be a critical component of the process.

Demonstrate That Your Desal System Design Will Reliably Perform as Advertised

Depending on your state and circumstances, regulators and stakeholders may have a variety of concerns (some well founded, and others perhaps not) regarding all or some aspects of the desalting process. Be prepared to demonstrate that your proposed approach relies on proven technologies for all critical aspects of the process, from feedwater intake to concentrate management, and including the membrane or other processes deployed for pretreatment and the desalting itself. Providing evidence from well designed and documented pilot tests, and/or from experiences gained at other utilities, will likely be critical components.

Demonstrate That You Will Monitor Your Performance and Address Any Issues That Arise

Acknowledge and commit to conducting suitable ongoing monitoring of how all key aspects of your desalting process are performing, once your receive approvals and start operating. Let regulators and the public know that if you receive permits and proceed to build and operate a desal facility, that you will meet and perhaps exceed requirements for monitoring and mitigating any observed adverse consequences.

For example, offer that once your coastal facility is permitted and operational, you will conduct reasonably extensive marine ecosystem studies over an initial period (perhaps above and beyond what the permit conditions might require) and make the results public. Commit to take suitable mitigating or offsetting measures if adverse impacts beyond what was anticipated are found. This approach provides comfort to some regulators and stakeholders who may feel that once they give your agency the green light, that they will have very limited leverage or opportunity to address issues that they are concerned may arise once the plant is operational.

UTILITY PLANNING AND MANAGEMENT

The evaluation, design, and implementation of a desal project involves a number of opportunities and challenges that must be addressed within the context of existing utility, community, and institutional systems. While the development of a desal project requires a long and involved process, proper planning can facilitate more rapid, less costly, and less frustrating implementation.

This following provides an overview of a desal planning and implementation framework (framework), developed as part of this project to facilitate desal project development. As shown in Figure 8.4 on the following page, the framework divides the desal planning and implementation process into six stages, as follows:

- Getting Started: Visioning and Goal Setting
- Implementation Planning
- Pre-Design
- Design
- Facility Construction
- Implementation

As depicted in Figure 8.4, for each stage of the planning and implementation process identified above, the framework identifies key questions to be answered, actions to be taken, and decisions to be made (before moving forward to the next stage). It is important to recognize that the stages build on each other, with each stage laying the foundation for the next. Costs are additive, and increase with each stage. It is therefore valuable to revisit the question, "Is desal a viable option?," at the end of each stage.

Further, given their complex nature, and the range of possible options, it is not uncommon for desal projects (especially seawater desal facilities) to be altered during the course of design, planning, public involvement and permitting. When such modifications are made, different stages of the process may need to be revisited.

In addition to the distinct phases of desal planning implementation, there are a number of processes that need to be conducted throughout the project period (i.e., during each stage of the planning and implementation process). These processes include:

- **Vision and planning**. The vision and plan for implementation should be revisited during each stage of the process. As more information is gathered or conditions change, the vision, and the steps necessary to achieve the vision, may need revision.
- **Leadership.** Effective leadership is essential to moving implantation forward and keeping it on track. For effective implementation, champions and leaders are needed both from managers and legislators (top down), as well as from those that will actually implement the process (i.e., engineers, operators). Having champions and project supporters from different stakeholder groups can also pay large dividends.

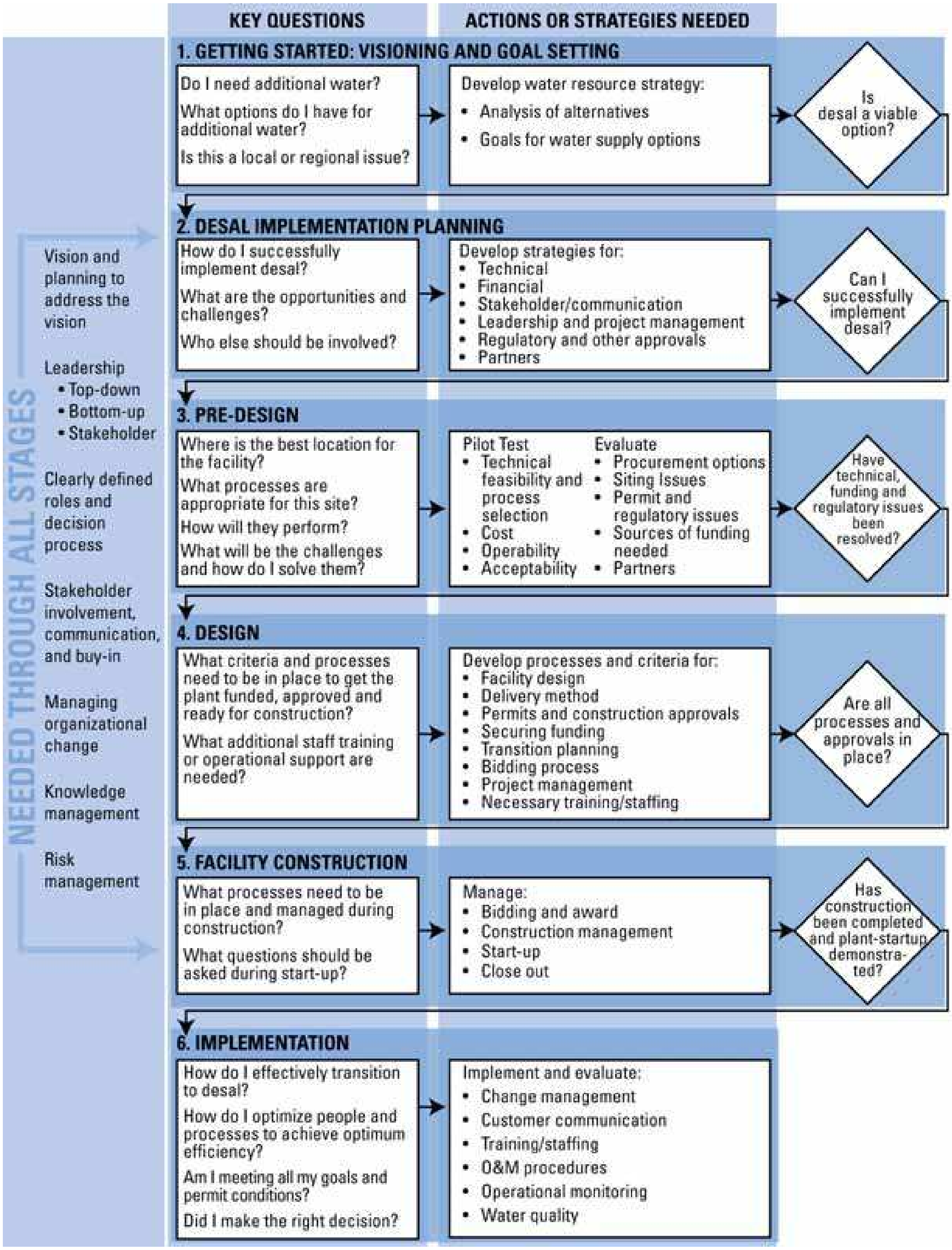


Figure 8.4 Overview of desal planning and implementation framework

- **Clearly defined roles and decision processes.** Implementing a major new process will require a wide range of staff, and in many cases, outside consultants. Defining roles is essential in ensuring that each task is effectively completed and to avoid duplication of effort. Understanding who makes the decision and/or process for decisionmaking should be defined.
- **Stakeholder involvement, communication, and support**. Also important to the planning process is engaging key stakeholders (e.g., boards, elected officials, regulators, environmental groups, and other third parties) and the broader public in the early stages of project development. Actively involved stakeholders are more likely to support and champion a project. Effective public involvement rests not only on early involvement but also in creating an open and transparent process that allows meaningful public input on issues of environmental, economic and community. Throughout the planning process, water providers should look for opportunities to involve stakeholders, and should be aware that stakeholders (especially elected officials) may change during the course of a project.
- **Managing organizational change**. Implementing a major new process can have a substantial impact on a water provider's workforce. Introduction of new technologies creates a level of uncertainty among employees with questions arising regarding how it will impact their job. This uncertainty can erode support for the project. Being aware and addressing change is essential for an efficient and functioning workforce.
- **Knowledge management**. Desal implementation requires the involvement of many people, numerous reports and documents, and a wide range of decisions. The project planning process typically takes several years prior to implementation. Personnel may change and/or key documents may be lost or forgotten. Knowledge management is needed to ensure that information is retained, updated, and available when decisions need to be made.
- **Risk management.** The planning and implementation framework essentially provides the water supplier with a process for risk reduction. Risks are greatly reduced through identifying and addressing key challenges. More information generally reduces risk, while lack of information increases risk. Key project risks include those associated with permitting, entitlement (ownership of land and infrastructure on site of proposed facility), availability and cost of power, changes in source water quality, changes in applicable regulations, uncertainties associated with unproven and new technologies and risks associated with the demand for desalinated water. Project risks should be evaluated at each stage of the implementation process.

Chapter 11 of this report provides additional detail on the desal planning and implementation framework, including a description of each phase of the process outlined above.

PROJECT DELIVERY METHOD

The process of planning, designing, financing, constructing, and operating a desal facility can be accomplished through a number of different approaches (i.e., project delivery methods) involving the water supplier (typically a public water provider) and multiple private service providers (NRC 2008). Project delivery methods vary based on the level of private involvement and the contractual relationship established between the public entity and the private service provider(s).

When planning and implementing new projects, public water providers have traditionally preferred a more utility-driven method of project delivery, referred to as DBB (Xu et al. 2009). This method allows for a high degree of involvement and control by the public water provider, because the public water provider oversees design and construction of the desal facility through separate contractual relationships. Under a DBB model, the public water provider is responsible for obtaining all permits, arranging funding, and will own and operate the plant when construction is complete. The primary disadvantage of this approach is that the public water provider bears responsibility for most of the cost, performance, and risk associated with the project (NRC 2008).

For many public water providers, the financial capacity and ability to perform desal under a DBB model is becoming quite limited. Water providers have therefore shifted towards alternative methods of project delivery that provide a higher level of private entity involvement and control. Alternative delivery methods can offer advantages over the traditional DBB model, including reduced total project costs and shorter time to project completion (NRC 2008). These different methods can also reduce the amount of risk taken on by public water suppliers (Voutchkov 2007a, NRC 2008).

Three of the most common alternative project delivery methods include (NRC 2008):

- Design-build (DB)
- Design-build-operate (DBO)
- DBOOT

The following sections describe the alternative methods of desal project delivery outlined above. Table 8.2 provides a summary of the advantages and disadvantages associated with each approach.

Design Build

A DB delivery approach is characterized by a single contractual relationship between the public water provider and a sole contractor, who designs the project and oversees its construction. This arrangement reduces the potential for conflicts or disputes, thus reducing the potential for delays, while offering single-point accountability. A DB approach provides the public water provider with a guaranteed cost, schedule, and performance for the project while transferring the resultant risk to the DB contractor. With the DB approach, the public agency may benefit from newer, innovative technology because the contractor is more focused on facility performance rather than on equipment or construction specifications. However, a public water provider must concede some control over design details (NRC 2008).

Table 8.2
Advantages and disadvantages of common project delivery methods

	Advantages	Disadvantages	Works best when . . .
DBB	• Well understood by all parties • Potential for high degree of control and involvement by owner • Independent oversight of construction contractor	• Segments design, construction, and operation and reduces collaboration • Linear process increases schedule duration • Prone to disputes and potential risk avoidance by designer and construction contractor • Low-bid contactor selection reduces creativity and increases risks • Risks mostly borne by owner • For new technologies, operability may not be primary design concern	• Operation of facility is minimal or well understood by owner • Requires high degree of public oversight • Owner wants to be heavily involved in design • Schedule is not a priority
DB	• Collaboration between designer and contractor • Parallel processes reduce duration • Reduces design costs • Reduces potential for disputes between designer and construction contractor • Single point of accountability • Can promote design innovation • Provides more certainty about costs at an earlier stage • Allows owner to assign certain risks to DB team	• Owner may not be as familiar with DB process or contract terms • Reduces owner control and oversight. • Owner's rejection of the design can entail large change orders and delay claims • Design and "as-built" drawings not as detailed • Eliminates "independent oversight" role of designer • Does not inherently include incentives for operability and construction quality • Higher cost to compete	• Time is critical but existing conditions and desired outcomes are well defined • Project uses conventional, well-understood technology • Owner willing to relinquish control over design details • Operational or aesthetic issues are easily defined • Early contractor input will likely save time or money

(continued)

Table 8.2 (continued)

	Advantages	Disadvantages	Works best when . . .
DBO	• Allows designer, construction contractor, and operator to work together collaboratively • Parallel processes reduce duration • Operator input on new technologies and design saves money • DBO contractor has incentive to assure quality since they will be the long-term operator • Single point of accountability • Allows owner to assign certain risks to DBO contractor • Economies of scale • Collaboration, long-term contract, and appropriate risk allocation can cut costs • Defines long-term expenses for rate setting	• Reduces owner involvement • Owner may not be familiar with DBO contracting • High cost to compete may limit • competition • May give operator incentives to overcharge for ongoing renewals and replacements or to neglect maintenance near end of the contract term • Operations contract may limit long term flexibility • Requires multiphase contract	• Owner's staff does not have experience operating the type of facility • Input conditions to facility can be well defined and the number of external influences affecting plant operations are limited • Owner is comfortable with less direct control
DBOOT	• Same as DBO and: • Can be used where project expenditures would exceed public borrowing capacity • Can preserve public credit for other projects is important • Can isolate owner from project risk	• Same as DBO	• Public financing cannot be obtained • Transfer of technology risk is important

Source: Adapted from NRC 2008.

Design-Build-Operate

A DBO project involves a single contractor for design, construction, and operation. Similar to the DBB method, the DBO approach also involves asset ownership by the public entity (Voutchkov 2007a). The DBO model streamlines the project schedule and reduces costs by eliminating separate selection processes for engineering, construction, procurement, and operating services. The contractor provides the public water provider with cost, schedule, and performance guarantees assuring that the project will perform as required, and that the equipment will be maintained, repaired, and replaced according to reasonable and measurable standards. Thus, like the DB model, the DBO model approach transfers certain risks from the public water provider to the private contractors (NRC 2008).

DBO is an option utilities often consider if they lack in-house technical expertise with desal or similar projects or processes. This method is particularly popular for fast-track or complex projects that include relatively new technology or specialized O&M expertise. With a vested interest in controlling operating expenses, DBO contractors have a greater tendency to accept the risk of employing new and innovative solutions to lower production costs and improve operability (NRC 2008).

Design-Build-Own-Operate-Transfer

DBOOT projects are an expansion of the DBO concept in which the contractor also finances the project and initially owns the facility. The public water provider commits to purchase some quantity of water from the desal facility at an agreed-upon price over some period of time. This water purchase agreement serves as collateral for the contractor to secure private financing for the project. DBOOT contracts contain provisions to transfer ownership of the facility to the public water provider at a mutually agreeable date (NRC 2008). Most large seawater desal projects Europe, Israel, Asia, the Caribbean, and the US are typically implemented using the BOOT method of project delivery (Voutchkov 2007a).

The primary benefit of the DBOOT method of project delivery is that a private enterprise assumes most of the risk associated with the project, including the risk of development, permitting, and financing. The public water provider and their ratepayers are relieved of the financial burden of the project; they pay only for water they have contracted to purchase (at a pre-determined rate). The public water provider will be financially protected by performance bonds, professional liability insurances, and liquidated damages provided by the contractor. In addition, the rate payers will benefit from the stabilization of rates (i.e., no rate increases) over the contract period. Although these measures provide some level of financial protection, certain consequences of plant failure will remain with the public water provider, which is obligated to meet customer demand.

Similar to DBO, under DBOOT contractors have a vested interest in controlling operating expenses. Thus, the contractors have a greater tendency to accept the risk of employing new and innovative solutions to lower production costs and improve operability. Voutchkov (2007a) reports that most technological advances in desal technologies have occurred under DBOOT contracts.

Traditionally, a drawback of the DBOOT approach has been that lower-interest-rate and tax-exempt public financing is not typically available to private-sector developers. This may prevent private developers from offering a competitive financing advantage, unless the promise of future public ownership through a DBOOT model can be used to obtain government financing rates. However, more recently, financing rates for private entities to implement desal have become competitive with those offered to public agencies. Regardless, private financing of is on the rise.

Private-Public Partnerships in Practice

Some members of the public, and some public officials, have expressed concerns over having private sector entities involved in desal projects. This stems from a deeper philosophical issue about what role (if any) the private sector should play in the provision of water as an essential good and public service (e.g., critical to life, health, safety, and welfare) (Stratus Consulting 2006).

In addition, many public agencies argue that the private model has few advantages over traditional approaches because the public sector has access to the same expertise and technology as the private sector. In some instances, public agencies can also obtain lower cost financing and may have greater access to development subsidies, both of which help keep water rates low (Xu et al. 2009). Many public agencies claim that the risks of water shortages are the same under private and public models, and thus there is no real mitigation of risk.

Despite these concerns, as public entities face growing budgetary constraints, many locally-elected officials are attracted to the perceived benefits of "privatizing" all or some of their water service responsibilities (CCC 2004). Concurrently, a number of domestic and multinational business entities have identified providing water or "water services" as an attractive profitable investment opportunity. In California, among the approximately two dozen desal projects currently proposed along the coast, at least six are proposed as private-held facilities or public/private partnerships, including two (in Huntington Beach and Carlsbad) that would be the largest coastal desal facilities in the US. As a private commodity, desal may be developed, managed, and marketed as a for-profit product subject to market forces and practices. The full range of public interest values might not be fully considered during planning, design and operation (CCC 2004).

Ashkelon Seawater Desalination Plant in Israel was the first large desal facility to successfully utilize the BOOT method of project delivery. The state government of Israel awarded a 24-year, 11-month contract to VID Desalination Company Ltd. The VID Desalination Company is a special purpose company, or consortium, established by Vivendi Water, IDE Technologies Ltd., and Dankner Ellern Infrastructures Ltd. to design and operate the desal plant. The agreement stipulated that the state could request VID Desalination Company to double plant production capacity during the term of the contract. Ultimately, this capacity extension enabled the VID Desalination Company to lower the desalinated water price below 1.89 US$/kgal (0.50 US$/m^3), a first in the desal history; the doubling of the capacity also made the Ashkelon project the largest SWRO desal plant in the world (Xu et al. 2009).

The experience of TBW demonstrates some of the potential disadvantages (e.g., loss of control) associated with public-private partnerships. In their case, it resulted in an inoperable facility and the need to then hire another private entity to fix their problems at considerably greater total cost than originally anticipated. In 1999, TBW selected Poseidon Resources, after an open competition, as the private partner for their planned desal project. As a DBOOT project, the agreement presumed that Poseidon would assume risk for the plant's development. The DBOOT agreement was intended to reduce costs while keeping tight government control, flushing out flaws in proposals and typically achieving lower prices through competition (Xu et al. 2009 as cited in Rand 2003). The DBOOT approach would also allow TBW to leverage the efficiencies of the private sector and still take advantage of the tax-free financing available to governments.

The DBOOT process demonstrated value when the plant constructors Stone and Webster and Covanta each had financial problems (e.g., associated with a collapse in the market post-September 11, 2001) (Xu et al. 2009 as cited in Rand 2003). In July 1999, Poseidon Resources originally selected Stone & Webster to design, engineer, and build the plant, but the company went bankrupt. Poseidon then brought in Covanta Energy in December 2000 to take over responsibility for plant construction. In 2002, due to technical challenges related to intake and pretreatment and contractor financing problems, TBW decided to acquire the desal plant, which was approximately 50% constructed. Since that time, plant costs increased from the originally estimated \$110 million to over \$150 million (construction oversight: \$4 million, remediation and improvements: \$36 million, attorney fees for lawsuits: \$6.8 million). The promised water price increased from \$1.71/kgal (\$0.45/m^3) in 1999 to \$3.19/kgal (\$0.84/m^3) in 2007 (Xu et al. 2009 as cited in Barnett 2007).

A key component of selecting a DBOOT contractor is to conduct a solid review of the company's financial strength. However, as made evident by the Tampa Bay experience, factors beyond the company's control (or the public agency's ability to anticipate) can greatly influence the DBOOT process. This represents a risk to the prime DBOOT contractor (e.g., in the case of Poseidon having to bring in Covanta Energy after Stone & Webster declared bankruptcy), and can delay the process.

In Texas, the use of several alternative project delivery methods was only recently made legal. Before 1995, with few exceptions, construction work in Texas was delivered by the DBB method, using competitive bidding with an award to the low, responsible bidder. In 2001, authority to use the DB method of project delivery was given to certain public entities, however, it was limited to vertical construction (construction of buildings). In 2007, with the passage of House Bill (HB) 1886, the authority was extended to horizontal construction (e.g., civil works types projects such as roads, streets, bridges, utilities, water supply projects, water plants, desal projects) provided certain specifications are met.

CHAPTER 9
CASE STUDIES OF DESAL PLANNING AND IMPLEMENTATION

This chapter provides a series of short case studies to offer useful insights across a range of desal implementation challenges. The case studies are organized according to the specific topic areas they address (e.g., seawater intakes, concentrate disposal, regional approaches). Table 9.1 provides an overview of these case studies to help guide readers to the specific examples and topics most relevant to them. The listing of the case studies shown in the table also corresponds to the order in which the write ups are presented in this chapter. Additional detail on several of these case studies can be found in appendix H.

LONG BEACH WATER DEPARTMENT: UNDER-OCEAN FLOOR SEAWATER INTAKE AND DISCHARGE

Background

LBWD is pursuing seawater desal as a new source of potable water for its service area. A 8.9 mgd (33,700 m^3/d) seawater desal plant is expected to provide 10% of the city's municipal water supply (LBWD 2009a). In addition to testing the operational feasibility of various desalting membrane technologies, including the patented two-pass nanofiltration (NF^2) process and traditional seawater RO, LBWD is also performing research to demonstrate that viable, environmentally responsive intake and discharge systems can be developed along the coast of California.

Traditionally, open ocean intake structures have been used to convey the seawater into the plant, drawing seawater through a meshed intake screen. However, the use of open ocean intakes can cause negative impacts on the environment, particularly when marine microorganisms become impinged on the screens or pass through the screens and become entrained within the plant process. Increasingly strict federal regulations require that I&E mitigation measures be employed for seawater intakes. Moreover, while the intake screens prevent debris and most aquatic life from entering, elevated levels of suspended solids and other constituents still have to be removed through pretreatment.

On the discharge side, open ocean outfalls have often been used to convey the concentrate stream back into the ocean. Because the RO concentrate contains salinity and other constituents in concentrations substantially higher than the receiving body, there may be negative environmental impacts associated if mitigation measures are not employed (LBWD 2009b).

Currently, LBWD is experimenting with an Under-Ocean Floor Seawater Intake and Discharge Demonstration System designed by LBWD and the USBR (LBWD 2009c). The filtration system is based on using perforated laterals placed under the ocean floor to collect or expel the water through either natural media found on the ocean bed, or alternatively, filter media placed into an excavated area on the ocean floor (ocean floor system). The intake system is based on the concept of slow sand filtration (< 1 gpm/ft^2), which should mitigate negative impacts by virtually eliminating both I&E. Additionally, the seabed will act as filter media and should offer some pretreatment benefits, including a reduction of organic and suspended solids.

Table 9.1
Overview of desal planning and implementation case studies

Case study	Description	Key issues addressed	Additional resources
Feedwater intakes			
Long Beach Water Department: Under-Ocean Floor Seawater Intake and Discharge	LBWD designed, constructed, and is currently operating a demonstration-scale subsurface seawater intake and discharge facility.	1. Subsurface seawater intake and concentrate discharge 2. Pilot and demonstration testing	http://lbwd-desal.org/SeawaterIntake.html
Municipal Water District of Orange County: Feasibility Studies of Slant Well Ocean Intake	At a coastal state park at Dana Point, MWDOC completed a demonstration project in May 2006 and a slant well feasibility study in March 2007. Currently the Phase 3 pilot-plant testing and water quality testing is in progress.	Testing protocols and initial results for a slant well approach to ocean water intake	http://www.mwdoc.com/documents/FinalDraftReport4-6-07.pdf http://www.mwdoc.com/documents/DanaPointOceanIS-MND8May2008wofigs.pdf
Case Studies on Evides and TBW Challenges of Using Cooling Water Discharge from a Co-Located Power Plant as Desal Source Water	Water quality and other operational challenges are described for two facilities using OTC water from co-located power plants as SWRO feed water: Tampa Bay, Fla., and Evides Integrated Membrane System in Terneuzen, Netherlands.	Elevated feedwater temperatures and factors create biofouling, corrosion, and other desal challenges	
Concentrate management			
EPWU: Inland Concentrate Disposal through Deep well Injection	Concentrate disposal is a challenge to inland desal facilities. The case study discusses the selection of deep well injection as compared to other options, and technical, operational, and permitting issues.	1. Regulations and permitting of deep well injection 2. Operating issues 3. Costs (capital and O&M)	http://www.ibwc.state.gov/Files/ibwc080907.pdf http://www.gwpc.org/meetings/uic/2009/proceedings/Hutchison,%20Bill.pdf
Perth Seawater Desalination Plant: Ocean Concentrate Disposal	The case study discusses the environmental impact and design of a standalone concentrate discharge ocean outfall, and monitoring results.	1. Environmental impact of concentrate ocean disposal 2. Dedicated outfall despite co-location with power plant 3. Outfall design and monitoring	Underwater footage from the Perth Desal Plant can be viewed at: http://www.watercorporation.com.au/_files/mmedia/Under_the_Surface_small.wmv

(continued)

Table 9.1 (continued)

Case study	Description	Key issues addressed	Additional resources
Desal projects—pilot and demonstration testing			
West Basin Municipal Water District: Pilot and Demonstration Testing for Seawater Desal	Pilot and demonstration testing of ocean feedwater intake options and membrane processes.	Experiences of pilot-testing and demonstration project will lay foundation for permitting, and design and operation of full-scale plant	http://www.westbasin.org/water-reliability-2020/ocean-water-desalination/overview
Phoenix Water Services Department: Feasibility Study and Pilot-Testing for Inland Desalting	Pilot and demonstration testing of desalting approaches, and concentrate management options.	1. Feasibility and economics of concentrate disposal options 2. Membrane performance treating surface and groundwater, high water recovery	
Energy saving and GHG emissions			
Ashkelon, Israel: Managing Energy Demand for Large-scale Seawater Desalination	This case study illustrates the strategies to meet energy demand and improve energy efficiency at large seawater desal plants.	1. "Center" design 2. ERDs 3. On-site power generation	Complete description available in Water Research Foundation report for project 4006
Thames, Perth, and Sydney: Use of Alternative Energy for Desalination	Renewable energy sources used in Thames, Perth, and Sydney desal plants.	1. Reduce GHG emissions by renewable energy 2. Public/political perception for use of renewable energy for large desal projects	
Carlsbad Seawater Desalination Plant: Climate Action Plan	Climate Action Plan.	1. GHG emission from the desal plant 2. Carbon offset projects and RECs	http://www.carlsbad-desal.com/environmental_stewardship.asp

(continued)

Table 9.1 (continued)

Case study	Description	Key issues addressed	Additional resources
Desal project development and regional collaboration			
Santa Cruz: Regional Coordination and Partnering Between Water Agencies to Facilitate Desal Implementation	Neighboring utilities determine that a joint coastal desal project provides a viable and advantageous approach to their water supply problems.	Forging cooperative arrangements to pursue mutually beneficial partnering	Extended case study, by Brent Haddad, provided in appendix H
Monterey County: Collaborative Desal Implementation to Solve Regional Water Resource Management Issues	A regional approach provides a more publicly viable and economically and environmentally advantageous approach compared to go-it-alone desal projects.	Challenges in utility-specific options mitigated with a broader, regional approach	Extended case study, by Steve Kasower, provided in appendix H
Chino Basin: Groundwater Desal as an Integral Part of Comprehensive Regional Water Resource Management	Triple Bottom Line (TBL) analysis of the benefits and costs of brackish groundwater desal.	Reveals how the benefits of desal may be magnified when desal is used as part of an integrated regional strategy to manage water resource challenges	Extended case study, by Robert Raucher, provided in appendix H.
Tampa Bay Seawater Desal: Issues in Project Delivery	History of desal project, technical and engineering challenges, financial and contractor challenges, permitting, and lessons learned.	Details experience using a public private partnership (DBOOT) to implement seawater desal	

For the discharge system, the concentrate will diffuse through the seabed mitigating potential negative impacts associated with point discharges.

Another advantage of this "sandbox" approach is that flow rates and system operation are not affected by waves and tides. In fact, the action of waves and tides is expected to function as a natural cleaning agent for the beach sand. The system is expected to be essentially maintenance-free, requiring no backwashing, cleaning, treatment, recharging, and/or rehabilitation, so there are no O&M costs.

This project is divided into two test phases: pilot and demonstration (LBWD 2009c). The pilot-scale testing will be conducted using 8-inch diameter columns to simulate the seabed, and the demonstration-scale testing will be conducted at a near-shore facility, with two 5-foot deep pits. The intake pit area measures 56 ft by 68 ft, and the discharge area measures 47 ft by 57 ft.

Pilot-scale Test Facility

The goals of the pilot-scale testing include:

- Evaluate the impacts of various filter media (two types) on the quantity and quality of seawater delivered to the desal process
- Evaluate the impacts of various intake filtration rates (0.05, 0.1, 0.25, and 1 gpm/ft^2) on the quantity and quality of seawater delivered to the desal process
- Evaluate the impacts of media and filtration rates on stability of operations (i.e., head loss, permeate production, water quality) for the intake system
- Derive suitable operational parameters for demonstration-scale testing based on the test results

The source of the raw water is the Haynes generation station intake, which is more stable in turbidity than that at the ocean floor system. Although the source water is not the same, an attempt is made to simulate and predict performance through pilot-scale testing. The pilot-scale test facility is located at the LBWD Prototype Seawater Desalination Facility. Six filtration columns are proposed to test three filtration rates and two types of engineered sand; one is the actual sand used for the demonstration-scale ocean floor system.

The pilot-scale testing started in May 2008, and will operate until 2011. The pilot test facility will be operating at infiltration rates similar to the demonstration project. The pilot will allow the collection of additional data (i.e., pressure loss through the filter) that are not available at the demonstration site due to facility limitations. In addition to operating the columns at the same initial slow rate of the demonstration ocean floor system, the pilot will test rates an order of magnitude greater than the typical slow sand filtration rate (1.0 gpm/ft^2). If the higher rates are proven successful, then the intake footprint could potentially be reduced by as great as one order of magnitude, which will significantly reduce footprint and environmental concerns during construction. Moreover, the higher rate tests will provide preemptive assessment of potential operational problems that may arise when operating at the higher rates, and provide foresight on how to properly proceed to the next steps at the demonstration scale. Lastly, the pilot testing will assess alternative media, which will provide insight into potential cost savings if the results prove that more commonly available media can be used for the ocean floor system (LBWD 2009c).

Demonstration-scale Test Facility

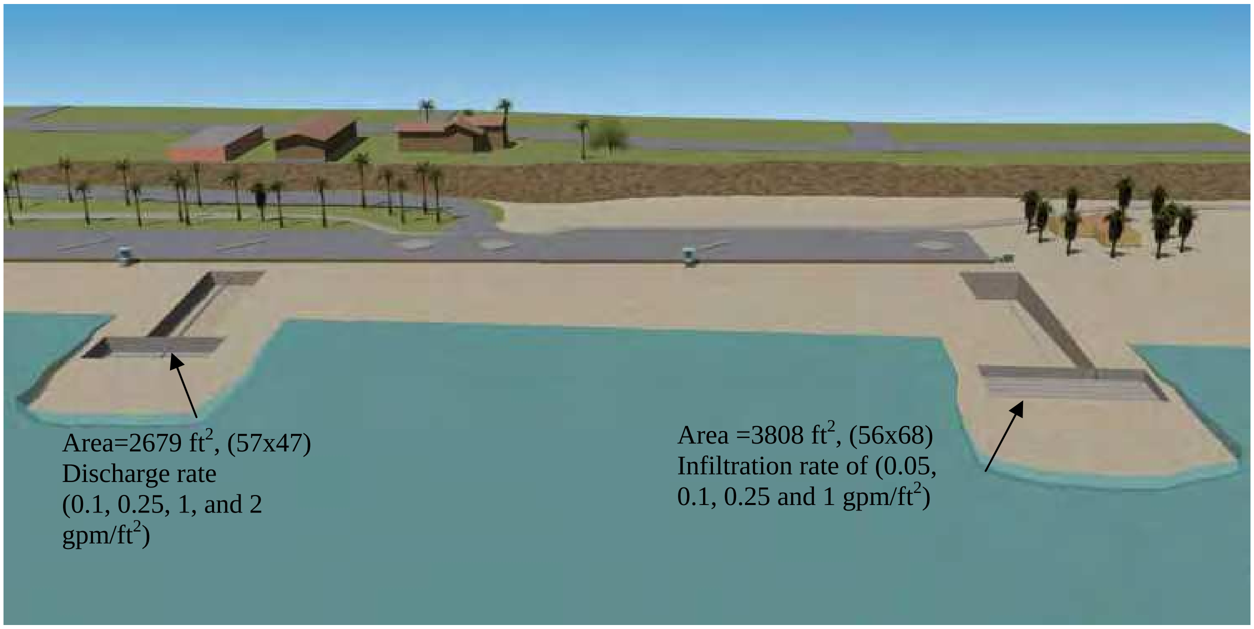
The goals of the demonstration-scale testing include:

- Determine the maximum intake filtration rate that can be sustained over a long-term period (up to six months).
- Evaluate the seasonal water quality impacts on the quantity and quality of water produced from the intake system.
- Evaluate the impacts of various discharge rates (0.1, 0.25, 1, and 2 gpm/ft^2) on the water quality of the receiving body from discharged concentrate.
- Evaluate the visual impacts of discharge such as ponding, artesian phenomenon, and media losses.
- Evaluate the seasonal impacts on the concentrate discharge system, and discharge flows through various tidal conditions.
- Based on the results of the tests, derive suitable parameters for design for the full-scale intake and discharge system.
- A tracer study, permit pending, will look at the effective system-wide diffusion of concentrate for full-scale design parameters, as the demonstration site will not be discharging concentrate.

The demonstration-scale intake and discharge structure is shown in Figure 9.1. The water will be collected through a series of six-inch diameter "V-Wire" screens with slot openings of 0.05 inches along the bottom of the pit (Figure 9.2). The influent water is then pumped to the discharge gallery, using the same screen and sand configuration as the infiltration gallery. The collector and discharge screen is placed in an "A-Symmetrical pattern" to allow variable infiltration and discharge rates.

Multiple agencies are involved in permitting the ocean intake, including:

- USACOE under section 10 of the Rivers and Harbors Act
- Regional Water Quality Control Board (RWQCB) under section 401
  - Waste Discharge Requirement (WDR) Permit
  - Stormwater Pollution Prevention Plan (SWPPP)
- CCC for Coastal Development Permit (CDP)
- City of Long Beach
- State Lands Commission



Source: LBWD.

Figure 9.1 Under-ocean floor seawater intake and discharge demonstration system

Source: LBWD.

Figure 9.2 Collector piping

The demonstration-scale testing started in June 2008, and was originally anticipated to consist of 12 months of testing, as limited by LBWD's CCC land use permit (LBWD 2009c). LBWD recently obtained a two-year extension from the CCC to continue operation and testing until 2012 (Eakins 2009, Wang et al. 2009). Preliminary testing results show that:

- Infiltration rate and production of the intake are not impacted significantly by tidal fluctuations
- Filtered water quality of the infiltration bed alone is not consistent compared to MF/UF pretreatment
- Both intake and discharge beds have not shown any signs of clogging at design conditions

LBWD will soon begin testing filter loading rates above design conditions (> 0.15 gpm/ft^2). Future work will also include assessment of the biofouling potential of the filtered seawater (Wang et al. 2009).

MUNICIPAL WATER DISTRICT OF ORANGE COUNTY: FEASIBILITY STUDIES OF SLANT WELL OCEAN INTAKE

South Orange County, California, is heavily dependent on imported water. Ninety-five percent of its drinking water is imported from Northern California and the Colorado River. The MWDOC is proposing a 15 mgd (56,800 m^3/d) ocean desal plant in Dana Point, which would increase its local water resource by 13% and improve system reliability for the area (MWDOC 2005).

MWDOC is particularly interested in testing the feasibility of a slant beach well technology for production of ocean water from sands and gravels that underlie the ocean. The first two phases of a three phased hydrogeologic investigation was conducted, and a fully buried 12-inch diameter, 350-foot long test slant well was constructed on Doheny State Beach (MWDOC 2007). A short-term aquifer and water quality pumping test was conducted to determine well performance, aquifer properties, water quality, and other parameters pertinent to RO operation. The slant well intake was found to have the least environmental impact on the ocean compared to other feedwater technologies evaluated, while providing very good yield and excellent feed water quality. The results of the preliminary testing are summarized below:

- Water produced from the test slant well has very low turbidity and SDI levels, indicating the effectiveness of the very slow natural sand filtration provided by the alluvial aquifer. The water may not require pretreatment prior to RO desal, which would substantially lower capital costs.
- The well will be influenced from fresh groundwater, and the feed water may be initially high in dissolved iron and manganese until equilibrium with the ocean is established (after pumping for approximately one to two months). Modeling predicts the slant wellfield would produce 95% ocean water, which has little iron. Oxidized, filterable iron and manganese solids may foul or degrade the RO membranes if not kept in an anoxic, dissolved form or removed. This may require modification in the design and startup operation of the RO desal facility.

Although preliminary pilot well tests have been promising, long-term testing is needed to more thoroughly establish water quality parameters and to establish full-scale desalting process design. Currently, Phase 3 pilot plant testing and water quality testing is being undertaken to measure changes in salinity and other water quality parameters affecting RO process performance (MWDOC 2009) (see Figure 9.3). This will require operating the test slant well for 18 months. In addition to measuring water quality, Phase 3 testing will provide hydrologic and radium isotope data, which will then be used to validate and refine the existing groundwater model. Finally, Phase 3 testing will evaluate whether pretreatment for low levels of iron and manganese are required, post-treatment requirements for RO product and RO concentrate, materials corrosion, and microbial growth when operating the test slant well with a nitrogen environment to maintain anoxic conditions in order to determine the oxidation state of water being pulled into the well. This information will also be useful in assessing corrosion and biofouling control approaches.

The test slant well wellhead is currently buried 3 ft vertically below the ground surface so as not to create any nuisance on the beach (MWDOC 2009). The well casing and screen extend perpendicular from the beach face offshore for 350 lineal ft at a 23° angle from horizontal. Dual rotary water well drilling technology was utilized in constructing the test slant well.

Source: Bell 2008.

Figure 9.3 Phase 3 extended pumping and pilot plant testing facilities, Doheny State Beach, feasibility investigation, Dana Point Ocean Desalination Project

The slant well intake approach has been well received by the CCC and the environmental community.

Since the fall of 2004, MWDOC's Phase 1 and 2 feasibility investigations received State Parks' approval and support, a State Lands Commission Lease, a Regional Board NPDES Permit and 401 Certification, a USACOE Nationwide Permit and Jurisdiction Determination, and CCC CDPs (Bell 2008).

The Phase 3 Extended Pumping and Pilot Plant Testing is fully funded and permitted. The Phase 3 test facilities are now under construction and are expected to be ready for operation in May 2010. MWDOC has recently retained a firm specializing in pilot plant operations and RO testing to provide professional engineering services for the Phase 3 work.

CASE STUDIES ON EVIDES AND TAMPA BAY WATER CHALLENGES OF USING COOLING WATER DISCHARGE FROM A CO-LOCATED POWER PLANT AS DESAL SOURCE WATER

Introduction

A desal facility co-located with a power plant can use the power plant's cooling water discharge as desal feedwater, saving the construction of a separate intake structure, intake pipeline, and screening facilities (i.e., bar-racks and traveling water screens). The cooling water discharged from the power plant's condensers is often warmer than the ambient source ocean water. This typically is a significant benefit because the RO process requires approximately 5–8% lower feed pressure when the influent seawater is an average of 6°C (10°F) warmer (NRC 2008). However, increased temperatures in the feedwater can result in an adverse increase in salt passage and potentially accelerated biofouling of the membrane. There are also other unforeseen O&M problems by using the elevated temperature water as source water.

This section contains two case studies (one from the Netherlands, and the other from Tampa Bay, Florida) to reveal practical experiences to illustrate the challenges of using cooling water discharge as source water for seawater desal. The key findings are that desal facilities may encounter serious biofouling, corrosion, and other unforeseen problems by using OTC water as source water. A thorough understanding of variability of source water quality, long-term pilot testing, adequate and robust pretreatment, flexible process design, and sufficient pretreatment capacity are critical to ensure adequate design and maintain sustainable operation of a desal facility.

Evides Integrated Membrane System in Terneuzen, the Netherlands

The DECO water treatment facility (operated by Evides Industriewater B.V.) produces demineralized water, cooling tower supply water, and ultrapure water for the Dow Benelux B.V. ("Dow") production facilities in Terneuzen, the Netherlands. This desal plant began as a two–pass seawater RO treating OTC water discharged from a co-located power plant in 2000, and has been converted to operate on secondary effluent from a municipal WWTP since 2006 (WDR 2009).

Van Agtmaal et al. (2007) discussed four years of practical experience with an integrated membrane system (IMS) treating the OTC seawater. The construction of the various water treatment installations started in 1998, and the 4.8 mgd (18,000 m^3/d) plant was operational in 2000. The temperature of the feed water is increased, on average, by approximately 10°C in the cooling system.

Contrary to the initially expected advantages of enhanced flux, reduced RO feed pressure, and decreased energy consumption due to elevated feedwater temperature, the use of preheated seawater from the tidal estuary as feedwater to the IMS has resulted in many unexpected problems in O&M of the IMS. Problems that included corrosion and biofouling were thought to be intensified by the higher temperature of the seawater. Another problem was the high turbidity loads in the water caused by the ships and barges at the open intake. Additionally, the design of the IMS was based on overly optimistic performance parameters, which had not been properly evaluated by means of a long-term pilot study.

Engineering failures and operational malfunctions surfaced directly after startup of the IMS plant. Other disadvantages became evident in time, including insufficient membrane cleaning processes, corrosion, limited process automation, and poor performance data processing. As a result, the design capacity of the IMS has never been achieved. Substantial modifications to the IMS were made in 2004.

In spite of the improvements and retrofits, as well as the optimization of the process, the cost of maintenance and the applied chemicals and energy of the IMS is considerably higher than expected. In 2006, the plant was re-engineered to treat municipal waste water originating from the City of Terneuzen. The plant continues to employ the existing MF system for RO pretreatment. The SWRO system was replaced with a two–pass BWRO system employing new fouling resistant Dow Filmtec membranes, while the existing second pass BWRO system remained unchanged. High-pressure feed pumps were replaced with lower pressure pumps and the process automation system was also replaced.

With the new feed water source and the implementation of low pressure feed pumps and process automation adjustments, water recovery has increased by 20% and operational expenses are half of a sea water treatment system. In addition, the city’s waste water is no longer discharged to the sea. Biofouling will continue to be a challenge with a waste water as feed source for the IMS system. The existing MF system will be replaced by an Norit X-Flow air-lift MBR system at the city wastewater treatment plant, where it will polish the effluent prior to feeding the RO (WDR 2009).

Tampa Bay Seawater Desalination Facility

The Tampa Bay Desalination Plant uses cooling water discharged from Tampa Electric’s adjacent Big Bend Power Station as feedwater during some times of the year. Gross pretreatment inadequacies were also encountered at the Tampa Bay Seawater Desalination Facility that uses the cooling water discharge from the co-located Tampa Electric Big Bend Power Station. The plant experienced serious startup problems related to particulate fouling and inadequate pretreatment of the raw water. As a result, the plant had to be shut down for repair due to the deficiencies in the design and construction of the pretreatment and intake units (Cooley, Gleick, and Wolff 2006; Xu et al. 2009).

The 25 mgd (94,600 m^3/d) seawater RO desal plant built in Tampa Bay, Florida, started construction in January 2001, and began producing water in March 2003. It operated intermittently through May 2005, supplying approximately 5 billion gallons of drinking water to the region over the time period. However, the plant did not meet contractual performance standards, and was taken offline for remediation in June 2005. Remediation of the plant was completed in March 2007. A redesign of the pretreatment system was a critical part in the remediation project. The new pretreatment consists of two identical parallel trains, each including raw water screening, dual flocculation, and sedimentation basins with a capacity for approximately 50 mgd. The new pretreatment project includes the following processes (Rodríguez 2008):

- Modifications were made to the existing continuous backwash upflows and filter to convert the system from a 16 dual-stage sand filter system to a 32 single-stage filter system, and improve overall and individual monitoring capabilities, independent filter control, and operating efficiency.
- A new diatomaceous earth (DE) precoat filtration system was also added between sand filtration and cartridge filters to prevent particulate fouling of the cartridge filters and RO membranes.

Operating experience revealed that membrane fouling is still a problem in the retrofitted plant. Periodically, the desal plant withdraws cool water from a point prior to the power plant condensers. This type of raw water withdrawal activity is severely constrained by permit conditions and can only be done when the power plant cooling water is too hot and would cause membrane performance problems. The operation of the desal facility is intrinsically tied to the operation of the power facility and essentially cannot operate if the power plant is down for any significant amount of time because the raw water intake and concentrate disposal is intimately tied to the power plant water flows.

Summary

By using cooling water discharge as source water for a desal facility, the process design and operation of membrane desal facilities may be challenged by biofouling, corrosion, and other problems. A thorough understanding of variation of feedwater quality is crucial, and should be accompanied by long-term pilot testing, adequate pretreatment, effective biofouling control measures, and corrosion control strategies to ensure an efficient operation of a seawater desal plant. The benefits associated with using cooling water as desal source water might be offset or even overwhelmed if significant extra costs are required for controlling biofouling and corrosion, or for remediation of previously unforeseen problems.

The water quality problems can be reduced through careful initial pretreatment design and thorough pilot testing. The operation of a co-located desal plant, however, is affected by the availability and water quality variation of the cooling water. For instance, the power plant water may be too hot and causes membrane performance problems, or the power plant sometimes shuts operations at times when the desal plant needs feedwater. Desal plants may need a dedicated intake to provide feedwater when the power plant cooling water is too hot, or when the power plant water is not available.

EL PASO WATER UTILITIES: INLAND CONCENTRATE DISPOSAL THROUGH DEEP WELL INJECTION

El Paso's available freshwater aquifers have been rapidly shrinking. The Hueco Bolson Aquifer, which provided 40% of El Paso's municipal water supply, has declined and brackish groundwater has intruded into areas that historically yielded fresh groundwater. EPWU began reducing its Hueco pumping in 1989 as a result of a variety of water management initiatives (Hutchison 2009a). A 27.5 mgd desal plant has been in operation since 2007 that will result in reductions in brackish groundwater intrusion, and allow EPWU to better utilize its fresh groundwater wells during droughts.

In total, 30.5 mgd of brackish groundwater from the Hueco Bolson Aquifer are pumped to supply the desalting operation. Of that total, 18.5 mgd of this brackish water is processed through the RO plant, which yields 15.5 mgd of permeate and 3 mgd of concentrate. The remaining 12 mgd of brackish groundwater is blended with the 15.5 mgd of permeate to yield 27.5 mgd of finished water with a TDS of between 600 and 700 mg/L. The concentrate is piped 22 miles to the injection wells for disposal.

A critical issue in the development of inland brackish water desal is the disposal of the concentrate that is produced by the desal process. Several alternatives were explored for concentrate disposal in El Paso, including injection wells, enhanced evaporations, and simple evaporation ponds. Passive evaporation for 3 mgd of concentrate would have required a 700-acre double-lined pond. Enhanced evaporation would have required a smaller pond and mechanical sprayers to enhance the evaporation rate. An economic analysis of the three alternatives completed in 2002 showed that deep well injection would be significantly less expensive than either of the evaporation alternatives, if a suitable site was located (Table 9.2).

Because of the attractive costs, a detailed investigation of the deep well disposal option was completed from 2002 to 2004, and consisted of geologic investigations, test drilling, geophysical studies, preliminary modeling, and culminated in the construction and testing of a pilot well in 2004. The results of the studies and the testing of the pilot well were used in 2004 and 2005 to prepare an application to the Texas Commission on Environmental Quality (TCEQ) for a Class V Authorization to inject concentrate into the Silurian Fusselman Formation, a fractured dolomite, and the underlying Montoya Formation, a fractured limestone.

Authorization from TCEQ was obtained on July 13, 2005, and included a provision that the injectate had to meet primary drinking water standards (Hutchison 2009a). This was because the receiving formation has a TDS below 10,000 mg/L, making it a potential USDW under the SDWA definition.

Table 9.2
Cost comparison of concentrate disposal options (millions US$, updated to 2009 levels)

Disposal method	Capital	Annual O&M	Total annualized cost (20 years, 6%)
Passive evaporation	$48.9	$1.2	$5.6
Enhanced evaporation	$27.4	$3.5	$5.9
Deep well injection	$8.4	$1.0	$1.7

Source: Adapted from B. Hutchison 2007, updated via Consumer Price Index (CPI).

The three injection wells are between 3,700 and 4,000 ft deep, and were completed to Class I UIC standards under the SDWA. The wells are completed with open holes in the injection zone (below 2,900 ft). The injection wells do not need pumps and the wells are capable of accepting water by gravity at rates that approach 2,000 gpm. The Surface Injection Facilities consist of yard piping, a 300,000-gallon storage tank at each site, a solar power system (with generator backup), and various instrumentation and controls to manage the injection and collect performance data.

The key considerations in operating the injection wells are:

- Avoid potential mineral precipitation (e.g., calcite, barite, and silica) in the wells and formation. To mitigate the mineral precipitation, the concentrate can be treated with hydrochloric acid to adjust the pH prior to disposal.
- Maintain the capacities of the injection reservoir. All three wells exhibit no upward trend in minimum depth to water during the initial 16-month operational period. It suggests well performance is considered acceptable and the injection rate does not exceed the limitations of the injection reservoir.
- Comply with the requirement that the injectate meets primary drinking water standards.

Currently, dilution water from Ft. Bliss wells has been added to the concentrate in an attempt to meet primary drinking water quality standards. Several of the monthly samples of the concentrate, however, slightly exceed the primary standard for arsenic and selenium despite using different combinations of wells for dilution. TDS of the injectate during this initial operating period ranges from 2,500 mg/L to about 5,100 mg/L, which is considerably below the receiving formation TDS of about 8,800 mg/L.

In response to the difficulties in meeting the primary standard requirement, especially for the ambient arsenic that is concentrated in the RO reject, EPWU initiated discussions with TCEQ and USEPA in December 2007 to obtain an aquifer exemption status under 40 Code of Federal Regulation (CFR Parts 144–146) and 30 Texas Administrative Code (TAC, chapter 331) for the injection zone. An Aquifer Exemption Application was submitted to TCEQ. If approved by TCEQ, it will then be submitted to USEPA for concurrence and final action.

Total capital cost of the project was about $91 million, and the annual and amortized costs are summarized in Table 9.3 (Hutchison 2009b):

- Production wells and collector lines: $32 million
- Plant and near-plant pipelines: $40 million
- Concentrate disposal: $19 million

Table 9.3
Annual and amortized costs of the El Paso Desalination Plant
(presumably 2007 US$ values)

Category	Annual operating costs (assuming $0.07/kWh and 80% operation)	Amortized capital and O&M ($/AF, assuming 5% discount rate)
Wells, collectors	$700,000	$189
Ft. Bliss (water and land)	$1,300,000	$42
Desal plant	$2,600,000	$232
Disposal	$200,000	$49
Finished water pipeline	$26,000	$22
Total	$4,826,000	$534

Source: Adapted from Hutchison 2009b

PERTH SEAWATER DESALINATION PLANT: OCEAN CONCENTRATE DISPOSAL

In western Australia, the Water Corporation (the state's water provider) has developed a 38 mgd (144,000 m^3/d, peak capacity) seawater desal facility at Kwinana, which supplies 17% of Perth's water demand (Crisp and Rhodes 2007). Besides GHG emission, the most serious concerns with the plant are the impacts on the marine ecological environment. The plant draws feedwater from an open intake in nearby Cockburn Sound. RO concentrate, including the concentrate used to backwash the dual media filters, is pumped to an outfall located at the bottom of the Cockburn Sound (Stover and Crisp 2008).

The Western Australia Environmental Protection Authority (WA EPA) has set strict criteria for salinity to which the plant must adhere, requiring that salinity within 50 m of the discharge point to be within 1.2% of background levels, and that by the time the seawater concentrate is 1 km from the discharge point, salinity must be within 0.8% of background levels (Strategen 2004, Crisp and Rhodes 2007).

To meet the required criteria and ensure there is no adverse ecological impact on the marine environment, the plant constructed outfalls with diffusers beyond the tidal zone. The outfalls can prevent the heavy saline plumes from accumulating at the ocean bottom in the immediate vicinity of the discharge. Despite the desal plant's siting adjacent to the Newgen Power Station, the two plants are discretely operated with no shared facilities. The key reasons for this included the timing of the development of the two plants, guarantee of supply, and complexity of both operations. It was also considered that blending of discharges was not necessarily ideal because it was important to prevent the warmer cooling water (combined with the desal concentrate) from becoming too dense and sinking to the seabed (Khan et al. 2006).

The Perth Desalination Plant outlet is 3.94 ft (1.2 m) in diameter and has a 175-yd (160-m) long, 40-port diffuser. These ports are spaced at 16.4 ft (5 m) intervals with a 0.72 ft (0.22 m) nominal port diameter, located 0.3 mi (470 m) offshore, at a depth of 32.8 ft (10 m), adjacent to the plant in Cockburn Sound (Crisp and Rhodes 2007). The diffuser is a bifurcated double-T-arrangement and incorporates a discharge angle of 60°. The velocity of the discharge is 4 m/s through nozzles spaced at 5-m intervals to ensure total mixing of seawater concentrate within 50 m of each side of the pipeline. This design was adopted with the expectation that the plume would rise to a height of 27.9 ft (8.5 m) before beginning to sink due to its elevated density (Rhodes 2006, Crisp and Rhodes 2007, Stover and Crisp 2008). To reduce the aesthetic impact caused by the disposal of ferric sulphate sludge to the ocean, a thickener is used to dewater the sludge. The dewatered sludge is then transported to a landfill for disposal.

Various models were applied to demonstrate the natural flushing in Cockburn Sound and show that the salinity would increase by less than 1% and that there would be no adverse ecological effect. Extensive real-time monitoring is currently being undertaken in Cockburn Sound to ensure that the model predictions are correct and that the marine habitat and fauna are protected (Rhodes 2006). This includes monitoring of dissolved oxygen levels via sensors on the bed of the sound. Visual confirmation of the plume dispersion was achieved by the use of Rhodamine dye added to the plant discharge. The experiment showed that the discharge rapidly mixed with the surrounding waters (Crisp and Rhodes 2007).

Recently, an independent report on the environmental impact of the Perth plant concluded that oxygen levels in Cockburn Sound have not been affected by the discharge from the plant (WC 2007). A documentary film on the adjoining ecosystem near the feed water intake and outfall diffuser has shed further light on this concern. The video shows prolific habitat growth in the area, suggesting a healthy ecosystem. The underwater footage from the Perth Seawater Desalination Plant can be viewed through the Web site at: http://www.watercorporation.com.au/_files/mmedia/Under_the_Surface_small.wmv.

WEST BASIN MUNICIPAL WATER DISTRICT: PILOT AND DEMONSTRATION TESTING FOR SEAWATER DESAL

About 65% of raw water supply tapped by the West Basin Municipal Water District (WBMWD), in the greater Los Angeles area of California, is imported from Northern California or the Colorado River. This water is becoming increasingly less reliable due to droughts, environmental restrictions, population growth, and other factors. In light of increased challenges to the imported water, WBMWD is planning to produce approximately 20 mgd of desalinated ocean-water as drinking water by 2020, constituting 9% of its total supply needs, adding to increased conservation (12%), recycled water (15%), and groundwater production by WBMWD’s retail agencies (21%), and reducing the percentage of imported water (WBMWD 2010).

Pilot Testing

Since 2002, WBMWD has operated a pilot facility at the El Segundo Generating Station, for research and water quality testing purposes. The facility produces 40 gpm of desalinated ocean water using MF and RO technologies. The results of more than 500 water quality tests performed monthly indicate that the quality of the product water meets current state and federal drinking water standards set by CDPH and USEPA.

Demonstration Project

After five years of research and more than 35,000 water quality tests, WBMWD has identified the optimal operating parameters for desal and will continue with research at the Pilot Project, focusing primarily on water quality. WBMWD has now embarked on a temporary ocean water desal demonstration facility.

With demonstrated pilot-testing experiences, and interactions with regulatory agencies and the public, WBMWD has received all the permits for the temporary demonstration project. The CCC approved the CDP application in April 2009. The Los Angeles RWQCB has recently approved the NPDES permit, which is the final permit needed for the construction of the plant. Construction could begin in 2010 on the site of the Los Angeles Conservation Corps' SEA Lab aquarium and educational center, in the City of Redondo Beach. The Demonstration Project will operate for two years.

This next step builds upon the research conducted in the pilot phase, but enables a variety of tests not possible at the pilot level by using full-scale equipment. The overall project goal is to provide insight regarding the appropriate design of a potential desalinated ocean water supply project in a manner that maximizes efficiency for construction and operation and minimizes environmental impacts.

Using full-scale equipment, the demonstration project can refine operating parameters, perform additional water quality testing, evaluate source intake methodologies, and assess energy efficiency. The project will produce 250,000 gallons of water per day and include the following major testing components:

- Ocean-water intake: to minimize environmental impacts, the project will utilize existing underground tunnels for intake and discharge. Based on the most up-to-date research available, the intake tunnel will be modified with a "pipe-in-pipe" concept and fitted with passive wedgewire screening technology to minimize impact to marine life.
- Alternative intake methodologies: the project will also include pilot testing of a Seabed filtration subsurface ocean-water intake, which will occur onshore.
- Data collection and analysis: The temporary demonstration project will test:
  - Prescreening and pretreatment
  - RO
  - Energy efficiency
  - Product water quality and residuals
  - Management processes
  - Alternative intake methodologies

In summary, WBMWD is taking a prudent and steady step-by-step approach to implementing the ocean desal project. The six successful years of study and tens of thousands of water-quality tests conducted at the pilot facility helped convince the regulatory agencies and public regarding the feasibility of ocean desal in the area. It is expected that the Demonstration Facility will further lay the foundation and develop data for the permitting, design, construction, and operation of WBMWD's proposed full-scale desal facility.

PHOENIX WATER SERVICES DEPARTMENT: FEASIBILITY STUDY AND PILOT-TESTING FOR INLAND DESALTING

Central Arizona is one of the fastest growing regions in the US. This region is also suffering from serious salt imbalance issues. The City of Phoenix Water Services Department is considering brackish water desal to meet its projected water needs, and improve the reliability of the city's water supply during times of drought. The city has supported several studies to investigate different desal technologies and concentrate management options, and it has been pilot-testing a combined groundwater and surface water desal facility in the area. The knowledge gained from the research will help the city develop a cost-effective desal approach and water management strategy.

In 2000, two membrane concentrate disposal options were evaluated for future advanced wastewater treatment plants (USBR 2000). The costs of evaporation ponds (10 square miles) and discharge to the Gulf of California via a Central Arizona Salinity Interceptor (CASI) regional pipeline (about 320 miles, based on cost sharing) were assessed. This study concludes that the cost of concentrate disposal using the CASI pipeline is about two-thirds of the cost using evaporation ponds because of its huge required space. Conveying salty concentrate waters across the border for discharge into Mexico, however, is a great challenge, and requires approval by Mexico. Because of the difficulties in these disposal methods, the city is evaluating other disposal options including concentrate volume minimization and ZLD.

In 2005, the city, in cooperation with the USBR, conducted a study of a novel desal technology—Dewvaporation at the City of Phoenix 23rd Avenue Wastewater Treatment Plant (Beckman 2008). A 10,000 gpd (37.85 m^3/d) dewvaporation pilot-plant was used to further reduce the volume of reclaimed water RO concentrate. Because no low-grade heat is readily available in the area, the dewvaporation systems will consume substantial electricity for desal and concentrate volume minimization, which is not a feasible technique to be implemented in the city.

Recently the City of Phoenix selected Carollo Engineers to test and evaluate desal and concentrate management technologies for its future Western Canal Water Treatment Plant (WCWTP). The primary goals of the two-year study are to (Carollo Engineers 2009):

- Demonstrate that intermediate concentrate chemical stabilization (ICCS) using conventional softening technologies can effectively remove inorganic membrane scale-forming constituents and enhance the RO system recovery from 85% to about 94–95%.
- Demonstrate that primary RO followed by the ICCS and secondary RO systems can successfully treat either brackish groundwater or surface water, or a blend of the two.
- Evaluate the fouling potential and the causes of fouling for the primary RO and especially secondary RO membranes treating both groundwater and surface water sources.
- Establish the design criteria and operational parameters that can be applied at full scale for the primary RO, secondary RO, and ICCS processes.

A two-stage primary brackish RO system was used to treat both brackish groundwater and surface water sources to achieve a sustainable recovery of 85%. The recommended flux rates from the pilot-testing were 15 gfd for the brackish groundwater and 12 gfd for the brackish surface water. The primary RO concentrate for both groundwater and surface water source was further treated by conventional lime softening and granular media filtration that is capable of removing most of sparingly soluble salts. A single-stage secondary RO process used a high reject, high productivity seawater membrane to increase water recovery from 85% to 94–95%. For a full-scale design, the system could be optimized with a 2-stage design to improve hydraulic conditions and reduce colloidal fouling. The recommended flux rate for the secondary RO was around 8 to 10 gfd (Carollo Engineers 2009).

Besides testing the concentrate volume reduction technology, RO membrane performance for a selected membrane was evaluated by pilot testing both local groundwater and surface water (He et al. 2009). The study also filled in data gaps in source water quality by conducting sampling for the tail end of the Western Canal and selected Salt River Project (SRP) groundwater wells. It is important to note that key water quality parameters such as TDS, silica, alkalinity, hardness, etc., impact the full-scale design dramatically for parameters including the blending ratio, the recovery, and the ICCS chemical dosage. The information obtained from water quality sampling and testing will help the city estimate the impacts of groundwater quality on the capital and O&M costs associated with the Western Canal well field groundwater desal facility.

In summary, long-term water quality monitoring and pilot testing answer critical unknowns that may otherwise impact the implementation of the future desal project in the area. With limited inland concentrate disposal options, selecting the right concentrate management strategy is critical to implement desal in Arizona.

ASHKELON, ISRAEL: MANAGING ENERGY DEMAND FOR LARGE-SCALE SEAWATER DESAL

The 87.2 mgd (100 million m^3/year) Ashkelon Seawater Reverse Osmosis Plant has been operating since 2005. The plant treats a feedwater with a salinity of approximately 41 g/L TDS and meets stringent product water quality standards, in particular, chloride < 20 ppm and boron < 0.4 ppm. The plant includes seawater pumping from open intake, conventional pretreatment, membrane desal, permeate water remineralization treatment, and brine disposal to the sea.

The Ashkelon plant is comprised of two identical plant facilities—north and south—which started operation in the middle and at the end of 2005, respectively. For large-scale seawater desal, it is more economical to use energy in a centralized form. Each facility of the plant employed a unique “Three-Center Design” approach to reduce energy demand and increase efficiency and flexibility in operation. The concept of a Three-Center Design includes a pumping center, a membrane center, and an energy recovery center (Liberman, Figon, and Hefer 2005). A pumping center comprised of 3+1 large high-pressure pumps, 5.5 MW each, supplies seawater to all 16 RO banks, 105 pressure vessels in each, via a common feed ring. The membrane center consists of a four-pass system in a Cascade design to meet final permeate water quality. An energy recovery center, made up of 40 Double Work Exchanger Energy Recovery (DWEER) devices, collects pressurized brine from all 16 RO banks, transfers the energy to the seawater, and pumps it to the same common feed ring.

The system is flexible in accommodating water demands which fluctuate seasonally and daily. When demand decreases and there is a corresponding decrease in water production, one or two high-pressure pumps are stopped with all RO trains kept in operation. The energy recovery system continues to operate at full flow and thus allows for lower recovery, lower feed-brine osmotic pressure, and lower specific power consumption. Requests for reduction in product capacity are immediately translated to reduction in specific power consumption. Increased production demand can be made rapidly by starting up standby pumps and ERDs.

The plant has 33% standby pumping capacity available on line. Stoppage of any one of the RO trains does not affect the water production of the entire plant. Each RO train, high-pressure pump, or energy recovery subsystem can be taken off-line for scheduled or emergency maintenance without the need to stop the plant. The same is true when returning that system back online.

The plant is connected to the electrical grid, but a dedicated combined cycle gas turbines (cogeneration) power station has also been installed. Fifty-six MW of the 80 MW produced by the power station is used by the desal process. This approach contributes to the high reliability of the project and increases its energy availability. From an operational point of view, the desal system works most of the time on a continuous "base load," thus avoiding frequent (daily) changes in the operation mode (Kronenberg 2004).

The use of proven RO technology and an advanced recovery system to reduce operating costs has achieved a very competitive price, \$2/kgal (\$0.53/m^3; data from Sauvet-Goichon 2007). About 42% of this price covers energy costs, variable O&M costs, and membrane and chemical costs. Fifty-eight percent covers capital expenditure and other fixed costs, including fixed O&M costs (Sauvet-Goichon 2007). The energy consumption of the SWRO plant is approximately 13.2–13.7 kWh/kgal (3.5–3.62 kWh/m^3), including all uses for pretreatment, desal, conditioning, transfer from intake to client reservoir, building lighting and air conditioning, and other electricity losses.

THAMES, PERTH, AND SYDNEY: USE OF ALTERNATIVE ENERGY FOR DESAL

GHG emissions associated with desal have received increasing concerns. SWRO energy demand in California is estimated to be 13.2 kWh/kgal (3.4 kWh/m^3) water produced, translating to 3.64 kg CO_2/kgal of water produced (0.94 kg CO_2/m^3), considering the current energy regime from the grid (Cooley, Gleick, and Wolff 2006). The 38 mgd (144,000 m^3/d) Kwinana desal plant in Perth, Australia, was estimated to emit 180,000 tons of CO_2 per year if RECs were not applied toward the plant (EPAWA 2002).

Use of alternative energy sources (e.g., wind, solar, biofuel, hydroelectric) has been an important step to promote desal as a viable and sustainable water resource option. In Australia, renewable energy has been selected to power the majority of the proposed large-scale desal plants. The Kwinana SWRO Plant in Perth is the first large desal facility in the world to be powered by RECs (WC 2007). Electricity for the desal plant, which has an overall 24 MW requirement and a production demand of 15.5 to 23.3 kWh/kgal (4.0 to 6.0 kWh/m^3), comes from the 80-MW Emu Downs Wind Farm (operated since 2006).

Similarly, the Kurnell SWRO Desalination Plant in Sydney entered a renewable energy supply agreement in which the plant would be powered by wind energy from the new 132-MW Capitol Wind Farm (MSJ 2008). In London, the Thames Gateway Water Treatment Plant (TGWTP) also declared the use of biodiesel to meet desal energy demand and ease the environmental concerns about the high energy consumption of the desal plant (BBC News 2007). The energy plan of the TGWTP desal plant as a case study is discussed below.

The energy consumption of TGWTP is estimated to be 7.44 kWh/kgal (1.92 kWh/m^3) and a predicted carbon output of 20,650 tons of CO_2 per year by using electricity from grid and at full operation (Lyon 2007). This is significantly higher than traditional treatment works in the surrounding area. Hornsey Water Treatment Works, a 13.2 mgd (50,000 m^3/d) slow sand filtration water treatment plant, for example, uses 0.23 kWh/kgal (0.06 kWh/m^3) (GLA 2005). Without the benefit of economy of scale, Radnage Water Treatment Works, a 0.5 mgd (2,000 m^3/d) groundwater treatment operation, uses 3.88 kWh/kgal (1.0 kWh/m^3) (GLA 2005). Desal requires twice as much as the estimated energy output of an indirect reuse plant previously considered (Lyon 2007).

Thames Water maintains that although the desal plant will require more energy, it has implemented Best Management Practices (BMPs) to reduce energy consumption. These practices include abstraction in a three-hour window close to low tide (ensuring lower salinity water is treated by the plant), use of variable speed drive pumps, and energy recovery turbines (S. Baldwin, Principal Project Manager, Thames Gateway Water Treatment Plant, personal communication, October 5, 2007). In addition, the TGWTP is not a base load plant and will be used only in times of supply shortages and for replacing regular supplies in emergencies, which will equate to an estimated average of 40% plant operational capacity (S. Baldwin, Principal Project Manager, Thames Gateway Water Treatment Plant, personal communication, October 5, 2007).

To further mitigate the CO_2 emissions issues, TGWTP plans to use renewable energy to coincide with the London Plan. The London Plan requires large development projects, such as the desal plant, to generate a minimum of 10% renewable energy onsite (GLA 2005). A number of on- and off-site renewable energy options were considered for the desal plant, including solar photovoltaic cells, tidal and hydro-energy generation, an on-site biomass plant, as well as onsite wind energy. All were discounted due to excessive cost and physical or environmental constraints (GLA 2005). However, Thames Water is still planning to use a 100% renewable energy source for the desal plant. Its current plans for renewable energy is to establish an onsite biodiesel combined heat and power (CHP) plant using biogas (methane) from sludge digestion, which may be obtained from the adjacent Beckton Sewage Treatment Plant to power the CHP engines (Thames 2007). In addition, Thames Water is still exploring options in wind energy and also potential reprocessing of locally discarded cooking fat and oil for energy generation (Thames 2007). Because of this commitment, TGWTP is expected to be one of the first major construction projects that will be covered 100% by renewable energy in the UK (S. Baldwin, Principal Project Manager, Thames Gateway Water Treatment Plant, personal communication, October 5, 2007). Although actual carbon offset from biodiesel has not yet been established, its use of renewable energy retains a social license with the public.

CARLSBAD SEAWATER DESALINATION PLANT: CLIMATE ACTION PLAN

Concerns regarding GHG emissions have compelled water producers to implement environmental management programs to achieve carbon neutral status for the desal plants. Introduction of a carbon neutral scheme may hold significant social value in applications of desal and is becoming an important component of the desal investment. In southern California, the Carlsbad Desalination Plant has committed to a carbon neutral plan for the proposed 50 mgd (189,000 m^3/d) plant (Poseidon 2008).

The proposed GHG emissions from the 50 mgd Carlsbad desal plant is estimated to be 97,165 metric tons of CO_2 per year based on the plant's annual electricity consumption and the power agency's emissions factor. The project offsets 190,641 MWh/yr of electricity consumption by water imports, corresponding to 67,506 metric tons CO_2/yr. The net emission resulted from the displacement of imported water from the SWP is 29,659 metric tons CO_2/yr. The carbon neutral plan is proposed to reduce the net GHG emission of 29,659 metric tons CO_2/yr (Poseidon 2008).

The net GHG emissions will be offset through a series of projects as well as REC purchases. Contracts for offset projects provide more price stability and are typically established for longer terms (10–20 years) than RECs (1–3 years). At approximately 1.5–2 years before operations begin, Poseidon will develop and issue a request for proposals for carbon offset projects and RECs.

Onsite carbon footprint reduction measures for the Carlsbad Desalination Plant will be achieved by applying high-efficiency ERDs, green construction of the desal plant, use of on-site solar power generation, CO_2 sequestration for post-treatment applications, energy reductions in supplemental water reclamation treatment, and sequestration of coastal wetlands. Overall, the associated annual emissions savings from onsite mitigation efforts is approximately 13,190 to 13,431 metric tons of CO_2 per year (Poseidon 2008).

Based on Poseidon's Desalination Demonstration Plant's pilot tests, the power savings associated with the use of pressure exchangers (PXs) will allow recovery and reuse of 33.9% of the energy associated with the RO process. The ERD will reduce the baseline from 31.3 aMW to 28.1 aMW, reducing the energy consumption to 3.2 aMW, corresponding to 28,244 MWh/yr and 10,001 metric tons CO_2 per year (Poseidon 2008).

SANTA CRUZ: REGIONAL COORDINATION AND PARTNERING BETWEEN WATER AGENCIES TO FACILITATE DESAL IMPLEMENTATION

Background

There are many well understood impediments to close coordination and consolidation between water utilities within a region. Water agency boundaries and legal status result from regional history, not necessarily ideal engineering or hydrological design. The historical trajectory of water agencies produces unique configurations of engineering, governance, and communications. Agencies differ in other ways: investment priorities and financial obligations, systems at different levels of upkeep and efficiency, and different levels of trust and styles of dialogue among staff, directors, regulators, and customers. They have different commitments to environmental sustainability, system reliability, cost allocation over time, and public oversight. So while shared aspects of neighboring water agencies suggests that they could increase their efficiency and quality of service simply by merging into one larger agency, many barriers exist that could negate or at least postpone the benefits of a merger. However, there are many forms of water utility coordination and cooperation that fall short of a merger, and which may often be advantageous to both utilities and may be more appropriate than outright merger (e.g., Raucher et al. 2006b).

Among the biggest drivers of regional coordination will be replacement and expansion of water infrastructure and water supply development. Both of these issues typically arise in the context of implementing coastal or inland desal projects, indicating that desal implementation will often proceed with greater likelihood of success if local water utilities find ways to coordinate and cooperate in the desal planning and project development process. For example, regions are likely to see significant financial benefits from sharing the cost of desal-related infrastructure and permitting activities. The locations of water supplies and outfalls may require agency coordination when the best sites are not all in the same service territory. Complete mergers of agencies should be considered when the future paths of neighboring agencies are clearly united through shared infrastructure needs and other similarities. But formal agreements that fall short of a merger may often be the better approach.

The Utilities' Need and Objectives for Desal

Two neighboring water agencies along the central California coast, the Soquel Creek Water District and the City of Santa Cruz Water Department (a branch of the municipal government), each determined that a desal facility would serve their long-term potable supply interests (see www.scwd2desal.org):

- Soquel Creek sought an additional year-round water supply of roughly 1.2 mgd to sustainably manage its aquifer system, its sole source of water. The district serves a population of about 49,000 through roughly 15,000 service connections.
- Santa Cruz sought additional drought reliability for their surface water system, roughly 2.5 mgd during April–November of drought years. The Water Department serves a population of about 90,000 through 24,000 service connections, and relies on surface water from rainfall captured in local reservoirs and streams (95%) and groundwater (5%).

For Santa Cruz, desal emerged as one of three parts of its long-term water supply strategy (Gary Fiske and Associates 2003). Drought supply reliability keyed to 1976–1977 conditions (the worst recent drought) was modeled. The three-part strategy include drought-period curtailment (i.e., drought-triggered water use restrictions) limited to no greater than 25% of normal-year demand, water conservation, and modest supply augmentation. The expected supply augmentation, 2.5 mgd during dry-season months of severe drought years, emerged from a combination of expected demand over time, current supplies, expected results of additional conservation investment, and the political choice not to reduce water consumption by more than 25% in worst-case scenarios. Without supply augmentation, models indicated a 45% curtailment would be necessary in severe drought years.

Numerous supply augmentation options were considered, including expanding groundwater use, water reclamation and reuse, and expanding surface impoundments. Numerous factors were evaluated, including cost, environmental impacts, ease of implementation, energy utilization, vulnerability to outside impacts, and impacts on aquifers. These led the city to select desal as the preferred choice for supply augmentation. The city expects to utilize the desal plant only during peak season drought years, about once every six years.

Studies by Soquel Creek Water District showed that the region's water use was exceeding the sustainable yield of its groundwater resources by roughly 600 AFY, with long-term projections of an annual overdraft of 1,280 AFY (ESA 2006). The district studied numerous supply options, including surface impoundments, regional purchases and imports, water reclamation and reuse, desal, and conservation. The District's customer base was too small to cover the entire cost of a desal plant. However, a joint desal plant was seen as within the means of the ratepayers. Like Santa Cruz, Soquel Creek is a coastal water agency. However, a careful study of its coastline did not identify suitable locations for a desal intake and outfall. This physical reality increased the likelihood that any desal plant built to serve Soquel Creek would likely be a regional facility.

Benefits From the Partnering Agreement

In terms of partnering on a desal project, numerous advantages emerged. A key advantage was that the two agencies had different purposes for the desal water produced. The city needed a dry-season drought supply, which, due to limited storage capacity, would need to be available during the drought. The district's demand, while preferable during dry periods, could be accommodated with year-round deliveries since aquifer recovery from subsurface inflows from the coastal mountains takes place year-round. While the city wanted to scale the facility to meet its modeled drought requirements, 2.5 mgd, the district's ideal facility size was even smaller, roughly half that size.

A formal agreement was clearly needed given the anticipated joint investment in desal and piping infrastructure and the major contribution the facility would make to long-term system reliability for both utilities. Use rights to produced water also needed to be spelled out. While the city had the financial means to construct a facility on its own, it is not clear that the district could have. Both sides saw the clear financial advantage of jointly pursuing the project since the additional costs of doing so (primarily building a distribution-system delivery point, and in Soquel Creek's case, scaling up from its ideally-sized plant) would cost far less than expected through cost sharing. The first agreement, signed in August 2007, established a Task Force comprised of two elected leaders from each agency, and jointly staffed. It also established a 50-50 cost share for engineering and permitting costs, all of which would be overseen by the Task Force. Another Task Force goal was to generate the eventual operational and cost-share agreement.

By late 2009, the Task Force had a draft interim agreement expressing ongoing commitment to the project and laying out operational and cost issues in an appendix. The Task Force was pursuing the project's environmental review. Following environmental review, the inter-agency agreement will be finalized and a political choice made by each agency whether to implement the project. A final decision on construction is expected in late 2010 following environmental review.

By pursuing a joint desal facility, the agencies will reduce their capital and operating costs while achieving separate water reliability goals. They will also utilize the region's preferred intake and outfall locations (in Santa Cruz). By building water-delivery infrastructure that links the two agencies, they will create a potential for regional supply assistance in the event of a water emergency (e.g., earthquake). And the two agency staffs have also built a strong understanding of each agency's infrastructure and plans, which will enable them to more easily negotiate future agreements on such topics as the management of their shared aquifer. In terms of challenges, the agencies will be blending desalinated, surface, and groundwater (at least in the "downstream" Soquel Creek district), which will require additional attention to water quality impacts. Ongoing coordination on a joint facility will be required. And each agency will expect and rely on the other to meet its financial obligations. Thus far, progress has been made with the understanding that the agencies are contracting together as partners; the expectation is that future issues will be handled in a similar manner.

MONTEREY COUNTY: COLLABORATIVE DESAL IMPLEMENTATION TO SOLVE REGIONAL WATER RESOURCE MANAGEMENT ISSUES

Background

The Monterey region along the central California coast faced water shortage, groundwater degradation, interagency disagreement, and public divisiveness. Solutions were proposed including a dam on the Carmel River and a seawater desal plant co-located at a nearby power plant. The dam was rejected by voters and the proposed desal plant faced public acrimony and litigation. With this as a background, the California Public Utilities Commission (CPUC) engaged the Center for Integrated Water Research (CIWR) at the University of California to facilitate a less costly, more politically acceptable, and environmentally friendly regional water solution. CIWR established a citizen-agency vetting process to find common agreement on regional solutions. The regional dialogue group is made up of local, regional, state, and federal representatives; water and wastewater agency managers; nongovernment organizations; and citizens.

The "Regional Project" plan that emerged from this dialogue is based on components that have been examined in the past by the water and wastewater agencies in the region but is now combined in synergistic combinations that take advantage of economies of scale both financially as well as spatially. The potential positive impacts to ratepayers are expected to be appreciable. Besides economies of scale obtained by including more beneficiaries to the project than just those in one service area, the public ownership nature of the Regional Project will allow favorable bond financing and access to state or federal funds generally available to public agencies.

Water Supply Challenges and Limited Options

The region has no imported water and has little opportunity to acquire it due to its geographic isolation. Water supplies from the Salinas River are already tapped and allocated for agricultural uses in the Salinas Valley. Due to a tradition of agricultural investments in Salinas River water, there is an overriding concern amongst agricultural water leaders to protect "their" water from urban incursions. This tradition results in strong political resistance to any opportunity to use excess Salinas River water for urban uses on the Peninsula. Thus, solutions to the Monterey water supply shortages were extremely limited.

Facing water rights enforcement for diverting more water than they had a legal right to take on the Carmel River and severe overdraft and adjudication in their other water supply, the Seaside Groundwater Basin, Peninsula communities were suffering. Water supply choices were narrowing after the public on the Monterey Peninsula voted against a new dam on the Carmel River. Nearly all of the recyclable wastewater is allocated to agricultural uses in the Salinas Valley during the irrigation season and thus, not entirely available to provide fresh new water supplies (MRWPCA 2009). Peninsula water users were already conserving aggressively due to their diminishing existing supplies so further conservation was not enough. Residents of the Monterey Peninsula use 70 gallons of water per person per day—approximately half of the water consumed by the average Californian (California American Water 2010).

Thus, besides squeezing more water from dwindling supplies, the Monterey region was forced to examine seawater desal as a source of new supply. The leading approach (Plan B) became a seawater desal plant located at the Moss Landing Power Plant site, to be developed and owned by Cal AM, which is an investor-owned utility providing water to the Monterey Peninsula communities. The plant was called the "Coastal Water Project" (CWP) and relied on OTC technology to obtain its feedwater. Commensurately, a public agency in the far north of Monterey County was also proposing a seawater desal plant to be located across the street from the CWP site at a former refractory site that had abandoned ocean intakes. This proposal from the Pajaro-Sunny Mesa Water District attracted a few groups in support. The main attraction was from groups who opposed a privately owned entity (Cal AM, an investor-owned utility) owning a desal plant. Interestingly, the Pajaro Sunny Mesa proposal had some private components as well. The refractory site was privately held and was not proposed to be sold to the public agency.

Not surprisingly, the Monterey community did not coalesce behind any of the desal alternatives. Increasing acrimony was evidenced by the failure of any consensus to materialize. Commensurate to the public acrimony and disharmony, political leaders began to avoid the water supply issue and its attendant acrimonious byproducts. It is no surprise that solutions were slow to emerge from this milieu. Once proposed, any solution became the target for attack by one group or another within the community.

A Regional Solution With Many Benefits

CIWR Senior Economist Steven Kasower recommended a regional solution to the water supply issues in Monterey. The initial focus of the regional process was the establishment of a diverse group of participants who would be willing to debate, discuss, and ultimately help identify a regional water supply alternative.

The Regional Project was created by re-examining a number of local projects and water management programs that have, at one time or another, been considered by local water and wastewater agencies, municipalities, or cities in the Monterey region. The water projects and programs were then screened in various combinations of project components that ultimately revealed opportunities for regional economies of scale and new agricultural and urban symbiosis that could lead to more stable and beneficial regional cooperation in the future. While some of the extensive "regional" benefits will not be enjoyed until and unless the complete Regional Project vision has been implemented, many economies of scale, cost-saving partnerships, and environmental and social benefits were evident even in the first phases of the project and garnered considerable and diverse support for just the desal component in Phase 1.

The complete Regional Project includes beneficial reuse of all wastewater discharges, river and groundwater diversions, and intruded seawater desal to add reliability to the overall program. These project components work together to create economic synergies. The brackish groundwater desal project has numerous beneficial aspects compared to the utility go-it-alone alternatives:

1. In the Phase 1 project, the approach to pumping from the brackish groundwater will contribute to the remediation of the Salinas Valley groundwater degradation by blocking and even helping to reverse the seawater intrusion problem. It also avoids issues associated with using coastal open water intakes for feedwater.

2. Locally developed green power will provide the energy to the project components. This power comes from electricity generated from the methane produced at the Monterey Regional Waste Management District (MRWMD). This green power would not be available at the individual utility sites proposed for their coastal desal facilities.
3. The use of near-shore brackish groundwater, in lieu of seawater, develops a desal water supply that requires less energy per unit water to treat, and also creates a brine waste that has a salinity much closer to that of ambient ocean water into which it will be discharged.
4. The regional project will provide desalted water at a considerably lower cost than the go-it-alone utility alternatives, \$2,290 per AFY produced contrasted to between \$3,490 and \$4,180 per AFY (see detailed discussion in appendix H).
5. Affordable water components and the role of water in facilitating the development of affordable housing for working families and those on fixed incomes is also integrated into the project plan (CIWR and MCWD 2008).

In order to comply with local regulatory agreements over groundwater use, only the proportion of seawater extracted from the wells will be allocated to the Peninsula. The remaining brackish groundwater will only be used within the Marina Coast Water District (MCWD) service area where use of this groundwater is already politically acceptable and defined from a regulatory perspective. The proportion of product water that represents what was from seawater can be allocated out of the basin to the Peninsula to solve the Carmel River endangered species and water rights infractions, and to recharge the Seaside Basin to remediate the overdraft as dictated by the court in adjudication proceedings (Seaside Groundwater Basin Watermaster 2008).

Conclusions

In sum, consideration of a broader collaborative and regional approach, wherein desal is well integrated with other key components of a comprehensive regional water resource management plan (e.g., water reuse), has emerged as a much more viable option, with several critical advantages over go-it-alone alternatives:

1. Political viability, stakeholder buy-in, and public support (as contrasted to deep divisions and strong opposition)
2. Economically advantageous (i.e., it is less expensive than utility-specific options by a considerable degree)
3. Environmentally beneficial, including the avoidance of an ocean intake, providing seawater intrusion control, minimizing brine management impacts, and tapping into green carbon negative energy
4. Socially acceptability, by providing a more equitable sharing of water, offering public sector ownership, and facilitating a joint resolution of both agricultural and urban water issues

As a consequence, a more regional and collaborative approach has led to a path that will greatly facilitate desal implementation. The regional approach will promote desal in a manner that will be more cost-effective, solve more problems, address more issues, and has a far greater likelihood of implementation than a more traditional, utility-specific go-it-alone approach.

CHINO BASIN: GROUNDWATER DESAL AS AN INTEGRAL PART OF COMPREHENSIVE REGIONAL WATER RESOURCE MANAGEMENT

A TBL Perspective

This case study applies a TBL perspective to describe the benefits and costs of the of brackish groundwater desal, as implemented jointly in the Chino Basin (southern California) by IEUA, CDA, and the Chino Basin Watermaster. In the Chino Basin context, the application of desal can be viewed broadly to reflect its role as an integral component of the region's overall water resource management program. In this instance, groundwater desalting not only provides potable water to supplement the area's overall supply portfolio, but it also is a foundational element of a groundwater remediation effort that provides several additional important benefits within and beyond the Chino Basin.

Within the TBL context, this case study describes the estimated magnitude of several of the key benefits generated, and provides a comparison of the benefits of desal to its costs. The benefits include the overall basin-wide savings in the cost of providing water over a 30-year period, and also indicates the magnitude and value of energy savings and the reduced carbon footprint associated with the desal-enabled groundwater management program.

Background

The "Inland Empire" is located about 40 miles east of Los Angeles. Beginning in the 19th century, the region grew to become a major agricultural center, including dairy farms, citrus orchards, and other activities. Beginning in the last quarter of the 20th century, the area has seen rapid conversion to residential and commercial uses, becoming one of southern California's fastest growing regions (Miller, Burton, and Manning 2007). The region's past as an agricultural center, and its current expanding water demands as a rapidly growing residential and commercial area, have created significant water resource management challenges in the Chino Basin. These water resource management challenges include both water quality and water quantity issues, and reflect the critical interrelationship between the two.

The primary water quality challenge relates to salt levels in Chino Basin groundwaters. Salt issues are reflected by elevated TDS levels, as well as elevated levels of nitrates. Some contamination by volatile organic chemicals (VOCs) is also present. Collectively, these impair local groundwaters and make them expensive or unsuitable for supporting potable municipal and industrial (M&I) and other uses.

The primary water quantity issue is meeting rapidly growing demands—as associated with rapid residential growth and commercial, institutional, and industrial (CII) development—in a basin that has a history of extracting groundwater at levels above sustainable yields. The water quantity challenge is magnified by the cost and uncertain availability of imported surface waters, the need to honor water rights of downstream and down-gradient entities, and the impact that the water quality issues have on the usability (and cost) of local water supply resources (including impacts on the storage capacity of the aquifer system).

Desal's Central Role in the Basin-Wide Management Program

In 1988, judicial and other pressures mounted on the Chino Basin Watermaster to undertake and implement an Optimum Basin Management Program (OBMP). The OBMP is implemented by the Chino Basin Watermaster, with the objective of managing the Basin's groundwater through monitoring and recharge. Key elements of the OBMP reflect the need to keep groundwater pumping levels up (notably in the southern, lower end of the Basin) in order to (1) enable better and increased use of the Chino Basin's groundwater resources (and thus avoid over reliance on imported water), and (2) preserve water quality in the Santa Ana River. In June 2000, the Chino Basin OBMP "Peace 1 Agreement" developed an institutional structure and funding plan for the expansion of the Chino 1 desalter, and for adding the Chino 2 desalter.

The original Chino Basin 1 Desalter (Chino 1) was completed by 2000 and produced 9,200 AF of product water annually. The Chino 1 expansion was completed in 2005, and annual production is now 14,200 AF (Miller, Burton, and Manning 2007). The Chino 2 desalter was completed and placed into operation in the spring of 2006, and produces 10,400 AF per year (Miller, Burton, and Manning 2007). Like Chino 1, the Chino 2 desalter splits its feedwater (drawn from eight wells) between ion exchange (IX) and RO treatment processes. These desalted waters are low enough in TDS and nitrate concentrations that they can then be blended with source waters that bypass the desalting units, to yield product waters that are forwarded to CDA's wholesale customers for subsequent delivery as potable supply (Miller, Burton, and Manning 2007). Combined, the Chino 1 and Chino 2 desalters now provide nearly 25,000 AF per year to the potable supply of the Chino Basin.

Future expansion of the desalting operation is in the planning stages, and may entail either a third desalter and/or the expansion of the existing facilities. Total desalter production by 2015 is projected to be 40,000 AF per year.

Groundwater Desal Costs

Annual O&M costs for the current desalting production of 24,600 AF amount to about $12.3 million annually (based on anticipated expenses as detailed in the proposed budget for fiscal year 2007/2008) (CDA 2007). This O&M cost averages to $500 per AF of delivered water.

The total cost per AF of desal water produced (including capital costs) is a bit more complicated to estimate, due to grants, rebates from the Metropolitan Water District of Southern California (MWD) under the Local Resource Program (LRP), and other factors. Ignoring the grants and subsidies, the annualized debt service would amount to about $10 million. This implies a cost of roughly $400 per AF for the annualized full capital expense.

Combining the above estimated total O&M cost with the total annualized capital expense (ignoring grants and subsidies), implies that the desalted water produced by Chino 1 and Chino 2 desalters has a full cost of approximately $900 per AF delivered.

The actual price paid by CDA customers is less than $900 per AF, due to grants that reduced the amount of capital outlay and other fixed costs borne by CDA. The estimated total incurred cost borne by CDA and its customers amounts to $727 per AF (CDA 2007). This implies that the grants supporting construction of the Chino desalters provides a $173 per AF subsidy to local users (~$900 minus $727).

In addition, MWD's LRP offers a $250 per AF rebate to its customer agencies for the development of approved local water supplies. This rebate is provided as an incentive to assist MWD's customer agencies in reducing their demands on increasingly scarce and expensive import water. After accounting for the MWD LRP rebate, CDA can deliver its desalted water for $477 per AF ($727 minus $250).

Desal Benefits From a Basinwide Management Perspective

One of the insights to be gleaned from this case study is how desal can be a critical component of a broad and highly integrated approach to regional water resource management, addressing both water quantity and water quality concerns. In the Chino Basin, desal is not simply one water supply option to be evaluated and contrasted to alternative supply options (such as reuse, importation, stormwater harvesting, and conservation). Rather, desal is but one element of a complex, multi-faceted approach that not only draws upon a wide array of alternative supply options, but also requires that these various supply components be carefully integrated in order to increase the value (or enable the use of) of the other supplies.

For example, the desal program enables in-basin productive use of the locally-generated reclaimed water for recharge. Prior to the desal program and the associated hydraulic control it provides of the groundwater contamination, reclaimed water produced by IEUA was mostly discharged to the Santa Ana River and captured downstream by Orange County Sanitation District (OCSD) (it could not be used for local recharge in the Chino Basin, since absent the desal-enabled controls, this would have flushed more contaminated water into the Santa Ana River). The hydrologically-based placements of the recharge and desalting activities are strategically aligned to take advantage of the groundwater gradient, and thus are integral to managing groundwater quality in the Basin. The desalter extractions at the low end of the groundwater gradient are used to control, capture, and treat the poorest quality waters. This accelerates groundwater remediation, while concurrently protecting the Santa Ana River from saline discharges. The desalting also provides a potable supply, and the groundwater quality improvement and management enables higher safe yields to be extractable from the Basin.

In addition, the cleansing and hydrologic control of the groundwater basin that is achieved through the integrated deployment of recharge and desalting program elements are necessary for enabling implementation of the MWD conjunctive use and related Dry Year Yield (DYY) programs. The DYY program entails the conjunctive use of imported SWP surface waters within the available storage capacity of the Chino Basin. In wet years, when SWP waters are relatively plentiful and relatively low in TDS, MWD covers the costs of storing up to 100,000 AF of its excess SWP supplies in the Chino Basin. In dry years, when SWP supplies are limited and in high demand, the Basin's users of imported MWD waters agree to extract stored SWP waters from the Basin in lieu of taking their allotments from MWD. This frees up scarce SWP waters in dry years, so that MWD can use those limited SWP waters to satisfy the demands of its other agency customers. This increases the reliability of the SWP supplies for the entire MWD service area (a significant benefit for all of Southern California). This also insulates the Basin's users of SWP waters from dry year fluctuations in their imported supply (an important "drought-proofing" benefit within the Basin communities). This valuable DYY program would

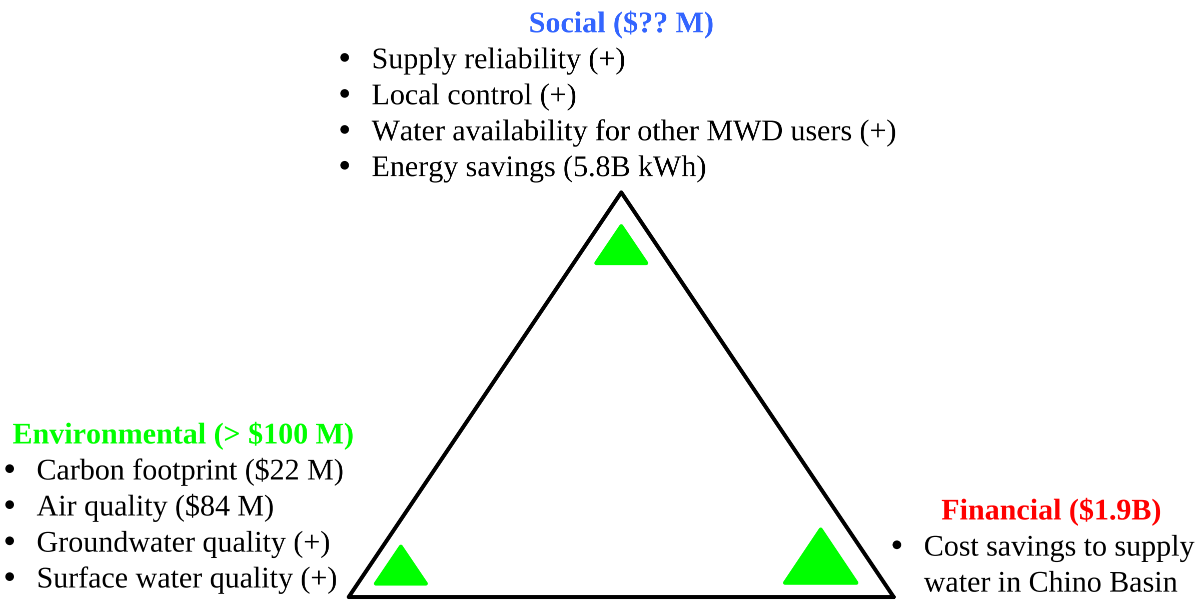


Figure 9.4 TBL results for Chino Basin desalting and OBMP

not be feasible if the desalting and related activities were not in place to assure groundwater quality control.

Triple Bottom Line Results

Within the TBL context, several types and magnitudes of environmental, social, and financial values are enabled by the application of desal, reuse, and related "nontraditional" sources of water supply. The TBL-associated benefits arising from desal reuse and other components of the integrated resource plan outweigh the costs by a factor of over 50% (i.e., a rate of return greater than 50% on investments made in reuse).

The largest financial benefits include the overall Basin-wide savings in the cost of providing water over a 30-year period (which amount to nearly $2 billion, US, in present value terms). Also included are the magnitude and value of energy savings and the reduced carbon footprint associated with the reuse-enabled groundwater management program. The results are detailed in appendix H, and summarized in Figure 9.4.

TAMPA BAY SEAWATER DESALINATION: ISSUES IN PROJECT DELIVERY

The Tampa Bay Seawater Desalination Project began as a privately owned DBOOT procured project. TBW chose this method of project delivery because they believed that the regulatory and technological risk associated with the project would be best managed by the private sector (NRC 2008). The DBOOT approach was envisioned as enabling TBW to maintain tight government control and achieve lower prices through competition. Further, with this type of agreement, TBW would be able to leverage the efficiencies of the private sector and still take advantage of the tax-free financing available to governments (Rand 2003).

In 1999, TBW selected Poseidon Resources of Stamford, Connecticut, after an open competition for a private partner in the project. In accordance with the DBOOT contract, Poseidon's job was to permit the plant, operate a pilot plant to ground-truth proposed systems, and put the plant online in accordance with a water purchase agreement. From TBW's perspective, this placed the financial and regulatory risks onto the private vendor, while the water purchase agreement was seen as guaranteeing the agency a targeted water yield at a favorable fixed price.

The DBOOT process demonstrated value when Stone & Webster, Poseidon's chosen engineering, procurement, and construction (EPC) contractor, had financial problems (Rand 2003). In July 1999, Poseidon Resources had selected Stone & Webster to design, engineer and build the plant, but the company went bankrupt. Poseidon then brought in Covanta Energy of Fairfield, New Jersey, in December 2000 to take over responsibility for plant construction. Poseidon was able to keep the project on schedule through most of 2001.

In December 2001, a contraction in the surety industry precluded the developer team from closing on permanent project financing because Covanta could not post the required performance and payment bond. In January 2002, further problems affecting Covanta's liquidity arose, which rendered Covanta unable to obtain the necessary performance or payment bond (Callahan and Polmann 2009).

After a three-month effort to reconfigure the financing, Covanta filed for bankruptcy, further complicating the ability of the project team to secure permanent financing and raising the potential cost of private financing. Covanta did commence with water production in March 2003; however, due to problems associated with intake and pretreatment (a problem that may have been identified and averted had proper pilot testing been undertaken), they were unable to satisfy 14-day acceptance test criteria. Consequently, TBW decided to take ownership of the facility earlier than expected, with the project near 50% completion (NRC 2008).

Through the buyout provision of the DBOOT contract, TBW assumed the original DBO contracts and contractors for construction completion and plant O&M. This process transitioned the DBOOT arrangement into a DBO arrangement which shifted project ownership and performance risk from the original developer to TBW.

In late 2003, TBW began to look for a replacement contractor to complete plant construction. In November 2004, TBW's Board of Directors approved a DBO contract with American Water-Pridesa, LLC (AWP) to remediate and operate the desal plant. The contract for remediation was at a fixed construction price of $29.1 million, including guarantees to protect the public's investment, plus a $2.5 million owner's allowance.

Xu et al. (2009) report that due to the technical challenges related to intake and pretreatment, as well as financing and contractors' problems, plant costs increased from the originally estimated $110 million to an additional excess of $40 million (construction oversight: $4 million, remediation and improvements: $36 million, attorney fees for lawsuits: $6.8 million) since TBW bought the facility in 2002. The promised water price increased from $1.71/kgal ($0.45/m^3) in 1999 to $3.19/kgal ($0.84/m^3) in 2007 (Barnett 2007).

As reported by NRC (2008), lessons learned from this experience include the following:

- Contract documents should be created at the beginning of the procurement process so the developer teams and contractors are submitting proposals for similar contract requirements. Any suggested contract changes should be required to be submitted with the proposals.
- If a DBOOT method is selected, anticipate ownership transfer at any stage of the project.
- Careful consideration should be taken prior to making a decision to transition project ownership in a DBOOT. The assuming owner should understand that they are stepping into the role of the original developer and, therefore, assuming liability for the original developer's decisions.
- A structured and transparent pilot testing program of proposed technologies that supports the design should be conducted prior to selecting a proposal. The pilot program should include pretreatment (including security filters) and RO processes.
- Specific desal project experience should be a qualification requirement before a proposal is accepted.

The TBW experience reveals that it is not simple transfer desal project risks to the private sector in a DBOOT context. The utility needs to consider a broad array of potential events, and arrange contractual agreements such that the utility maintains a reasonable degree of oversight and control throughout the process.

CHAPTER 10
PERMITTING AND REGULATORY CHALLENGES

INTRODUCTION

With the need for desal as a water supply becoming more pronounced in many regions, and given that desal also is becoming relatively more attractive on an engineering and economic basis, the largest obstacles to more widespread desal application are often “institutional” issues. These institutional issues typically are dominated by regulatory and related permitting requirements, and also may reflect concerns from some stakeholders and local citizens over growth inducement and other “non-technical” matters. These issues may impede desal implementation because they increase uncertainty, add costs, create delays, or in other ways pose “barriers.” These barriers, in turn, may adversely affect the ability of a water utility to obtain needed permits, gain support from citizens and governing officials, get a facility built, and/or successfully operate a desal facility.

This chapter provides an overview of desal regulatory and permitting issues, and offers a general common sense strategy for working effectively with regulators and permitting agencies to increase the odds of success and reduce the likelihood of delays and roadblocks. The discussion provided here also is aimed at helping utilities work more effectively with stakeholders and public officials who, if opposed to desal, often use the regulatory and permitting process as the mechanism for expressing their concerns and raising impediments to implementation.

The issues and approaches described here also are raised throughout various portions of this report and the associated PIM tool, hence this chapter provides a relatively concise description of key issues and guiding principles. Relevant supplemental materials are provided in chapters 5 and 8; appendices C, D, and E; and other portions of this report. Much of this material also has been developed for a prior report developed by some members of the research team for the Joint Water Reuse & Desalination Task Force, consisting of the Water Research Foundation, the WateReuse Foundation, Sandia National Laboratory, and the USBR (Raucher, Strange, and Hallett 2006).

OVERVIEW OF PERMITTING ISSUES

The implementation of a desal project typically requires multiple permits from federal, state, and local agencies. In general, applicable regulatory programs and permitting processes revolve around three components of the desal process:

- Where and how the source water is obtained
- How the desal-generated water will be used
- How the brine concentrates and other wastestreams will be managed

Other required permits (e.g., building, site work, roadway crossings) are similar to those required for construction of other types of water treatment facilities. These other types of common permits are not addressed here.

In general, water agencies and other practitioners have indicated that desal permitting can be a lengthy, uncertain, costly, and arduous process. It is not the fact that numerous permits are often required that poses the greatest obstacle to implementing a desal project. Rather, the greatest challenge may arise from the manner in which the permit applications are evaluated. Desal is a relatively new and uncharted territory for many regulators. Hence desal facilities (and their potential impacts and wastestreams) are atypical of the type of operations that regulators normally monitor and permit. In other words, desal may be a round peg in regulatory settings that are set up with square holes to address square peg operations (Raucher, Strange, and Hallett 2006). In addition, because desal is relatively novel, regulators have expressed some reluctance to issue permits, fearing that they will inadvertently establish precedent with possibly unforeseen or unintended consequences for future facility permitting.

In some states (e.g., California), as many as seven state and/or federal permits are needed before one can receive final permission to begin the planning/design/construction of a desal facility. Several of these permits may, in turn, entail consultations and approvals from various other state, local, or federal entities before the issuing agency signs off. Where federal funding is involved, planned facilities are also subject to review under the National Environmental Policy Act (NEPA). Overall, the permitting process—especially for a large coastal facility in a contentious location (such as California)—can take between three and eight years, and cost as much as $3 to $12 million (Voutchkov 2009a).

Some state and local authorities may require permits in addition to those discussed below. For a detailed discussion of state and local requirements in key desal states (California, Florida, Texas), see appendix E. The following sections provide an overview of key federal permit requirements (and some typical state requirements), and discuss strategies for facilitating the overall permitting process.

SOURCE WATER (FEEDWATER) PERMITS

The source water feeding the desal process—and the manner in which these waters are obtained—are major determinants of the types and numbers of state and federal permits and approvals required. In coastal waters, institutional issues depend on whether the desal plant is co-located with a power plant, or is a standalone facility.

Coastal Desal Facilities Co-located With Power Plants

With co-located facilities, there typically is no need for a new water intake pipe or any notable increase in the volume of coastal waters taken in (other than when the power plant is not operating). This eliminates the need for permitting *new* intakes, and avoids ecosystem disruption that would arise from placing new intake pipes into the coastal environment. There is also generally no added I&E of aquatic species, beyond what is already occurring due to the existing power plant operations. This also serves to minimize permitting requirements.

While co-location of desal with coastal power plants offers several advantages, there are also some problems that may arise because coastal power plants are often the target of strong opposition by many parties. There also are several operational challenges that may arise when a desal facility is co-located with and dependent upon the operation and management of the co-located power facility. These and other issues arising from co-location are discussed in chapters 8 and 9.

Whether co-located with a power plant or not, a coastal desal facility is also likely to require a coastal use permit, as managed by applicable state agencies such as the CCC. Coastal use permits raise a series of issues associated with the mandate of the relevant permitting agencies to protect coastal resources, including public access for a variety of popular and highly valued uses, coastal zone ecologies, highly visible scenic aesthetics, and security concerns (Luster 2009, Voutchkov 2009a).

Coastal Standalone Desal Facilities

A standalone desal plant in coastal waters will need to develop and permit an intake structure, develop beach wells, or use HDD to develop under-sea well intakes some distance from the shore. This is likely to entail several permits and approvals, including:

- A CWA Section 404 permit for the intake pipe (one is also needed for any new discharge pipe), since placing a pipe in the water is considered “fill.” This is administered by the USACOE, but typically requires buy-in and approval from other agencies, such as the NOAA and/or relevant state or regional bodies that have jurisdiction over fisheries and other coastal resources and impacts (see Table 10.1).
- The Rivers and Harbors Act permit for the intake pipe (again, a separate permit also will be required for a discharge pipe). This is also administered by the USACOE, and again they will typically will not issue such a permit unless other agencies (e.g., NOAA) are consulted and sign off.
- In some states, a permit will be required from the state coastal authority (e.g., the CCC).

A prime concern with permitting and developing an independent desal intake is the potential for I&E of aquatic species and associated impacts on the coastal ecosystem. I&E impacts from desal plant intakes are typically expected to be minor compared to power plants using OTC. This is because desal facilities use feedwater intake pipes that are considerably smaller in diameter, apply much lower intake velocity (allowing more fish to swim away rather than get impinged in the screen), and the total volume of water taken in is much smaller. Nonetheless, citizens and regulators are likely to have concerns about I&E impacts.

There is some concern that standalone surface water facilities will be regulated as cooling water intake structures by USEPA under Section 316(b) of the CWA. Section 316(b) states that any standard established pursuant to Section 301 or 306 of the CWA and applicable to a point source

> shall require that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available (BTA) for minimizing adverse environmental impact. [33 United States Code 1326(b)]

Currently, USEPA’s 316(b) regulations do not consider desal facilities. However, through their participation and compliance with the federal Coastal Zone Management Act, coastal states may review permits granted by federal agencies, and may deny a permit if it is considered to be inconsistent with the state’s coastal management plan.

Table 10.1
Potential environmental and permitting issues for seawater desal plants

	Specific feature					
	Intake		Concentrate disposal[a]			
	Surface water	Sub-surface	Open ocean[b]	Other surface water	Sub-surface (beach)	Overall
Environmental issues						
"New" impingement	SA					
"New" entrainment	SA					
Seafloor alteration	SA					
Additional marine habitat alteration due to increased salinity and contaminant concentration[c]			SA CL	SA CL		
Continued/expanded use of OTC	CL					
Permits/requirements						
CWA						
Section 316(b)	CL		CL	CL		
Section 404 (Dredge and fill)	CL SA		CL SA	CL SA		
NPDES			CL SA	CL SA	CL SA	
Section 401 (Water quality)			CL SA		CL SA	
Rivers and Harbors Act Section 10	SA CL		SA CL	SA CL		
SDWA: UIC permit (if concentrate injection used)						
ESA Section 7 consultation						CL SA
State authority responsible for						
Drinking water quality[c]						CL SA
State lands						CL SA

Source: Adapted from Raucher, Strange, and Hallett 2006.
SA = standalone facility, CL = co-located facility.
a. Additional disposal methods may be available (e.g., evaporation ponds, zero discharge, and others).
b. Includes discharge by mixing with power plant's cooling water.
c. E.g., California Department of Health Services (CDHS).

Subsurface (below the seabed) intakes, when feasible, can greatly reduce potential impacts of I&E and associated permitting requirements. Where subsurface intakes are likely to be feasible and reliable, their adoption is likely to facilitate the process of securing several of the necessary permits. Chapter 8 of this report provides an overview of some of the advantages and disadvantages associated with subsurface intake facilities.

Inland Groundwater and Surface Water Desal Facilities

Inland groundwater is easily accessed through wells and may not require any significant regulatory review and approval (unless water rights and/or pumping permits are an issue). Desal source water intake wells will typically require the same permits as any other water supply well.

In addition, desalting groundwater may often be pursued in concert with an environmental restoration effort (e.g., where TDS and other contaminant levels in the aquifer are elevated due to irrigation, agricultural run-off, or other activities). In these contexts, desal can be viewed as part of an environmental improvement regime (i.e., making contaminated waters usable, and/or creating a barrier to limit the intrusion of lower quality water into other water resources).

Therefore, accessing feedwater for desalting inland groundwaters can be relatively easy to arrange with regulators, is less likely to engender public concerns, and in fact may often be portrayed and seen as an environmental plus. Permitting and public perception, however, may present challenges for the management of concentrate from inland desal facilities, as discussed below.

Also, there are some settings where inland desalting may rely on high TDS surface waters as its feedwater source. The regulatory and permitting issues associated with feedwater intake from saline rivers or lakes probably would not entail any significant differences from other intakes in freshwater rivers and lakes.

POTABLE WATER PERMITS

Most desal-generated waters are expected to provide water to enhance potable supplies, and as such will require permitting as a drinking water treatment plant (i.e., require a potable water permit from the SDWA primacy agent, typically the state public health or environmental protection agency). This should not pose any unusual challenges for water suppliers. This permit is not required if the desalted water is used for nonpotable (e.g., irrigation) purposes.

The potable water permit requires periodic compliance monitoring. One unique aspect of this permit for desal is the need to identify the monitoring points in the treatment process for filtration efficiency and turbidity compliance. A potential regulatory challenge facing coastal desalters is that there may be complications in meeting applicable Maximum Contaminant Levels (MCLs) related to DBPs, due to the potential formation of various DBP species (e.g., brominated species) when desalted waters are blended with other supplies.

A potential permitting challenge may arise where regulators are unfamiliar with membrane systems. Interviews with SDWA primacy agents from several states indicated that in many regions, membrane processes are not (yet) widely applied or well understood by the regulators or the local utilities and their regional consulting engineers. There are suspicions among some of these state regulators that membrane processes may prove unreliable, not perform up to manufacturer or vendor claims, and that utilities and their consultants will not have the expertise to ensure proper membrane selection, installation, and/or operation.

PERMITS FOR THE DISCHARGE OF BRINE CONCENTRATES AND ASSOCIATED WASTES

Currently there are multiple levels associated with the regulation of concentrate management, including federal, state, and often local agencies with specific requirements. The federal laws associated with the management of concentrate and associated wastes from desalting plants are described in the following sections.

At present, desal concentrate is regulated through a default classification as an industrial waste under the CWA because it does not specifically address byproducts from drinking water treatment plants. However, in the State of Florida, concentrate has been given some regulatory distinction, as it is now called a "potable water byproduct" if produced by plants of size 189 m^3/day (50,000 gpd) or smaller. Pending state legislation may extend this to plants of larger size (Mickley 2006). This regulation is intended to reduce restrictions that apply more to actual industrial waste rather than desal concentrate. Nationally, separate classification of drinking water treatment plant byproducts would require an amendment of the CWA.

Coastal Co-located Desal Facilities

With co-located coastal desal facilities, concentrate is typically discharged with the cooling water return flows from the power plant. This provides considerable dilution of the brine wastes in the discharge line (i.e., before the point of discharge into coastal waters), and may even serve to slightly cool the thermal power plant discharge. The blending of desalter concentrates with power plant OTC water may thus facilitate the dispersal of thermal and brine discharges so that they have less impact on the receiving marine environment.

Nonetheless, there are environmental concerns (and permitting requirements) associated with the discharge of brine concentrates from co-located facilities. Although the brine concentrates are essentially the same compounds found in the coastal waters drawn as the desal source, they will have been concentrated to levels that could pose environmental risk to aquatic organisms, if they are not adequately diluted and/or dispersed. Concern also arises because the discharge may contain anti-scaling or other cleaning agents and other compounds used in the desal process.

State primacy or federal regulators will impose federal CWA NPDES permits on desal facility discharges (even when the wastewater is released through a power plant discharge line, with its own permit). Key issues include levels of local mixing, dispersion, and dilution, and the potential presence of any special status species. Presumably, reasonable pilot testing and periodic monitoring should identify if any impacts of concern may arise. However, a potential hurdle for desal facilities may arise where concentration-based limits (or bio-monitoring) are set and measured at challenging compliance locations that do not reflect coastal conditions (e.g., toxicity testing inside the discharge pipe rather than in the receiving marine environment).

Coastal Standalone Desal Facilities

Coastal desal plants that are not co-located with power plants or other wastewater discharging facilities will face permit requirements for their discharge pipes that are similar to those for their intake, as follows:

- A CWA Section 404 permit for the outfall, since placing a pipe in the water is considered “fill.” This is administered by the USACOE, but typically requires buy-in and approval from other agencies, such as NOAA, which have jurisdiction over fisheries and other coastal resource impacts.
- State primacy or federal regulators will impose federal CWA NPDES permits on desal facility discharges.
- Rivers and Harbors Act (Section 10) permit for the outfall pipe. This is also administered by the USACOE, but the Corps will typically not issue such a permit unless other agencies (e.g., NOAA) are consulted and sign off.
- In some states, a permit will be required from the state coastal authority (e.g., the CCC).

Inland Groundwater and Surface Water Desal Facilities

Absent available brine lines or other means of conveying and discharging brine concentrates to coastal outfalls or large inland rivers (those without salinity issues), most inland desal facilities will probably need to rely on deepwell injection of concentrates. High cost and energy-intensive brine minimization, ZLD, and near zero-liquid discharge (n-ZLD) approaches may also be viable options, although to date, ZLD methods have been prohibitively expensive for municipal desal applications.

Deepwell injection is viable if geologic conditions are such that regulators will permit such an approach under the federal SDWA’s UIC program. Regulators will seek hydro-geologic evidence that indicates the injected wastes will remain physically isolated from other groundwater systems. Issues may also arise about whether the concentrate is a hazardous waste, and/or whether MCLs apply to the waste to be injected (as in the El Paso case study in chapter 9). Water supply agencies will want some assurance that the concentrate will not clog the pores of the target underground system, and thus limit the volume of concentrate that can be injected over time.

Inland desalting operations may also seek discharge permits to surface waters (i.e., NPDES permits), though this may prove challenging depending on the nature of the concentrate and the targeted receiving waters. In some locations, however, agencies may have circumstances that allow for or necessitate innovative approaches that eliminate the need for a discharge permit. For example, in Coachella Valley, a desalter is planned to feed a constructed salt marsh, and then the outflow from the marsh will flow to the Salton Sea—thus providing environmental benefits (and, possibly, eliminating the need or basis for an NPDES permit) (Raucher, Strange, and Hallett 2006).

Finally, evaporation ponds may be an option for managing concentrate disposal. However, the area of land required (600 acres was the estimated land area needed for the El Paso desalting plant), and the likely requirement for lining (and probably double-lining) such large-scale facilities, make such an option impractical and extremely expensive at this time. There also are concerns over potential impacts to wildlife due to hazardous chemicals or trace elements found in the desal concentrate as well as with the windblown transport of potentially hazardous concentrated materials in the dried out brines.

Other concentrate management and disposal options are being considered and researched, including ZLD, n-ZLD, and other processes that effectively reduce the volume or potential toxicity of the wastestream, or perhaps reveal an economic beneficial use of the concentrate byproduct. These potential approaches, based on largely on hoped-for technological advances that will reduce the costs and energy requirements of concentrate minimization, are discussed in other portions of this report and the accompanying PIM (see, for example, chapter 8).

As a final note, although concentrate minimization technologies (e.g., ZLD) have merit in that they improve the efficiency of the desal process, they exhibit environmental and permitting challenges similar to present technologies in terms of concentrate disposal. Concentrate volume reduction eliminates the use of most conventional disposal options because due to the higher concentration of salinity and other water quality constituents, the concentrate becomes even less compatible with the receiving water or environment. Further, the high level of solids produced (including additional solids produced by processes such as lime softening that allow high recovery processing) results in high landfill costs. Management of these solids, in many cases, requires dedicated monofills to be constructed.

Other Potential Regulatory Issues for Concentrates and Other Desal Wastes

In addition to the key permitting requirements listed above, NRC (2008) notes that the following federal laws that should also be considered:

- Resource Conservation and Recovery Act (RCRA). The byproducts of desal plants are typically not considered RCRA wastes; however, it is the utility's responsibility to confirm if the concentrate produced meets the definition of a hazardous waste under RCRA.
- Solid Waste Disposal Act. This law applies to nonhazardous solid waste disposal and would apply to desal plants using a solid waste disposal method.
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This law is applicable only if the desal plant has stored, treated, or disposed of a hazardous waste as defined by RCRA. This law might apply to desal concentrate from groundwater that contains high levels of toxic elements exceeding drinking water standards.
- Hazardous Materials Transportation Act. This law applies if any hazardous residuals (e.g., cleaning waste) are transported offsite.
- Toxic Substances Control Act (TSCA). This law, which controls the sale of toxic chemical substances, applies if concentrate is defined by the TSCA chemical inventory as toxic and sold for reuse (e.g., blended with treated wastewater for reuse).
- If the waste contains technologically enhanced, naturally occurring radioactive materials (TENORMs) exceeding certain levels, disposal or storage may require additional permits. Numerous state and federal regulations govern the disposal of waste that contains radionuclides, although there are currently no federal regulations that specifically address TENORMs (USEPA 2005).

SUMMARY OF PERMITTING REQUIREMENTS

The number and types of permits needed to build and operate a desal facility will depend on the source water, end use, and disposal regime pursued by a water agency. For example, for a coastal standalone facility in California, there are likely to be seven major federal or state permits required. Several of these permits may, in turn, entail several consultations and approvals from numerous other state, local, or federal entities before the issuing agency signs off. Numerous local agency permits also are typically required (although some are construction and land use permits that would typically be required for any project, not just desal). Tables 10.1 and 10.2 provide a summary of the key permitting requirements and environmental issues discussed above for seawater desal facilities.

For example, as of 2006, the California-American utility at Monterey had worked with 25 different permitting agencies (including seven federal and 11 state) in search of the 41 permits it needs to pursue a desal facility planned for co-location with the power plant at Moss Landing (Raucher, Strange, and Hallett 2006). In contrast, through some creativity and favorable local circumstances, the Coachella Valley Water District was pursuing a groundwater desalting program that they believed (as of 2006) would have two (at most) major permits, and if they proceed according to their plan, the program may not require any major permit (Raucher, Strange, and Hallett 2006).

STRATEGIES FOR WORKING WITH REGULATORS TO ADDRESS KEY ISSUES

Round Pegs in a World of Square Holes

The number of permits and approvals, and the associated number of government entities to be engaged, may seem daunting for a desal project. However, it is not the fact that numerous permits are often required that poses the greatest potential obstacles to implementing a desal project. Rather, the greatest challenge may arise from the manner in which the permits applications are evaluated. This is because regulatory permitting is often implemented in a manner that does not reflect or accommodate the specific circumstances that pertain to a desal facility in terms of its location and/or its planned mode of operating.

The research team conducted interviews with water agency leaders and other practitioners to identify key barriers to desal implementation. A central theme to emerge from these conversations pertains to the inter-related issues of (1) how regulators view and address desal, and (2) how water agencies work with the regulators.

Desal is a relatively new and uncharted territory for regulators, and desal facilities (and their potential impacts and wastestreams) are atypical of the type of operations that regulators normally monitor and permit. For example, some traditional regulatory approaches and protocols—such as issuing NPDES permits for wastewater discharges—may not be relevant for key aspects of desal operations. In other words, desal may be a round peg in regulatory settings that are set up with square holes to address square peg operations.

Table 10.2
Seawater desal projects—issues, regulatory agencies, and required permits/approvals

Issue/intent	Permit/approval	Lead agency	Consulting/ commenting agency	Seawater desal plant: Power - plant — Currently existing permit/ approval	Seawater desal plant: Co-location — Use existing permit/ approval	Seawater desal plant: New — Need new permit/ approval
Feedwater intake						
CWA 316 (a) and (b) apply only to intake and out-take structures of thermal power plants. A co-located desalination intake and out-take may be subject to 316 (a) and 316 (b), however that may be on a case-by-case basis. ***(A)***	**Section 10: Rivers and Harbors Act:** Applies to the construction of any structure in or over any navigable water of the United States if the structure or work affects the course, location, or condition of the water body. The law applies to any dredging or disposal of dredged materials, excavation, filling, rechannelization, or any other modification of a navigable water of the US, and applies to all structures, from the smallest floating dock to the largest commercial undertaking. **(B)**	**USACOE**	**US Coast Guard**: Acts as consulting agency only if construction of intake structure. Reviews permits and approves operations for traffic safety and navigation. **NOAA National Marine Fisheries Service (NMFS):** Acts as commenting agency under USACOE. **US Fish and Wildlife Service (USFWS)**: Acts as commenting agency for the USACOE. **California Department of Fish and Game (CDFG)**: Acts as consultant for impacts on biological resources. Conformity to NEPA and Public Interest Review if applicable. **(C)**	X	Investigate possibility of using existing permit for power plant.	Requirements under evaluation.
	Section 404 Permit: CWA: Required for activities that would result in discharges of dredged or fill material in navigable waters, their tributaries, and adjacent wetlands**.** Applies to seawater intake; offshore pipeline to shore; and outfall line in navigable waters.	**USACOE**	**US Coast Guard**: Acts as consulting agency only if construction of intake structure. Reviews permits and approves operations for traffic safety and navigation. **NOAA NMFS:** Acts as commenting agency under USACOE. **USFWS**: Acts as commenting agency for the USACOE. **CDFG**: Acts as consultant for impacts on biological resources. Conformity to NEPA and Public Interest Review if applicable. **(C)**	X	Investigate possibility of using existing permit for power plant.	Requirements under evaluation.

(continued)

Table 10.2 (continued)

Issue/intent	Permit/approval	Lead agency	Consulting/ commenting agency	Seawater desal plant: Power-plant — Currently existing permit/ approval	Seawater desal plant: Co-location — Use existing permit/ approval	Seawater desal plant: New — Need new permit/ approval
	Coastal Development Permit—Coastal Consistency Determination. (1)	**CCC and/or City of Project Location Federal Agency**	**CDFG**: Acts as consultant for impacts on biological resources and California Environmental Quality Act (CEQA) review. **NMFS:** Acts as commenting agency for impacts on marine life for the CCC. **(C)**		May require updated entrainment/ impingement study **(A)**	Energy Commission: If Energy Commission involvement, may require entrainment studies, rather than 316 (b) studies. **(A)**
	Operating permit: Offshore intake structure. Operation of plant as potable water supply. Meet state requirements. **(2) Source Water Assessment and Protection Plan:** Assess quality of delivered water, proposed treatment facilities, and offshore intake structure. **(4) (D)**	**CDHS Office of Drinking Water and Toxic Substances Control Division**		X		Wholesale Domestic Water System Permit.
Outfall/brine						
CWA 316 (a) and (b) apply only to intake and out-take structures of thermal power plants. A co-located desalination intake and out-take may be subject to 316 (a) and 316 (b), however that may be on a case-by-case basis. ***(A)***	**NPDES Permit:** CWA sets requirements for discharge water quality. **RWQCB**: Ocean Plan, Basin Plan, Thermal Plan, California Toxics Rule, and Anti-degradation Policies. **401—Water Quality Certification:** Certify that discharge into Corps jurisdiction will not have adverse water quality impacts. **(2)**	**RWQCB**	**CDFG**: Acts as consultant for impacts on biological resources. Review of Draft NPDES Permit. Will review Environmental Impact Report (EIR)/ Environmental Impact Statement (EIS) under CEQA. **USFWS and NMFS:** Consulting agency for NPDES permit.	X	Investigate possibility of using existing power plant permit.	Requirements under evaluation.

(continued)

Table 10.2 (continued)

Issue/intent	Permit/approval	Lead agency	Consulting/ commenting agency	Seawater desal plant: Power-plant — Currently existing permit/ approval	Seawater desal plant: Co-location — Use existing permit/ approval	Seawater desal plant: New — Need new permit/ approval
	Section 10: Rivers and Harbors Act: Applies to the construction of any structure in or over any navigable water of the US if the structure or work affects the course, location, or condition of the water body. The law applies to any dredging or disposal of dredged materials, excavation, filling, rechannelization, or any other modification of a navigable water of the US, and applies to all structures, from the smallest floating dock to the largest commercial undertaking. **(B)**	**USACOE**	**US Coast Guard:** Acts as consultant if construction modification. **NOAA NMFS:** Acts as commenting agency for USACOE. **USFWS:** Acts as commenting agency under the USACOE. **(C) CDFG:** Acts as consultant for impacts on biological resources.	X	Investigate using existing permit for power plant.	Requirements under evaluation.
	Section 404 Permit: CWA: Required for activities that would result in discharges of dredged or fill material in navigable waters, their tributaries, and adjacent wetlands. Applies to seawater intake; offshore pipeline to shore; outfall line in navigable waters.	**USACOE**	**CDFG:** Acts as consultant for impacts on biological resources. **US Coast Guard:** Acts as consultant if construction modification. **NOAA:** Acts as commenting agency for USACOE. **USFWS:** Acts as commenting agency under the USACOE. **NMFS:** Acts as commenting agency for impacts on marine life. **(C)**	X	Investigate using existing permit for power plant.	Requirements under evaluation.

(continued)

Table 10.2 (continued)

				Seawater desal plant		
				Power - plant	Co-location	New
Issue/intent	Permit/approval	Lead agency	Consulting/ commenting agency	Currently existing permit/ approval	Use existing permit/ approval	Need new permit/ approval
General: any project component that involves state/federal agencies						
Trenching/Excavating within State Highway	**Encroachment Permit**	**California Department of Transportation (Caltrans)**				
Onshore/Offshore Coastal Development (Siting)	**Coastal Development Permit: Local Coastal Plan—Consistency Determination Federal Agency. (1)**	**CCC and/or City of Project Location Federal Agency**	**NOAA NMFS:** Acts as commenting agency for impacts on marine life for the CCC. **(C)**	X	Investigate using existing permit for power plant. May require updated entrainment/impingement study **(A)**	Requirements under evaluation.
Pipeline Installation in City Streets	**Ministerial Encroachment Permit**	**City of Project Location**				Additional permit required from city.
Operation of Project as Stationary Source (Decarbonator)	**Construction Permit, Title V Permit:** Construction and operation of the project as a Stationary Source. **CEQA Review. (3) (5)**	**Local Air Quality Management District**		X		If project includes a decarbonator, additional permit required.
Federal Funding Involved	**NEPA**	**USBR:** Acts as lead agency if USBR funding involved. Issues approval.	**RWQCB, NMFS, USEPA, USFWS, USACOE**			

(continued)

Table 10.2 (continued)

				Seawater desal plant		
				Power - plant	Co-location	New
Issue/intent	Permit/approval	Lead agency	Consulting/ commenting agency	Currently existing permit/ approval	Use existing permit/ approval	Need new permit/ approval
CEQA Requirements	**CEQA Review:** Must be completed before any permit approval/decisions are made. **(3)**	**CCC and/or City of Project Location**	**CCC. City of Project Location. NMFS:** Acts as commenting agency for impacts on marine life for the CCC. **(C)**	X	May require updated entrainment/ impingement study **(A)**	
Development in Tidelands	**State Lands Commission Permit/Approval:** Any structures or change in use on state tidelands requires approval (Public Resources Code Sections 6801 and 6223). **(A) 404, 10 (B)**	**State Lands Commission USACOE**				
Modification of Power Plant Over 50 MW	**CEQA Review:** California Energy Commission may act as lead agency for CEQA review. Only if modification of power plant over 50 MW. Projects of less than 50 MW go through standard review subject to applicable permits (e.g., local permits, air quality permits, coastal development permit from Coastal Commission). **(3) (A)**	**California Energy Commission**		X	May require updated entrainment/ impingement study **(A)**	Requirements under evaluation.

(continued)

Table 10.2 (continued)

Sources: CDHS 2002; MWDOC 2002; City of Huntington Beach 2003.

Notes:
(1) Some locations will require a Coastal Development Permit from both the local jurisdiction and directly from the Coastal Commission; however, both of these permits are not processed jointly. In an area with a certified Local Coastal Plan, the local jurisdiction completes its permit review separate from any review by the Coastal Commission, although the two processes can be coordinated and can require similar information. Generally, though, the local jurisdiction does not review offshore issues, such as marine biology and water quality, unless its Local Coastal Plan includes provisions that address those issues. If the facility is a federal project, a Coastal Consistency Determination Permit replaces the Coastal Development Permit.
(2) In compliance with CDHS requirements, facilities will need to be permitted as a Wholesale Domestic Water System. The water utilities receiving the water will need to obtain an amended domestic water supply permit pursuant to the Regulations Relating to Domestic Water Systems. This includes the submission of (1) information necessary to comply with the Technical, Managerial, and Financial (TMF) Capacity Requirements; (2) a water quality Emergency Notification Plan (ENP); (3) an Engineering Report describing how the proposed new facilities will comply with the treatment, design, performance, and reliability provisions of the Surface Water Treatment Rule (SWTR); (4) CEQA clearance information; and (5) a plant operations plan (CDHS 2002).
(3) The CEQA Process (Public Resources Code Section 21000 et seq.) includes the following basic steps (please note: this brief summary of the CEQA process is not exhaustive, but serves to show an outline of the process): The lead agency analyzes the proposed project and if the lead agency determines that the project may have significant effects on the environment, then the lead agency for the project prepares a draft EIR. Following completion of the draft EIR, the responsible agency (lead agency for review) reviews the draft EIR and a public review period takes place to ensure compliance with CEQA requirements. Based on the comments and review of the draft EIR, revisions may be made and a final EIR is completed and submitted for approval. A final decision on the project is made and the state and local agencies file a Notice of Determination with the Office of Planning & Research and the County Clerk. Detailed Information on the CEQA process can be found online at the following Web site: http://ceres.ca.gov/ceqa/.
(4) If beach wells are to be used for seawater extraction, then the County/Local Health Departments are usually involved for the issuance of a drilling permit.
(5) Permit provisions for similar projects include but are not limited to: (1) submittal of plans and specifications for CDHS approval prior to construction; (2) compliance with the SWTR, including the treated water turbidity, disinfection residuals and contact time (CT) levels; (3) all water must be treated—no bypassing; (4) complete water quality analyses conducted by an approved laboratory; (5) adequate corrosion control; (6) adequate cross-connection control program; (7) updated watershed sanitary survey every five years; (8) mandatory use of American National Standards Institute (ANSI)/National Science Foundation (NSF) approved chemicals; (9) raw water bacteriological monitoring; (10) certified treatment and distribution operators; and (11) submission of monthly operation reports and a report after the first year of operation detailing the effectiveness of the plant's performance, a list of any violations, and a list of any needed additions or operational changes (CDHS 2002).
Comments from the following sources were inserted into the above information:
(A) Tom Luster, CCC.
(B) Corice Farrar, USACOE.
(C) Bob Hoffman, NOAA.
(D) Heather Collins, CDHS, Division of Drinking Water and Environmental Management.

There are two approaches (at least) that can be used concurrently as a way of working constructively with regulators in the "round peg-square hole" context of desal facilities and operations (Raucher, Strange, and Hallett 2006):

- First, there needs to be an open, advance dialogue with regulators (perhaps aimed at the higher management levels of key agencies, so that cooperative signals flow down to field staff) that explains the desal issues and needs, and tries to set up a reasonable set of protocols for permit approval
- Second, research that generates key findings, or establishes desal-suitable testing/ monitoring protocols, will help give comfort and reassurance to regulators that find themselves facing permitting issues in desal's unfamiliar territory

One example is the discharge of concentrates to the estuary from which the water was originally extracted. NPDES permits, driven by the total maximum daily load (TMDL) process, tend to set *concentration-based* discharge limits. This may make sense for industrial facilities that are using or formulating various chemical or other materials, and discharging wastewaters that introduce these compounds into the effluent-receiving waters. However, for a desal facility, concentrate disposal is (in most cases) simply returning the same elements already present in the source water to the environment; it is returning slightly less mass of these compounds, but at higher concentrations than in the source water. While the amount of dilution and dispersion of concentrated brines in the vicinity of the outfall is a matter of environmental concern and should be considered, does it make sense to have concentration-based rather than *mass-based* limits at the point of discharge for a desal facility returning matter to its source?

Finally, it is interesting to note how different states appear to be addressing the desal issue. In Texas, the state's Commission on Environmental Quality and the Texas Water Development Board have taken a fairly open and supportive view of desal, and the latter agency's Web site offers useful guidance for water agencies considering desal options. In contrast, State of California agencies have a varied and generally more skeptical view of desal. Appendix E provides further information comparing the state regulatory requirements in California, Texas, and Florida.

Tips for Facilitating the Permitting Process

The California Desalination Handbook (CDWR 2008) provides a number of facility design options and/or characteristics that can help facilitate the permitting process. These suggestions are based on the idea that designing a proposed project using the applicable regulatory requirements as design constraints can help complete the project successfully.

CDWR recognizes that the following suggestions are not feasible for every facility, however, under conditions where they are applicable, the following may facilitate the permitting process:

- Inland facilities or facilities away from the shoreline are typically easier to permit than coastal facilities
- Subsurface seawater intakes are likely easier to permit than open-water intakes

- Publicly-owned facilities are likely easier to permit than privately-owned
- Facilities with known service areas are likely easier to permit than facilities with unknown or extensive service areas
- Facilities that are part of a coordinated local or regional water portfolio are likely easier to permit than facilities proposed by a single, independent entity
- Proposed desal projects that have undertaken a thorough, transparent planning process will more likely be easier to permit than those which have not
- Early and ongoing coordination with permitting agencies and the public is likely to make the process easier than with little or no coordination

These points are consistent with the recommendations made earlier, in the portion of chapter 8 that addresses permitting issues. They also are consistent with the CCC perspective (Luster 2009). Luster (2009) provides examples of how adhering to these guidelines can limit the time required to secure a CCC permit to as little as two to six months, and how other outstanding permits from the CCC have taken over three years (and counting) because some of these tips have not been followed.

OTHER INSTITUTIONAL ISSUES

Numerous other institutional issues can have an impact on desal implementation. Several of these issues also are mentioned in the California Coastal Act (CCA), as summarized in Table 10.3. While these issues are not directly linked to regulatory and permitting authorities, their applicability to a specific planned desal project may directly or indirectly influence how regulators and permit-granting authorities consider the applications. Issues in addition to those detailed in Table 10.3 are detailed below.

Ocean Versus Estuarine Waters

There are often important differences between a desal facility that is located along, takes in water from, and discharges to the ocean, as opposed to desal facilities that rely on estuarine water bodies. Both types of facilities may be considered "coastal," but they may face various different physical and institutional issues, and in some instances will need to work with different permitting agencies.

There are several technical advantages to using estuarine waters in lieu of ocean waters. These include lower salt concentrations and higher water temperatures (making it easier and less expensive to desalinate to potable quality).

Table 10.3
Institutional issues in seawater desal in California (with specific regard to the 1976 CAA)

Issue	Impact/issue	Potential mitigation	Related policy
Energy use	Significant energy requirement for operation.	Cogeneration, energy recovery, renewable resources (e.g., solar).	Section 30253(4) Coastal Act: new development required to minimize energy consumption.
Environment			
Air quality	Increased energy usage will increase air emissions.	Reduce energy use and select energy sources to minimize emissions.	Section 30253(3) Coastal Act: new development required to comply with standards set by State Air Resources Control Board.
Marine environment	The feedwater intake method, waste discharge method employed, and composition of concentrate affect the local marine environment.		
Intake	Direct intake from surface waters generally leads to impingement (marine organisms are injured/killed due to impact with screens) and entrainment (smaller marine organisms are pulled through the screens, killed during plant processes). Currents around intake structure may be altered, affecting natural marine environment.	Reduce entrainment/impingement: site structures to avoid sensitive habitat, reduce intake velocities (< 0.5 ft per second), improve intake design (use of velocity caps, traveling screens, and fish return systems). Avoid I&E: use subsurface intake methods (beach wells, infiltration galleries, or HDD).	Section 30230 Coastal Act: requires maintenance and enhancement (even restoration where possible) of marine resources.
Composition of waste discharge	Depends on the quality of the feedwater, pretreatment, and membrane cleaning/storage. The discharge may be characterized by higher temperatures, salinity, and turbidity levels than the receiving waters. Chemical composition will vary, but may include biocides, sulfur dioxide, coagulants, metals, and anti-scalants. To varying degrees, wastes may have an adverse impact on marine organisms near the outfall, benthic communities, migrating fish, and the overall marine habitat.	Natural filtration by beach wells may reduce pretreatment needs. Mixing and diluting brine with power plant cooling water to reduce salinity of final discharge.	

(continued)

Table 10.3 (continued)

Issue	Impact/issue	Potential mitigation	Related policy
Waste discharge method	The construction of new direct ocean outfall pipes may cause alterations to the seafloor and other adverse impacts to the marine habitat. Mixing discharge with power plant cooling water may not be well received by the public or regulators due to negative association with OTC.	Utilizing the power plant's outfall pipe could eliminate new construction in the marine environment. Using beach wells for disposal will eliminate association with OTC.	Section 30231 Coastal Act: requires minimizing the adverse impacts of entrainment and waste discharges.
Growth	Desal may be perceived as a means to an "infinite" water supply source, essentially removing a substantial constraint to coastal development. The impacts of growth may be realized in the communities hosting the desal facilities as well as those receiving the water.	Coordination with growth management plans and appropriate plant sizing (with respect to desired level of development for the region). Educate public about "type" of water (particularly if it is considered to be replacement or supplemental water, rather than a new source).	Section 30254 Coastal Act: requires that public works facilities be "designed and limited to accommodate needs generated by development or uses permitted consistent with the provisions of this division."

Sources: Adapted from CCC 2004 and Raucher, Strange, and Hallett 2006.

However, there are also some institutional disadvantages:

- A richer and more sensitive aquatic ecosystem being impacted, because estuaries provide critical habitat for many marine species, especially for reproductive cycles and sensitive early life stages. This implies that I&E impacts may be of greater ecologic significance (and perhaps also adversely impact commercial and recreational fisheries). Discharges to these waters may also be of greater concern than in ocean waters (perhaps less rapid mixing and dispersion, and perhaps the presence of greater numbers of sensitive aquatic receptors, compared to ocean outfalls).
- Potential consumer concerns about making drinking water from bay waters known to receive discharges from various point and nonpoint sources (as contrasted to what is often viewed as the vast, and thus more pristine ocean).

Regarding environmental concerns that are heightened for estuarine waters, the Surfrider Foundation, an advocacy stakeholder group focused on coastal environmental quality issues, has noted (Surfrider 2006):

> There has been a dramatic loss of estuarine habitat in California—especially in the southern region of the state. Most of our coastal wetlands and estuaries have been filled and developed or are highly degraded from pollution and unnatural sediment loading. Consequently, estuarine habitat is a precious commodity and this creates heightened threats to aquatic and terrestrial life that depend on estuaries for some stage of their life history (e.g., birds, fish, invertebrates).
>
> Therefore, desalination facilities that rely on estuarine "source" water should be viewed with heightened scrutiny. Many of the entrainment and impingement issues that impact marine life and healthy marine ecosystems are arguably made worse when they impact estuarine species and the intricate ecological balance of estuarine ecosystems.

Private Sector Involvement

Some members of the public and some public officials have expressed concerns over having private sector entities involved in desal projects. This stems from a deeper philosophical issue about what role (if any) the private sector should play in the provision of water as an essential good and public service (e.g., critical to life, health, safety, and welfare). There is a tension that may arise between divergent perspectives about viewing water in general (desalted or otherwise) as a commodity as opposed to a basic human entitlement. This sentiment is expressed in the following example (Water for All 2006):

> Privatization of water delivery service is fundamentally at odds with the belief that fair access to water for all people is a fundamental human right. The need to regulate and protect the public interest is best demonstrated through retaining public ownership and oversight of any water project. Private water utilities can also claim proprietary information related to their technology and

> refuse to publicly disclose information vital to public oversight & environmental review.

Beyond the philosophical debate, which at some level may not ever be resolved to the satisfaction of either side, there may need to be important distinctions drawn between *"merchant" desal facilities* (plants developed by private entities, with the intent of selling their product to water utilities) and *investor-owned water utilities* (private sector entities that are publicly regulated utilities which have a contractual obligation to serve the public). In the case of merchant plants, the owner is providing water as a commodity. In the case of an investor-owned utility, water (and water distribution and delivery services) are provided with public sector oversight and pricing control.

For those opposed to private provision of water as a commodity, it is not clear whether they recognize the distinction between merchant plants and privately-held utilities. If this distinction is (or becomes more widely) appreciated, it is not clear whether this might alter the views of opponents of private sector involvement in desal (i.e., perhaps there is broader acceptance of private utilities adding desal to their water supply portfolio than there is of private companies making desal water for wholesale marketing).

Finally, in some locations (e.g., Monterey County, California), the aversion to private sector water production has led to a local ordinance that prohibits private sector involvement with desal projects. Whether this local act is constitutional is not yet tested, but the sentiment expressed has been a factor in how water supply issues, and desal, have been pursued in Monterey County (see the case study in chapter 9, and appendix H).

The CCC report on desal (CCC 2004) raises a number of concerns regarding private ownership of desal facilities. The Surfrider (2006) Web site points out (based on the report):

> Historically, the ocean has been regarded as a public resource to be utilized and enjoyed by all people and animals in a sustainable, non-extractive manner. Using the ocean as a source of drinking water (clearly an extractive use) changes all that. While one desal facility may not have a significant effect on the ocean, many such facilities (see cumulative impacts discussion below) may have detrimental effects.
>
> Typically, most of the water supply infrastructure in the United States is owned and operated by public or semi-public agencies. Quality of the water, reliability of the water supply system, and the price of the delivered water are all subject to the scrutiny of various regulatory agencies, local governmental bodies, and the general public. A water supply system operated by a private company (perhaps a multinational company) may not be subject to the same restrictions. Their profit goals may encourage rate increases, reductions in quality, and promotion of more water use, as opposed to calls for more water conservation and recycling.

Foreign Ownership

Similar to the opposition in some circles to private sector desal provision, there is a related concern over foreign ownership of desal facilities. This too stems from philosophical beliefs about control over water as an essential good. While contracts can be drawn that assure protections for both parties to an agreement—regardless of owner type or point of origin—the aversion to foreign ownership may impede some desal projects where the merchant vendor, or the investor-owned utility, has foreign ties.

There have even been some concerns aired regarding international trading and investment agreements such as the North American Free Trade Agreement (NAFTA) and General Agreement on Tariffs and Trade (GATT). The CCC has raised ". . . concerns about potential conflicts between trade rules and state regulatory authority" (CCC 2004). The subject of ownership by a multinational private company raises additional concerns regarding potential challenges to US laws that a multinational corporation might regard as restrictions on "free trade" or an "undue limitation on their ability to make a profit" (Surfrider 2006).

Asserted Jurisdictional Control

In some instances, utility professionals have stated to the research team a belief that some state or local agencies established conditions (i.e., set requirements or restrictions) on desal activities that were not within their legal jurisdiction or authority. In these cases, the utility was forced to either test the legality of the asserted authority by filing a legal challenge (implying long delays and high costs), or adhere to the asserted (but probably unauthorized) demands. The typical choice is to bow to the demands, and consider the imposed conditions to be part of the cost of getting needed approvals (even if the situation seems like a form of blackmail).

Making concessions to appease an over-reaching regulatory body may simply be a practical reality in some instances, but in other circumstances the impediments created may warrant a challenge to the legality or constitutionality of such actions. Asserted (versus actual or tested) permitting jurisdiction may be used in attempts to limit the types of entities can be involved in a desal project (e.g., precluding private entities or organizations with foreign ownership), or may impose other conditions on a local water supply agency (e.g., demanding more public access, changes in design or processes).

Challenges also tend to arise when a desal project entails crossing jurisdictional boundaries, including cases where a transmission line crosses a local municipal border. This introduces new additional players to the permitting process, with the parties often seeking some quid quo pro (in water or other services) in exchange for their cooperation.

Finally, some utility professionals noted that it is not always clear when a state agency staff person comment reflects an official policy position of the agency they represent, or is simply a personal observation. Casual or unofficial statements, especially when captured by the news media, can morph (intentionally or not) into apparent policy positions that may be difficult to reverse.

Growth and the "Sociology of Water"

In many communities, there is considerable concern about the potential magnitude and pace of population growth and its associated impacts on the local "quality of life." This is a legitimate concern in many areas, and water supply provision serves as one convenient point of leverage with which parties can limit growth. This is not necessarily an issue about desal; rather, it is about expanding the local water supply in general regardless of the source or method. However, because desal is the promising new alternative that is emerging as the potential solution to growing water scarcity, desal has become a primary target of no- or slow-growth advocates.

Ideally, local citizens and public officials concerned about how to manage growth would rely on policy tools directly aimed at the problem, such as local zoning requirements. However, there is a long tradition through much of North America of "zoning by infrastructure." This term implies that by directing the location and pace of expanded local water and/or wastewater infrastructure, interested parties (developers included) have been able to impact property values, traffic patterns, and the general level and location of population growth in localities.

There may not be any practical way in which research can help avoid the issues that come from growth-related concerns about desal. Desal is a logical place for growth opponents to impose a bottleneck into community expansion, just as growth is a logical target for encouragement by developers and other pro-growth advocates.

Water Rights for the Ocean

Currently, the ocean's water is a common property resource, and no water rights are required to divert such waters. There has been discussion in some circles about the possible need or merit of considering near-shore waters as part of the public trust and, therefore, making them subject to some regulatory control for desal extractions or other such uses. It is not evident that this issue of establishing ocean water rights (or some similar mechanism through which a government establishes authority and management over the quantities of ocean withdrawals) is likely to have much impact or traction in the near term.

ADDITIONAL REGULATORY ISSUES

This section addresses some additional regulation-related topics that are relevant to the discussion of desal planning and implementation.

Defining Best Technologies Available for Desal

Among the key challenges in desal permitting is the fact that many regulators are not sure what is reasonable to look for in terms of technology and operational choices and their associated performance. Likewise, utilities may be frustrated by the degree of uncertainty created by the current lack of regulatory uniformity across states and other jurisdictions, and by the delays caused by regulator uncertainty and lack of precedent. As a consequence, there have been suggestions that Best Technologies Available (BTAs or BATs) be established for the key components of desal projects (e.g., for coastal feedwater intakes, pretreatment, membrane selection, concentrate management).

The rationale for this suggestion is that if specific technologies and associated design standards and operational guidelines can be established, then this will provide a degree of certainty and uniformity for both the regulators and the utilities. The regulators can more quickly approve projects that adhere to BTAs, and utilities would also face simpler planning processes as well as expedited and less uncertain permitting.

The difficulty with this suggested approach, however, is that the feasibility and desirability of desal-related technologies and operational guidelines are highly site specific. For example sub-seabed feedwater intakes (e.g., beach wells) are not technically feasible in some hydrogeologic settings. In other settings, they may be feasible, but their long-term performance may be highly suspect (e.g., in terms of clogging and providing adequate feedwater inflows). Thus, while the simplicity and uniformity associated with a BTA-oriented approach sounds appealing, it is not a suitable solution to the highly site-specific nature of desal facilities.

The Potential Role of USEPA

In a similar vein, there have been some proponents of the notion that a larger federal role is needed to promote uniformity across states about how desal is permitted and operated. This is difficult given the many issues touched on by desal projects, and the associated crossing of jurisdictional boundaries between federal agencies (e.g., USACOE, NOAA, USFWS, USBR, USEPA, and others).

One suggestion is for USEPA to issue "guidelines" for desal projects, along the lines as the Agency's guidelines for water reuse. If the USEPA were to issue federal guidelines or regulations pertaining to desal under its SDWA mandate, on what should those federal guidelines focus? In general, such guidelines probably should focus on membranes, and associated issues such as membrane performance and quality, and monitoring requirements.

Desalinated Waters

Desalinated (and some membrane filtered) waters differ from many natural waters because of their initial low TDS and (in coastal settings) their seawater origins. However, from a health risk perspective, it should be understood that many surface water supplies historically and currently utilize source waters that are impacted by upstream treated wastewater discharges, but the "conventional treatment" that they receive is significantly less effective and comprehensive than the advanced highly effective treatments applied in desal and planned indirect potable reuse.

Public water supplies are subject to drinking water regulations under the SDWA that is partly reflective of source. For example, surface water supplies and groundwaters under the influence of surface water are subject to the Long Term 2 (LT2) requirements of the enhanced SWTR, designed to protect against *Cryptosporidium* contamination in the source water. This is because those "worst case" microorganisms are ubiquitous, unaffected by chlorine disinfection, and difficult to filter. The LT2 rule requires an assessment of the range of concentrations of *Cryptosporidium* in the source water and specifies the level of treatment technologies with projected log removal capacities, along with turbidity values that should be applied to assure negligible transport of the microorganisms to the finished drinking water.

Saline source waters are less likely to contain high levels of microorganisms like *Cryptosporidium,* unless the intakes are proximal to wastewater discharges. Even in instances where these saline source waters contain significant microorganism contamination, the desalting processes applied to those waters (be they RO membrane or thermal desalting processes) are highly effective in removing those microorganisms. Pretreatments that are commonly employed may also well have an effect on reducing many of the microorganisms. Whether saline waters (or source waters with an associated wastewater history) should be subject to special regulations or guidelines is an appropriate issue to consider.

Regardless of the source, any finished water would always be required to meet the prevailing national drinking water regulations, whether MCLs or treatment requirements. Desal in the US is likely to be heavily dominated by membrane processes, due to the energy requirements of thermal processes. Common membranes are polymeric materials such as originally cellulose triacetate or more likely polyamides and polysulfones. Membranes are typically layered or thin film composites. The surface contact layer (rejection layer) is adhered to a porous support, which can be produced from the same material as the surface. Membrane thickness is on the order of 0.05 mm. Selection factors for membranes include pH stability, working life, mechanical strength, pressurization capacity, and selectivity and efficiency for removal of solutes.

Membranes are located in a module and they can be configured as hollow fibre, spiral, plate, and tubular. Each has its own characteristics that affect selection in particular cases. Hollow fibre and spiral configurations generally have more favourable operating characteristics of performance relative to cost and they are most commonly used. Operating pressures are in the range of 250–1,000 psi (17 to 68 bar, 1,724 kPa to 6896 kPa). Membranes used for ED are 0.13 to 1.0 mm and typically 0.5 mm polymeric materials assembled in plate and frame type stacks. These membranes operate at feed pressure of 20 to 100 psig and are oxidation resistant.

There are numerous compositions of membranes within each category. Table 10.4 provides some generalized performance expectations for four major categories of membrane systems. The larger pore membranes like MF and UF are often used as pretreatments to remove larger particulate contaminants and to reduce the loadings on the more restrictive membranes like RO, and extend their performance and run times (WHO 2007).

Cryptosporidium fall in the size range of 4 to 6 μm so even MF will effectively remove them. Viruses are removable by UF, and enhanced MF can also significantly reduce microbe loadings. Hence, intact RO membranes have excellent capability to remove any microorganisms of concern. Therefore the regulatory or guideline issue would revolve upon the quality of the membrane, and assurance of its function during the life of the unit process.

Table 10.4
Comparison of membrane process performance characteristics

Membrane type	Nominal pore size (in μm) (approximate)	Constituents removed
Microfiltration	0.1 to 1	Particulates, bacteria, protozoa
Ultrafiltration	0.001 to 0.1	Viruses, large and high MW organics
Nanofiltration	+/- 0.001	Multivalent metal ions, some organics
Reverse osmosis	0.0001 to 0.001	Seawater, brackish water desal, organics >100 daltons

Source: Adapted from Applied Membranes 2009.

Membrane Quality

Reliable membrane quality and performance are key elements to assure that purchasers of membranes can be confident that they will function effectively and as expected. This was probably a greater problem in the past because uniformity and performance has been improving. Warranties (first party assurance) and pretesting (pilot testing) prior to acceptance may be sufficient to address this issue.

On the other hand, it is worth considering whether there would be value added if initial membrane quality and reliability would be handled by third-party consensus standards, much as already exist for all other drinking water contact chemicals and surfaces. Thus, the regulatory requirement could be that membranes certified to an appropriate third-party standard would be used. Such standards are not known to exist as yet, but they could be developed if/as the market demands it.

Assuring the integrity and performance of the membrane system (seals and membranes) in use is a different issue. Current regulations require suitable technology to be employed and their performance is determined by frequent turbidity measurements on individual filters and on the aggregated drinking water. There is not a complete consensus on the most appropriate techniques for determining the effectiveness of membranes. Turbidity would have a role and other parameters such as conductivity, Total Organic Carbon (TOC), and pressure changes are being seriously examined. The performance expectations being considered are significantly more stringent than are currently applied to conventional coagulation sedimentation and granular filters, which actually are less effective. Ultimately, it is possible that performance requirements will become regulated, although guidance may be very effective and sufficient until such time as a technical consensus is reached.

Finished Water Quality

The finished drinking waters must meet all promulgated drinking water regulations. It may be desirable to supplement regulations to include Health Advisory Guidance values and include constituents specific to a particular source or system.

In addition, guidance on the stabilization of the water prior to distribution will be important to assure that the water will not be aggressive to the distribution system. Guidance may also be valuable with respect to consequences of interactions between membrane treated water and conventional waters which may be blended (e.g., with respect to bromide and chloramine residuals).

It also would be appropriate to consider whether the lack of mineralization and particular ions like calcium and magnesium might render desalted water less than optimal with respect to beneficial aspects that are related to minerals intake (e.g., cardiovascular disease or osteoporosis risks). This issue was explored by WHO (2009), and studies are underway to examine whether water composition is important as a supplement to dietary intakes of several ions. The same issue exists for softened water and naturally very soft waters.

Implications for Monitoring Requirements

Assuming that RO and NF membranes perform as expected, there are many potential drinking water contaminants that would not be expected to be found in the permeate used for drinking water. Therefore, it would not make sense to require extensive monitoring for these effectively removed constituents. Instead, any potential future regulatory requirements related to monitoring membrane-treated (i.e., RO or NF) desalted waters should focus on those contaminants that desalting membranes may not remove effectively.

CONCLUSIONS

As described above, there are myriad regulatory, permitting, and related institutional issues that may impact desal projects. Many arise out of legitimate technical concerns for protecting natural resources and the environment, and some arise out of philosophical differences and opinions. Research and growing field experience from pilot and demonstration testing and from full-scale desal implementation probably can help resolve many of the technical questions about environmental impacts (i.e., Will negative impacts occur? Will the adverse impacts occur at levels of concern? And if so, can these negative impacts be mitigated or offset in a practical and satisfactory manner?). Research and increased field experience may also help address some of the issues arising out of political or philosophical differences (although the prospects for doing so may be less tangible).

Regulatory Framework and Permitting

A significant issue is how regulators and other agencies involved in the permit review and approval process view desal, and whether they are willing and able to account for the important ways in which desal may differ from the other entities they regulate. There are various ways in which research, and other efforts, may help establish a regulatory framework that is more suitable for desal (i.e., creating a round hole pegboard for the round pegs).

One approach may be to develop a workshop (or series of workshops) that brings regulators from different states and agencies together, along with various technical experts, to review desal concerns and permitting procedures. The sessions would provide a forum for the exchange of ideas on regulatory approaches (i.e., the approach in Texas as contrasted to California), and the sharing of technical information. This sharing of information and perspectives, including input from credible and objective technical experts, may alleviate some regulator concerns. This type of exercise might help reveal a uniform set of regulatory tools and standardized approaches (e.g., for monitoring discharge or intake impacts) that are suitable to desal and provide regulators with sufficient comfort.

Ultimately, it seems like a useful objective to try to define some standardized approaches to desal permitting and other regulatory issues, using credible and appropriate approaches to address legitimate concerns (and avoiding unnecessary or irrelevant steps and procedures).

Citizen and Public Official Outreach Needs

Much of the discussion with concerned citizens and public officials focuses on addressing their concerns about desal. Research, pilot testing, and field experience can help address many of the technical issues that may concern some of these stakeholders. There may also be various approaches that utilities can deploy to help steer the dialogue in a more constructive direction, such as by helping water agency managers explain the rationale for and advantages of desal (e.g., see appendix D).

It may also be useful to explore ways of communicating about the problem(s) to be solved by adding desal to the portfolio of local supply options. For example, desal has progressed with relatively little public opposition in Tampa and in Texas locations. There are some indications that this may be because in the relevant locations it is broadly recognized that there is a serious water shortage problem, and that desal is a cutting edge way of helping address the needs of the community.

To help reveal where there is a need, and to help reveal the extent of that need, utility efforts may be directed in the following areas:

- Identifying the baseline for community X, when looking forward 10 to 30 years in the future, if desal is not added to their water supply portfolio. Will there be water shortages? What will the impacts be? The problem of projecting reasonable future scenarios to reflect realistic baseline (i.e., without desal) conditions is not a simple exercise. Developing and portraying a "no desal" future may be helpful as a way of helping communities focus on their alternative futures.
- While "growth" can be a lightening rod issue, it may be worth some effort to investigate what growth scenarios are likely under existing state and regional planning procedures and documents. Deflecting the growth projections away from the desal project, and pointing instead to the official growth projections laid out by relevant state and regional governing bodies, may help.
- Articulating the benefits of desal. Not all water supply options pose the same types or levels of reliability risk, and desal offers some important advantages to traditional surface water sources that are linked to drought cycles.

CHAPTER 11
GUIDANCE FOR UTILITIES ON DESAL PLANNING AND IMPLEMENTATION

As detailed in previous chapters, a primary objective of this research project is to help water utilities and other water professionals better navigate their way through the desal planning and implementation process. One of the key principles guiding this work is the adoption of a broad systems planning approach intended to help utilities integrate desal systems into existing technical and institutional systems.

Accordingly, the project team has developed a "desal decision framework" to help guide utilities through the technical and institutional challenges associated with the development of desal facilities. The following sections provide an overview of this framework, highlighting each stage of the desal planning and implementation process.

OVERVIEW OF DESAL DECISION FRAMEWORK

As shown in Figure 11.1 on the following page, the framework divides the desal planning and implementation process into six stages, as follows:

1. Visioning and Goal Setting
2. Desal Feasibility Analysis and Implementation Planning
3. Pre-Design
4. Design
5. Facility Construction
6. Implementation

As depicted in Figure 11.1, for each stage of the planning and implementation process identified above, the framework identifies key questions to be answered, actions to be taken, and decisions to be made (before moving forward to the next stage).

It is important to recognize that the stages build on each other, with each stage laying the foundation for the next. Costs are additive, and increase with each stage. At the end of each stage, it is therefore valuable to revisit the question, "Is desal a viable option?" Further, given their complex nature, and the range of possible options, it is not uncommon for desal projects (especially seawater desal facilities) to be altered during the course of design, planning, public involvement, and permitting. When such modifications are made, different stages of the process may need to be revisited.

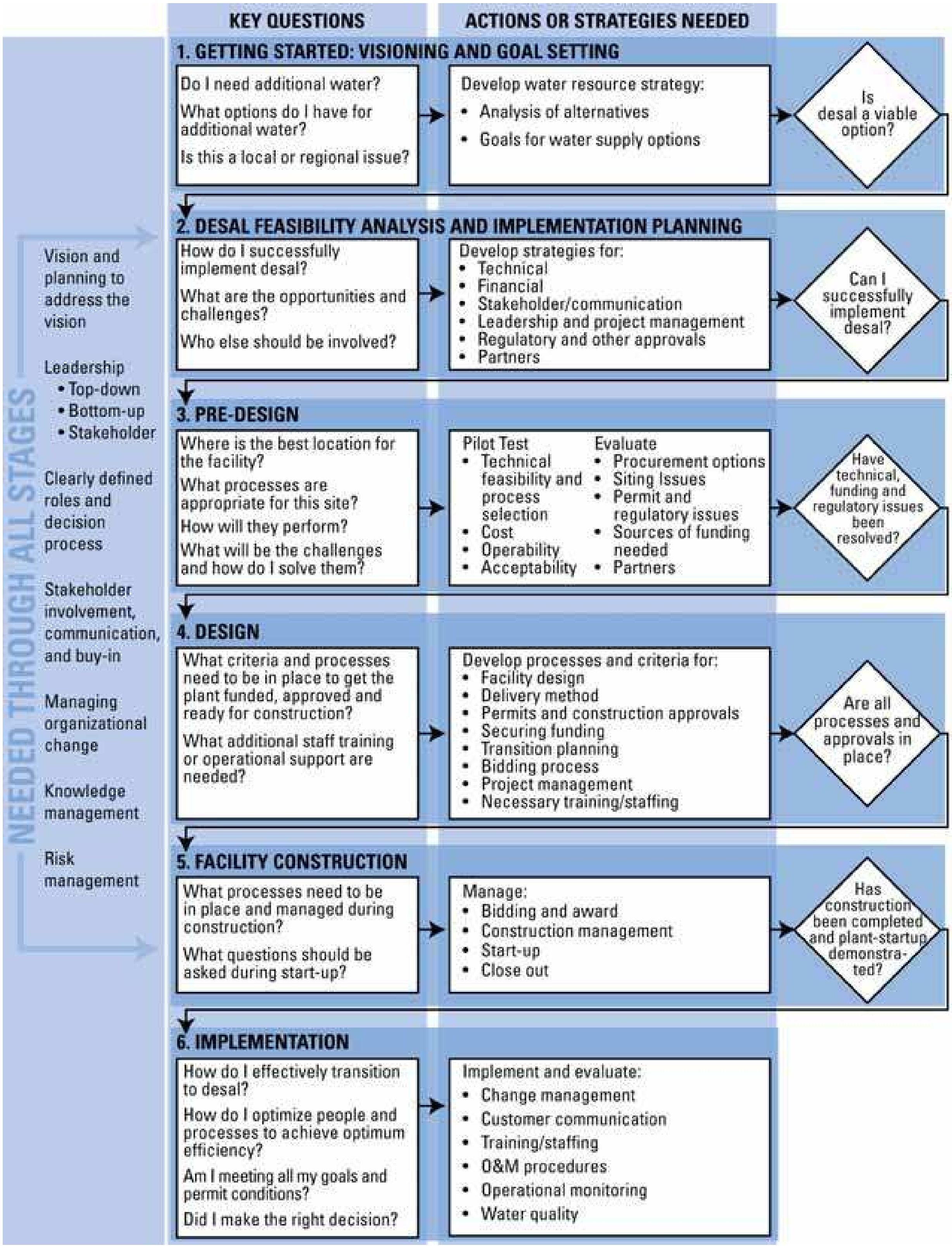


Figure 11.1 Overview of desal decision framework

In addition to the distinct stages of desal planning and implementation identified above, there are a number of processes that need to be conducted throughout the desal project period (i.e., during each stage of the planning and implementation process). These processes include:

- **Vision and planning**. The vision and plan for implementation should be revisited during each stage of the process. As more information is gathered or conditions change, the vision, and the steps necessary to achieve the vision, may need to be revised.
- **Leadership.** Effective leadership is essential to moving implantation forward and keeping it on track. For effective implementation, champions and leaders are needed both from managers and legislators (top down), as well as from those that will actually implement the process (e.g., engineers, operators). Having champions and project supporters from different stakeholder groups can also pay large dividends.
- **Clearly defined roles and decision processes**. Implementing a major new process will require a wide range of staff, and in many cases, outside consultants. Defining roles is essential in ensuring that each task is effectively completed and to avoid duplication of effort. Understanding who makes the decision and/or process for decisionmaking should be defined.
- **Stakeholder involvement, communication, and support**. Also important to the planning process is engaging key stakeholders (e.g., boards, elected officials, regulators, environmental groups, and other third parties) and the broader public in the early stages of project development. Actively involved stakeholders are more likely to support and champion a project. Effective public involvement rests not only on early involvement but also in creating an open and transparent process that allows meaningful public input on environmental, economic, and community issues. Throughout the planning process, water providers should look for opportunities to involve stakeholders, and should be aware that stakeholders (especially elected officials) may change during the course of a project.
- **Managing organizational change**. Implementing a major new process can have a substantial impact on a water provider's workforce. Introduction of new technologies creates a level of uncertainty among employees with questions arising regarding how it will impact their jobs. This uncertainty can erode support for the project. Being aware and addressing change is essential for an efficient and functioning workforce.
- **Knowledge management**. Desal implementation requires the involvement of many people, numerous reports and documents, and a wide range of decisions. The project planning process typically takes several years prior to implementation. Personnel may change and/or key documents may be lost or forgotten. Knowledge management is needed to ensure that information is retained, updated, and available when decisions need to be made.
- **Risk management.** The planning and implementation framework essentially provides the water supplier with a process for risk reduction. Risks are greatly reduced through identifying and addressing key challenges. More information generally reduces risk, while lack of information increases risk. Key project risks include those associated with permitting, entitlement (ownership of land and infrastructure on site of the proposed facility), availability and cost of power, changes in source water quality, changes in applicable regulations, uncertainties associated

with unproven and new technologies, and risks associated with the demand for desalinated water. Project risks should be evaluated at each stage of the implementation process.

STAGES OF PLANNING AND IMPLEMENTATION

The following sections provide further detail on the different stages of the decision framework described above. For each stage of the process, additional information is available in other areas this report and in the accompanying project resources. Accordingly, the following sections present the general principles. When appropriate, references to different sections of this report and other project resources are provided.

Stage 1: Getting Started: Vision and Goal Setting

Desal projects often emerge as a component of a broader utility planning effort designed to address the following questions (Figure 11.2):

- Do I have enough water to meet future demand projections?
- What options do I have for meeting this demand?
- Is desal an option for meeting this demand?
- Are there opportunities for local coordination?

These questions are typically evaluated through the development of a water resources strategy that begins with an understanding of available water supply options and predicted future demand. Alternatives for meeting future demand are evaluated, and desal may emerge as a potential option. Desal should be considered in conjunction with water conservation, reuse, additional storage, importing water, etc., to address future needs. In addition, opportunities for a regional desal strategy should be evaluated.

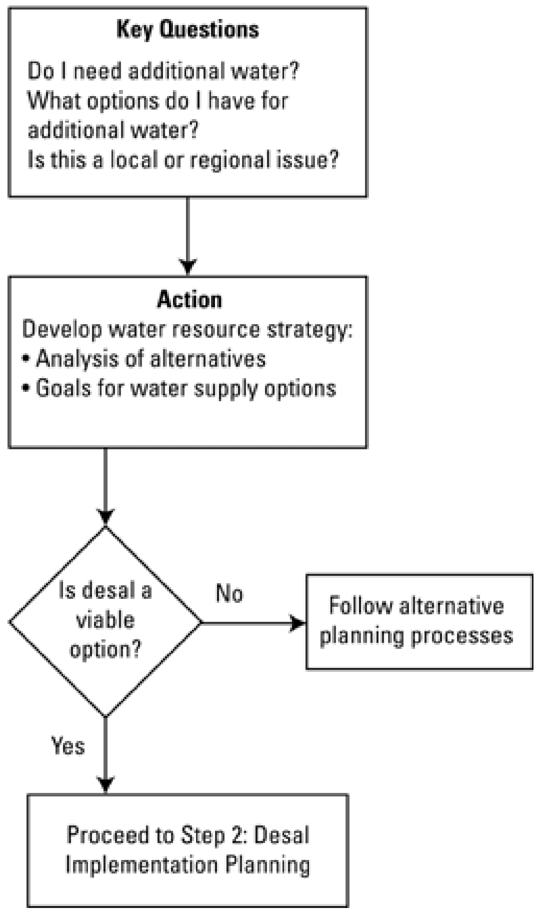


Figure 11.2 Stage 1. Getting started: Vision and goal setting

The water resources strategy should determine when additional water resources will be needed and how to integrate different water supply options into a broader strategy for meeting stated goals (often called a water portfolio). When identifying preferred options, characteristics of different supply options that might impact supply (e.g., reliability, quality) should be taken into account. For example, desal has the advantage of being able to be introduced directly into the potable supply. Recycled water does not currently have this direct potable feature, which can cause a more lengthy process of identifying customers and installing dual delivery infrastructure, or for setting up indirect potable reuse approaches. Different water supplies have different benefits and therefore should be valued differently. Information on trade-offs, options, and alternatives should be very complete even if this information extends beyond what the utility is used to researching. In addition, the social and environmental costs and benefits associated with each option should be evaluated. Ultimately, during this stage, a decision is made in regards to whether or not desal is an appropriate option for meeting some, or all, of the future projected demand. Stage 1 serves as a first tier "fatal flaw analysis" in terms of assessing the feasibility of desal.

Having a water resources strategy is essential in working with decisionmakers and stakeholders. Having stakeholder and public support for desal can greatly facilitate implementation. It is also important to document decisions up front, as decisionmakers and stakeholders may change during the course of a project. A water resources strategy should be updated periodically as conditions such as predicted demand and available supply change over time.

Stage 2: Feasibility Analysis and Implementation Planning

If it is determined that desal is a potential option, the water supplier or project proponent continues with Stage 2: Desal Feasibility Analysis and Implementation Planning. Key questions addressed during this stage include (Figure 11.3):

- What needs to be done to successfully implement desal?
- What opportunities or barriers need to be considered?
- Who else should be involved in this decision process?

This stage is characterized by assessing the feasibility of desal and planning for implementation by identifying challenges and opportunities, understanding how they might impact implementation, and evaluating what can be done to address them. In addition to technical issues (e.g., cost, performance, site conditions, energy usage), it is important to include institutional issues (e.g., permitting, environmental issues, stakeholder acceptance, funding) in this stage of the planning process. Failure to address institutional issues early on

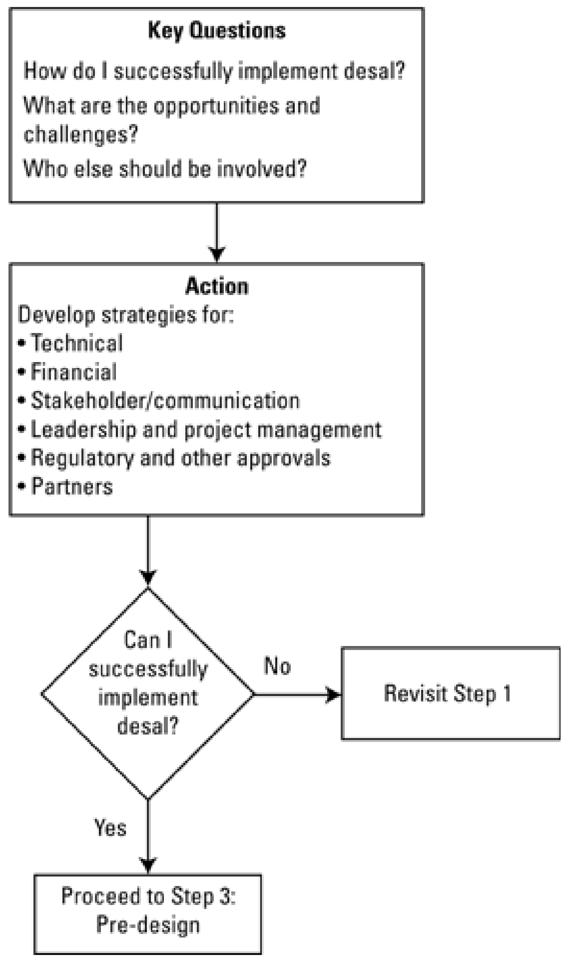


Figure 11.3 Stage 2. Feasibility analysis and implementation planning

can lead to substantial delays and increased costs. It is important to recognize that with time, additional opportunities and challenges may arise that will require this process to be revisited.

Table 11.1
Example list of implementation barriers

Barriers related to water utility culture	Technical barriers	Regulatory barriers	Stakeholder barriers
Risk adverse, concerns of a new technology	Site constraints at proposed location	Multi-agency involvement in permitting	Balancing the needs of multiple stakeholders
Resistance to change	Performance uncertainties (longevity, life cycle, integrity)	Limited regulatory experience to review and approve	Short-term vs. long term mindsets
Lack of a clear strategic direction	Water quality concerns (red tides, boron, blending)	Contradictory and/or evolving regulations	Environmental degradation concerns
Need for a champion	Environmental degradation issues (residuals, energy use, I&E)	Long approval time	No-growth advocates
Lack of expertise	Lack of standards for design and regulatory approval		Environmental justice concerns
Financing and difficulty in raising rates	Feasible solution for concentrate disposal		Public health concerns related to quality of the source water
			Siting concerns

Table 11.1 provides a list of potential issues associated with desal implementation typically addressed during this stage of the planning process. This list of potential issues relates to challenges associated with the existing water utility culture, technical issues, regulations, and stakeholder perceptions and concerns.

With an understanding of the potential barriers to implementation, strategies for addressing these barriers can be developed. Ultimately, given the challenges identified, an implementation plan should be developed that includes strategies for addressing:

- Technical issues (e.g., identifying and addressing constraints associated with possible locations for the desal facility, intake and outfall, including availability of power)
- Regional approaches (e.g., identification of opportunities for regional collaboration, including potential partner utilities, municipalities, and project sponsors)
- Financial issues (e.g., identification of major project costs, development of a preliminary "financing plan" for capitalizing the project, as well as sustaining the ongoing operation)
- Stakeholder communication (e.g., assessment of public perceptions and awareness; identification of major stakeholders; development of a strategy to address concerns and perceptions, including why desal is being pursued, its potential impacts and benefits, and its relationship to the overall water supply portfolio)
- Regulatory and other approval needs (e.g., identification of key permitting agencies, establishment of permit review committee)
- Leadership and change management

During and after these plans are developed, it is important to ask the question, "Can I successfully implement desal?" If the answer is yes, then move onto Stage 3: Pre-design.

Stage 3: Pre-design

In the pre-design stage, data and information needed to design and implement a desal project are collected. Building upon the strategies developed during the implementation planning stage, pre-design should include a more detailed evaluation of both technical and institutional issues. On the technical side, key questions include (Figure 11.4):

- What is the best location for the proposed desal facility (including intake and outfall)?
- What processes are appropriate for this site?
- How will they perform?

Pilot testing is often done during this stage to evaluate the cost and performance of different desal systems. If a pilot project is utilized, the water provider will need to work with relevant regulatory agencies to obtain needed permits and develop a schedule for proceeding with the project (including construction, monitoring, evaluation, etc.). It is generally recommended that public outreach also be conducted to ensure public understanding of the pilot project, and to minimize the opportunity for misconceptions about the project and its relationship to a potential full-scale project. Guidance for pilot testing is provided in chapter 8 and appendix C of this report.

The selection of a specific location and specific desal technologies allows for a more detailed examination and resolution of financial, social, environmental, and institutional issues. At this stage, examples of key questions include:

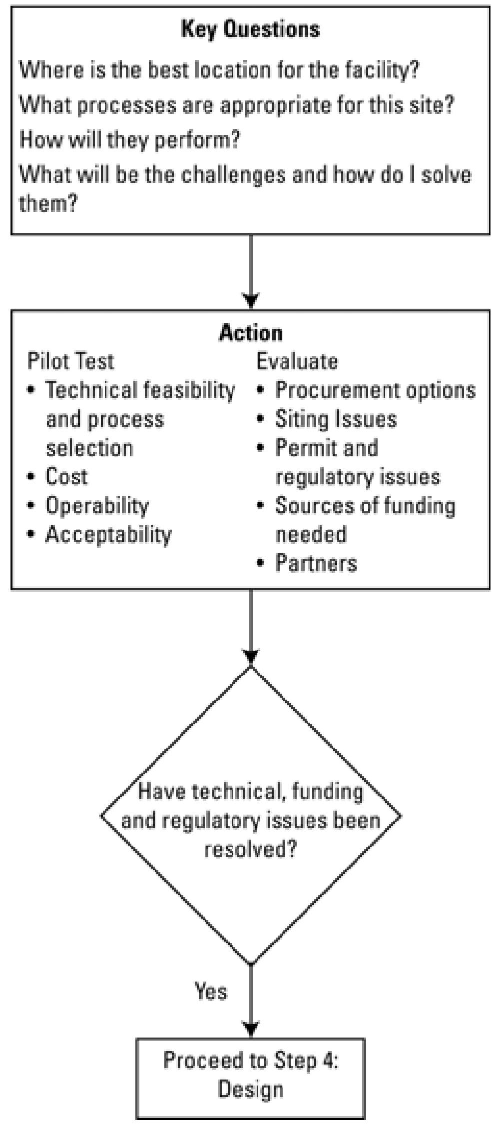


Figure 11.4 Stage 3. Pre-design

- What will be needed to obtain the necessary permits and/or approvals?
- What are the feasible procurement options, partners, and sources of funding?
- What are the primary environmental concerns at the site (e.g., I&E, concentrate management, carbon footprint)?

- What are the social and political issues associated with the project (e.g., concerns associated with the specific site, growth issues)?

The decision at the end of this stage is, "Have technical, funding, and regulatory, issues been resolved?" At this stage, appropriate technical and institutional process(es) will need to be to selected in order to move forward to Stage 4: Design.

During Stage 3, a comprehensive assessment of the environmental and social impacts of proposed project alternatives, such as is conducted through an Environmental Impact Assessment (EIA), should be initiated. An EIA identifies, describes, evaluates, and develops means of mitigating potential impacts of proposed activities on the environment. In an EIA, information on the environmental consequences of a project is provided to the public and to decisionmakers. A detailed EIA is often required for large infrastructure projects, such as a desal facility. Depending on the proposed project, it is incumbent on national authorities to individually define the need, scope, and complexity requirements for each EIA (Lattemann 2008; Cotruvo et al. 2010). Although the EIA should be initiated in Stage 3, it will carry over into Stage 4: Design (for further information on EIAs, see Lattemann 2008).

Stage 4: Design

During the design stage, the water provider focuses on clearly defining each technical process component and developing specifications, criteria, or other plans that can then be used to construct or implement these processes. Design criteria include specifications for equipment, materials, systems, and quality and performance goals. Key questions at this stage include (Figure 11.5):

- What are the design criteria and specifications for the facility?
- What is needed to be in place to get the plant funded, approved, and ready for construction and implementation?
- What training or operational support is needed to support the implementation?

A component of this stage is to develop bid and construction documents that define the exact specifications of the facility. A final financial analysis should also be completed and the financial viability and security aspects of the project should be

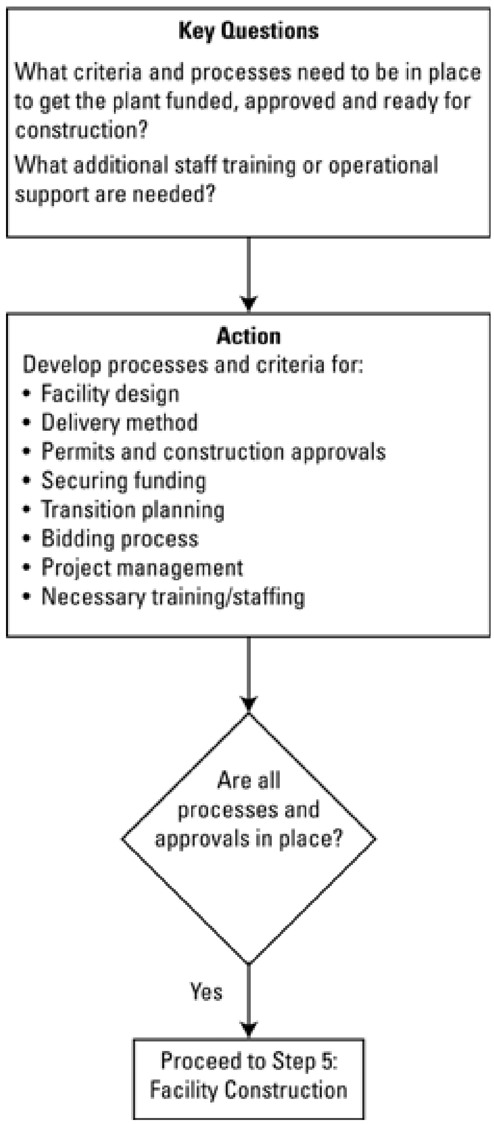


Figure 11.5 Stage 4. Design

documented (e.g., the cost of money, cost of energy, availability of subsidies, and other income streams to support the project).

Beyond technical and financial criteria, key institutional issues to be addressed at this stage include:

- Defining the contract delivery method (DBO or DBOOT) and develop the appropriate bidding process
- Obtaining permits
- Obtaining funding and project partners

Supporting functions should also be considered, including:

- Development of a transition plan which defines considerations for implementing the new process with existing processes. This should include staffing and training needs.
- Development of a project management and contractor selection process.

At the end of this stage, clearly defined criteria necessary for bidding and construction, as well as items needed to support implementation are developed.

Stage 5: Facility Construction

During the construction stage, work is conducted to build what was developed during the design stage. Key questions during this stage include (Figure 11.6):

- What processes need to be in place and managed during construction?
- What questions should be asked during start-up?
- What constitutes an acceptable project?

A typical construction project has stages of bidding, award, management, start-up, and close-out. During these stages the project manger will need to manage the contractor, subcontractors, team members, project reporting and payments, quality assurance/quality control (QA/QC) and inspections, scheduling, recordkeeping, and other project controls. The project manager also needs to communicate with stakeholders and manage any internal organizational issues.

Having criteria for project close-out and approval is particularly challenging and processes should be established during the design stage of the project. Along with performance-based criteria, considerations for recordkeeping and documentation should be included in

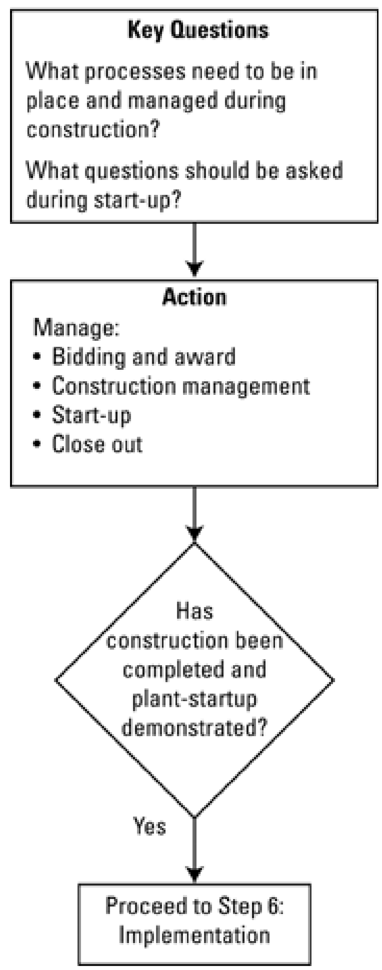


Figure 11.6 Stage 5. Facility construction

the final decision. At a minimum these should include as-built plans and O&M manuals.

At the end of this process, construction should be completed and plant start-up should be successfully demonstrated. When this has occurred, the water provider can move into full implementation of the desal facility.

Stage 6: Implementation

Following construction, the project transitions to full implementation. Key issues to be addressed during this stage include (Figure 11.7):

- How do I effectively transition to desal?
- How do I optimize people and processes to achieve optimum efficiency?
- Is additional training needed?
- Am I meeting all my goals and permit conditions?
- Did I make the right decision?

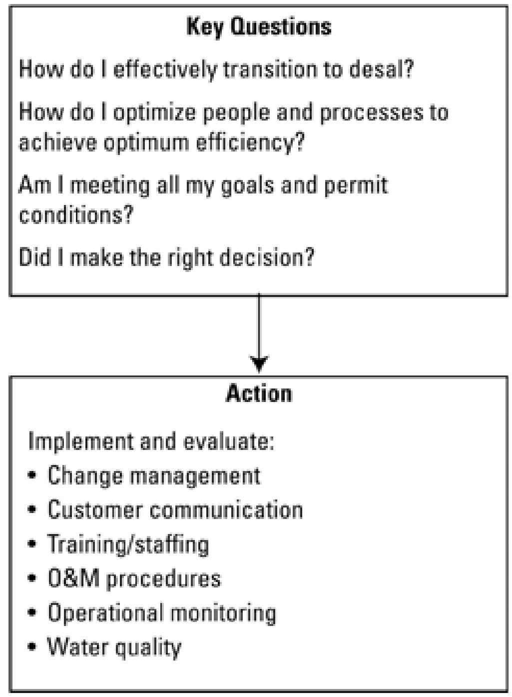


Figure 11.7 Stage 6. Implementation

Implementing a new technology, such as desal, requires transition of processes and people. For desal, examples of new processes include issues such as maintaining water quality when adding desalinated water into the distribution system, and conducting any additional monitoring that may be required. For people, change management becomes important as staff are being required to address the challenges of a new process. A change management strategy should include training and developing new O&M procedures.

Finally, throughout project implementation it is important to check back with the vision and goals of the project to evaluate whether implementation continues to meet the original goals of the project. If not, determine what additional steps may need to taken. Stakeholder feedback and communication are also needed.

SUMMARY

The evaluation, design, and implementation of a desal project involve a number of opportunities and challenges that must be addressed within the context of existing utility, community, and institutional systems. While the development of a desal project requires a long and involved process, proper planning can facilitate a more rapid, less costly, and less frustrating implementation process.

The framework provided above is intended to serve as a guide to the different issues associated with desal planning and implementation. Ultimately, each project will need to be evaluated within the context of site-specific issues and challenges.

CHAPTER 12
FUTURE RESEARCH NEEDS

This chapter provides several suggested avenues for future research that would assist with the planning and implementation of desal, especially in the US. The specific topics are organized according to the major types of challenges that currently inhibit and complicate desal implementation. There are a vast number of potentially beneficial research topics related to desal, and in this chapter we focus on general themes for future research rather than the many highly specific research topics that could be usefully pursued. We also focus on those topics that are most likely to assist with near-term institutional hurdles, rather than longer-term technology development.

OVERVIEW OF EXISTING DESAL RESEARCH THRUSTS

There are numerous research efforts currently directed toward desal, including projects conducted or funded by the USBR, or funded and managed by the Water Research Foundation, the WateReuse Foundation, and others. As noted by Voutchkov (2009b), many of these efforts have recently focused on technology enhancements, including an emphasis on topics including:

- Developing a better fundamental understanding of the relationship between source water quality, membrane fouling, and pretreatment mechanisms
- Enhancing the performance of existing membrane pretreatment and RO processes
- Improving existing technologies to attain higher productivity, lower energy use, and/or better product water quality
- Developing non-membrane, hybrid, or other new forms of salt separation technologies
- Minimizing concentrate and addressing brine disposal challenges
- Linking desal facilities to alternative energy sources

These are all important issues for long-term investigation and research. However, below we focus on topics that may be more valuable in terms of addressing near-term, practical desal implementation barriers.

RESEARCH NEEDS ORIENTED TOWARD NEAR-TERM DESAL CHALLENGES

As noted throughout this report, the main obstacles to wider implementation and acceptance of desal in the US today are the often inter-related topics of environmental impacts from seawater feedwater intake and concentrate disposal:

- High costs and energy use
- Complex, convoluted, and time-consuming project permitting processes
- Limited public understanding of the role, need, importance, benefits, and environmental challenges of desal

There are a large number of potentially valuable research projects that can help address these needs. Many are discussed in the white paper developed by Voutchkov (2009b) for the WateReuse Foundation's 2009 research needs workshop. In addition, there were 28 desal-oriented research projects developed by the WateReuse Foundation's Research Advisory Committee (RAC) in February 2010. Below, we offer some generalized research needs, which overlap with some of the more specific topics suggested elsewhere (some of the following were drawn from the WateReuse Foundation's project descriptions and compiled and ranked highly by the RAC).

GAINING A BETTER UNDERSTANDING OF THE I&E IMPACTS OF OPEN WATER DESAL INTAKES

Much of the current scientific knowledge and environmental concern over open seawater intakes stems from I&E experiences with coastal OTC power plants. Power plants using OTC typically need to take in significant volumes of water, often an order of magnitude more in daily volumes per day than a large-scale desal plant. In addition, the velocity of the water intake is typically very high for power plants. The volume and velocity requirements of the power plants using OTC are the major determinants of the I&E rates observed in these facilities.

In contrast, desal facilities can take in much lower volumes of water, and can do so at much lower velocities (especially if configured with some feedwater storage capacity). As a consequence, standalone desal facilities with open water coastal intakes may impose far less I&E than an OTC power plant, yet little scientific evidence seems to have been compiled in this area. Sound biological assessments of I&E at desal-scaled open water intake volumes and velocities would seem to be a highly valuable endeavor. In concert with that effort, the impact of desal I&E with a mix of alternative mitigation measures (e.g., a range of intake cap and screening designs, biological avoidance measures, and so forth) would help identify which suite of design and operational approaches perform best for I&E minimization.

DOCUMENTING CONDITIONS THAT SUPPORT (AND THOSE THAT DO NOT) SUBSURFACE (SUB-SEABED) INTAKE APPROACHES

There is considerable interest, especially in the regulatory community, of promoting the use of beach wells and other forms of coastal feedwater systems that rely on sub-seabed rather than open water intakes. However, sub-seabed designs are not feasible in some locations due to various physical characteristics. In other locations, the approaches may appear viable, but the ability to perform adequately over the expected desal facility lifetime is unclear (i.e., there may be clogging and other problems that render the intakes unusable or inadequate after a relatively short period).

Research is needed that helps identify and clearly articulate conditions under which various sub-seabed intake systems are technically feasible and likely to perform adequately over a suitably long duration. This would help regulators and utilities jointly recognize where it is suitable to push for such systems, and where it is suitable to instead be more focused on open water intake approaches.

PERFORMANCE AND COST REVIEW OF EXISTING DESAL PLANTS THAT USE CONVENTIONAL AND MEMBRANE PRETREATMENT PROCESSES PRIOR TO RO

Very little published, unbiased research information is available to water treatment industry professionals to qualitatively and comparatively assess the performance and costs of existing desal plants using conventional and membrane pretreatment. This project would help address this need. The objective of the work is to assist in the planning-phase and in assessing treatment process treatment feasibility issues amongst existing media filtration and membrane filtration pretreatment systems on surface water treatment plants utilizing RO.

The research approach could be a desktop-based project consisting of a review of existing published information, facility audits, and a collation and assessment of results. The audit could be performed by sending custom-developed data forms for facilities to complete and then followed up by telephone. The review could focus on documentation of feedwater conditions (and associated variations in feed water quality including but not limited to temperature, TSS, turbidity); identification of equipment operational conditions and constraints, chemical consumption, power consumption, generation of wastes, online time, filtered water quality, O&M costs, capital costs, and if available, operation during periods of elevated biomass events (e.g., as measured by cell counts, phytoplankton, or Chlorophyll-a).

INVESTIGATING BEST-IN-CLASS CONCENTRATE MANAGEMENT TECHNOLOGIES FOR INLAND DESALTERS

This project could be used to identify specific parameters that determine the use of various concentrate management options and technologies and how it relates to the specific location. This might include mapping the location and related regional characteristics and parameters of relevance (e.g., desal treatment technology, source water quality, finished water quality, concentrate management technologies/methods, relative cost per finished water gallon, and kWh per finished water gallon).

This information could help identify potential uses of those technologies and locations where they could most likely be applied. Much of this information exists in past surveys; this project will consolidate that information and extend it by adding costs, and reviewing regional application feasibility and implementation issues. It would help determine the applicability of concentrate management technologies to future projects, avoid reinventing the wheel every time a new inland desal project is decided, and develop site-specific concentrate management costs, which go beyond what has previously been done.

ONSITE USE OF DESAL CONCENTRATE FOR IMPROVED IN-PLANT WATER AND ENERGY EFFICIENCY

This project could investigate issues such as beneficial in-plant use of concentrate for pretreatment filter backwash, generation of sodium hypochlorite, addition of minerals to RO permeate, generation of electricity via pressure RO, and sequestration of CO_2. The project could consist of the following:

- Identify all potential beneficial on-site use opportunities for concentrate
- Identify constraints for using concentrate for each of the on-site uses

- Research means and methods and associated costs for removing constraints
- Develop preliminary design criteria and process diagrams for making use of concentrate for each potential on-site beneficial use
- Identify any incidental negative consequences of using the concentrate for the intended use
- Develop cost estimates for each application of concentrate
- Identify the cost or savings that would be achieved over what the alternative would have been
- Identify the cost of the alternative disposal methods
- Demonstrate the cost and benefit of implementing beneficial uses

REGULATORY WORKSHOP ON CRITICAL ISSUES OF DESAL PERMITTING

Currently the desal industry has a limited understanding of the key problems and issues regulators have with permitting of desal projects. Such understanding could only be built in an environment of a non-project specific interaction of the desal industry with the regulatory community (i.e., with key state agencies in Florida, California, Texas, and Arizona) in a non-adversarial (i.e., workshop) setting.

A beneficial step in this direction would be a WateReuse-facilitated and sponsored regulatory workshop or series of workshops, which aim to gain common ground and understanding of what background information and data/studies on various aspects of desal the regulatory community needs to be able to expedite project permitting (e.g., investigation of desal technologies and equipment, their pathogen removal performance, and reliability; source and product water quality; contaminants in the desal discharge and their impact on the environment). The main outcome of such workshops would be the development of a regulator "wish list" which could be used to formulate a set of research topics for various research institutions, and which specifically target issues the regulatory community perceives as bottlenecks in the permitting process.

THE VALUE OF WATER REUSE AND DESAL TO CUSTOMERS AND COMMUNITIES: DEVELOPING TBL VALUES AND EXAMPLES

The objectives of this project would be to help promote suitable desal applications by objectively demonstrating how large the environmental, financial, and social (TBL) benefits are when desal options are included in the community water supply (using a regional water resource management perspective). It could provide examples and guidance for how to objectively evaluate desal options—alongside other community/regional alternatives—in a full TBL context (e.g., including GHG and other such impacts).

The research approach could identify and articulate the important types of TBL benefits that accrue to reuse and desal projects, and how they compare to these and other benefits associated with other water options. The project might conduct case studies to illustrate how to estimate and communicate the key TBL values that accrue to customers and communities from desal. Case studies should draw on a range of North American and other projects (e.g., EU, Australia). The TBL values could include reliability values, local control benefits, community economic vitality, and ecosystem impacts. The project also could be used to indicate how regional and multi-utility approaches to desal may help magnify the benefits and contain the costs of desal, especially where desal is considered within a broader context of regional water resource management challenges, rather than solely as a way to augment or offset local potable water supplies.

UNIFORM COSTING GUIDELINES FOR TBL-BASED EVALUATIONS OF DESAL PROJECTS

The objectives of this project include establishing a clear, standardized basis (as guidelines and/or templates) for how to fully and fairly estimate and portray the costs of desal projects, and other water supply programs to which they may be compared. This would aim to ensure that the full capital, O&M, and GHG-related costs of water supply projects (reuse, desal, conservation, imports, and other options under consideration) are reflected in a consistent and appropriate manner, so that the costs of relevant options can be fairly compared on an apples-to-apples basis. It also should include GHG (and any use of green energy or energy-efficient options) and other important social and environmental costs, so that the cost comparisons can be used within a TBL context.

The research approach could include a review of past cost estimation guidelines and examples from utility project evaluations, to help identify good practices and typical shortfalls. It should include international experience (e.g., EU, Australia), and include Life Cycle Analysis (LCA), energy supply options, and carbon footprint accounting methods.

The project should provide specific guidance and examples of how to identify and interpret sensitivity analyses that focus on key costs items which can impact cost levels and how options rank in an evaluation (e.g., energy costs, chemical costs, permitting). It also should account for variations in how final water quality and potential water uses across various options impact the overall water portfolio and wastewater management costs. The benefits of the project are that it would promote fair and unbiased comparison of the true TBL and LCA costs for desal options, as well as for other alternative supply options under consideration.

APPENDIX A
EMERGING AND HYBRID DESAL TECHNOLOGIES

Emerging and hybrid technologies are being developed to improve certain aspects of the performance limits of existing desal processes, such as higher recoveries, reducing fouling, and decreasing energy consumption and costs. These new technologies include dewvaporation, MD, FO, membrane process enhanced by VSEP, CDI, and development of new membranes. Hybrid configurations and processes are developed to increase water recovery and reduce concentrate volume, such as physical-chemical or biological treatment of primary RO concentrates followed by secondary RO, seeded slurry processes to remove scaling compounds in a controlled fashion, EMF for scaling control, RO/ED, and RO/EDR.

DEWVAPORATION

Dewvaporation is a process of humidification-dehumidification desal (Figure A.1). Brackish water is evaporated by heated air, which deposits fresh water as dew on the opposite side of a heat transfer wall (Hamieh, Beckman, and Ybarra 2001; Hamieh and Beckman 2006a, 2006b; Beckman 2008). The energy needed for evaporation is supplied by the energy released from dew formation. Heat sources can be combustible fuel, solar, or waste heat. The tower unit is built of thin plastic films to avoid corrosion and to minimize the cost of equipment. Towers are relatively inexpensive because they operate at atmospheric pressure.

The technology of dewvaporation has been pilot tested by treating reclaimed water RO (Beckman 2008), and produced water generated from oil and gas production (Godshall 2006). The positive attributes of dewvaporation are that scaling is not a potential problem because the evaporation occurs at the liquid-air interface and not at the heat transfer wall. The major challenges facing dewvaporation are that energy demand is high if low grade heat is not available. Volatile organic compounds may cause contamination in product water.

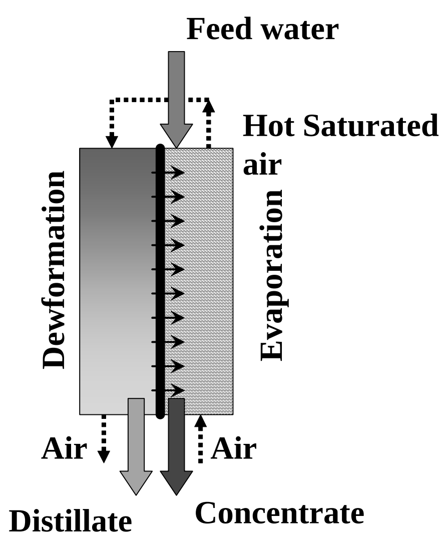


Figure A.1 Schematic of dewvaporation

MEMBRANE DISTILLATION

MD is a novel, thermally driven membrane separation process that may utilize a low-grade heat source to facilitate mass transport through a hydrophobic, microporous membrane. The driving force for mass transfer is a vapor pressure gradient between a feed solution and the distillate, and is the only membrane process that can maintain process performance (i.e., water flux and solute rejection) almost independently of feed solution TDS concentration, even for TDS exceeding 35 g/L. MD is most likely capable of producing ultra-pure water at a lower cost compared to conventional distillation processes. Membrane materials commonly employed for MD include polytetrafluorethylene (PTFE), polypropylene (PP), and polyvinylidenedifluoride (PVDF).

MD may be operated in four basic configurations: direct contact membrane distillation (DCMD), vacuum membrane distillation (VMD), air gap membrane distillation (AGMD), and sweeping gas membrane distillation (SGMD) (Lawson and Lloyd 1997). During DCMD a warm feed stream flows on one side of the membrane, while a cooler aqueous solution flows counter-currently on the opposite side of the membrane. Molecules of water evaporate and diffuse through the pores of the membrane. Upon contact with the cold distillate solution on the product side of the membrane, the vapor condenses and is assimilated into the distillate solution. AGMD works on a similar principle as DCMD; however, instead of a cooler distillate stream, the permeate side of the membrane contains an air gap and a cold plate. As water vapor diffuses through the membrane, it enters the quiescent air gap and condenses on the cold plate. A general illustration of the principles of DCMD and AGMD is shown in Figure A.2.

Theoretical rejection for all non-volatile solutes [including sodium (Na), silicon dioxide (SiO_2), boron (B), and heavy metals] is 100%; however, compounds with higher volatility than water will diffuse preferentially faster through the membrane. As a standalone process MD may be capable of achieving similar water recoveries as BWRO. Recovery may be improved to greater than 80% when coupled with crystallizer technologies to reduce scaling (Martinetti 2007).

One benefit of MD is that the membranes are more chemically inert and resistant to oxidation than traditional RO and NF membranes, which allows for more efficient, chemically aggressive cleaning.

FORWARD OSMOSIS

FO is an osmotically driven membrane process. During FO, water diffuses spontaneously from a stream of low osmotic pressure (the feed solution) to a hypertonic (draw) solution having a very high osmotic pressure. Unlike RO and NF, FO systems operate without the need for applying hydraulic pressure (Figure A.3). The membranes used for this process are dense, non-porous barriers similar to RO membranes, but are composed of a hydrophilic, *cellulose acetate* active layer cast onto either a woven polyester mesh or a micro-porous support structure.

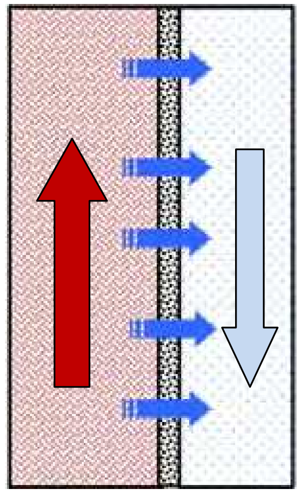


Figure A.2 Generalized illustration of the principles of MD. A warm feed stream containing various non-volatile solutes and water is depicted on the left side of the image. Water vapor diffuses through the membrane and enters the distillate solution or condenses onto a cold plate.

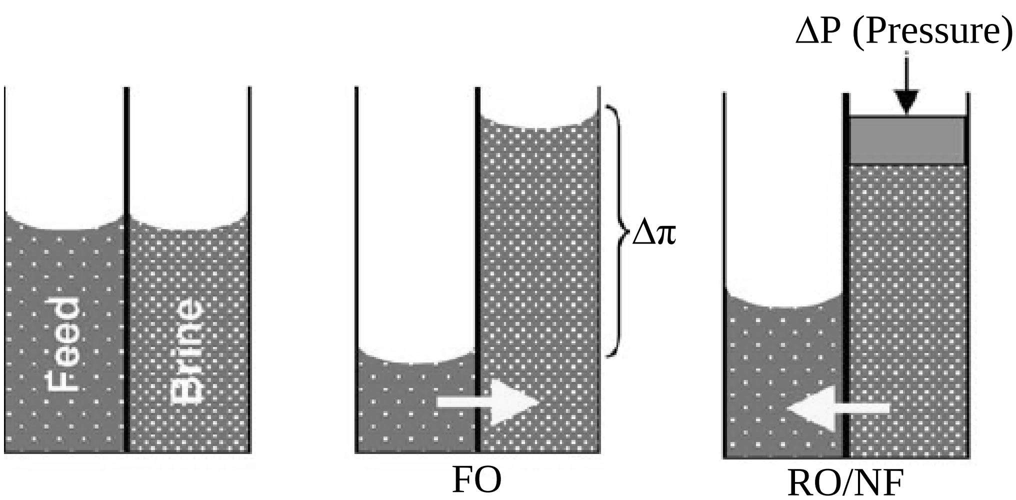


Figure A.3 Direction of water diffusion in FO and pressure driven membrane processes RO and NF. For FO, ΔP is approximately zero and water diffuses to the more saline side of the membrane. For RO and NF, water diffuses to the less saline side due to hydraulic pressure ($\Delta P > \Delta\pi$).

Typically, the FO draw solution is composed of sodium chloride (NaCl), but other draw solutions composed of ammonium bicarbonate (NH_4HCO_3), sucrose, and magnesium chloride ($MgCl_2$) have been proposed (Cath, Childress, and Elimelech 2006). During FO the feed solution is concentrated while the draw solution becomes more dilute. Figure A.4 illustrates a generic industrial scale application of FO, which requires the continuous reconcentration of the draw solution for sustainable system operation. One prominent method for reconcentrating the draw solution is to utilize an RO subsystem.

FO membranes are capable of rejecting all particulate matter and almost all dissolved constituents (greater than 95% rejection of TDS). These attributes also allow FO to achieve very high theoretical recoveries while minimizing energy and chemical demands. An additional benefit of FO is that the process occurs spontaneously, without the need for applied hydraulic pressure. The hydraulic pressure applied in pressure-driven membrane processes is responsible for compacting foulants onto the membrane, which substantially intensifies irreversible flux decline. Fouling layers that accumulate on FO membranes may be readily removed with cleaning (e.g., increasing cross-flow velocity, osmotic backwashing) or with chemicals, and irreversible flux decline is minimized (Martinetti 2007, Mi and Elimelech 2008). FO processes are capable of operating with feed TDS ranging from 500 mg/L to more than 35,000 mg/L, and may achieve recoveries in excess of 96% when treating brackish water (Martinetti 2007). The FO draw solution may require infrequent disposal and addition of a new draw solution as sparingly soluble solutes and other membrane foulants slowly accumulate in the draw solution reconcentration loop (Hancock and Cath 2009).

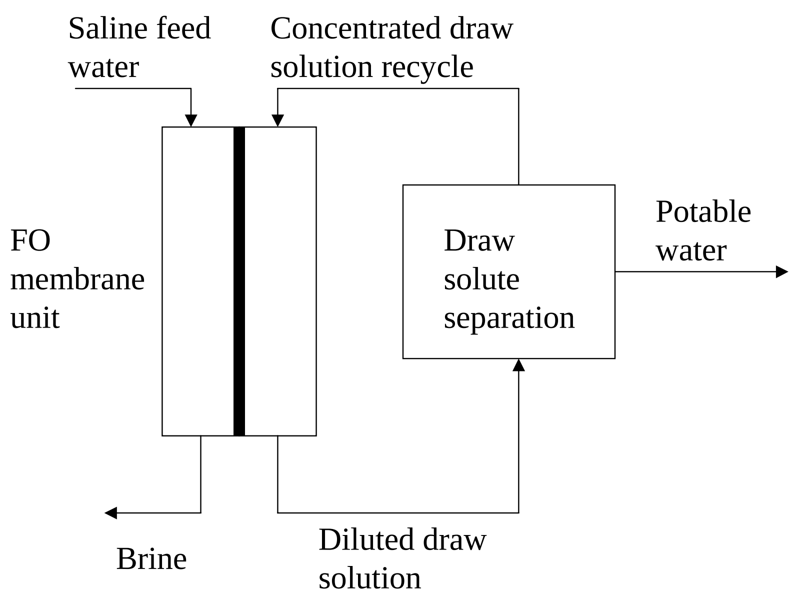


Figure A.4 Schematic of a generic FO system for desal

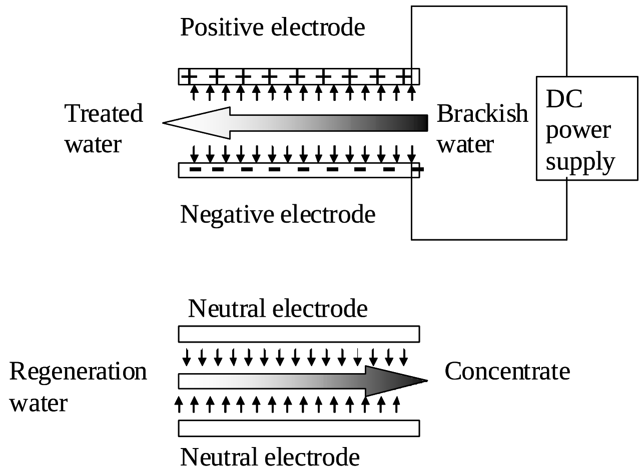


Figure A.5 Schematic of capacitive deionization

CAPACITIVE DEIONIZATION

CDI is an electrosorption process to remove salts from aqueous solution using porous electrodes by adsorbing ions under an applied electrical field (Figure A.5). Liquid is flowing between the high-surface electrode pairs having a potential difference of 1.0–1.6 volt direct current (DC). The negative electrodes attract positively charged ions such as calcium, magnesium, and sodium, and the positive electrodes attract negatively charged ions such as chloride, nitrate, and sulfate. The major mechanisms related to the removal of charged constituents during water treatment are physisorption, chemisorption, electrodeposition, and/or electrophoresis. Unlike IX, no additional chemicals are required for regeneration of the electrosorbent in this process. Adsorbed ions are desorbed from the surface of the electrodes by eliminating the electric field, resulting in the regeneration of the electrodes. The efficiency of CDI strongly depends on the surface property of electrodes such as their surface area and adsorption properties. When the electrodes contain large interfacial areas, they can store a substantial amount of salts in the electrical double layer region on the electrode-solution interface. This renders CDI an attractive alternative technology for desal and salt recovery.

The early work of CDI was initiated in 1960s by Arnold and Murphy (1961) and Caudle et al. (1966). They used flow-through capacitors with porous activated carbon electrodes for desal of seawater. Later, Johnson and Newman (1971) continued the study on CDI and developed a porous electrode model to simulate ionic adsorption on porous carbon material. The intensive studies undertaken by Johnson and Newman were eventually discontinued, mainly because of the instability of the electrodes, particularly the anode (Oren 2008). Since the 1980s, a substantial amount of research has focused on understanding the fundamental mechanisms of CDI, and developing novel electrode materials to improve the efficiency of CDI. The Lawrence Livermore National Laboratory (LLNL) developed and optimized carbon aerogel materials, which are ideal electrode materials because of their high electrical conductivity, high specific surface area, and controllable pore size distribution (Farmer et al. 1996). Shiue et al. (2005) improved the CDI efficiency by using a spiral-wound electrodes (activated carbon coated on titanium foil) cartridge. Besides carbon aerogel, other materials are also being investigated as electrodes for CDI, such as nanoporous activated carbon cloth (Oh et al. 2006), titania incorporated activated carbon cloth (Ryoo and Seo 2003), carbon aerogel-silica gel composite electrodes (Yang et al. 2005), and carbon nanotubes (CNTs) and nanofibers (Li et al. 2008).

Recently, Atlas and Wendell developed the Electronic Water Purifier (EWP), which is a hybrid CDI and electrodeionization (CDI-EDI) technology using activated carbon electrodes that has a coating and a conductive material (Atlas and Wendell 2008). ENPAR Technologies Inc., located in Ontario, Canada, developed a small-scale DesEL unit—a CDI-based technology—for pilot-testing reclaimed water.

Despite the intensive worldwide activities devoted to CDI, CDI has not emerged from the laboratory or the small pilot-scale and demonstration units to a commercial technology. The main challenges that hinder the commercialization of CDI into an industrial-size technique for water treatment and wastewater reuse include (Xu, Drewes, and Sethi 2008; Oren 2008):

1. Lack of ideal porous electrode materials that are highly stable with a long lifetime, inexpensive, easy to manufacture for large-scale application, and fast regarding salt diffusing, charging, and discharging
2. Limited understanding of electrochemical reactions on electrode surfaces, degradation of electrodes, and propensity of electrode fouling and scaling due to presence of sparingly soluble salts and organic substances
3. Lack of optimization in unit configuration and design.

VIBRATORY SHEAR ENHANCED MEMBRANE FILTRATION

The patented VSEP™ technique was developed by New Logic International in California. The VSEP membrane filter pack consists of leaf elements arrayed as parallel discs and separated by gaskets. The shear waves produced by the membrane vibration cause solids and foulants to be lifted off the membrane surface and remixed with the bulk material flowing through the membrane stack. This high shear processing exposes the membrane pores for maximum throughput that is typically between 3 and 10 times the throughput of conventional cross-flow systems (New Logic Research 2004). Compared to conventional RO systems, VSEP is not limited by the solubility of minerals or the presence of suspended solids. It can be used in the same applications as crystallizers or brine concentrators and is capable of high recoveries (up to 90%) (Lozier et al. 2007). The VSEP system can be configured employing either RO or NF membranes in a single-stage or multiple-stage arrangement. The configuration depends upon feed water quality, water quality goals for the VSEP permeate, and targeted water recovery.

The manufacturer claims that the VSEP process has several advantages over the conventional membrane process (New Logic Research 2009), including minimal pretreatment, low fouling and scaling potential, high permeate flux, and low energy consumption (0.27 kWh/kgal filtrate).

The VSEP technology has been used in industrial applications treating waters with high dissolved and particulate solids concentrations, such as dairy (Akoum et al. 2004, Frappart et al. 2006), livestock (Lee et al. 2004, Yoon et al. 2004), pulping (Huuhilo et al. 2001), landfill leachate (Zouboulis and Petala 2008), and reclaimed wastewaters (New Logic Research 2008).

The combined advantages have also made VSEP an attractive technology for treatment of desal concentrate (Madole and Peterson 2005, Lozier et al. 2007). Pilot test results showed that both the VSEP RO and NF membranes can reduce the conventional RO system concentrate volume by up to 85%, if a two-stage VSEP unit is implemented (Lozier et al. 2007). VSEP recoveries exceeding 85% resulted in less than optimal operation of the unit (e.g., decreased flux and high feed pressure), with increased lifecycle costs. Acid and caustic cleanings of the VSEP membrane module are required to maintain flux. Cleaning frequency is estimated to be twice per week, a high frequency relative to conventional RO. The VSEP RO membrane exhibited better performance than the NF membrane at similar flux range; permeate quality for the RO membrane was excellent.

The application of VSEP to treat potable water sources or other high-quality water has been investigated much less extensively (Shi and Benjamin 2008). It is reported that except in unusual situations, use of VSEP technology for large-scale production of drinking water is probably impractical because of issues related to its cost and mechanical complexity (Shi and Benjamin 2008).

DEVELOPMENT OF NEW DESAL MEMBRANES

Thin-film composite (TFC) membranes and spiral-wound configurations have become industrial standards for pressure-driven membrane technologies. Although RO/NF technology appears to be maturing, substantial R&D has been conducted to further improve membrane performances that include development of membranes of higher salt rejection and permeability, reduced membrane fouling, higher resistance to oxidants and chemicals, and high temperature.

Modification of Commercial Membranes to Reduce Membrane Fouling

Membrane properties such as roughness, hydrophobicity, and surface charge affect the rate and extent of membrane fouling. Modification of commercially available membranes to modify surface characteristics to reduce fouling, while maintaining or improving flux and selectivity, is an important area that shows promising results for RO and NF membranes (Belfer et al. 2001, 2004; Abitoye, Mukherjee, and Jones 2005; Yang, Lin, and Huang 2009). Many of these developments have resulted from the addition of polymer to smooth the surface, increase membrane hydrophilicity, or surface modifications such as the addition of different functional groups to change the surface charge. Nanoparticles (e.g., silver) can also be coated on membrane surface, or added during membrane manufacture, to reduce biofouling (Yang, Lin, and Huang 2009). While these improvements are promising, the fouling-resistant membranes are yet to be commercialized.

Development of Nanocomposite Membranes

The polymer nanocomposite membrane is an important recent development to improve membrane selectivity and permeability. In the structurally engineered nanocomposite membranes, the nanoparticles act to create preferential permeation pathways for selective permeation, while posing a barrier for undesired permeation in order to improve separation performance (Jadav and Singh 2009).

Jeong et al. (2007) prepared mixed matrix RO membranes by interfacial polymerization of nanocomposite thin films in situ on porous polysulfone supports. Nanocomposite films comprise NaA zeolite nanoparticles dispersed within 50–200 nanometer thick polyamide films. Nanocomposite membranes displayed smooth, hydrophilic, and negatively charged surfaces. A major attribute of this approach is that it can easily be incorporated into existing membrane production facilities. However, the performance of reported nanocomposite membranes did not exceed that of commercial RO membranes (Jeong et al. 2007).

Jadav and Singh (2009) used interfacial polymerization to produce polyamide nanocomposite membranes using two types of silica nanoparticles. The nanocomposite membranes exhibit superior thermal stability than the pure polyamide membranes; and in both the nanocomposite types, the best membrane performance in terms of separation efficiency and productivity flux was observed in the membrane with a certain amount of silica loading. The nanocomposite membranes show a promising development in enhancing membrane performance. Further research, however, is required on refining the synthesis method of nanocomposite membranes.

Carbon Nanotube Membranes

CNT membranes have received considerable interest for water treatment and desal. Previous experimental measurements and theoretical studies have indicated that water can permeate through CNTs with unexpectedly high mass transport (Hinds et al. 2004, Holt et al. 2006, Noy et al. 2007). Theoretical studies and molecular dynamics simulations suggest that hydrophobic channels, like CNTs, can have considerable water occupancy and that the flow of water in CNTs is frictionless, except for the energy barriers at the entrance and exit of the tubes (Corry 2007). The absorbed water molecules can exist inside the CNT segments and tend to organize themselves into a long-lasting hydrogen-bonded network between adsorbed water molecules. The smooth and frictionless CNT surfaces resulted in weak carbon-water attractive interaction and hence facilitated the extremely high-flow velocity. Using molecular dynamics simulations, Corry (2007) calculated that membranes comprising CNT with sub-nanometer diameters can provide an efficient means of water desal when used in RO. The narrow pores reject ions and water permeability may be many times higher than existing membranes (Corry 2007).

Current research efforts and the development of nanotechnologies have the potential to advance CNT membranes for water and wastewater treatment as well as desal (NRC 2008). While the experimental observations and theoretical simulations are promising, studies are required to demonstrate the rejection performance and fouling potential of CNT membranes. It is worth noting that the primary causes of salt rejection and water transport in the previous studies is the narrow, smooth, nonpolar nature of the CNTs. The adsorption of organic solutes, proteins, algaes, and other contaminants in water may cause CNT fouling and prevent water conduction. Other efforts are required for manufacturing engineered CNTs, modification of membrane and CNT nanostructures, and demonstration of energy-efficiency and costs of production.

HYBRID DESAL SYSTEMS TO IMPROVE WATER RECOVERY AND MINIMIZE CONCENTRATE VOLUME

Numerous methods have been proposed to enhance recovery and minimize concentrated brine volume generation resulting from membrane desal processes. Many of these methods couple multiple stages of membrane-based treatment processes with intermittent chemical precipitation or caustic addition. These processes include: dual RO with chemical precipitation, dual RO with softening pretreatment with high pH operation (High Efficiency RO, HERO™), and dual RO with slurry precipitation and recycling reverse osmosis (SPARRO). Other membrane hybrid processes include novel combinations of RO with other established or novel membrane technologies, such as coupling FO with RO, and coupling RO with ED or EDR.

Dual RO With Chemical Precipitation

Dual RO with chemical precipitation is a physical-chemical method for enhancing recovery of conventional RO processes through treatment and minimization of concentrate. The process employs established technologies such as lime soda softening and a second stage RO (Williams and Cohen 2002, Gabelich et al. 2007, Rahardianto et al. 2007). As illustrated in Figure A.6, this approach is based on treatment of the concentrate from a primary RO system using a physical-chemical process, followed by subsequent treatment in a secondary RO system. The chemical treatment step utilizes precipitation to remove calcium, magnesium, and other sparingly soluble salts, and is followed by filtration (e.g., media filtration or membrane filtration) for removing solids carryover from the precipitation process. The secondary RO system is then operated at a higher TDS, and requires higher pressures compared to the primary RO system. The combined recovery of the process is reported to be 95% or greater for brackish water.

The positive attributes of this technology include the application of established unit processes and relatively low additional energy requirements. Negative attributes include additional chemicals, production of sludge from the chemical precipitation process, and footprint and costs of chemical feed and storage facilities.

Dual RO With Softening Pretreatment and High pH Operation (HERO™ High Efficiency RO)

This patented technology (Mukhopadhyay 1999) consists of a hardness and alkalinity removal step, a degasification step to remove CO_2, and intermediate caustic addition to increase the pH of the RO feed water. This technology was developed to produce water of exceptionally high purity for the micro-electronics industry.

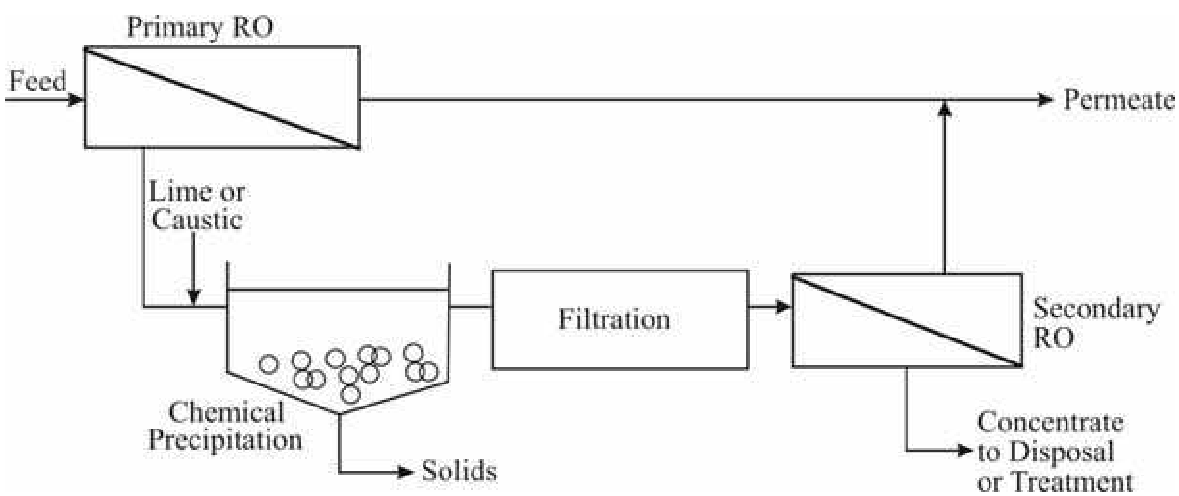


Figure A.6 Dual RO with intermediate chemical precipitation

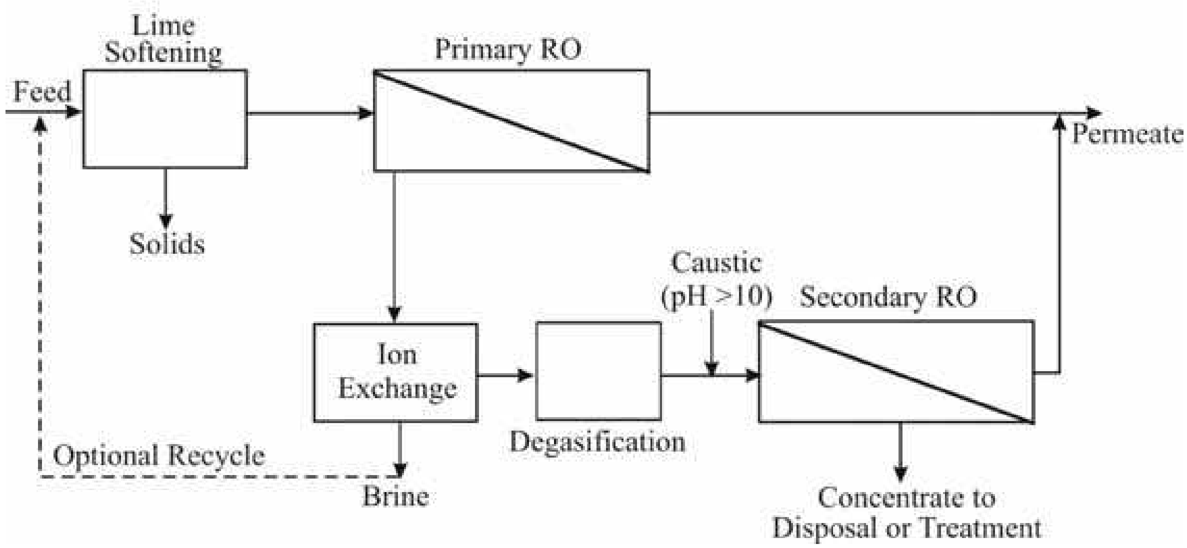


Figure A.7 Schematic of a dual RO system that incorporates a softening pretreatment and intermediate high pH operation (HERO^{TM})

For municipal brackish water, the process combines a two-phase RO process with chemical pretreatment of primary RO, intermediate IX treatment of primary RO concentrate, and high pH operation of secondary RO (Jun et al. 2004). The approach is illustrated in Figure A.7. The secondary RO step operates as a "high-efficiency" system due to IX pretreatment and high pH operation.

The concentrate of the primary RO is treated in weakly acidic cationic (WAC) exchange resins. The CO_2 from the concentrate is stripped and the pH is increased with caustic addition to above 10. This allows for the secondary RO to operate at high recoveries. Operating the negatively charged membranes at a high pH is reported to allow better removal of both weakly ionized anions as well as the strongly ionized species. The solubility of silica is increased at high pH, which allows for greater recovery rates when treating water that contains high concentrations of silica. The combined recovery of the process is estimated to be greater than 90% for brackish water, with typical target recovery rates of approximately 95%.

The HERO^{TM} system has been utilized to enhance recovery of surface water (Colorado River water) during desal (Rahardianto et al. 2007). Results demonstrated that recoveries of 95% to 98% were achievable with the HERO^{TM} system. A demonstration scale facility at the Arlington Valley Power Station in Arizona was constructed (Aquatech International 2009). The facility is designed to treat 2.4 mgd of cooling tower blow down that contains 10,000 mg/L of TDS and is saturated with SiO_2.

Dual RO With SPARRO: Slurry Precipitation and Recycling RO

This approach uses the concept of adding specific crystals to precipitate scaling compounds in a membrane application. The application of adding crystals to tubular RO membranes for preferential precipitation, and the concept of recycling the seeded slurry was first patented in 1980 (Herrigel 1980). The approach involves introducing seed crystals in a tubular RO membrane such that the scaling compounds are precipitated (on seed crystals rather than on the membrane) and removed in a controlled fashion. The concept involves circulating slurry of seed crystals within the RO system. The seed crystals serve as preferential growth sites for calcium sulfate and other calcium salts and silicates, which begin to precipitate as their solubility products are exceeded during the concentration process within the membrane tubes. The preferred growth of scale on the seed crystals prevents scale formation on the membrane surface. Because the seed slurry is recirculated within the membranes, the process is confined to the use of a membrane configuration that will not plug, such as tubular membrane systems. Gypsum crystals are used to precipitate calcium sulfate.

Another patent was later awarded that focused on the methodology of determining adequate seed crystal concentration in the preferential precipitation systems (Herrigel 1986). A series of pilot tests were also performed by the Resources Conservation Company based on the original patented technology (Herrigel 1980, 1986). Subsequently, there have been other tests of the technology based on the concept of adding seed crystals to a tubular membrane configuration. Two variations of the further testing are discussed below. The first approach is illustrated in Figure A.8 (Juby and Schutte 2000).

The water to be desalted is mixed with a stream of recycled concentrate containing the seed crystals and fed to the RO process. The concentrate with seed crystals is processed in a cyclone separator to separate the crystals, and the desired seed concentration is maintained in a reactor tank by controlling the rate of wasting the upflow and/or underflow streams from the separator. The combined recovery of the process is estimated to be greater than 90%.

A pilot testing of this approach for concentrate treatment was tested at the Eastern Water Municipal District in California (Juby et al. 2008). Another variation of the seeded slurry approach involves a two-pass process, with the first pass employing a tubular NF system with seeded slurry recycle and the second pass employing a spiral wound RO system (Enzweiler 2005). The process was developed for an agricultural drainage water reclamation application and tested at bench scale. The process, known as double pass, preferential precipitation, reverse-osmosis process, or DP_3RO^{TM}, is proprietary and the patent is pending.

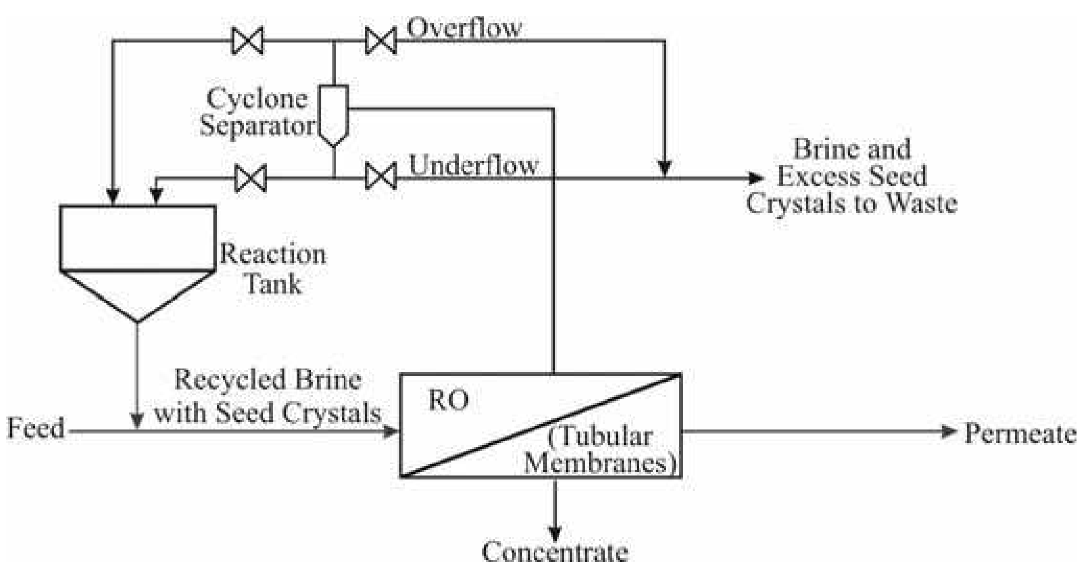


Figure A.8 Schematic of seeded slurry precipitation and recycle RO

FO/RO Hybrid System

During FO the feed solution is concentrated while the draw solution becomes more dilute. For the process to be sustainable on an industrial scale, the draw solution requires continuous reconcentration. One prominent method for reconcentrating the draw solution is to utilize an RO subsystem. Reconcentration with RO is a viable option because the draw solution does not contain high levels of sparingly soluble salts or foulants. Recent studies have shown that synergistically coupling FO with RO creates an exceptionally robust, multi-barrier system for treatment of highly impaired streams (Cath et al. 2005; Cartinella et al. 2006; Holloway et al. 2007; Lundin 2008; Martinetti, Cath, and Childress 2009). A system diagram is shown in Figure A.9.

Hybrid FO/RO systems have undergone pilot-scale testing at the Denver Water Recycling Facility with a feed source consisting of secondary and tertiary effluents (Lundin 2008). Full-scale testing of a hybrid FO/RO system was completed at a landfill in the Pacific-Northwest of the US (York, Thiel, and Beaudry 1999). During full-scale testing the system was employed to treat landfill leachate.

The physical limit on the applicable TDS range for this process is the requirement that the draw solution have a higher osmotic pressure than the impaired feed water stream, and that the osmotic pressure of the draw solution is not prohibitive for reconcentration by RO. These limitations indicate that FO/RO systems are most applicable for feed water TDS ranging from 500 mg/L to 35,000 mg/L. An FO/RO system provides two significant barriers, in the form of two dense, non-porous membranes, which allows for the system to treat highly impaired water with high rejection of solutes. The FO membrane will act to reject most contaminates in the feed water, including scale-forming minerals, most organic compounds, and microorganisms. Employing a SWRO membrane for the RO stage will ensure high NaCl rejection (exceeding 99.7%) (Lundin 2008; Martinetti, Cath, and Childress 2009). The estimated water recovery for a FO/RO system is in excess of 96% (Martinetti, Cath, and Childress 2009).

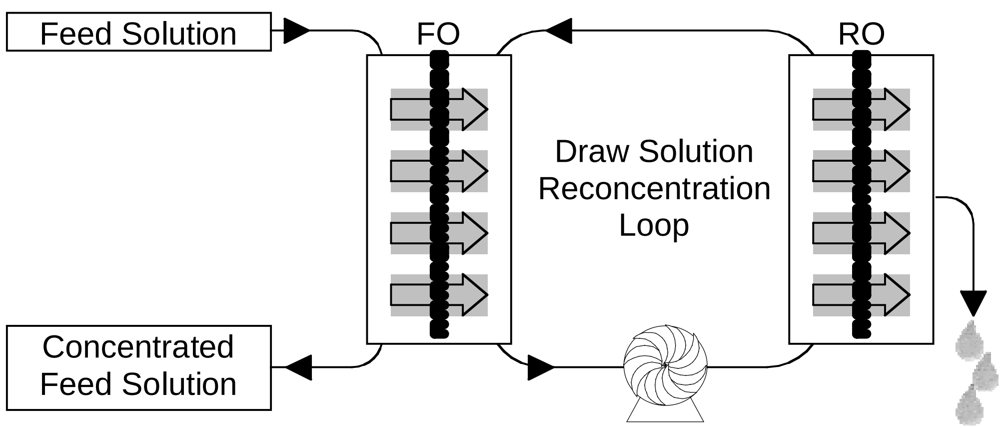


Figure A.9 Schematic of a hybrid FO/RO system. Impaired feed water contacts one side of the FO. Water is driven by a chemical potential gradient to diffuse from the feed solution into the draw solution. A RO stage is then employed to reconcentrate the draw solution and produce pure water permeate.

Hybrid RO/ED and RO/EDR

Hybrid RO/ED systems have been studied to remove salts from RO concentrate and increase the overall water recovery. This approach can either operate in series or in parallel. Pellegrino, Gorman, and Richards (2007) tested a parallel RO/ED system in which hollow fiber RO membranes were placed as spacers between the IX membranes of a pressurized ED cell. The ED unit continuously removes ions from the RO feed. The overall recovery can be increased as a result of decreased osmotic pressure of the feed and the reduced concentration polarization effect on the RO membrane surface. The more the recovery of permeate through the RO hollow fibers, the greater the energy savings. Many conditions have been identified for which energy savings from 10 to 20+% can be realized. The overall analysis indicated that the conductivity of the IX membranes became the limiting factor on the possible energy savings (Pellegrino, Gorman, and Richards 2007).

High Efficiency Electro-Pressure Membrane (HEEPM) technology, developed by EET Corporation, integrates ED with NF and/or a RO membrane in a single synergistic unit (EET 2008). The ED serves to maintain or lower the feed to the NF/RO membrane elements so that the NF/RO permeate quality remains high even at high overall recoveries. In addition, the recycled NF/RO concentrate serves to maintain the ED feed at levels that provide the most efficient current utilization and separation. Compared to NF/RO systems alone, the recovery of HEEPM can reach 99%.

Serial RO/ED system has been investigated to recover salts from seawater by integrating the production of fresh water and salts (Tanaka et al. 2003, Davis 2006). In 1986, Ionics used a large EDR system for RO concentrate reclamation in a major aerospace facility (Reahl 1992). The EDR water recovery was about 83–86%, resulting in an overall RO/EDR water recovery of about 97%. Xu, Drewes, and Sethi (2008) used ED to treat primary RO concentrates of different brackish water types. Depending on the chemical composition of the brackish water, intermediate precipitation may be required, and ED treatment could recover at least 80% of RO concentrate. In comparison to using a second RO as post-treatment for the primary RO concentrate, the ED or EDR system is less sensitive to pre-treatment. The ED/EDR system is able to operate with water carrying a SDI average of 12, as compared to 3 for RO systems. The ED/EDR system can also be operated with a continuous free chlorine residual of up to 1 mg/L, and unlimited silica concentration to saturation level (Pilat 2001, Reahl 2006).

EMF for Scale Control

Recently an EMF-based device, and originally developed in South Africa and now owned by GrahamTek Singapore, was tested in a pilot plant treating iron-rich, saline groundwater (Pelekani et al. 2005). The EMF device was proved to be effective in controlling scaling caused by silica mixed with calcium/magnesium carbonate, barium sulphate, strontium sulphate, and iron. The Grahamteck EMF technology has also been used on a large-scale treating tailing wastewater (Palmer et al. 2005). The wastewater has a salinity in the range of 5,500–7,500 mg/L TDS and contains significant amounts of ammonia, sulphate, magnesium, and silica. It also contains the sparingly soluble salts barium and strontium. The EMF antiscaling technology has been effective in preventing magnesium silicate scale formation, while permeating the two-stage RO process, and operates at an overall water recovery > 85%.

Although EMF has been reported as being effective in scale control in numerous studies (Gabrielli et al. 2001, Vedavyasan 2001, Palmer et al. 2005, Pelekani et al. 2005), the mechanisms of scaling control by the EMF still remains unclear. Its effect might be either to reduce deposition, remove existing scale, or produce a softer and less tenacious scale (Baker and Judd 1996). A study funded by the USBR, however, reported an insignificant effect of EMF on increasing membrane permeability and scale control (Carnahan, Barger, and Ghiu 2005).

The controversial reported results are likely related to the feedwater chemistry and the magnetic treatment devices employed. Moreover, there are sustainable limits beyond which the EMF could not adequately control scaling (Palmer et al. 2005, Pelekani et al. 2005). More research work is required to understand EMF mechanisms and demonstrate the effectiveness of EMF in scale control with different water matrices.

APPENDIX B
CHALLENGES IN INTEGRATING MEMBRANE PROCESSES

ABSTRACT

Design and implementation of a seawater or brackish water desal facility requires complete understanding of the desal process. Desal facility design is site-specific and requires careful consideration of a number of physical, institutional, and cost factors, beyond those of conventional water treatment facility design. The implementation of a desal facility is not a simple “plug and play” operation. A complete understanding of the local and federal regulations and permitting requirements is essential to the desal design process. For these reasons, it is important for utilities to employ properly trained and experienced personnel in all phases of the project including initial planning, permitting, design, implementation, and operation.

The purpose of this document is to provide an overview of the technical and managerial considerations for designing, implementing, and operating a full-scale desal facility. This appendix will also highlight the importance of hiring a qualified engineering firm for facility design as well as the importance of properly training desal facility staff.

INTRODUCTION

Growing concern over water supply availability has encouraged many utilities to turn away from conventional water sources and begin to explore the possibility of alternative supplies. Of particular interest in recent years has been the area of desal. Desal has become an increasingly viable option for utilities with the increasing need to find alternative or supplemental water supply sources in an effort to conserve their existing resources.

The practice of desal removes excess salts from source waters to produce drinking water. In practice, there are several different desal processes, of which there are two distinct categories: thermal processes and membrane processes. Thermal processes use heat and pressure to separate pure water vapor from dissolved and suspended solids. Thermal processes consume a large amount of energy, and are seldom used in public water supply applications in the US, as they are generally not cost-effective.

The alternative and most widely used desal process in the US continues to be RO, otherwise known as a high pressure membrane process. In addition to being more economically feasible for water purification, membrane processes are adaptable to different kinds of source waters.

The design of membrane facilities is typically more involved than standard treatment facilities due to the complexity of the systems involved. Membrane facility design hinges heavily on the site-specific characteristics of the source water used. As such, these installations are not “plug-and-play” designs, and require experienced and knowledgeable engineering to ensure proper design.

While it is not the intent of this appendix to describe the intricacies of membrane facility design in detail, there are general characteristics of this process that warrant mention. This paper will outline the basic principles of membrane desal facility design as related to the treatment process.

For the purposes of this appendix, source waters will be categorized in two ways: surface water (including brackish surface water and seawater) and groundwater (including brackish groundwater and seawater strength groundwater).

Introduction to Desal

Salinity

The salinity (expressed in parts per thousand) of a source water is an indirect measure of the concentration of the TDS present (expressed in mg/L). Desal facilities can be generalized into two categories, brackish and seawater strength, based on the salinity or TDS concentration of the source water. Brackish water is defined as water with a TDS concentration from 500 to 30,000–32,000 mg/L, whereas seawater is defined as water with a TDS concentration over 30,000–32,000 mg/L and up to 45,000 mg/L in some regions of the world. In the US, USEPA regulates the TDS concentration of potable water to 500 mg/L under the secondary drinking water standards.

Desal Basics

In the US, water supply desal is accomplished primarily by the use of membrane filtration, specifically through RO (Watson, Morin, and Henthorne 2002) Membrane filtration processes use applied pressure to force water molecules through a semi-permeable membrane which will only allow a small fraction of the dissolved constituents to pass through. The water passing through the membrane is known as permeate, whereas the stream containing rejected dissolved solids is called concentrate. Figure B.1 shows a basic schematic of a membrane process.

The design of a full-scale desal facility requires a comprehensive analysis of many factors, including source water characteristics, pretreatment process availability and selection, ease of operation, available site size and location, operating costs, capital costs, governmental regulation, permitting restrictions, concentrate disposal options, and finished water quality goals.

Desal plants consist of multiple unit processes connected together to form a treatment process train. These unit processes typically include one or more pretreatment processes, the primary desal process, and post-treatment processes.

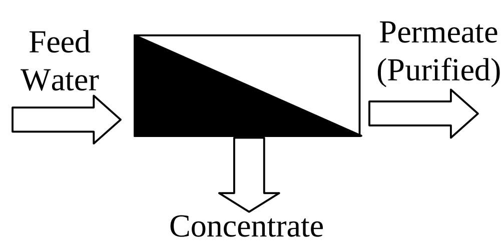


Figure B.1 Membrane process schematic

DESAL FACILITY DESIGN

Source Water

The first step in the design process is identification of the source water which will be treated to produce potable water. Desal sources include brackish groundwater, seawater-strength groundwater, brackish surface water, and seawater; and desal facility design will differ for each type of source. Water supply selection can be complex and several factors must be considered, including water quality and subsequent treatment, proximity to water demand, available water quantity, reliability, regulatory requirements and restrictions, costs, and public perception.

The main factor influencing desal facility design is the source water quality as it directly affects the selection of the treatment processes (Faller 2007). Comprehensive characterization of source water options is recommended in order to establish a reliable baseline (especially for groundwater), evaluate quality variations (for surface water), and assess potential water quality issues. This characterization is accomplished by sampling and laboratory analysis of all source water options, and potential site locations within the source. Analysis of samples taken from the same source in two different locations may yield drastically different results depending on differing environmental factors.

Surface sources typically have higher concentrations of suspended solids and organic matter, as these sources are open to the environment. Groundwater sources are replenished by water which percolates through the soil, and thus is naturally filtered to remove most particles, leaving only dissolved solids in the water.

While salinity is the most important characteristic in membrane process design, there are many other factors which may influence overall facility design, particularly in surface water sources. Since surface waters are exposed to the environment, the water quality tends to vary unlike groundwater supplies. This fluctuation in water quality may require additional pretreatment or post-treatment processes to be included in the facility design.

Site Location

The location of a membrane facility depends on three geographical factors: source location, demand location, and concentrate disposal location. Additionally, there are other considerations such as environmental or economic implications which may influence site selection. Environmentally sensitive areas may not be viable site options for intake structures or concentrate disposal locations due to environmental permitting issues. While aspects of site location such as this are important, this section will focus on the geographic aspects of site selection. The goal of proper site selection is to minimize the amount of transmission or well piping necessary to carry the feed water, finished water, and concentrate to their respective destinations in order to reduce capital and operational costs. Local geography and hydrology, coupled with the dynamics of the source create unique scenarios for each facility, and as such sites must be selected on a case by case basis. In addition the type of source (i.e., groundwater versus surface water) can determine where a facility will be constructed.

Intake piping distances and costs can be minimized by the use of existing intakes such as those at power plants. However, other factors must be considered in selecting the appropriate desal facility site. For example, while utilizing an existing intake (such as at a power plant) will save on capital costs, elevated source water temperatures associated with the power plant cooling water could lead to increased biological fouling and salt passage through an RO system (Reiss et al. 2008).

Source Water Withdrawal Configuration

The choice of which method of raw water withdrawal to select depends on several factors such as water quality, proximity to an existing power plant, permit implications, environmental considerations, and costs.

In surface water desal projects, source withdrawal configuration is critical since it directly determines the quality of raw water, and more importantly dictates the subsequent treatment requirements. For example, an offshore intake will provide a more consistent salinity and less influence from surface water runoff and tidal changes than an on-shore intake. Figure B.2 illustrates the difference between and offshore intake and an onshore intake. Direct surface water filtration may be feasible in the case of the off-shore configuration, but would not likely be feasible in the case of an on-shore configuration (due to the potential of high suspended solid content). A decision would have to be made between direct withdrawal of seawater via intake (either on-shore or off-shore), indirect withdrawal via beach wells, or the use of cooling water from a co-located power plant.

Figure B.3 shows typical source-demand-disposal scenarios for both groundwater and surface water desal facilities.

Pilot Study

A pilot study is a small-scale preliminary study using equipment representative of the full-scale plant to determine the feasibility of the desal process prior to full-scale design. The data gathered from pilot studies are therefore scalable to the full-sized process. These studies are configured to simulate the complete treatment process train, and provide utilities with the opportunity to evaluate the performance of proposed systems under site-specific conditions. Data gathered from pilot studies is fed back into the planning and design process and adjustments are made accordingly. The result is a more complete design, more refined cost estimates, and a more accurate understanding of the viability and potential challenges of the proposed full-scale project.

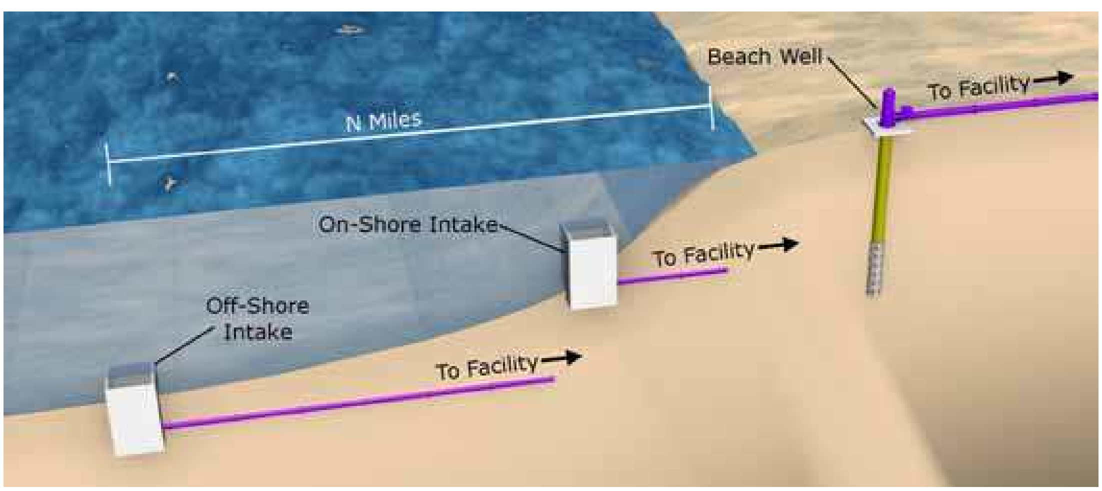


Figure B.2 Surface water intake types

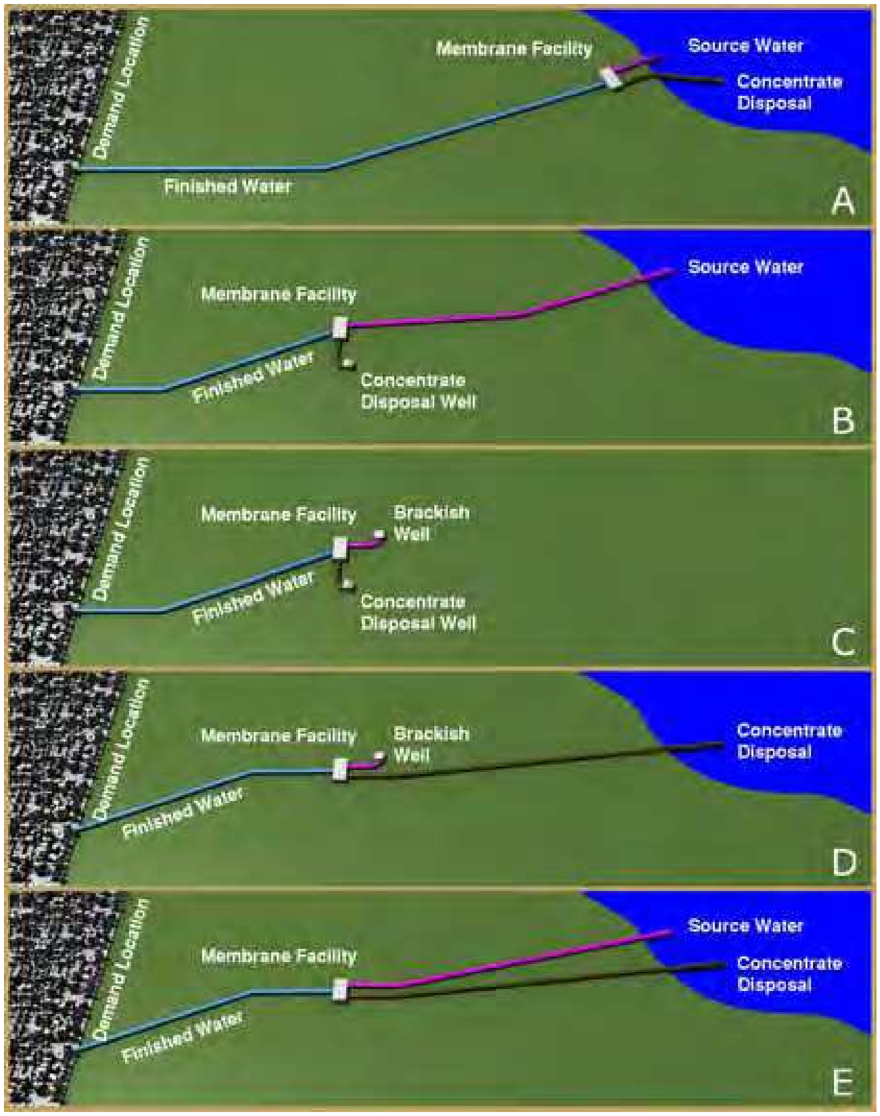


Figure B.3 Examples of site selection scenarios: (a) surface water source and concentrate disposal, (b) surface water source and deep well concentrate disposal, (c) groundwater source and deep well concentrate disposal, (d) groundwater source and surface water concentrate disposal, and (e) economically infeasible site selection

As with the design of desal facilities, pilot studies are site-specific. In addition, general pilot testing requirements, such as test duration and costs, for groundwater versus surface water desal facilities may differ. For this reason, it is imperative that utilities hire experienced engineers to properly design pilot studies.

Pretreatment

The primary goal of pretreatment is to remove any substances from the source water which may be damaging or detrimental to the desal process.

Pretreatment system designs can vary considerably and directly affect plant production sustainability. Inadequate pretreatment will result in poor performance of the pretreatment system itself and the RO membrane system, therefore leading to an increase in O&M costs.

For surface water desal, pretreatment represents the most significant design consideration due to the higher suspended solids and organics levels associated with surface water (Faller 2007). The designers should consider different filtration technologies such as one- or two-stage media filtration, or membrane filtration such as MF and UF. In situations where suspended solid concentrations are low (use of off-shore water or beach well groundwater), direct filtration may be a feasible pretreatment option. Key design criteria for pretreatment systems include the loading rate for a media filtration system, or flux for a membrane system. The loading rate and flux have a direct impact on the backwash frequency and cleaning frequency, which in turn impacts the operation of the facility. Pretreatment design should also address any potential biological growth issues. Different options to control or minimize biological growth and fouling include ultraviolet (UV) light, injection of a biocide, and intermittent chlorine cleaning. The inclusion of a pretreatment process in the pilot study allows engineers to confirm and validate the effectiveness of the selected pretreatment design.

Unlike surface water desal, the pretreatment requirements for groundwater sources are minimal. Pretreatment could consist of filtration and/or the addition of a scale inhibitor and an acid to control salt precipitation on the RO membranes.

Reverse Osmosis Treatment Design

Overview

The design of the RO system is mainly a function of the source water quality (especially the TDS), and the water quality goals; however, other considerations can be integrated in the design of the RO skid (such as space constraints or energy recovery methods). Based on the source water quality and water quality goals, a membrane type can be selected and system design criteria such as recovery and flux can be defined.

RO system recovery (the ratio of permeate flow to feed water flow) is limited by the salt solubility of the source water. If too much water is removed from the feed stream (high water recovery), the dissolved salts may precipitate out of the solution, and scale the membrane elements. Additionally, the higher recovery requires higher applied pressure, resulting in elevated energy costs. The applied pressure in a membrane system must be at least 50–100 psi (depending on the membrane) higher than the intrinsic osmotic pressure in order to produce clean water through the membrane. The typical recovery for seawater strength systems ranges from 40% to 60%, and brackish water systems range from 55% to 85%. Generally, source waters with lower TDS concentrations will yield a higher recovery than those with high concentrations of TDS (Mallevialle, Odendaal, and Weisner 1996).

The flux is defined as the flow per unit area of the membrane. In terms of recovery, the flux will be a function of the source water quality. The more brackish the source water is, the lower the flux will be, in order to minimize polarization effect on the membranes.

System Configuration

Once a preliminary recovery and flux have been designed, the system can be sized. The flux will dictate the number of membranes and pressure vessels necessary to produce the desired flow. The recovery will dictate if either a one-stage or a multiple-stage system is required. The concept of a multiple-stage system is that the concentrate of one stage is further treated in the next stage. In most cases, a recovery of up to approximately 60% can be achieved in a one-stage system (Watson, Morin, and Henthorne 2002). If higher recoveries are desired, a two-stage or even three-stage system may be designed. Given these recoveries, brackish systems are typically multiple stages, while seawater strength systems consist of only one-stage, and are commonly called one-pass systems. Figure B.4 shows the configuration of a two-stage RO system.

In the sizing phase of the design, only the source water quality is considered to configure the RO system. Based on this preliminary configuration, the finished water quality can be estimated. Projection software from different membrane manufacturers is available, which can estimate the water quality of the finished water based on the manufactured characteristics of the membrane elements. The estimated finished water quality goals may further define the configuration of the RO system, especially for a seawater system. A one-pass system will generally meet the primary and secondary standards (including TDS and chloride standards). In situations where the predicted finished water quality does not meet the water quality goals, further treatment of the permeate is required. A system in which the permeate is treated by another RO system is known as a two-pass system. For example, a two-pass system is usually required when the chloride and/or boron goals are stringent. Chloride concentration in the permeate will generally meet the USEPA secondary standard of 250 mg/L, but may not meet a more stringent goal, set by the utility for example, of 100 mg/L or less. Boron (not typically regulated in the US, except in California) rejection by a typical seawater desal facility is poor and would not meet the World Health Organization (WHO) goal of 0.5 mg/L.

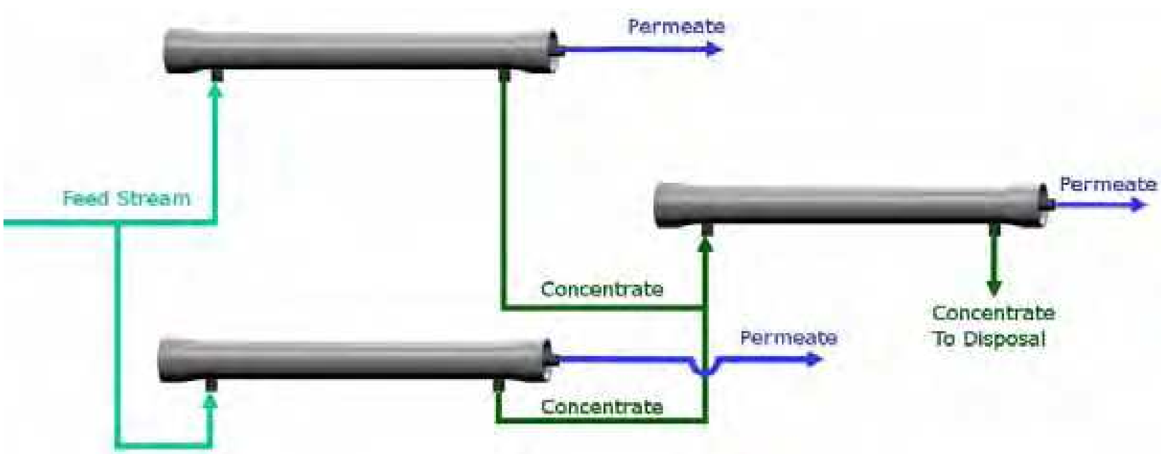


Figure B.4 Two-stage RO system

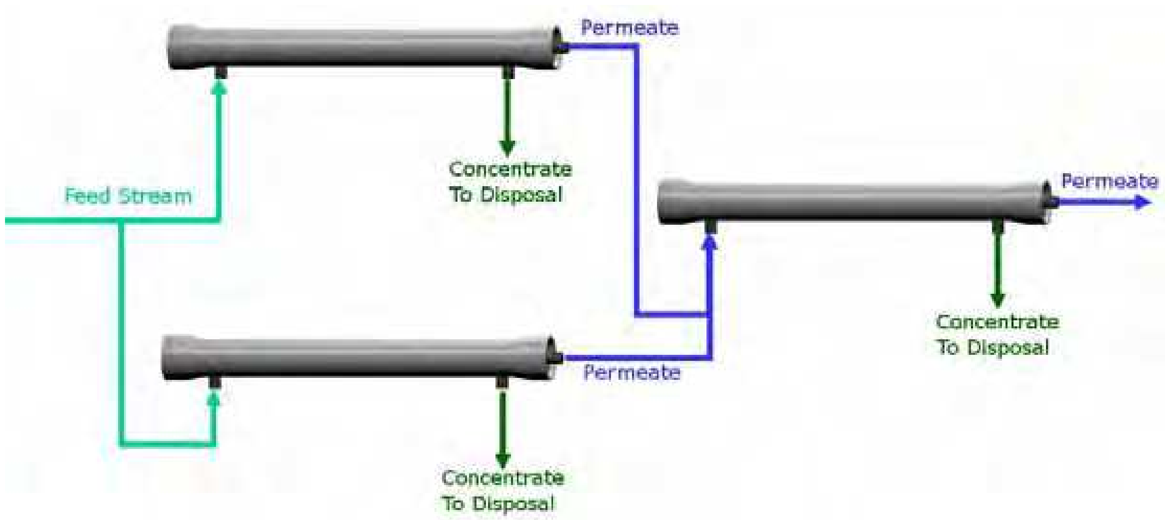


Figure B.5 Two-pass RO system

Different configurations of a two-pass system are available. Depending on the water quality of the first-pass permeate and the water quality goals, only a portion of the first-pass permeate flow or the entire flow could be treated through the second pass. The second-pass configuration is typically a two- or three-stage system where high recovery (up to 90%) can be achieved. This is generally feasible, since the first-pass permeate is considered fresh water. When only a portion of the first-pass permeate has to be treated, the common practice is to treat the permeate of the back-end of the first pass. The first pass could also be configured such that permeate from the front-end and permeate from the back-end of the pressure vessels are separately collected. The front-end permeate quality is higher than the back-end permeate quality, and is likely to meet the stringent goals. Figure B.5 shows a two-pass RO system.

In summary, the design of a RO system must take into account a variety of factors. The water quality goals and source water characteristics impact the configuration of the system and consequently the costs of the facility.

Other Design Considerations

There are other design aspects of desal that should be considered during design of an RO system. A significant physical consideration encountered in many membrane facilities is the sizing and layout of the RO skids. Pressure vessels that contain the membrane elements are grouped by manufacturers on prefabricated skids based on the individual requirements of the facility. These skids are typically larger than most other equipment, requiring that the layout and installation to be planned out prior to equipment delivery. Similarly, the size and configuration of the high-pressure pumps that feed the membrane process should correspond with the process requirements, and streamlined facility design.

Finally, the design and integration of an energy recovery device must be considered in order to ensure a facility is cost-effective and efficient. Energy recovery devices such as turbo-boost, Pelton wheels, the DWEER system, and PXs are used to recycle the high pressures associated with membrane concentrate streams to reduce the electrical draw of the facility and, subsequently, reduce operating costs.

Considerations such as these are more related to civil or mechanical design than process design, however, they must be considered when planning, designing, and implementing a full-scale membrane facility.

Post-Treatment Design

Post-treatment of membrane permeate is an important aspect of the facility design. Water processed via membrane treatment contains very low concentrations of TDS and alkalinity and is therefore corrosive. Regardless of the type of source water used, all membrane permeate must be stabilized prior to distribution (Watson, Morin, and Henthorne 2002). This stabilization is achieved during post-treatment, and involves the addition of chemicals to adjust the pH and the alkalinity and to remineralize the water. Design of post-stabilization depends on the corrosion control goals and intended use of the finished water. In addition to stabilization, desal facility effluent will require disinfection prior to distribution. For surface water facilities, disinfection must be designed such that the concentration x time requirements for pathogen removal and inactivation are met, and the disinfection residual does not exceed its respective standard in the distribution system. For water from groundwater sources not under the influence of surface waters, the concentration x time requirements do not apply.

Facilities treating groundwater sources may require additional treatment such as dissolved gas stripping prior to distribution. These sources are not exposed to air, and thus may contain entrained gases such as hydrogen sulfide, which must be stripped prior to distribution to prevent taste and odor issues and to prevent sulfide precipitation during chlorination.

The Role of Concentrate Management in Desal Facility Design

The goal of desal is to produce clean, potable water by concentrating contaminants in a segregated waste stream. The waste steam will contain high levels of contaminants which, with the exception of ZLD facilities, must be properly disposed. The nature and concentration of the contaminants again depend largely on the characteristics of the facility feed water.

While concentrate management should be considered as part of the overall facility design, it does not directly impact the design of the desal process. The chosen concentrate management method could include construction of a discharge pipeline or deep injection well, but these activities will not influence process design. However, in the event that a facility is designed with concentrate flow restrictions (federal or local regulations), the facility design may need to be modified to produce a concentrate stream which is within the approved flow requirements.

ADDITIONAL CONSIDERATIONS

Importance of Experienced Engineering

From a general standpoint, there are a number of things a utility needs to know prior to selecting a design firm in order to make an informed decision, and avoid costly setbacks during the design and implementation of the facility.

Utility staff should be familiar with all local, state, and federal regulations and permitting requirements governing the design, operation, and concentrate management of a desal facility in their area. Local environmental agencies, as well as professional organizations such as the Water Research Foundation, AWWA, American Membrane Technology Association, and IDA can provide utilities with relevant regulatory references and documentation. Research in this area allows management staff to have informed and educated discussions with potential design firms, and better gauge their qualifications and knowledge of the desal design process.

Utilities should research a design firm's background and past experience in the desal field. As stressed throughout this document, the design of a desal facility differs greatly from that of a conventional water treatment plant, and as a result, the engineer selected for the design contract needs prior experience in desal facility design.

In short, utilities should be familiar with their respective regulations and permitting requirements as they apply to desal. In addition, utilities should know each prospective engineer's background and experience in desal, including prior desal design projects. These two components will allow the utility to make an informed decision and hire a properly qualified and experienced design engineer.

Importance of Proper Operations Training

Once the facility has been constructed and brought on-line, it must be properly operated and maintained. Desal facility processes (including pretreatment, treatment, and post-treatment) can potentially be much different than those of a conventional water treatment plant, requiring specific knowledge for proper operation. Utilities must ensure that operations staff are properly trained and certified on all processes within the facility.

Failure to properly train personnel could result in inefficient or costly operation of the plant, degradation of the finished water quality, increased operational upsets, regulatory violations, or even total plant failure. While it is the engineer's responsibility to ensure the proper design of the facility, it is up to the owner, operations staff, and maintenance personnel to completely understand the proper operation of the facility.

There are numerous organizations and resources available to utilities and operations directors for the proper training of personnel, including the Water Research Foundation, AWWA, American Membrane Technology Association, and IDA, as well as numerous regional associations. A list of design resources can be found under the Research Center section of the Water Research Foundation's Web site.

CONCLUSIONS

The process of designing and implementing an efficient, cost-effective desal facility requires extensive research and planning prior to starting technical design tasks. As such, it is important that utilities acknowledge the complexities and intricacies of the process prior to preliminary design. There are many factors to consider in designing and implementing a desal facility, including:

- Source water selection
- Site location
- Withdrawal configuration

- Pilot testing
- Pretreatment requirements
- Finished water quality goals
- Treatment requirements and configuration
- Post-treatment requirements
- Residual management and disposal

It is also equally important that a qualified, experienced engineering firm is used for the technical design, as they will better understand the process, and properly design the facility based on accepted practices.

While the proper design of a desal facility is important, it is equally as critical that O&M staff be properly trained and acquainted with the equipment used in the design. It is the responsibility of the owner to supply their personnel with proper training and certification prior to final acceptance of the facility.

APPENDIX C
PILOT TESTING GUIDANCE

ABSTRACT

Development of desal facilities requires accurate and appropriate design and cost information. Every desal facility is constructed from a custom design that takes into consideration numerous site-specific factors. This requires multiple design decisions relative to the type and configuration of a treatment system. Pilot studies provide the opportunity to evaluate the performance of proposed treatment systems under site-specific conditions. The base objectives are to confirm the ability of the desal system to meet finished water quality goals, operate for sustained periods of time and, in the case of surface water desal, withstand seasonal changes in raw water quality.

Data gathered from pilot studies are fed back into the planning and design process and adjustments made accordingly. The result is a more complete design, more refined cost estimate, and a more accurate understanding of the viability of a proposed project. Pilot studies provide utilities with an excellent opportunity to gain the public's acceptance of the potential design and implementation of a desal facility in their community. The selected treatment systems must be robust enough to ensure sustained operation under all possible conditions that might be encountered. This assessment is most effectively accomplished through field testing as part of a pilot study.

This paper describes the importance of pilot testing for development of both seawater and brackish groundwater desal systems including key logistics and considerations for pilot study implementation. The investment in a pilot study typically represents less than 1% of the total costs of a desal facility. In return, risk is mitigated both in terms of ensuring a sustainable and appropriate design as well as a true and accurate project cost estimate.

INTRODUCTION

Planning and implementing a desal facility is a significant effort that requires action in the areas of funding, environmental considerations, public involvement, design, and permitting. Pilot studies are a fundamental and vital element in desal facility design, and the data obtained are used to support the principles of design. A pilot study is a field demonstration test, using commercial-sized equipment under site-specific conditions, of the proposed desal technology.

Desal plants consist of multiple unit processes connected together to form a treatment process train. These unit processes typically include one or more pretreatment processes, the primary desal process, and post treatment processes. Pilot studies are configured to simulate the complete treatment process train and provide utilities with the opportunity to evaluate the performance of proposed systems under site-specific conditions. Data gathered from pilot studies is fed back into the planning and design process and adjustments are made accordingly. The result is a more complete design, more refined cost estimates, and a more accurate understanding of the viability and potential challenges of the proposed full-scale project.

The purpose of this document is to provide an understanding of key factors associated with implementation of a pilot study and the potential benefits that can be realized. This analysis includes the following areas of consideration:

- Key factors for a municipal manager to consider
- What a pilot study provides—a more detailed analysis of a pilot study
- Pilot logistics and operational considerations
- Pilot study cost considerations

KEY FACTORS TO CONSIDER FOR PROJECT MANAGERS

Prior to investing in a pilot study, desal facility project managers should consider key aspects of the study that could have an impact on the viability of the project results and costs, including finished water quality goals, pilot set-up, pilot test duration and regulatory requirements.

Finished Water Quality Goals

Establishing finished water quality goals is one of the first steps of developing a desal project. Water quality goals are based, at a minimum, on regulated primary and secondary drinking water standards. Additional goals can be established by the utility in order to take into account specific conditions of the water system. For a specific source, the water quality goals established will be the basis for selecting the configuration of a desal system.

Pilot Set-Up

Depending on the source water quality and the size of the full-scale plant, a utility may consider pilot testing multiple treatment trains. For brackish groundwater desal, the implementation of one pilot train is typically standard. However, because surface brackish waters contain significant amounts of suspended solids advanced pretreatment is required. In this situation, pilot testing of multiple pretreatment processes is usually recommended because there are several potentially feasible pretreatment options. The seasonal variation in surface brackish water quality may also be considered in selecting pretreatment processes. For seawater treatment requiring advanced pretreatment, the implementation of two or more pretreatment pilots is usually used in conjunction with the use of one or two RO pilots. By testing different trains simultaneously, engineers are able to gather enough data to make the best decision on the most efficient pre-treatment units. In the multiple train pilot studies, the same RO element would typically be used in all the trains, but the pretreated waters would differ. This is done to determine which pretreatment option is more suitable for optimal RO production sustainability. Testing multiple treatment trains also minimizes the risk of testing only one treatment technology that might not be suitable for seawater treatment.

Utilities may also choose to test different RO membrane elements in order to determine the different pressure requirements for each membrane while still meeting the water quality goals. In addition, for cases where boron removal is a key aspect of the seawater project, specific boron removal membrane could be tested against a more traditional membrane.

It is important to note that the choice of how many pilot trains to use in a pilot study, the RO elements sizes, and the number of RO membranes tested can significantly impact the cost of the pilot study. However, the more extensive a pilot study is, the better the risk mitigation it can provide. Decisionmakers must balance the cost considerations associated with a pilot study with the risk mitigation.

Pilot Study Size

In order to provide representative and scalable data, pilot equipment configuration should represent production-sized unit processes. For the RO process, the pilot unit would consist of pressure vessel(s) containing 6–8 membrane elements of either 4 or 8 inches in diameter. Eight-inch elements are commonly used in large-scale municipal drinking water facilities throughout the US. The 4-inch diameter elements are usually used for pilot study, even though there is currently a tendency of using 8-inch diameter elements. The decision to make between the 4-inch and 8-inch is most of the time driven by the available source water flow and/or pretreatment pilot unit capacities. The 8-inch diameter element can be used for demonstration projects. The use of a single-element pilot unit or a pilot unit using a 2.5-inch diameter element would not provide representative data for a full-scale facility and should only be used, if deemed necessary, as a membrane screening phase prior to the pilot study.

Pilot Test Duration

For a seawater desal facilities and surface brackish water facilities, pilot testing over the course of a 12-month period is typically performed to capture seasonal effects on the source water. For example, dry season testing typically requires the highest operating pressures due to higher salinity. Conversely, wet season testing will require lower operating pressure, but is typically more challenging for pretreatment processes due to higher suspended solids and organic levels associated with surface water runoff. Variations in source water quality and temperature may significantly impact the design of the seawater and surface brackish water treatment units and therefore impact the costs of the full-scale facility.

For a brackish groundwater desal facility, water quality is relatively constant, and thus pilot testing can be conducted for a shorter period of time. The pilot test duration for a groundwater desal facility is typically about three to six months, with three months being the minimum time required to evaluate the fouling rate of a RO membrane.

For both seawater and brackish water studies, typical pilot operation is continuous (24 hours per day, seven days per week) through the completion of the study. However, in some cases pilot operation may reflect the anticipated operation of the future full-scale plant, such as intermittent operation. In all cases, pilot operation should be representative of the full-scale plant operations.

Pilot testing may be performed multiple times through the course of a project. Testing is usually performed as part of planning efforts to define items such as anticipated costs, design alternatives, and environmental factors. Following issuance of a bid request, competing bidders may conduct a second pilot study to finalize the costs associated with their bid. This second pilot study may not occur in all cases or may be of shorter duration than the original test. Lastly, pilot testing may be performed through the course of construction for the purposes of public outreach and further proof testing of the treatment concept.

Regulatory Requirements

Some State regulatory agencies may require a pilot study to demonstrate the feasibility of seawater treatment. In such States, it is the responsibility of the utility conducting the pilot study to comply with all regulatory requirements which may apply.

WHAT A PILOT STUDY PROVIDES—A DETAILED ANALYSIS OF A PILOT STUDY

There are several factors a utility must consider in planning a desal pilot study to ensure its success in providing meaningful results for the full-scale facility design. The nature of a desal project is site specific and the planning effort involves addressing key areas of importance that affect the overall viability of a project as well as specifics associated with how it is developed and configured. A pilot study provides information to support the planning efforts in the following areas:

- Intake/Well Siting
- Pretreatment Design
- Desalination Design
- Post-treatment Design
- Environmental Impact
- Concentrate Management
- Permitting
- Public Outreach
- Costs/Funding (Reiss 2004)

A more detailed description of these key areas is presented in the following subsections for brackish groundwater and seawater desal.

Intake/Well Siting

The choice of what method of raw water supply will be used depends on several factors such as water quality, co-location with a power plant, permit implications, environmental considerations, and costs. The pilot study is one of the tools that will validate the decisionmaking.

Seawater Desal

In seawater desal projects, seawater withdrawal configuration is critical since it directly determines the quality of raw water, and more importantly dictates the subsequent treatment requirements. For example, an offshore intake will provide a more consistent salinity and less influence from surface water runoff and tidal changes than an on-shore intake. In the case of the off-shore configuration, direct seawater filtration might be feasible but would likely not be feasible in the case of an on-shore configuration. Prior to implementing a pilot study, a decision would have to be made between a direct withdrawal of seawater via intake (either on-shore or off-shore), an indirect withdrawal via beach wells or, the use of cooling water from a co-located power plant. Once the choice is made the pilot study would have to reflect that decision and demonstrate its feasibility. During the pilot study adjustments can be made, however, changing of type of withdrawal would likely require changes in the treatment process train resulting in delaying the pilot study and increasing the pilot study cost.

An acceptable level of pretreatment required for one intake location versus another may be difficult to determine at the desktop-scale. Pilot-scale testing over an extended period allows direct and scalable assessment of the suitability of an intake location and its associated raw water quality. For example, data gathered from a pilot-scale study may be used to determine the impacts of shipping channel traffic on raw water quality. Shipping channel traffic stirs up sediments and has been known to impact raw water quality in some pilot studies, such as at the 25 mgd Tampa Bay Desalination I project in Florida, and the 29 mgd seawater facility in Trinidad (Reiss 2004).

Groundwater Desal

Unlike seawater, the options to withdraw brackish groundwater are limited and are centered around the use of multiple wells. Selection of the well site will be based on preliminary water quality investigation, yield of the well, and costs associated with the wells and transmission pipes. A pilot study will validate the water quality of the brackish groundwater.

Pretreatment Design

Pretreatment system designs can vary considerably and directly affect plant production sustainability. Inadequate pretreatment will result in poor performance of the pretreatment system itself and the RO membrane system, therefore leading to an increase in operation and maintenance costs. A pilot study can be used as a tool to help utilities select the proper pretreatment system, pretreatment design criteria, and refine the capital and operational costs of the full-scale plant.

Seawater Desal

Pretreatment represents the most significant design consideration in a seawater desal facility due to the higher suspended solids and organic levels associated with seawater. The pilot study could help the utility in first defining which pretreatment technology to utilize (either one- or two-stage media filtration or membrane filtration such as MF and UF for example) for seawater treatment. A pilot study can be used to provide key design criteria of the pretreatment system such as loading rate for a media filtration system or flux for a membrane system, backwash frequency and cleaning frequency. Pilot studies also present the opportunity to address any issues with biological growth. Based on pilot study results, decisions can be made on pretreatment system design and the costs can be refined.

Groundwater Desal

Unlike seawater and surface brackish water desal, the pretreatment requirements for groundwater sources are minimal. Pretreatment could consist of filtration or only the addition of a scale inhibitor and an acid to control salt precipitation on the RO membranes. A pilot study provides the opportunity to optimize the addition of these chemicals or even to demonstrate that the acid addition may not be required. Based on the pilot study results, pretreatment design and cost can be refined.

Desal Design

Surface water and groundwater desal system designs involve decisionmaking relative to a number of design criteria such as flux, recovery, and water quality. The selection of a design approach involves balancing competing interests to develop an optimal desal facility that meets other project objectives such as those related to costs, permitting, and environmental considerations. For example, a higher water recovery on a RO system reduces the size and cost of the upstream pretreatment and reduces the flow of the concentrate to be managed. However, higher recovery requires a higher pressure and associated power costs. Design criteria are typically “proof-tested” during the pilot sturdy to validate the design concept. In addition, design criteria can be adjusted at pilot-scale in order to optimize the operation of the seawater facility. This can result in project cost savings, improved potential to meet permitting requirements, or other project benefits.

There are numerous national and international organizations and resources available to utilities to aid in the desal design process including the Water Research Foundation, AWWA, American Membrane Technology Association, IDA, as well as numerous regional associations. A more detailed description of the desal design considerations can be found in other portions of this report.

Post-Treatment Design

Post-treatment is the final step prior to delivering finished water to the customers. In addition to meeting water quality goals and drinking water standards, blending considerations must be taken into account for the post-treatment design. In some cases, use of desalinated finished water will likely mean blending of the finished water with an existing drinking water source. Blending of two different treated waters can lead to increased pipe corrosion rates and distribution system water quality issues, due to re-equilibration effects, including red color, and taste and odor issues. A pilot study can be used to perform distribution system blending studies to minimize re-equilibration effects once the desalinated water is introduced in the distribution system. Blending studies support post-stabilization/blending approaches to be utilized as part of the integration of this new source of supply into an existing public water system. Communities that have proactively utilized pilot studies and/or blending studies as part of development of RO water treatment plants include the City of Clearwater, Fla.; TBW; and others.

Environmental Impact

The environmental impact of a desal facility is an important issue to permitting agencies and to the general public. A major environmental consideration is the potential adverse impact of concentrate disposal into water bodies on marine life and other wildlife. Incorrect or inadequate concentrate management methods may lead to permitting agency and/or general public opposition, unless it is demonstrated that regulatory requirements are met, and that any necessary mitigation measures are implemented. A pilot study will determine the environmental impact of building and operating the proposed desal facility.

Concentrate Management

Disposal of concentrate from desal facilities is fast becoming a more challenging issue as the number of desal facilities increases and permitting requirements become more stringent. Concentrate management is an especially important issue for inland desal facilities. Inland concentrate disposal alternatives include surface water discharge, deep well injection, sanitary sewers, evaporation pond, land application and dewatering (ZLD). The most common methods for inland concentrate management in the US are surface water disposal, sanitary sewer disposal and deep well injection. Each of these concentrate management methods has stringent permitting requirements and varies in cost. A pilot study is used to characterize the concentrate in order to evaluate several alternatives and ultimately select the best concentrate management method based on technical, regulatory and economic feasibility.

Permitting

Production of drinking water from seawater or brackish sources will result in the generation of by-products. Utilities must obtain the necessary federal, state and local permits in order to manage these by-products in compliance with permitting agencies. The main by-product generated in a desal facility is the high salinity concentrate, and its disposal feasibility is a key factor in the implementation of a full-scale seawater facility. Data gathered from a pilot study can be utilized to determine the concentrate water quality and therefore, the disposal feasibility. Facilities discharging concentrate to surface waters (e.g., ocean outfalls) will require an NPDES permit in addition to the other permits required for construction. The concentrate water quality data from a pilot study are representative of the full scale process and can be used by the utility to apply for the NPDES or underground injection permits. In addition, the permitting agencies may require more quality data from a pilot study to provide reasonable insurance that the proposed method of concentrate disposal is feasible.

Other waste streams generated by desal facilities include spent chemical solutions, and sludge (in the case of seawater desal). Disposal of these streams also requires a permit, typically issued by a local government entity. Characterization of chemical and sludge waste streams can be performed during the pilot study, and the results used to support the permit applications

Performing water quality characterizations during the pilot study and assessing the disposal possibilities of the waste streams is a key step in determining whether or not the full scale facility will be feasible.

Public Outreach

Public involvement and outreach is an important element of any desal project, particularly in communities with little to no experience with desal. A functional and operational pilot system can be toured by the public, the media, elected officials, and policymakers, allowing them to gain knowledge on the operation and benefits of the desal process. This can be one of the most effective methods to fully and effectively provide information regarding the proposed desal project. Information regarding drinking water quality, project benefits, concentrate management, and environmental impacts can be shared. In one pilot study, concentrate generated from the process was discharged into a salt water aquarium to demonstrate the environmental compatibility of the concentrate generated. Innovative demonstrations such as this serve to educate the public as to the nature of the desal process, and gain public support of the design (Reiss 2004).

Costs and Funding

One of the key issues when developing a seawater desal project is the difficulty in establishing reasonably accurate, site-specific project cost estimates. Typically, well-defined costs are needed to support funding efforts at a time in the development of the project that design specifics are only being generated 'on paper'. As a project progresses, a pilot study can be utilized to optimize and clarify process design alternatives as described above. The data obtained from a pilot study can be fed back into the design to further refine the project costing analysis. As a result of these efforts, capital and operating cost estimates become better defined and more precise. The ability to more accurately assess total project costs is one of the most important benefits resulting from a pilot study.

KEY PILOT LOGISTICS AND OPERATIONAL CONSIDERATIONS

Key pilot logistics and operational considerations must be taken into account during the implementation of a pilot study. Based on the preliminary design concept of the desal facility a pilot study protocol must be developed. In addition to the logistic description, the pilot protocol describes what, when and how testing should be performed to meet the project goals as well as to comply with regulatory requirements. In addition, the protocol will describe what water quality parameters to test for, and what operational parameters to monitor and how often. The protocol should also describe the operational procedures such as the start-up/shut-down/cleaning procedures. The pilot protocol is important, and should be approved by the entire project team.

Even though pre-treatment and RO pilot units are generally automated, the presence of on-site personnel 8 hours a day is usually required. This is especially important when there are more than two pilot units on-site. Tasks such checking the correct operation of the units, taking samples, performing water quality analysis, and repairing and replacing parts can be time consuming, and usually require at least one full time operator on-site to ensure the proper operation of the pilot.

Data monitoring and interpretation are also key aspects of any pilot studies. Data reporting will include a combination of manual data recording on templates as well as on-line sensors with data log capability. Data should be compiled from the pilot systems continuously and interpreted by engineering team members on at least a weekly basis (daily basis is preferred). Instructions to field staff should be provided daily relative to operational changes or other adjustments necessary to comply with the protocol, project objectives, and information learned through the course of testing. Timely engineering interpretation of pilot results can be one of the most difficult objectives to meet given the large volume of data generated by a pilot study. However, the absence of such timely input can result in generation of unexplainable or undesirable performance from the pilot system that cannot be rectified after the fact. Therefore adequate and expert engineering resources should be applied to oversee the pilot study and analysis of the results.

Pilot Study Costs

Pilot study costs can vary widely depending upon the degree to which other upfront planning activities have been completed. However, for surface water desal, based on the assumption that intake selection and development of the design concept are complete, the cost for a one-year study typically ranges from $600,000 to $1.5 million (Reiss 2004). For groundwater desal, the cost for a three- to six-month study typically ranges from $100,000 to $250,000.

The range in costs reflects the range in “in-kind” services that may be provided for a particular project. Items that may or may not be provided as “in-kind” include pilot operations labor, laboratory analyses, use of heavy equipment, buildings/shelter, electrical setup, raw water and drain piping installation, treatment equipment, and chemicals. Entities that may provide “in-kind” services or equipment typically include chemical suppliers, equipment suppliers, or the municipality.

In addition, the scope of a pilot study can vary significantly. A pilot study designed for public tours may have more aesthetically pleasing facilities constructed, and thus higher associated costs. Pilot testing of two alternative treatment process trains will double sampling requirements and significantly increase field and engineering labor requirements. Use of pilot study results for permit applications will increase sampling requirements. Therefore it is important to understand the costs associated with the specific project of interest versus comparison to other pilot study projects with dissimilar scopes of work.

Despite the wide range of costs identified for completion of a pilot study, expenditure associated with a pilot study represents less than 1% of the total plant design project costs. The value of the data obtained from the use of a pilot study far outweighs the associated costs.

CONCLUSIONS

- Development of a desal facility requires a clear project vision as well as successful execution of many associated details
- While desktop assessments and bench-scale studies can provide some vital planning, design and implementation process of a desal facility, the results are not directly scalable to the full-size facility
- Only data obtained from a pilot study is directly scalable to the full size facility
- A pilot study is a representation of the project vision and serves as a key planning tool to fill in details related to finance, design, permitting, and public outreach
- With a well thought out scope, the specific information obtained through pilot testing can be leveraged to answer questions in almost all areas of project planning and can move a project to the next level of completion
- The timing of implementation, the scope of the study, and the value obtained from the pilot study can vary from project to project
- Public involvement and outreach is an important element of any pilot study, as it provides an opportunity for the utility to educate the public and address any existing concerns

APPENDIX D
TOOLS TO ENHANCE STAKEHOLDER UNDERSTANDING OF DESAL

INTRODUCTION

In evaluating stakeholder and public perception issues surrounding desal acceptance, the research team examined institutional challenges as well as the challenges represented by individual stakeholder groups. It was noted that there are an assortment of public perception and stakeholder issues such as water supply planning gaps, and concerns about growth, land use, environmental impacts, and environmental justice.

Evaluations from a survey of utilities conducted early in the project were divided by coastal and inland facilities, which offered insight into the different issues that desal represents in these areas. For instance, coastal facilities identified advocacy groups (including environmental groups, anti-growth, or other nongovernmental organizations) as their biggest challenge related to decisionmaking. Both coastal and inland utilities identified State and Federal regulators and permit writers as a relatively large challenge for implementing desal. Overall, it seems that stakeholder issues are less of a problem for inland facilities.

Coastal facilities identified strategies for working with stakeholders and a decision support strategy or framework as being a potentially useful tool. Utility participants in a project workshop conducted early in the project noted that impediments to desal permitting included a need by the water supply community to better articulate and justify the need for (and value of) adding desal to the water supply portfolio for a specific utility, and/or for a specific region or State. It was noted that this will help convince stakeholders that the need for desal (or for any expanded water supply options) is legitimate and to evaluate desal in a comparative context, to reveal how it stacks up to alternative water supply options across a broad array of relevant impacts, including costs and environmental impacts. Putting desal into a holistic context may be able to help with an open dialogue with stakeholders which would assist in problems related to perception versus science.

Though it is not perceived that technicians need new tools to determine if desal is a necessary water supply option, new tools were advised as a means to help utilities with stakeholder and interest group discussions. Also if the public is better informed, governors and legislatures will also be better informed, which is presumed to have a positive impact on regulatory requirements so that inconsistencies between freshwater and saline water project permitting can be alleviated where suitable.

A classic guidance document for stakeholder involvement needs to enable utilities to better inform the public and media on desalination so that there can be a better marriage of science, technology, and public understanding of water desal. This guidance should also broadly address water supplies in general, and provide context to establish desal as a viable option to address the problem. Underpinning any desal stakeholder guidance is the need to forge effective partnerships between citizens and decisionmakers, which requires a program that can foster open communication to create and enhance project understanding.

Addressing these challenges demands a comprehensive understanding of water and water scarcity as well as how demand management/conservation fits within the water supply scenario. To be successful, desal must be seen as a part of wise water stewardship.

Stakeholder guidance must enhance understanding of water supply issues in general, and of desal technology in specific.

Consideration of institutional issues and decision processes should include an outreach program that provides substantive information prior to a consultation program. Developing an outreach program grounded in providing information could mitigate against the negative, time consuming challenges, and regulator reluctance that may lead opinion leaders to reject desal. Making public education and outreach a key component of the decisionmaking process can productively channel stakeholder input when a consultation program is initiated.

SUGGESTED STAKEHOLDER OUTREACH TOOLS

Turning seawater or brackish water into a valued and valuable resource requires a carefully crafted public education and outreach strategy. Desalting brackish water likewise involves the need for public understanding though this approach would appear to be less controversial.

We recommend a stakeholder approach of developing a quality decision process coupled with an outreach program. Without careful thought to the public outreach and decisionmaking process, a desal project could receive negative, time-consuming challenges, fail to gain commitment from key opinion leaders, or fail to be carried out at all. Public education and outreach is a critical component of the project decisionmaking process, and is needed to mitigate issues related to risk perception and environmental justice. Once people are upset it is hard to calm them down. Such an approach does not guarantee that desal will be approved but it does mitigate against concerns born from misinformation.

During our workshop and survey it has been noted that there are some issues that are not desal related—such as growth control. Without a careful strategy of public outreach, understanding, and involvement, these issues take center stage and understanding desal can become confused. We recognize that concerns about desal may surface issues about growth inducement and land use that will need to be channeled into approach processes so that they can be addressed properly.

Stakeholders need access to information about quality and long-term health effects from those they trust. They need to have questions answered and need to have a sense of confidence in the consultation program that will be used to make the ultimate decision. Answers to key questions such as those related to disposal of concentrate (brine), as well as the economic impact on users including possible rate impacts and the potential for economic growth, will need to be answered as a part of the stakeholder engagement.

Also since many stakeholders and stakeholder groups tend to distrust messages that come directly from a consultant or even a utility, access to independent sources to answer questions is important. If utilities do not provide this access, concerned stakeholders often do their own research on the Web. Information on a utility Web site or links to such a site from an independent science and technology panel may be helpful—especially if there is a means for stakeholders to ask the group questions.

Research study after research study (i.e., those sponsored by the Water Environment Research Foundation and the WateReuse Association) has concluded that the public's evaluation of projects often differs markedly from that of the consensus of experts in the engineering and science fields. Processes that are found to be successful in addressing public perceptions and evaluations are those that make an effort to:

- Put issues in context
- Acknowledge all arguments
- Share control
- Are transparent, open, and accountable
- Engender trust between the utility and the public

The following components to a desal education and outreach program are suggested as techniques that fulfill these objectives.

Water Supply Information Kiosks, Videos, and Cable Programs

Developing a public kiosk can be a powerful tool to convey information about project need, eliminate fear of the unknown, and create broader and more inclusive outreach at the same time. It can also establish a feedback mechanism to let the utility know the reactions of citizens to varying pieces of information. Seeing is believing and if this kiosk can include video or animation of desal projects and processes, it can convey information in a meaningful way. Short video documentaries about desalination in other areas can be helpful. Videos can be helpful in providing information about the future of water supply and putting desal in context.

Videos can visually depict treatment technologies in an understandable manner that removes mystery and the resulting fear of the unknown. The resulting product could also be cablecast or duplicated and provided free to libraries or even local video rental stores.

The technique is especially powerful because it will reach the public in their own space and can be seen at their own pace. Such techniques are much less alarming than calls to attend a public meeting; recent research tell us that fewer and fewer stakeholders attend meetings to get information. This technique also communicates an honest approach—it does not hide, but rather conveys factual information in an open, inclusive, and transparent fashion. By emphasizing public health and the environment and other positive aspects of the facility, support is incrementally developed.

Tours/Tastings

Arranging tours and tastings at any proposed pilot or demonstration site is another way to secure public support and add an element of fun.

Educational Displays, PowerPoint Presentations, and Speakers Bureaus

Information to provide information and answer questions can be provided through a number of venues including displays and presentations. Video clips can also be used.

Media Outreach

Outreach through the media will be a critical factor in gaining support for the desal pilot project, and will involve several strategies:

- Creation of a standard press kit including fact sheets and other background information about the project and desalination trends
- Hold up to two to three editorial board meetings between the utility or desal spokespeople and newspapers to help editors and reporters develop a base knowledge about desal, and puts the desal project in the context of overall water supply needs and planning
- Web programs and interactive content

Survey and workshop participants alike mentioned the need for new tools to enable stakeholders to understand desal. Coupling desal understanding with the emerging reliance on Web-based tools could expand stakeholder understanding.

For instance, an interactive water supply planning game, similar in format to a computer game, could be prepared to enable stakeholders to learn firsthand about a utility's current and projected water supply status, what options are available (imported water, water reuse, etc.) to resolve their water supply shortages, and the pros and cons of each option. With this tool customers try their hand at developing future water resources from various available options. It can show the dollar costs and environmental pros and cons of each approach so that the customer is informed of the consequences of each choice. This program will be customized by using a utility's own water supply related variables and data as the inputs. Setting the construct for the need for water supply solutions to ensure a sustainable source of supply allows stakeholders to creatively engage in the decision process and mitigates the impact of special interests who may demand a disproportionate amount of attention.

Another interactive computer-/Web-based tool could show the entire water supply and treatment process beginning with the water entering a desal plant for pretreatment, going though the various treatment process such as RO (or distillation), and continuing to post-treatment. It could be customized to provide information on processes by including animations. Detailed information about the facts of desal could be placed on the Web through engaging graphics. Specific issues related to a particular area's environment could be included.

Finally it may be possible to put together a Web-based program on desal around the world. A tour of the globe which shows the public the desalination facilities that have been built and are being built around the world may assist them with understanding that desal is a proven, safe technology.

Web information can help stakeholders feel that they are part of the planning process that protects the environment, finds stable water sources, and is cost-effective.

Table D.1 lists Web sites with information available to the public.

Table D.1
Survey of Web sites with information available to the public

Southern Desalination Plant (SSDP), Water Corporation of Western Australia, Perth, Australia	http://www.watercorporation.com.au/_files/PublicationsRegister/15/PER/Public_Environmental_Review.pdf
Kwinana Desalination Plant, Perth I, Water Corporation of Western Australia, Perth, Australia	http://www.watercorporation.com.au/D/desalination_environment.cfm
Victoria Desalination Plant	http://ourwater.vic.gov.au/programs/desalination/EES
Adelaide Desalination Plant	http://www.sawater.com.au/SAWater/WhatsNew/MajorProjects/EIS.htm
Sydney Desalination Plant, Sydney, Australia	http://www.sydneywater.com.au/EnsuringtheFuture/Desalination/ Environmental Assessment http://www.sydneywater.com.au/EnsuringTheFuture/Desalination/pdf/EnvironmentalAssessment.pdf#Page = 1 Preferred Project Report http://www.sydneywater.com.au/Publications/_download.cfm?DownloadFile = ./EnsuringTheFuture/Desalination/pdf/PreferredProjectReport.pdf
Marin Municipal Water District (MMWD), California	EIS http://www.marinwater.org/controller?action = menuclick&id = 428 Engineering Report http://www.marinwater.org/controller?action = menuclick&id = 413
Coastal Water Project, California	http://www.cwp-eir.com/downloads/PEA_v1.pdf
Huntington Beach, California	Overview http://www.hbfreshwater.com/
Gold Coast Desalination, Australia	Overview http://www.desalinfo.com.au/Home.asp Marine Studies http://www.desalinfo.com.au/Environment.asp

APPENDIX E
PERMITTING AND REGULATORY REQUIREMENTS, A THREE-STATE COMPARISON

ABSTRACT

In the US, there are a host of institutional issues that utilities must address in planning and implementing desal projects. Utilities planning to implement desal facilities must comply with a number of regulatory and permitting requirements from federal, state and local agencies. Several statewide agencies have yet to cast regulations regarding the application of this technology on a local scale. As a result, many utilities with an interest in implementing desal projects have no guidelines by which to begin the process.

One way to address this issue is to provide utilities with practical and informative guidelines that will serve as decision making tools in obtaining permits from regulators and contracting qualified engineering consultants to perform desal water services. There are approximately 250 desal facilities with a design capacity greater than 0.025 mgd in the US. Of these facilities, nearly 50% of them are in Florida and about 15% of them in California and Texas. Therefore, these three states can be considered key states in the desal movement in the US. The purpose of this paper is to provide both utilities and governing agencies with an overview of regulations adopted among the three key states in the desal movement as an example by which project planning can begin locally.

INTRODUCTION

Regulatory and permitting requirements are the main institutional consideration in developing a desal project. The types and number of permits required to implement a desal project are site specific and could vary from state to state and even on a local level. Desal facilities typically require permitting from federal, state and local agencies. For example, Tampa had to obtain 18 different permits from the state and local governments in order to build and operate the TBW Desalination Facility and associated pipelines.

Florida has the largest full-scale seawater desal facility in the US. In addition, in Florida there are multiple desal facilities treating brackish groundwater. California is the leading state in the process of implementing seawater desal facilities. There are several brackish groundwater desal facilities in Texas, and the State is involved in the implementation of a regional seawater desal facility. This paper provides an overview of the regulations and permitting requirements that apply to these three key states since full implementations of seawater facilities are more likely to occur in these three states, due to their proximity to seawater sources. The paper also provides a comparison of some of the state and local regulatory and permitting requirements in each of the three key states. The objective is to exemplify the institutional variability of the desal planning process within the US and to encourage utilities to research their respective regulatory and permitting requirements.

Information related to regulatory and permit requirements in the three key states and their comparison was divided into three main categories:

1. Desal Facility
2. Source water
3. Residuals Management

For the purposes of this paper, source waters will be categorized in two ways; surface water (including brackish surface water and seawater) and, ground water (including brackish groundwater, and seawater strength groundwater).

REGULATORY AND PERMIT REQUIREMENTS: DESAL FACILITY

Regulatory requirements for the desal facility itself differ for the three key states.

Pilot Study Regulatory Requirements

In the three key states a pilot study is necessary to obtain a construction permit from the state for a RO seawater facility. However, a pilot study is not required for a RO treating brackish groundwater in Florida and California, whereas in Texas, a pilot study is required. Following the pilot study, results and demonstration that the seawater desal is feasible using RO membranes are submitted to the State for approval. It is only after approval from the state, that a construction permit can be applied. In Texas, the regulatory requirements for any membrane pilot study (seawater and brackish groundwater) include water quality monitoring of streams such as source water, permeate and by-product streams, and process performance in terms of production sustainability. In Florida and California, the seawater pilot study must demonstrate the effectiveness of the membrane process in terms of pathogen removal. It should be noted that a pilot study may be required by the local government (City/County) even though the requirement is not part of specific regulations.

Pathogen Removal/Inactivation Credit Regulatory Requirements

The log credits for pathogen inactivation by membrane are different in the three states. Log credits affect how the seawater desal facility will meet the pathogen inactivation requirements. These requirements are 4 log for viruses, 3 log for *Giardia*, and from 2 to 5 for *Cryptosporidium* (depending on the *Cryptosporidium* concentration in the source water). In Florida, 2.5 log credits for *Giardia*, 2 log for viruses, and 2 log for *Cryptosporidium* are given to RO membrane process based on a pilot study demonstration per 62-550 Florida Administrative Code (FAC). In Texas, log credits for viruses for RO membranes vary from 0 to 2 logs depending on the RO pre-treatment.

In addition, log credits for *Giardia* and *Cryptosporidium* will be based on a challenge study performed at the pilot scale for seawater facilities. In California it must be demonstrated to the CDPH that the alternative technology provides at a minimum 2 log removal for *Giardia*, 1 log for viruses, and 2 log for *Cryptosporidium* per 22 CCR 64653. The demonstration shall be based on the results from a prior equivalency demonstration or a testing of a full scale installation that is treating water with similar characteristics and is exposed to similar hazards as the water proposed for treatment. A pilot plant test of the water to be treated may also be used for this demonstration if conducted with the approval of the Department. The demonstration shall be presented in an engineering report prepared by a qualified engineer.

Construction Permit Requirements

In all three states a construction permit is required from the state [Florida Department of Environmental Protection (FDEP) for Florida, TCEQ in Texas, and CDPH in California]. The construction permit is typically more process oriented. A utility must demonstrate that the treatment will meet drinking water standards and that the design is sound and follows adopted design practices. The process to obtain the permit from the three states is different. In Florida, a permit application is submitted to FDEP with either an engineering report with 60% design drawings or 100% design drawings and specifications. In California in addition to an engineering report, the Notice of Documentation must be submitted with the permit application to comply with the CEQA. CDPH will issue a water supply permit once the application complies with the CEQA regulatory requirements.

A building permit for a seawater facility is required by the local government (City or County) to ensure compliance with local building codes and rules. Some local governments may have special permitting requirements such as removal and replacement of trees, and right-of-way permits.

SOURCE WATER

Regulatory Requirements

In order to supply water to the desal facility, permits must be obtained for water withdrawal and for withdrawal infrastructure. The type of permits and the permitting agencies may vary depending of the nature of the source water.

Withdrawal Permit

A permit is required in order to withdraw source water from a surface water body or an aquifer. The permit requirements for withdrawal from both surface water and groundwater sources are outlined below.

Surface Water Withdrawal

In Florida, a withdrawal permit (Consumptive Use Permit or Water Use Permit) must be obtained from the State; more specifically, from one of the five Water Management Districts (WMDs). The permit will quantify the volume that can be withdrawn on annual average flow basis and a maximum monthly flow for example.

In Texas, water rights for surface water withdrawal must be obtained from the State (TCEQ).

In California, water rights for surface water withdrawal must be obtained from the State Water Resource Control Board—Division of Water Rights. The permitting process must comply with the CEQA and the Statements of Water Diversion and Use as appropriate. In addition, approval from the CCC and the CDWR must be obtained. The CCC approval is required for seawater withdrawal in order to comply with the CCA, which regulates protection of the coast whereas. CDWR is the organization responsible for the development and protection of water resources. CDWR approval may be required to ensure that a proposed seawater project fits within the State projects implemented by CDWR.

Groundwater Withdrawal

The groundwater withdrawal permit requirements for groundwater are the same as those for surface waters. In addition, order to apply for this permit, there are several regulation requirements to comply with, such as demonstration of "no impact" on the environment (such as wetlands) while withdrawing groundwater.

In Texas, water rights for groundwater withdrawal must be obtained from local Groundwater Conservation Districts for groundwater.

In California, water rights for water withdrawal must be obtained from the State Water Resource Control Board—Division of Water Rights. The permitting process must comply with the CEQA and the Statements of Water Diversion and Use as appropriate.

Infrastructure Permit

An intake permit for seawater withdrawal or well permit for brackish groundwater must be obtained at the federal and/or the state level. Typically, if the seawater intake is within navigable water, then permits from both federal and state agencies will be required. In Florida, permits from the USACOE (under Section 10 Rivers and Harbors Act Permit and Section 404 Permit for Excavation and Fill), USFWS (under Section 7 Endangered Species Act), and possibly US Coast Guard would be required for a seawater intake. An FDEP construction permit would be required at the State level for a brackish groundwater well (FDEP in Florida). Additional State level permits may be required by the Bureau of State Lands (Submerged Lands Authorization) and the Florida Fish and Wildlife Commission.

In California, in addition to the above mentioned federal agencies, the Monterey Bay National Marine Sanctuary (under the National Marine Sanctuaries Act) and the NOAA (under the Marine Mammal Protection Act and Small Take Authorization for Incidental Harassment) may also be involved in the seawater intake permitting process. State agencies involved in the permitting process include the CCC (under the CCA) and the State Lands Commission (Younos 2005).

In Texas withdrawal infrastructure permits are managed by the TCEQ for surface water intake infrastructure and local Groundwater Districts for groundwater infrastructure.

RESIDUALS MANAGEMENT

Concentrate

The concentrate, produced from the desal process contains high levels of TDS and must be managed of in a manner that minimally impacts the environment. The nature and concentration of the TDS depends largely on the characteristics of the source water and facility treatment. In the United States, there are two main methods of concentrate disposal employed by existing desal facilities. The most widely used methods are surface water discharge and underground injection via deep well. The two main influential factors that determine the method of concentrate disposal or even the viability of the project are the cost of disposal and the environmental implications of disposal.

Regulatory Requirements

An NPDES is required to dispose of concentrate into surface water. Typically, the NPDES permit is issued by the State. However, the State is likely to seek approval of several federal agencies including USEPA. Even though the State may have primacy, USEPA could supersede State's decision (approval or denial) on the permit. A permit under the UIC program must be obtained to dispose of concentrate into a deep well.

In Florida, a permit from FDEP is required to discharge into surface water or into a deep well.

In California the Monterey Bay National Marine Sanctuary, NMFS, NOAA, and the USFWS may all be involved in the residuals management permitting process on the Federal level. On a State level, CCC, the California Department of Boating and Waterways, the CDFG, and the State Water Resources Control Board may also have permitting requirements for residuals management.

In Texas, residuals management permits are required from the TCEQ to discharge into surface water or into a deep well. Other local permitting agencies under the jurisdiction of TCEQ may also be involved in the permitting process.

Infrastructure Permit

A concentrate outfall permit must be obtained at the federal and/or the state level for the infrastructure. Regulation and permit requirements for concentrate outfall are similar to those for intake infrastructure permits.

A construction permit for a deep well should be obtained from the State. Once the well is constructed, an operation permit must be obtained after demonstrating the proper operation of the well.

Other Permits

Regulatory requirements to dispose of wastewater, including spent cleaning solutions used to restore membrane system performance, in a sewer are typically determined by the local government (City/County) that operates and maintains the collection system and the wastewater treatment facility. The same is true for sludge disposal which typically occurs in a landfill. Permits or approvals to dispose of wastewater and sludge would have to be obtained from the local government.

CASE STUDIES

Tampa Bay Water—FL

The Tampa Bay Seawater Desalination Plant is the nation's largest seawater desal facility. The plant provides the Tampa Bay region with up to 25 mgd of drinking water. Construction and operations of the Tampa Bay Seawater Desalination Plant and pipeline required 18 separate permits. The permitting process was lengthy and extensive, particularly the FDEP permitting process. Over an 18-month period, the Department of Environmental Protection (DEP) reviewed scientific research and public comments before permitting the facility. The plant's permit applications were reviewed by several agencies, organizations and citizens concerned with protecting Tampa Bay, including the Agency on Bay Management, the Hillsborough County Water Team, the Audubon Society, the Tampa Baywatch, and Tampa Estuary Program (TBW 2008).

Carlsbad—CA

The Carlsbad Seawater Desalination Plant, which is currently in the implementation phase, will be a 50 mgd seawater desal plant (including associated water delivery pipelines). The project is located at the Encina Power Station in the City of Carlsbad, and will provide San Diego County with a locally controlled supply of water. The Carlsbad Desalination Project began construction in 2009 after a five-year permitting process that involved several Federal, State, and local agencies. Some of the State agencies involved in the permitting process included the CCC, the State Lands Commission, and the RWQCB.

Brownsville—TX

The Brownsville Seawater Desalination Pilot Plant Study, which was completed in December 2008, was developed to support implementation of a seawater desal facility that is expected to have a capacity of 25 mgd. The Brownsville project is based on RO membrane technology therefore is required to meet TCEQ membrane criteria, particularly since this facility is slated to treat coastal surface water with the potential for pathogen contamination from surface water runoff. In addition, discharge of desal concentrate to coastal waters, as is planned for the Brownsville facility, will require a NPDES permit

Melbourne—FL

The Melbourne 5 mgd RO Plant treats brackish groundwater from the Floridian Aquifer and supplies Melbourne and its surrounding area. The concentrate from the RO Plant is discharged into the Eau Gallie River. In addition to infrastructure permits, the city was required to obtain a source water withdrawal permit and an NPDES permit for concentrate discharge from the FDEP. Due to stringent surface water discharge regulations, the NPDES permitting process involved several studies and took nearly five years.

Although all three seawater desal plants are in different phases (from the planning phase to being fully operational) it is possible to make a comparison of the permitting requirements for each of the plants based on the proposed and existing designs, as shown in Table E.1. The purpose of the brackish groundwater desal plant case study is to illustrate the similarities and differences in the permitting requirements for a surface water source and a groundwater source. The purpose of this comparison is to illustrate the difference and, in some cases, similarities in the permitting requirements among the three key states.

Table E.1
Case study permitting

Permits for TBW Desalination Facility	Permits for Carlsbad Seawater Desalination Facility	Permits required for future Brownsville Full-scale Seawater Facility	Permits required for Melbourne Brackish Groundwater Facility
DEP Industrial Wastewater (NPDES) Permit	San Diego Regional Water Quality Control Board NPDES Permit	USACE Dredge and Fill Permit	DEP Industrial Wastewater (NPDES) Permit
DEP Public Drinking Water Facility Construction Permit	CDHS Drinking Water Permit	USACE Intake Permit	DEP Public Drinking Water Facility Construction Permit
DEP Standard General Environmental Resource Permit (ERP)—Storm water	CCC CDP	TCEQ Water Right Permit	DEP Standard General ERP—Storm water
EPA NPDES Storm Water Discharge during Construction Activities	State Lands Commission Approval	TCEQ Public Water System Plan Review	EPA NPDES Storm Water Discharge during Construction Activities
Hillsborough County Planning and Growth Management Department Review Construction Plan Approval	Encina Wastewater Authority Industrial Waste Permit	TCEQ Air Permit	Brevard County Construction Plan Approval
State Department of Health On-Site Sewage Disposal System Construction Permit	Floodplain Special Use Permit	TCEQ Petroleum Storage Tank Registration	St. Johns River Water Management District Consumptive Use Permit for Groundwater Withdrawal
DEP Air Pollution Sources Permit—Non-Title V	Development Agreement	TCEQ NPDES Permit—Concentrate	
Hillsborough County Natural Resources Permit	City of Carlsbad, Vista and Oceanside Right-of-Way permits	TCEQ NPDES Permit—Storm water	
DEP Public Drinking Water Construction Permit	City of Carlsbad, Vista and Oceanside Encroachment Permits	TCEQ Registration for solid residual disposal	DEP Public Drinking Water Construction Permit
Individual ERP Permits for Wetland Crossings	City of Carlsbad, Vista and Oceanside Easements/Acquisition of Right-of-Way	City/County Permit for wastewater disposal	
Corp of Engineers Dredge and Fill Permits for Wetland Crossings	City of Carlsbad, Vista and Oceanside Grading Permits	City/County Building Permit	

(continued)

Table E.1 (Continued)

Permits for TBW Desalination Facility	Permits for Carlsbad Seawater Desalination Facility	Permits required for future Brownsville Full-scale Seawater Facility	Permits required for Melbourne Brackish Groundwater Facility
Hillsborough County Environmental Protection Commission Wetland Impact Approval for Wetland Crossings	City of Carlsbad, Vista and Oceanside Haul Route permit	City/County Tree Removal Permit	
DEP Standard General ERP—Storm Water	City of Carlsbad Water Purchase Agreement	City/County Erosion Permit for construction	
EPA NPDES Storm Water Discharge during Construction Activities	Water Purchase Agreement	Texas General Land Office Easement permit	
Hillsborough County PGMD Review Construction Plan Approval	Habitual Management Plan Permit	Texas Department of Transportation Utility Permit	
Tampa Port Authority Permit	Redevelopment Permit	City/County Permits	
Florida Department of Transportation Utility Permit	City of Vista and Oceanside Land Use and Development Permits	—	
Hillsborough County Right-of-Way Use Permit	Permits to connect to facilities of various local water districts	—	

Sources: R.W. Beck 2004, NRS Consulting Engineers 2008, Owen 2008, Poseidon 2009.

CONCLUSIONS

The institutional considerations as they apply to the development and implementation of a desal project are an important factor in determining the viability of the project and avoiding costly non compliance issues. Permits or regulatory approval may be required for the different aspects or phases of a desal project including pilot studies, source withdrawal, facility construction and operation and residual management. Therefore, it is important that every utility with the intention of designing and implementing a desal facility be aware of its federal, state and local regulatory and permitting requirements and uses them as decision making tools. These institutional requirements are site specific and vary by state.

A comparison of the regulatory and permitting requirements and the permitting agencies in three key states, Florida, California and Texas, demonstrates the institutional differences and, in some cases, similarities on a state level.

The information presented in this paper is intended to illustrate the institutional challenges and considerations a utility may face in planning and implementing a desal facility. In general, these challenges and considerations will be in the categories out desal facility design, source water and residuals management.

APPENDIX F
IMPROVING THE PROCESS FOR IMPLEMENTING SEAWATER DESAL: VALUE AND PUBLIC PERCEPTION ISSUES

This appendix provides an outline of key issues and information associated with the process of implementing ocean water desal. It also includes the following tools and resources:

- Checklist for Proposing Desal
- Key Challenges Related to the Public Dialogue about Desal
- West Basin Water Reliability 2020 Case Study

The information discussed below is based on one-on-one interviews with water industry executives, collaborative group discussions with water professionals in Southern California on desal messages, and the branding work of John Ruetten, Resource Trends, Inc.

KEY DESAL PLANNING ISSUES AND CONSIDERATIONS

Perceived Need Drives Implementation

When looking at how to improve and/or speed the process of implementing ocean desal, it is useful to remember that the driving forces behind any proposal have a profound impact on people's behavior and the pace of implementation. If people's lawns are dying because of water cutbacks, then implementation of desal will certainly move faster if there are no other obvious solutions to the problem. This illustrates the simple but powerful idea that the perceived need is the impetus that drives progress. In a crisis, people act quickly and barriers often fall like dominoes. It is not a big stretch to see that an important perceived need accelerates the process much more than efforts to address specific permitting issues or other specific barriers.

The Need for Early Implementation

Clearly, waiting for a crisis is not an acceptable management practice. This is especially true with ocean desal or other major water investments which take many years to implement. Failure to implement early may result in multi-year water shortages and restrictions on water use. The negative impacts on the economy and overall quality of life far outweigh the cost of early implementation. Also, implementing in a crisis could result in a project that does not have all the environmental issues addressed, including coastal land use, marine impacts, and energy use/carbon footprint. Early implementation with a well-thought-out process for developing support from community leaders and policymakers can include environmental mitigation and benefits.

Planning and Leadership

Prior to a crisis, the perceived need for desal and the urgency to implement it will be determined by the leadership qualities of the sponsoring utility. This includes its planning expertise, and its ability to lead a dialogue with the community that yields good policy decisions.

In order to lead this dialogue, utilities must grapple with several key issues including the following:

- How their planning function considers water resources risks
- The need to invest in new water supplies
- The value of desal compared to alternatives
- How best to present environmental features and benefits

All of these issues relate to leading a meaningful and productive debate about the merits of investing in desal. However, there are many challenges in leading this debate. A full list of these challenges is included in appendix B of this report.

Some of these challenges include being able to consider the value of new water supplies to the entire watershed for example, estimating the value of being able to use desal to save water for inland aquatic environments. This ability is typically beyond the traditional roles or competencies of many utilities. With respect to desal the need for regional and/or watershed cooperation and leadership is an important component of proposing the most effective and efficient investments.

PLANNING AND INVESTING IN WATER RELIABILITY

New Planning Challenges. Serious consideration of desal will likely occur when business as usual with respect to water supply planning will not do. This is because utilities considering desal will likely be dealing with several major issues, including the following:

- Stretched water supplies due to growth
- Uncertainty about the future of water supplies due to environmental needs for water
- Increasing water rights disputes as more communities *need* more water, whether it be virgin flows or rights to recycled water
- Increased risk to natural water supplies due to climate change

These conditions increase water reliability risks and require new ways of thinking about water resource planning and the features of available supplies. In fact, the issues noted above can emerge fairly quickly and outpace the utilities' ability to change its planning function or think differently about water reliability.

Strong Leadership Related to Investment in Reliability. Expanding on the idea that this is not "business as usual," a passive or bureaucratic approach to planning and investing in reliability (and possibly implementing desal) can result in investment that is too late to avoid water shortages and the related negative impacts. Investing too late is a disservice to the community. A more aggressive stance on water reliability investment and a willingness to take into account increasing water-supply risks is clearly necessary in order to maintain quality of life. Whether this happens or not will depend on the following:

- The utility's commitment to water reliability and clarity on water reliability standards
- The culture of problem solving and leadership in the utility
- How water reliability or water supply risks are analyzed

- The strength of the utility's message related to water reliability risks and potential solutions
- How the utility presents the beneficial environmental features of desal in order to expedite community support and the permitting process
- How the utility goes about helping policymakers feel comfortable with voting for a significant investment in desal

The environmental issues and the challenges of ensuring good policy decisions will be addressed in later sections of this report. This section deals primarily with planning and investment related to water reliability.

Commitment and Clarity on Water Reliability. It is hard to believe that a utility would not be clear on its commitment to water reliability. However, the level of clarity inside a utility regarding reliability roles will depend on how significant water reliability has been in the past. For example, West Basin Municipal Water District's aggressive stance on investment in water supplies stems from a history of addressing water reliability. This history goes back to the 1940s when West Basin was formed to bring in a new water supply for the coastal areas of Los Angeles. Today, West Basin's "brand" and mission is water reliability. West Basin takes this mission seriously and views water shortages or restrictions as failure. This level of commitment to water reliability may not be present in an organization where water supply issues have not been a concern, or where water reliability has been assured due to infrastructure decisions made decades ago by previous administrations or other organizations.

Discussing water restrictions highlights another important point. What is the appropriate standard for water reliability in a community or region? Are water restrictions a failure? Surely one could argue that a constant state of restriction is not acceptable. How about restrictions every 3, 5, or 10 years? Even saying that investment in new water supplies "will ensure that water shortages or restrictions will be rare" is a standard. Without some form of reliability standard, it is difficult to determine water supply needs or propose appropriate investment in new supply.

Assessing Water Supply and Water Reliability Risks. When planning for new water supplies, the issue often boils down to assessing risks. If a community is growing rapidly, it can be fairly obvious that new water supplies are needed. However, what if water reliability is threatened more by growing uncertainties due to water rights disputes, increasing awareness about environmental needs for water, or climate change? In these cases determining the actual risk and appropriate response may not be as straightforward. The defining issue may be how the utility or water agency addresses problems and risk. Does the organization constantly challenge its current activities and approach in order to continuously improve? How well does the organization analyze the world around it and assess new risks?

Risk assessment is difficult because it is not an exact science. Despite this, significant investments to reduce risks may be necessary. For example, communities in Southern California get water from both the Colorado River and Northern California. However, the infrastructure on the Colorado River provides 10 times more water storage than the Northern California water system. This difference in storage impacts how certain one can be about receiving a consistent volume of water from each system in a given year. How do utilities assess this risk of relying more heavily on the Northern California water supply given that it has less storage, and what is the appropriate response? How much "analysis" is required to make a decision? The answers to these questions determine the likelihood of making a proactive investment in new water supplies and potentially desal.

No One Wants to Hear About Problems. Another challenge with communicating risks relates to how elected officials and policymakers respond to utility staff members bringing up risks. Often, staff members believe that policymakers want to steer clear of anything that looks like a problem. These feelings are understandable. This is unfortunate because accepting that a problem exists can be the best way to get people to make an investment. Certainly when water restrictions are in place, or infrastructure is failing, the money flows. As mentioned at the beginning of this report, the objective is to secure investment before failures occur. Given this, bringing up problems as future risks is necessary and is consistent with the need for long-term thinking. The idea of long-term planning so water investments can be made well ahead of the need should be an important message in any community dialogue. This changes the tone of the message from a negative to the positive (proactive long-term planning).

Investment Options and Levels of Investment. Analysis and planning are performed to make good investment decisions. If, as is the case in Southern California, the decision was that water reliability was significantly reduced due to a heavier reliance on a system with less storage, then the next question is how to respond. If a viable alternative greatly reduces risk and only costs water customers $15 per month more than they are currently paying, then the prudent course would be to make the investment. If the costs were $50 per month, more analysis may be required to reassess the risks or find a lower-cost solution. Calculating the cost per month to rate payers for a specific investment is an important step. It is the only meaningful way for the average person to appreciate cost information and accurately assess his/her WTP. Percentage rate increases are less meaningful because many people do not even know the amount of their average water bill. A 30% increase may sound like a lot until a person realizes that this is $12 per month. Also, rate increase/benefit assessments must be very specific. People want to know what they are paying and exactly what they are getting in return.

COMPARING WATER SUPPLIES—WHY DESAL?

All Water Supplies are Equal? It is easy to view conservation, recycled water, and desal as somewhat equivalent solutions from a water-supply perspective. This is illustrated by the fact that many utilities compare the costs of these supply alternatives as if they were equal in value. They are surely perceived differently from an environmental perspective, but they also have different water resource benefits. This means their value is not equal, and this value will vary depending on the specific needs of the community.

New Water into the Watershed. The most evident difference for desal is that it brings new water into the watershed, which is especially valuable if the planning process predicts reduced flows from rain or snowpack. Conservation and recycled water have limitations if natural flows have dropped significantly. Also, ocean water desal produces water that can be added directly to the potable water system which is not yet the case with recycled water. This is a very important distinction. Some agencies have stated that they could forgo implementing desal for the foreseeable future if direct potable reuse were feasible from both a regulatory and public perception standpoint.

The Brand of Desal. Desal is often branded as expensive, energy intensive, and damaging to the marine environment. There is some truth in these perceptions when viewed as isolated qualities. However, these judgments are misleading if desal's unique value and the specific needs of the community are not fully considered. So, it may be an error to assume that conservation and recycled water should always come before ocean desal because of lower costs, energy usage, or environmental impacts.

It is useful to look specifically at the brand of desal with respect to cost. Often the term "least-cost principles" is brought up in debates over choosing the best water investments. This terminology suggests that the option that costs the least should be implemented before other options, as if all the options are equal from a reliability, quality, and overall value standpoint. It is clear this is not the case. Furthermore, few people would say they want to live in "least-cost" communities. Least-cost thinking can lead to decisions like co-location of desal plants with power plants, which in the long run may not be the best solution or the best implementation of desal. People will pay more than least cost if they understand the value they are getting, including environmental benefits and reserving water for inland environments. However, they cannot choose this value if they are never given the choice, which can happen if the utility is driven by least-cost thinking.

ENVIRONMENTAL ISSUES

A significant barrier to implementation of ocean desal is the negative impact on marine life and the amount of energy it uses. One of the most contentious of these issues appears to be I&E of aquatic species. Environmental issues can certainly slow down the permitting process. Environmental groups tend to be very supportive of recycled water but less supportive of desal, preferring to consider it as an emergency supply. As mentioned above, a limitation of recycled water compared to desal is that it cannot be introduced directly into the potable water system. Given the benefits of desal as a direct potable supply, the obvious question is why utilities do not just propose environmentally-friendly desal plants. The reason for this appears to stem from the following issues:

- Water utilities have a tendency to propose least-cost solutions
- Water engineers can get hung up on the technical merits of environmental features and often believe they are not worth the additional expense
- Utilities (both staff and policymakers) often conclude that environmental features are "cost prohibitive" prior to this being discussed with community leaders and the public
- Uncertainty about the production readiness of sub-ocean floor water intakes or other methods for protecting marine life

The first three of these issues relate to cost-centered thinking instead of value-centered thinking and a bias that technical arguments are primary. There is strong precedent for non-technical issues driving project features, especially in recent projects where the public is more actively engaged. For example, many water engineers would argue that using RO membranes for treating recycled water used to replenish groundwater supplies is not necessary. Still, RO is becoming the standard (at least in coastal communities) primarily due to public perception issues. The fourth issue noted above is a significant technical risk (sub-ocean floor intakes) that requires more attention and research. This research will be slow unless utilities make it part of their feasibility studies and offer it as an option in the community dialogue.

Assessing WTP for Environmental Features. Ultimately, investment in the desal plant and its features will be determined on the water reliability and environmental benefits that policymakers are willing to invest in. In many cases this is based on their instincts and possibly some data on public sentiments and what people are willing to pay for. It is not unusual for a utility to assume that something is cost prohibitive before the issue has been put before the public in a meaningful way. For example, the incremental rate increase (in $ per month) of building a carbon neutral plant with sub-ocean floor water intakes could be presented to community leaders to assess WTP.

Utilities often have general information on people's WTP to improve water quality or water reliability, but the type of specific information sharing noted above is seldom done. Making environmental features part of the initial specification of the plant not only helps in assessing people's WTP, but forces the utility to analyze the feasibility of these features. Not including environmental features in an initial proposal likely dooms them to being left out unless environmentalists force them to be included. This scenario slows the permitting and approval process. Not only can the pace of permitting be slowed due to environmental issues, but the probability of post-permit legal challenges increases. Utilities are recognizing these issues and to varying degrees acting accordingly.

The Environmental Brand of the Water Industry. The discussion above brings to light an important overarching issue related to the environmental debate over ocean desal. The environmental reputation of the water industry and the utility affect how environmentalists perceive and trust utilities. Utilities have a history of focusing on how to provide water for people at the least cost. This puts their environmental ethics in question, especially when you ask members of environmental groups. The brand of the industry and the brand of the utility have a significant impact on trust and the productiveness of the environmental debate. Water utilities need to be aware of this when planning their outreach activities and assessing the behavior of environmental groups. Proposing a plant with strong environmental features (including communicating the incremental costs of these features) gives environmental mitigation a fighting chance and improves the brand of the utility, even if the features are rejected by the community.

Realizing the Environmental Benefits of More Water. Obviously, the great benefit of ocean desal is that it provides water that is independent of climate or the water rights of other communities or regions. It would seem that a laudable benefit of desal would be to ensure that more water is left for inland aquatic environments. Unfortunately, the mechanism for earmarking water produced by a desal plant for protecting inland environments is not well developed. This is where regional cooperation would help. Desal plants creating clear benefits for inland environments could help to balance out localized environmental impacts of desal and improve the environmental brand of desal. This is where implementation of what is often referred to as a TBL approach might help provide balance and make the dialogue about desal more productive.

ENSURING GOOD POLICY DECISIONS

Water investment decisions are typically made by policymakers. By policymakers we mean an elected or appointed water board for special service districts or a city council or water commission for municipalities. However, policymakers do not operate in a vacuum. They are concerned about the opinions of community leaders and they want to protect their reputations and careers. So what can utility staff members do to make certain that good policy decisions are made related to water reliability and desal? Here are some key steps:

- Develop a “strategic direction” that makes a clear and compelling case for investment in water reliability well ahead of the need for more water
- Focus communication activities on helping policymakers feel safe to support an investment in reliability and desal

The Strategic Direction. The strategic direction provides the reason for talking to the community about investment in water reliability. It may be based on a long-range strategic plan that looks out 30 years or more, but it specifically addresses the investment needed to resolve issues that range from 5 to 15 years out. A strategic direction that proposes desal as part of the solution should articulate future water reliability risks, communicate alternatives for addressing these risks, and propose a course of action. The information should also include the incremental costs of mitigating environmental impacts, which can be used to gauge WTP. The strategic direction provides a reason to talk with community leaders about needed investments. It gives the community a reason to pay attention, which is important because people are busy and distracted by a myriad of other important issues.

The Problem With “Public Education.” The strategic direction provides the message, but the message still needs to be delivered. Utilities typically invest in a variety of outreach activities that are designed to educate the public. However, there are several problems with the idea of “public education.”

- A single utility does not always have the resources to reach and make an impression on or educate the general public
- People often do not have the time or desire to be educated
- The term “educate” is often viewed as condescending by adults
- When the objective is to educate, there is no clear standard for results and generally the relationship between communication activities and policy decisions is not well-defined

These issues lead to conditions where the information supplied by utilities is often not very meaningful, often not read, and not always well received.

Building Community Relationships. The best use of the information in the strategic direction is not to educate but to build relationships with community leaders, the media, and the interested public. This relationship-building process allows staff to stimulate a dialogue, listen to concerns, garner support for investment from the people who matter the most to policymakers. It also allows for an ongoing dialogue with policymakers about community support and what people would like to see in a project or series of projects. These activities provide policymakers with information that helps them feel “safe” in voting for the appropriate investment in water reliability and desal, instead of what they speculate is politically palatable.

WHY DESAL IS SPECIAL

A Simple Solution to Our Water Problems. It seems, more than any other type of water project, desal has captured the attention of the general public. Why is this so? On closer examination the reasons turn out to be straightforward. First, desal taps into a limitless supply. People want water problems to go away and desal seems like a promising alternative. In fact, desal is pretty simple when viewed from a technology and construction perspective: “just go build the plant and solve the water shortage problem." These sentiments stem from people's tendency to think in simple terms and their desire to make problems disappear.

Alternatives Can Be More Complicated. It turns out that the public's instincts related to the simplicity of desal are correct. This is because when the debate turns to alternatives, the discussion can get more complicated. The typical alternatives are increased conservation and increased use of recycled water. However, in many cases, these solutions are not as simple as desal. In many communities the low-hanging conservation fruit has already been plucked (e.g., through low-flow shower heads and high-efficiency toilets and washing machines).

What remains is landscape irrigation conservation which, in some locations, has the potential to save a lot of water (although in other locations, it has been very aggressively pursued already and additional water savings may be hard and expensive to come by). Unfortunately, these potential water savings involve asking entire industries to change their beliefs and behavior with respect to soil health management, irrigation methods and practices, plant selection, and maintenance practices. It is much easier to build something new than to change entrenched practices. You also need to have an organization that is capable of leading this level of change, which most water utilities are hard-pressed to do.

On the recycled water side, potable use of the water is limited by regulatory constraints. Non-potable use requires construction of separate piping systems which are fine for new communities but can be disruptive and time consuming to install in built-out communities. Signing up customers for non-potable recycled water is a difficult task. Being able to easily implement indirect or direct potable reuse would solve this problem, but this has its own set of significant challenges.

GUIDELINES AND CHECKLIST FOR UTILITIES

Based on the information and considerations detailed above, the following provides guidance for utilities to reference throughout the desal planning process.

1. **Examine thinking and commitment to reliability.** Make sure that utility managers are thinking clearly with respect to water reliability. This includes understanding any planning or procedural changes that might be necessary given new water supply needs and changes in water supply risks. Old thinking and methods may not work given the new challenges. Does the utility take water reliability seriously and view water shortages or restrictions as a planning and investment failure? One way to assess current thinking is to make sure you have articulated a clear water reliability standard. For example, how many years out of 20 should the community experience water shortages or restrictions, if ever?
2. **Asses risks and propose high reliability.** Regularly inquire into changes in water supply and water supply risks. Collect as much planning data as possible, but do not assume that the risks need to be highly calculable in order to propose a significant investment. Also, do not soft sell the risks so everyone feels good. The community wants a conservative approach to water reliability, and will pay for an adequate supply of water. The wedge that will drive action is a perceived need to invest in new supplies and to invest early. Passivity will not do, and the community will surely react very negatively if problems occur that could have been avoided by timely investments.

3. **Emphasize the need for long-term thinking.** Communicate issues as future problems or risks that can be avoided or reduced if we invest early. Long-term planning and investing are the keys to future reliability, which is a very positive message.
4. **Plan with the watershed in mind.** Communities and regions are now more connected than ever due to the increasing need for water and changes in the climate. Wherever possible, water supply planning needs to consider the impacts on the watershed and the region. Desal provides the opportunity to secure investment from a variety of sources given the increasing environmental needs for water and the need for communities to retain water they have historically exported, including discharged wastewater.
5. **Develop a compelling strategic direction.** Develop a strategic direction that articulates your commitment to water reliability, outlines future water supply and reliability risks, lists the alternatives for resolving the problem, and recommends a course of action. This strategic direction provides the framework for reaching out to the community and is the context for investing in desal.
6. **Make sure risks to the economy are well-represented.** Connect water availability with economic health, using case studies if possible. This will help garner support from businesses and unions for investing in water reliability and desal, and potentially offset negative branding of desal due to environmental issues.
7. **Be clear on the value of different water supplies and options.** Avoid making costs the only standard of comparison, as if all supply alternatives are equal. Water from ocean desal has the advantage of being able to be introduced directly into the potable supply. Recycled water does not currently have this feature, which can cause a more lengthy process of identifying customers and installing dual delivery infrastructure. Different water supplies have different benefits and therefore should be valued differently. Information on trade-offs, options, and alternatives should be very complete even if this information extends beyond what the utility is used to researching. Those involved in the debate will expect an exhaustive look at the options and the logic behind recommendations.
8. **Make sure the current state of investment is communicated.** If a state of under-investment in water resources or infrastructure exists, then the incremental cost of new supplies may seem very high. It is important for water rates (or at least the future rates that will be compared to rates associated with desal) to reflect "full-cost pricing." This allows community members to make a true assessment of the price and value of desal.
9. **Understand and manage the "brand" of desal.** Desal has been branded in both positive and negative ways. It is a limitless, local, and drought-proof water supply, but it is also viewed as expensive, energy intensive, and harmful to the coastal environment. These branding issues can be addressed by comparing future costs, energy use, and environmental impacts with other water supplies. The brand of desal may also be improved by employing a TBL approach that results in water being reserved for inland aquatic environments.
10. **Make costs meaningful.** Share the cost of all investments and alternatives in terms of the impact on rates or fees in dollars per month. This is the only representation of cost that is meaningful to rate payers and therefore policymakers. Sticking with rate

impacts leads to better decisions and increased investment. Water rate increases in dollars per month are usually fairly small compared to other expenditures. This means if people understand the value, even if portrayed as a reduction in water reliability risk, they will support the increase.

11. **Don't assume an investment is cost-prohibitive.** Do not assume desal or features of a desal plant are cost-prohibitive before you have meaningful dialogue with the community. This dialogue begins by sharing specific information on features, benefits, and rate impacts. The more specific and meaningful the value is, the more people are likely to agree to pay.
12. **Avoid "least-cost" thinking.** People will pay for value they understand. Remind people that they do not live in nor should they desire "least-cost" communities. Desal is a drought-proof and locally-controlled water supply of extremely high quality that does not in itself stress inland aquatic eco-systems. A high-value desal plant could be a desal plant with several environmental features related to marine life and energy use.
13. **Give people the environmental choice.** Propose an environmentally-friendly plant and communicate the incremental costs of these environmental features (in dollars per month as noted above). Listen to what community leaders have to say about these features and their WTP for them. Remove these benefits only if there is a strong sentiment that they are too expensive given their value. This gives the community a voice in the environmental decision and maintains or enhances the environmental reputation of utility.
14. **Build your environmental brand.** Giving members of the community the environmental choice is an important way of building trust and an environmental brand. Strong recycled water and conservation programs also build the environmental brand. Building trust related to the environment will improve the dialogue about the environmental impacts of desal. Traditionally, water utilities have been unclear about their role in preserving water for the environment and in many cases have a negative environmental reputation due to the impacts of their operations.
15. **Use the strategic direction to build relationships.** Develop relationships with community leaders using the strategic direction as defined in Item 5. Remember, the objective is not to educate the public, but to build relationships with people that policymakers are interested in and concerned about. These people are sometimes referred to as the "authorizing public." Listen to their concerns, identify opposing points of view, and build a list of supporters. Secure written support if possible by having people sign a support card.
16. **Lead a meaningful dialogue with policymakers.** Use the information from the relationship development efforts to inform policymakers about support, opposition, and WTP for proposed environmental benefits. Give them the information to replace intuition and help them feel confident enough to vote for the best implementation of desal for their community.

CHALLENGES RELATED TO THE PUBLIC DEBATE OVER DESAL

Utilities need to show strong leadership in planning and communication to help desal get fair consideration in a community or region. However, desal can prompt a difficult debate (barring a serious water crisis) for the following reasons.

Convergence of Several Important Factors

The dialogue over desal is occurring at a time where several factors are coming together, making the debate more complex and challenging. These factors include the following:

- Stretched water supplies, more demand-hardened systems, and increased uncertainty in water supplies due to climate change
- Growing awareness of the environmental needs for water
- Growing desire from the public for environmental issues to be factored into decisions
- Need for better risk assessment and sensible risk reduction strategies related to water resource availability and water resource planning
- The increased connection between communities as growth makes watersheds look a lot smaller, including entire regions such as the southwest US

The Trade-Off, Options Debate

- The fact that desal offers a "limitless" supply gets some people very excited while others get concerned due to the risks of over-exuberance and/or careless implementation.
- The trade-offs in implementing desal often extend beyond the normal boundaries of utility responsibilities. For example, it can be difficult for utilities to address energy usage issues and allocating water for the environment outside of their jurisdictions.
- The debate over trade-offs can get fairly complicated. For example, how would you compare the negative impacts of marine life entrainment in the ocean with the ability to keep more water in a smaller inland water environment? Which has the bigger benefit if the marine life or aquatic environment is preserved? What stakeholders value one outcome over the other?
- In general, the debate over desal occurs among principals and special interest groups and not the general public. This means that much of the information being shared in the debate can be biased by organizational points of view.
- Environmentalists may see things such as sustainability (especially eco-system sustainability) as being foremost in the "public interest" whereas the general public likely views having a reliable supply of water as a pretty important part of the public interest.
- Principles and special interest groups often see the debate as a technical argument and not an argument about investing in (or addressing conflicting sets of) value.
- It is not clear whether environmental restoration or green energy options that may offset desal-related impacts will be acceptable to regulators, public officials, or stakeholders.

- Conservation, recycled water, and desal are often talked about in ways that suggest that they are equivalent alternatives. Each of these has different features, benefits, and implementation challenges.
- Anti-growth activists often use the debate over water as a way to oppose growth. This is not a desal-specific issue and does not address the root of the problem: poorly managed growth.

Cost Effectiveness and Value

- A key issue is that while desal is often considered "expensive," the question of its true cost is often not properly cast relative to either of the following relevant benchmarks:
  - The "values" that desal may offer to the community (e.g., increased reliability).
  - The full cost of providing *additional* water to the community from alternative supply options (i.e., the true marginal cost of the next best supply alternatives).
- The debate over desal does not always adequately address "value." The terms "cost effectiveness" and "least-cost principles" are used quite a bit in these debates but often fail to consider that the majority of people will pay more when the added expense secures them the added value that they desire.
  - Arguably, people want to live in communities that are not "least-cost" communities. Despite this, many still stay that they want water managers to practice "least-cost planning." This least-cost thinking fails to appreciate that we enjoy a quality of life that is to some degree based on investing in abundance and paying more for value.
- Some of the value desal can provide is that of a more reliable (i.e., drought insensitive) and locally/regionally controlled supply of extremely high quality water, without stressing inland aquatic ecosystems. Desal costs should be compared to the future, full-cost price of other alternatives. For example, the cost of importing water in Southern California will rise significantly over the next 10 years. It is confusing and not productive to compare the cost of desal to costs borne for water supplies developed or acquired in the past, as these tend to not reflect their full cost, nor are they typically available as an option to provide *additional* new supply.
- Desal is often branded as expensive. However, even if all 20 proposals for large coastal desal plants in California were implemented over the next 25 years this would still represent only 6% of the overall water supply in California. This means that the average impact of desal on actual water rates would be small. This impact would be greater in some communities, but in these communities the benefits would likely be high in the form of increased water reliability and quality of life. Also, increases in water and sewer rates could be much more impacted by deferred maintenance and the need to upgrade infrastructure.
- Water rate increases over the next 20 years will range in the $30 (rough estimate) dollars per month range even if we fund an abundance of water. This is still relatively small compared to other more discretionary expenditures on the part of consumers.
- Water utilities have long had the significant challenge of getting approval for investment in water resources and infrastructure. These decisions to invest need to early in order to avoid water shortages and system failures. This means that utilities are often shy when it comes to proposing environmental features, or anything, that

increases cost (even though the associated delays and challenges associated with proposing least-cost versions of desal may well cost the utility more in the long run).

- Desal is put under the microscope related to future costs including energy costs. Alternatives and current supplies need to get the same scrutiny.
- Proposed co-location of desal plants stems from "least-cost thinking" that has complicated the debate over desal. In fact, all of the issues and complications related to the co-location model have not surfaced. Water utilities may increasingly recognize the difficulties in managing this partnership and the problems with not having the autonomy to implement the "best desal plant."

Issues That Challenge Utility Roles and Competencies

- Implementation of desal (or not) can have far-reaching effects. For example, lack of confidence in implementing desal in Southern California has caused some in Arizona to look at a bi-national agreement to build a plant in Mexico.
- There is a lack of appreciation by many parties of how long it takes to complete water projects. Utilities are sensitive to this issue because they have to get it done.
- There is a lack of appreciation for difficulties with respect to conservation and recycled water that challenge utility competencies. This includes signing up customers for recycled water and influencing customer behavior related to water conservation. This is why utilities are interested in projects that replenish the potable supply using recycled water.
- Full consideration of alternatives challenges the competencies of utilities on several fronts: planning, supply risk assessment, customer behaviors and customer service, environmental impacts, overall outreach, and community dialogue skills.
- Growth has effectively shrunk the watersheds inside state boundaries and across state boundaries which makes everyone and everything much more connected. Crossing of jurisdictions is difficult. Managing this issue is not an easy task for an individual utility.

CASE STUDY—WEST BASIN'S WATER RELIABILITY 2020 PROGRAM

WBMWD in Los Angeles, California, provides a good example of employing a diverse portfolio of water supplies and using a compelling strategic direction to make a case for implementing ocean desal.

Conservation

During the period of 1990–2005, West Basin's service area added 100,000 people but water demand remained constant due to conservation efforts.

Recycled Water

West Basin has a history of aggressive implementation of recycled water. West Basin produces five grades of recycled water ranging from "ultra pure" for high-pressure boiler water applications to water for irrigation. These five grades include water that is used for replenishing the potable water aquifer. As of 2009, West Basin produces 30,000 acre-feet of recycled water every year. This experience with using advanced technologies such as MF and RO has prepared West Basin for successfully implementing ocean desal.

The Strategic Direction—Water Reliability 2020

Based on a series of changing conditions and increased risks to imported water supplies, West Basin has embarked on a program to maintain high water reliability for the communities it serves. The program, named Water Reliability 2020, has a stated goal of reducing its dependence on less reliable, imported water supplies from 66% today to 33% by the year 2020. Stated in the positive, this will mean that West Basin will have 66% local control of its water supply by the year 2020. This goal will be achieved by increasing conservation, increasing the amount of recycled water, implementing ocean desal, and increasing people's knowledge of water issues. West Basin has developed information and an ongoing relationship-building process designed to solicit feedback and build support for Water Reliability 2020.

The Background Information

West Basin's message begins with important information about water, water issues in Southern California, and the overall global need for fresh water. Related to the water situation in Southern California, West Basin employs a very interesting and graphic metaphor. It equates the region to a theme park, because the water features, vegetation, and surroundings are basically manufactured due to the water that is brought in from the outside the area. Without this water, the region reverts to a desert. West Basin goes one step further by stating that the two man-made features that astronauts can see from space are the Great Wall of China and the water canals of California. These metaphors and information start to give people a sense of the planning, investment, and infrastructure necessary to ensure water reliability and high quality of life in Southern California. The ideas of planning and appropriate investment are extremely important messages. They provide the context for the investment necessary to achieve the goals outlined in the Water Reliability 2020 program.

The Problem Statement

The problem statement for Water Reliability 2020 is the region's dependence on increasingly variable and risky imported water supplies. West Basin pulls no punches in its statement of the problem. It addresses the following water supply risks:

- Population growth
- Sacramento Bay Delta supplies that are increasingly unreliable due to aging levies and environmental restrictions on water use
- Loss of Sierra Nevada mountain range snowpack due to climate change
- Reduced water from the Colorado River system due to drought and increasing demand from other regions with priority water rights

The overall conclusion based on these issues is that imported supplies will not be as reliable as in the past. West Basin translates these conditions into risks that people can understand:

- Higher rates for everyone and significantly higher rates for water wasters
- Mandatory water restrictions
- Loss of jobs, especially in agriculture and related businesses
- Lack of water for the environment and landscapes
- Less water for future generations

Water reliability is offered as a better idea, designed to avoid mandatory water restrictions and the negative impacts of water uncertainty and scarcity.

Water Reliability 2020—Taking Control of Our Water Future

The key message associated with Water Reliability 2020 is "taking control of our water future" by doing the following:

- Implementing more water recycling
  - Going from 30,000 AFY to 70,000
- Increasing water conservation
- Expanding water education
  - Through outreach on the Water Reliability 2020 Program
  - Award-winning school programs
  - Partnering with environmental groups including Surfriders, Roundhouse Aquarium, SEAlab, and others
  - Public tours of recycling plants
- Implementing responsible ocean desal

An important issue related to Water Reliability 2020 is the cost to rate payers. Due to rising prices of imported water and the ability to secure outside funding for innovative projects, the cost of Water Reliability 2020 will be no more than the cost of continuing to import water at similar levels. This means that the cost of staying heavily dependent on imported supplies is no more than the cost of being much more independent. This is a compelling argument.

The Water Reliability 2020 message is delivered using a comprehensive outreach program designed to reach community leaders in the region.

Implementing Responsible Desal

West Basin's message related to implementing desal is to do it in a responsible manner. West Basin defines responsible implementation as:

- Maintaining a diversified water portfolio where desal is less than 10% of the overall water supply.

- Implementing a temporary demonstration project to test wedge wire screens for open water intakes and sub-ocean-floor water withdrawal.
- Diluting concentrate discharge to protect ocean life. This will be tested in an actual aquarium.
- Increased energy use over imported water (15% more than imported) will be offset by buying renewable “green” energy.

Clearly, the debate surrounding the implementation of ocean desal centers on costs and environmental issues. West Basin has observed that environmentalists strongly support recycled water while support for desal is much less and often opposed. However, West Basin has received its permit for the desal pilot plant. The district appears to have some credibility with environmentalists because of its track record and future plans on conservation and recycled water. This is good news because it suggests that environmentalists are willing to look at desal projects on a case-by-case basis and not just categorically oppose them. This may be surprising to some because environmentalists are known for (and to some degree get their funding by) opposing any environmental impacts. West Basin’s credibility demonstrates the positive branding that comes with having strong conservation and recycled water programs.

The Water Reliability 2020 Outreach Effort

West Basin’s outreach effort is both simple and effective. It focuses on building relationships with important community leaders and expanding people’s knowledge about water and water conservation. It is important to remember the reason for people to be interested in conservation, increased water reuse, and ocean desal. The reason is increased water reliability, which is the mission of the Water Reliability 2020 investment program. As of May 2009, West Basin has received support letters from the following individuals representing larger constituencies and over 700 support letters from individuals. This support helps policymakers feel more confident in supporting Water Reliability 2020 and ocean desal.

Cities

- City of Carson, *Mayor Jim Dear*
- City of Culver City, *Mayor Andrew Weissman*
- City of El Segundo, *Dana Greenwood, public works director*
- City of Inglewood, *Mayor Roosevelt F. Dorn*
- City of Lomita (City Council passed a support resolution December 1, 2008)

Civic/Social Organizations

- Palos Verdes Peninsula Lions Club, *Danni Selway, president*
- Redondo Beach Rotary Club
- Rotary Club of Inglewood, *Jaimee Sul, president*
- Rotary Club of Palos Verdes Peninsula
- West Torrance Lions Club, *David Haden, treasurer*

Elected Officials

- Assembly member Curren Price, *California State Assembly 51st District*
- Senator Rod Wright, *California State Senate, 25th District*

Environmental Groups

- Volunteers and Organizations Improving the Community Environment, *Gina Conner, communications director*

Businesses

- Body Glove and Dive 'N Surf, *Bob Meistrell, founder*
- Veolia Water North America, *Craig Walkins, senior vice president*
- South Bay Association of Realtors, *Sheri Fejeran, president of the board*
- Carson Chamber of Commerce, *John Wogan, president*
- El Segundo Chamber of Commerce, *Jim Hart, president*
- Gardena Valley Chamber of Commerce, *Wanda Love, president*
- Harbor City/Harbor Gateway Chamber of Commerce, *Joeann Valle, executive director*
- Inglewood/Airport Area Chamber of Commerce, *Norm Cravens, president*
- LAX Coastal Area Chamber of Commerce, *Jim Ferro, chairman of the board*
- Lomita Chamber of Commerce, *George Kivett, president*
- Regional Hispanic Chamber of Commerce, *Sandy Cajas, president and CEO*
- South Bay Association of Chambers of Commerce, *Marcella Low, chair*
- PV Peninsula Chamber of Commerce and Visitor's Bureau, *Randy Bowers, chairman*

Associations and Unions

- Local Union South Bay, *Gaylord R. Roten, business representative*
- South Bay Association of Realtors, *Sheri Fejeran, president of the board*
- Southwest Membrane Operators Association, *Scott McClelland, president*

Academic

- Dr. Burton H. Jones, *professor, Marine Biology and Biological Oceanography, University of Southern California*
- Dr. Dave Caron, *professor, Department of Biological Sciences, University of Southern California*
- Dr. Dave Mayer, *PhD in Fisheries and Quantitative Sciences from the University of Washington*

Water Organizations

- Water Replenishment District of Southern California, *Rob Katherman, president*

Miscellaneous

- USACOE, *Brig. General John McMahon, Commander, South Pacific Division*
- Dr. James Crook, *environmental engineering consultant*
- Geoff Maleman, *past president, Westchester Rotary*

APPENDIX G
DESAL COSTS

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, Gleick, and Wolff 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. In addition, some international plant cost estimates may have currency exchange rate hedging elements. 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. This appendix provides a review of published cost estimates and summarizes the key factors influencing desal project costs. The first section provides an overview of reported desal costs and compares cost estimates for specific projects. The second section identifies key variables that significantly affect overall costs, while the third section discusses specific costs associated with different components of the desal process. Finally, recent and expected trends in desal costs are also identified.

REPORTED DESAL COSTS

The following sections provide an overview of desal cost components and reported costs for both seawater and BWRO facilities. As noted above, due to the variation in circumstances of individual projects, as well as in the basis upon which reported costs have been calculated, the costs reported below should be evaluated within the context of site- and project-specific conditions.

In addition, when reviewing cost information, it should be noted that unit water cost is a strong function of plant utilization. Some facilities will be used intermittently, which will result in higher life cycle costs per unit of water produced. For example, the TGWTP in London is planned to provide supplementary water under dry conditions. It will be used as a backup supply for meeting future peak demands. The cost of desal at TGWTP at 40% capacity is estimated to be approximately $1.18/kgal ($0.31/m^3) as opposed to $0.51/kgal ($0.13/m^3) at 100% capacity (Lyon 2006). In addition, some costs may also reflect the "over-sizing" of some components in order to accommodate potential future plant expansions.

SWRO Facilities

The costs associated with SWRO desal have generally been reported within a range of \$1.90 to \$3.50 per kgal (\$0.50 to \$0.70/m^3) of water produced (Miller 2003, Dore 2005). Miller (2003) reports that it has generally become accepted that SWRO can be carried out in the US for less than \$2.00/kgal (\$0.50/m^3). The Pacific Institute (Cooley, Gleick, and Wolff 2006), however, reports that in California, the cost of desalinated water production ranges from \$3.00 to \$3.50/kgal (roughly \$0.79 to \$0.92/m^3) for large, efficient plants, and can be as high as \$8.35/kgal (\$2.21/m^3) for plants of smaller capacity (Cooley, Gleick, and Wolff 2006). 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 CDWR (2003) encompasses most of the estimates reported above, ranging from \$1.52/kgal to more then \$5.70/kgal (\$0.4 to \$1.5/m^3), depending on the size of the desal facility. Table G.1 shows the unit costs of seawater desal, by plant size, as reported by CDWR (2003).

The Pacific Institute (Cooley, Gleick, and Wolff 2006) attempted to standardize reported costs of produced water from SWRO seawater desal plants around the world. Table G.2 shows the results of this analysis in US 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, Gleick, and Wolff 2006).

SWRO Cost Components

Based on an evaluation of reported costs for existing plants, the NRC Committee on Advancing Desalination Technology, provides a breakdown of annual costs for SWRO desal plants (NRC 2008). Figure G.1 shows the typical breakdown of annual costs for a 50 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 five years; the nominal interest rate is 5%; and the depreciation period is 25 years. Annualized capital costs include both principal and interest payments.

Miller (2003) shows a slightly different distribution of SWRO 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.

Table G.1
Unit costs of desal as reported by CDWR (2003)

Plant size	\$/kgal
Large plants (>10 mgd)	\$1.52–3.80
Medium plants (1–10 mgd)	\$3.80–5.70
Small plants (<1 mgd)	Over \$5.70

Costs assumed to be reported in 2003 US\$ 2003 (year of report conducted by CDWR), however US\$ was not specifically reported. Costs have therefore not been adjusted for inflation.

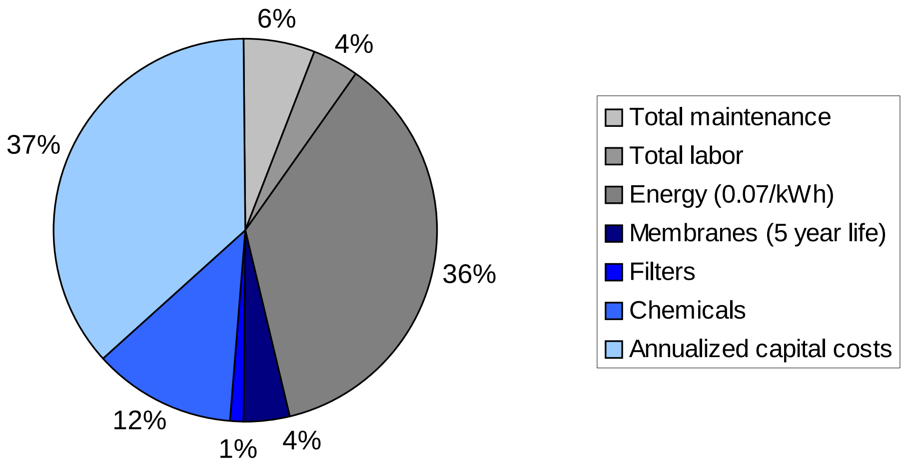
Table G.2
Summary of reported first-year cost of produced water for RO plants

Facility/location	US$/kgal (first year)	US$/$m^3$ (first year)	Operational?	Year	Sources
Ashkelon, Israel	2.03	0.54	Yes	2002	EDS (2004), Segal (2004), Zhou and Tol (2005)
Ashkelon, Israel	2.00	0.53	Yes	2003	NRC (2004)
Ashkelon, Israel	2.10	0.55	Yes	2004	Wilf and Bartels (2005)
Ashkelon, Israel	2.34	0.62	Yes	2005	Red Herring (2005), Semiat (2000)
Bahamas	5.60	1.48	Yes	2003	NRC (2004)
Carlsbad, CA (Poseidon)	2.90	0.77	No	2005	San Diego Daily Transcript (2005)
Dhekelia, Cyprus	4.14	1.09	Yes	1996	Segal (2004)
Dhekelia, Cyprus	5.40	1.43	Yes	2003	NRC (2004)
Eilat, Israel	2.80	0.74	Yes	1997 (est)	Wilf and Bartels (2005)
Hamma, Algiers	3.19	0.84	No	2003	EDS (2004), Segal (2004)
Larnaca, Cyprus	2.84	0.75	Yes	2000	Segal (2004)
Larnaca, Cyprus	3.20	0.85	Yes	2003	NRC (2004)
Larnaca, Cyprus	3.23	0.85	Yes	2001 (est)	Wilf and Bartels (2005)
Moss Landing, CA	4.75[a]	1.28[a]	No	2005	MPWMD (2005)
Moss Landing, CA (Poseidon)	3.63	0.96	No	2005	MPWMD (2005)
Perth, Australia	3.49	0.92	No	2005	Water Technology (2006)
Singapore	1.75	0.46	Yes	2002	Segal (2004)
Singapore	1.70	0.45	Yes	2003	NRC (2004)
Sydney, Australia	4.21[b]	1.11[b]	No		Not reported
Tampa Bay, FL	Four bids from 1.75 to 2.18	0.46–0.58	No	1999	Semiat (2000)
Tampa Bay, FL	2.10	0.55	No	2003	Segal (2004)
Tampa Bay, FL	2.18	0.58	No	2003 (est)	Wilf and Bartels (2005)
Tampa Bay, FL	2.49	0.66	No	Unknown	Arroyo (2004)
Trinidad	2.77	0.73	Yes	Unknown	Segal (2004)
Trinidad	2.80	0.74	Yes	2003	NRC (2004)

Source: Adapted from Cooley, Gleick, and Wolff (2006).
a. May include conveyance costs from the desal facility to the existing distribution mains.
b. May include some or all distribution costs.

The distribution of costs shown in Figure G.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 SWRO 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% above the desal process costs (NRC 2008 as cited in Mickley 2007).

As presented in Table G.3, NRC (2008) also reports the breakdown of annual costs at the Tampa Bay SWRO desal facility. These are somewhat consistent with breakdown of costs reported by NRC (2008) and Miller (2003), with capital and fixed costs accounting for about 44% of total costs.



Source: Adapted from NRC 2008.

Figure G.1 Annual cost breakdown in a 50 mgd SWRO plant with conventional pretreatment

Table G.3
Desal cost components at Tampa Bay SWRO facility

Feedwater TDS (ppm)	26,000
Average output (kgal/day)	25,100
Operations and maintenance ($/kgal)	1.71
Admin and general ($/kgal)	0.08
Capital consumption ($/kgal)	0.84
Fixed costs ($/kgal)	0.57
Total ($/kgal)	3.15[a]

Source: NRC 2008 from J. Maxwell, Tampa Bay Water, personal communication, 2007.
a. Xu et al. (2009) report a cost of $3.19/kgal for the first year after remediation. The cost to TBW will reduce to net $2.85/kgal upon receipt of $85 million in co-funding from Southwest Florida Water Management District. In addition, information provided by TBW on operating costs from late 2007 through 2008 indicates that O&M costs have dropped to $1.54/kgal.

The total unit cost shown in Table G.3 is higher than the estimates reported for Tampa Bay in Table G.2. However, Table G.3 likely reflects a number of unexpected costs that were incurred in the later phases of the project. Xu et al. (2009) report that due to contractor problems and technical challenges related to intake and pretreatment, costs at Tampa Bay increased by more than $40 million from the original $110 million estimate (construction oversight: $4 million, remediation and improvements: $36 million, attorney fees for lawsuits: $6.8 million). The promised water price increased from $1.71/kgal ($0.45/m^3) in 1999 to $3.19/kgal ($0.84/m^3) (or $3.15/kgal as reported by NRC 2008) in 2007 (Xu et al. 2009 as cited in Barnett 2007).

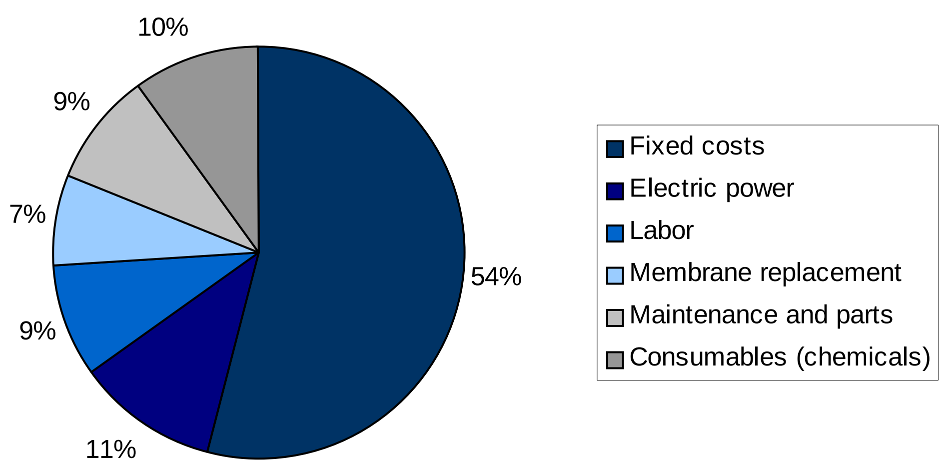
BWRO

Due to lower levels of salinity compared to seawater, brackish water requires substantially less energy to desalinate. The unit costs of brackish water desal are therefore generally much lower than the costs reported above. In addition, compared to seawater sources, brackish water aquifers are often located relatively close to consumers; dramatically reducing treated water distribution costs. Many brackish groundwater sources also have a low level of suspended solids and require far less pretreatment than seawater sources (Pankratz Undated).

CDWR (2003) reports that the costs of brackish water desal range between \$0.40 and \$3.80/kgal (\$0.10–\$1.00/m^3). Others report a tighter range, with costs between \$0.76 and \$1.33/kgal (\$0.20 to \$0.35/m^3) (Miller 2003, Dore 2005, AMTA 2007).

Figure G.2 shows the contribution of various factors to the overall cost of BWRO desal as reported by Miller (2003). The capital investment required to build the plant typically accounts for more than half of total costs. The remaining portion is split among various operating costs. Compared to SWRO, the energy consumption associated with BWRO is relatively low, accounting for only about 11% of total costs. The consumables category, which includes various chemicals that are used to pre- and post-treat the water, accounts for 10% overall. Maintaining the plant, including replacing the membranes approximately every three years, makes up about 16% of total costs.

One conclusion that can be drawn from Figure G.2 is that apart from fixed costs, improvements in any one aspect of plant operation will only result in an incremental improvement in the overall cost of BWRO (Miller 2003).



Source: Adapted from Miller 2003.

Figure G.2 Annual cost breakdown of a typical BWRO plant with conventional pretreatment

Table G.4 shows a breakdown of the costs for brackish water desal at the facilities built and operated by the Inland Empire Water Agency in southern California (as reported by NRC 2008). The costs presented in Table G.4 are generally in line with the information reported by Miller (2003) (see Figure G.2), with 46% of total costs being attributed to capital or fixed costs. However, the unit cost of \$2.39/kgal (\$0.63/m^3) falls within the higher range of estimates reported in the literature.

EPWU reports much lower costs for brackish water desal at the Kay Bailey Hutchison Desalination Plant. A joint project of EPWU and Ft. Bliss, El Paso's desal plant produces 27.5 million gallons of fresh water daily, and is the largest brackish water desal facility in the world. Table G.5 presents the amortized capital and O&M costs for this project, as reported by EPWU.

The estimates presented in Tables G.4 and G.5 are difficult to compare due to different underlying assumptions and reporting methods (e.g., capital and O&M costs are reported as an amortized total for El Paso while these costs for Inland Empire are reported separately). However, it is interesting to note the lower costs reported for El Paso relative to Inland Empire. At the El Paso facility, concentrate is disposed of via deep well injection, while the Inland Empire facility has access to the SARI, which serves as a direct "brine line" to the ocean.

Table G.4
Desal cost components at the Inland Empire BWRO facility[a]

Feedwater TDS (ppm)	800–1,000
Average output (kgal/day)	7,150
Operations and maintenance (\$/kgal)	1.18
Admin and general (\$/kgal)	0.11
Capital consumption (\$/kgal)	0.72
Fixed costs (\$/kgal)	0.38
Total (\$/kgal)	2.39

Source: NRC 2008 from R. Atwater, Inland Empire Water Agency, personal communication.
a. The offsets that Inland Empire receives (\$0.76/kgal or \$250/AF from the MWD) are not factored into the costs reported above.

Table G.5
Amortized capital and O&M costs (\$/kgal) at Kay Bailey Hutchison Desalination Plant

Feedwater TDS (ppm)	1,200–15,000
Average output (kgal/day)	26,420
Wells, collectors	\$0.58
Ft. Bliss (water and land)	\$0.13
Desal plant	\$0.71
Disposal	\$0.15
Finished water pipeline	\$0.07
Total	\$1.64

Source: Project Webcast presentation by John Balliew, Vice President, EPWU.

As discussed in subsequent sections, deep well injection is typically much more expensive than direct surface water disposal. Indeed, the facility at El Paso entailed significant costs for concentrate management. Concentrate disposal wells and lines accounted for 26% of the reported $87 million facility capital cost. The estimated annual operating and maintenance costs for the concentrate management were lower, representing 0.04% of the estimated $4.8 million costs (Xu et al. 2009 based on E. Archuleta, EPWU, personal communication, 2006).

One advantage the El Paso facility may have over the desal plant at Inland Empire is the benefit of economies of scale. In addition, it is important to note that the costs reported for El Paso reflect cost per unit of production capacity. Because the El Paso facility does not operate to full capacity, costs per unit of water produced could be much higher than those reported in Table G.5. A much more detailed examination of costs, or a more uniform reporting method (with a clear reporting of underlying assumptions), would be necessary to determine the factors accounting for the large differences in reported costs between these two facilities.

KEY VARIABLES INFLUENCING OVERALL DESAL PROJECT COSTS

The following sections provide an overview of the key variables that can significantly influence desal costs. Subsequent sections present specific cost estimates for different components of the desal process.

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.

NRC (2008) reports that as a general rule, it will cost about 50% more (per unit of water) to produce freshwater from seawater than from brackish water (assuming a brackish water salinity of approximately 2,000 ppm). However, source water from rivers and lakes can have much higher levels of turbidity, organics, nutrients, and other man-made pollutants compared to seawater. Costs associated with removal of these contaminants by pretreatment or post-treatment may cost more than the savings associated with the water’s lower TDS concentration (Voutchkov 2007a).

Plant source water temperature has a measurable effect on SWRO feed pressure requirements and membrane performance (and associated energy-related costs). Voutchkov (2007a) reports that for source water with temperatures between 12 and 40°C, every 10°C increase can reduce RO feed pressure by 5 to 8%. For source water with temperatures between 4 and 12°C, the temperature effect is even more dramatic: for every 2°C temperature increase, SWRO feed pressure requirements can decrease by 5 to 10%. At temperatures below 4°C, source water begins to freeze and desal can become infeasible.

Source water temperatures above 40°C can have negative effects on membrane performance that may negate the positive effect on membrane pressure. First, higher temperatures can result in a change in membrane material behavior, which can reduce the useful life of the membrane. Second, higher temperatures can accelerate membrane biofouling, due to the effect of temperature on bacterial growth. With increased temperatures, membrane salt rejection can also be reduced. Operation at high source water temperatures (typically 30°C and higher) may compromise product water quality in terms of TDS, chlorides, boron, sodium, and other requirements. Thus, additional steps (partial or full second pass RO) may be required to meet water quality goals (Voutchkov 2007a). Many co-located facilities (which utilize power plant cooling water as feedwater) have experienced problems related to high temperature feedwater (Xu et al. 2009).

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 (e.g., < 5.0 mgd) to medium-sized (e.g., 10–20 mgd) plants, but are not as important as one moves from medium to large (e.g., > 25 mgd) plants. A doubling of size from 2.5 to 5.0 mgd, for example, might reduce cost by 30%, while a doubling from 25 to 50 mgd might reduce cost by only 10% (NRC 2008). Economy of scale benefits are minimal for plants larger than about 50 mgd, mainly due to the added complexity of flow distribution, treatment and operations (Voutchkov 2007a).

Cost and Availability of Power

The costs associated with desal energy requirements (power) are dependent on two key components: the power tariff and associated unit cost of power, and the amount of power used to produce desalinated water (Voutchkov 2007a).

The power tariff (or cost of power as expressed in $/kWh) typically consists of a power generation charge and a power grid distribution charge. These charges depend on whether energy is purchased from an independent power generation supplier or is obtained/generated on sight (e.g., such as through direct connection to a power plant's generation units at a co-located facility or through generation of electricity on sight). For more information on reducing energy requirements and/or lowering power costs, see section 8.5 of this report as well as Xu et al. (2009).

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.

Unless there is a way to greatly reduce the actual amount of energy used in desal processes, the share of desal costs attributable to energy will rise as energy prices rise. NRC (2008) estimates that an increase in energy costs from $0.04 to $0.10/kWh can result in an increase in total costs of over 35% for SWRO desal (assuming production of 50 mgd).

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). Reductions in energy use for brackish water desal will not result in substantial cost savings overall (energy accounts for only about 11% of total costs).

Membrane Life

The cost of membranes has fallen in recent years, and this is widely cited as one explanation for the increasing attractiveness of desal. Membrane costs are now quite modest, ranging from only 3 to 5% of annual costs. However, 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 five to three 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. At higher energy costs, the impact of fouling on annualized operating costs is even more severe (NRC 2008). On the other hand, for conventional systems, total project costs can be reduced by 3% if membrane life can be extended to 10 years over the 5-year baseline period that is common today.

Subsidies

When comparing project costs, it is important to note the effect of subsidies (e.g., long-term energy contracts, reduced land costs, or low-interest loans). For example, five projects in Southern California have qualified for a $0.77/kgal ($0.20/m^3) subsidy from the MWD. The proposed Poseidon project in Carlsbad is reported to cost about $2.90/kgal ($0.77/m^3) without this subsidy and about $2.15/kgal ($0.57/m^3) with the subsidy. Since water customers in Southern California ultimately pay for the subsidy, the subsidized cost is potentially misleading (Cooley, Gleick, and Wolff 2006).

Sometimes subsidies are difficult to quantify. As reported in Table G.2, all four of the original bids for the Tampa Bay SWRO project were within the range of $1.75 to $2.18/kgal ($0.46 to $0.58/m^3) (Semiat 2000). These were among the lowest costs ever proposed for a significant desal project, in part because a Florida regulatory entity provided low-cost capital. Similarly, the Ashkelon, Israel, desal plant that opened in August 2005 involved initial payments of about $2.00/kgal ($0.53/m^3). The land on which the plant is constructed, however, was provided at no cost by the Israeli government (Cooley, Gleick, and Wolff 2006 from Professor Raphael Semiat, personal communication, 2006). As a result, it is misleading to compare the cost of Ashkelon with that of a new facility on the California coast, where land is expensive (Cooley, Gleick, and Wolff 2006).

Cost of Money

With any capital investment, interest costs (or the cost of money) are invariably one of the larger components of total project cost. For example, the total repayment of a $1 million loan over 30 years at an interest rate of 5% is $2.5 million. More importantly, interest costs rise significantly as interest rates rise (NRC 2008). In the example above, an increase in the interest rate from 5 to 7% would lead to a 24% increase in annual costs. 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.

Financial institutions establish the interest rate of the funds they lend to a project based on an evaluation of the project risk profile (Voutchkov 2007a). In order to provide low-interest financing for a given project, lending institutions demand strong assurances that the project will be permitted and built in a timely and cost-effective manner, the power supply contract and tariff for the project will be reasonable; the O&M of the plant will be professionally handled by an operations staff that has successful prior experience, and that the regulatory and permitting risks of the project are minimal (Voutchkov 2007a).

As a general rule, project fund lenders are only willing and able to take risks that are quantifiable. Typically, lenders are not involved in the construction, operation or insurance activities related to project implementation. Therefore, they will not take risks associated with these activities and especially risks they are not familiar with or that can be more appropriately borne by other parties involved in the project. In order to mitigate risks at early stages, lenders may want to be involved in key aspects of project development and implementation, including the negotiation of project contracts, review of key project design and construction activities, as well as review and approval certification of project completion, and project acceptance testing (Voutchkov 2007a).

Project Delivery and Financing Method

The project delivery method can have a significant effect on the cost of desal. Voutchkov (2007a) 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 DBOOT or BOOT method of project delivery.

A DBOOT project involves a single contractor for design, construction, and operation of the desal facility. This method of project delivery streamlines the project schedule and reduces costs by eliminating separate selection processes for engineering, construction, procurement, and operating services. The public water provider commits to purchase some quantity of water from the desal facility at an agreed-upon price over some period of time. This water purchase agreement serves as collateral for the contractor to secure private financing for the project. DBOOT contracts contain provisions to transfer ownership of the facility to the public water provider at a mutually agreeable date.

The primary benefit of a DBOOT project is that a private enterprise assumes the technical and commercial risk associated with the project, including the risk of development, permitting, and financing. With a vested interest in controlling operating expenses, DBOOT contractors have a greater tendency to accept the risk of employing new and innovative solutions to lower production costs and improve operability. These projects often are driven by the magnitude of total project costs because a single entity is responsible for design, construction, and O&M. A more detailed discussion of different types of project delivery methods is included in section 8.10 of this report.

Permitting and Related Environmental Mitigation Costs

In many locations (e.g., coastal California), there may be considerable expenses associated with the desal facility permitting processes and related public outreach and legal efforts. Because SWRO projects are relatively new to many permitting agencies, the time and effort required for permitting this type of project are typically more extensive than those for conventional water and wastewater treatment plants. In the US, 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. Difficulties encountered with permitting of the Tampa Bay SWRO project was one of the key reasons why the public utility that initiated the project decided to proceed with project implementation under a BOOT method of delivery, which allows the risk and associated permitting costs to be transferred to the private sector (i.e., the BOOT contractor) (Voutchkov 2007a).

In addition, permitting requirements for environmental mitigation or protection requirements can substantially increase costs, especially in sensitive coastal settings like California and where I&E might be an issue, and special screens or intake facilities and/or extensive monitoring may be required. For many desal plants currently in the planning phases, costs associated with environmental mitigation activities are proving to be quite substantial.

Target Product Water Quality

Product water quality has a measureable 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 (Voutchkov 2007a).

Voutchkov (2007a) demonstrates the relationship between target product water quality and costs for overall water production. He used the costs to produce water with a TDS of 500 mg/L, chloride level of 250 mg/L, boron of 1.0 mg/L, and bromides of 0.8 mg/L as a basis for comparison to costs to achieve more stringent water quality goals. Results of this analysis show an increase in the overall cost of water of up to 50% (for achieving the most stringent regulations of TDS = 30 mg/L, chloride = 10 mg/L, boron = 0.3 mg/L, and bromide = 0.1 mg/L). His analysis reflects the fact that costs vary based not only with product water quality targets, but also with source water quality.

Costs associated with meeting different water quality standards will 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. In the US, water produced by desal is often blended with water from other freshwater sources before distribution. When desalinated product water is blended with freshwater, water quality related specifications for the desal process may be relaxed because the product water from the desal process will be diluted with water from other sources. Therefore, a less perfect separation may be acceptable, which can help reduce costs.

Contractor Experience

Contractor experience with designing, constructing and permitting desal facilities can also affect final costs, although there is no clear trend. In some cases, experience may lower cost or may increase the likelihood of winning a contract. A team that had previous experience in Eilat, Israel, and Larnaca, Cyprus developed the Ashkelon facility in Israel (Cooley, Gleick, and Wolff 2006 from Professor Raphael Semiat, personal communication, 2006), which is among the plants with the lowest produced water cost. The Algiers facility is only somewhat more expensive than the plant in Trinidad, despite the upward trend in energy and capital costs described above. Ionics/GE is the developer of these facilities, and successful experience in Trinidad may have helped to win the contract in Algiers and temper the price increase.

By contrast, a lack of experience may also result in unrealistic, and ultimately unobtainable, cost estimates. The development team in Tampa Bay, Florida, for example, did not have much previous experience. Problems with design, construction, and management led to delays of nearly six years, and much higher than estimated costs (Cooley, Gleick, and Wolff 2006).

Other Cost Factors

Additional factors such as regulatory design standards; schedules mandated by third parties; comprehensiveness of construction, equipment and consumable supplier markets; local labor and material costs and shortages; and construction time constraints driven by local noise and traffic related ordinances and limitation of hours of operation of equipment can also affect overall project costs.

DESAL COMPONENT COSTS

The cost of desal includes both capital costs and O&M costs. Capital costs include all expenditures associated with the implementation of a project from the time of its inception through commissioning and acceptance testing for normal operation. O&M costs include costs associated with plant operations (e.g., power, chemicals, labor); maintenance of plant equipment, building and utilities; and compliance with operational and environmental permits, and regulatory requirements.

The total cost of water includes all project capital and annual O&M expenditures associated with water production, and is typically presented as a monetary unit per unit volume of water produced (e.g., \$/kgal or \$/m^3). The cost of water is calculated by dividing the sum of annualized capital costs and annual O&M costs by the average annual desal plant fresh water production volume (e.g., kgal/year, m^3/year).

The following sections provide a more detailed look into the capital and O&M cost components of desal. Due to the nature of available research, the information presented below is written primarily within the context of SWRO facilities. Where relevant, we discuss costs associated with brackish water facilities.

Capital Costs

Expenditures for project construction make up the largest component of desal capital costs. Construction costs are referred to as direct capital costs because of their direct association with the construction of physical facilities. Construction costs typically account for 50–85% of the total project capital costs (Voutchkov 2007a). The remaining 15–50% of desal capital costs are referred to as indirect costs. Indirect costs include costs associated with engineering, administrative, and financing efforts. This includes the costs of securing permits, funds and contractors needed to build and operate the plant.

Table G.6 shows the breakdown of project capital costs for typical low-complexity and high-complexity SWRO desal projects within a capacity range of 1.3 to 52.8 mgd (based on Voutchkov 2007a). Subsequent sections discuss each of the major capital cost components in turn.

Table G.6
SWRO project capital cost components

	Percentage of total capital cost	
	Low-complexity project	High-complexity project
Direct capital (construction) costs		
1. Site preparation	1.5–2.0	0.5–1.0
2. Intake	4.5–6.0	3.0–5.0
3. Pretreatment	8.5–9.5	6.0–8.0
4. RO system equipment	38.0–44.0	30.5–36.0
5. Post-treatment	1.5–2.5	1.0–2.0
6. Concentrate disposal	3.0–4.0	1.5–3.0
7. Waste and solids handling	2.0–2.5	1.0–1.5
8. Electrical and instrumentation systems	2.5–3.5	1.5–2.5
9. Auxiliary and service equipment and utilities	2.5–3.0	1.0–2.0
10. Buildings	4.5–5.5	3.0–5.0
11. Start up, commissioning, and acceptance testing	1.5–2.5	1.0–2.0
Subtotal direct (construction) costs (% of total capital costs)	*70.0–85.0*	*50.0–68.0*
Indirect capital costs		
Project engineering services		
1. Preliminary engineering	0.5–1.0	0.5–1.5
2. Pilot testing	0–0.5	1.0–1.5
3. Detailed design	3.5–4.5	5.0–6.0
4. Construction management and oversight	1.0–2.0	2.5–3.5
Subtotal engineering services	*5.0–8.0*	*9.0–12.5*
Project development		
1. Administration and contracting	1.0–1.5	2.0–3.0
2. Environmental permitting	0.5–3.5	4.5–5.0
3. Legal services	0.5–1.0	1.5–2.0
Subtotal project development	*2.0–6.0*	*8.0–10.0*
Project financing costs		
1. Interest during construction	0.5–2.5	1.0–4.5
2. Debt service reserve	2.0–5.5	4.5–8.5
3. Other financing costs	0.5–1.0	3.5–4.5
Subtotal project financing	*3.0–9.0*	*9.0–17.5*
Contingency	5.0–7.0	6.0–10.0
Subtotal indirect capital costs (% of total capital costs)	*15.0–30.0*	*32.0–50.0*

Source: Adapted from Voutchkov 2007a.

Site-Related Costs

Costs related to project site development include the costs of land acquisition and preparation for construction (e.g., plant site clearing, grading and fencing), as well as costs associated with the construction of access roads to the plant and to all buildings, facilities, and equipment within the plant. These costs can vary significantly from one location to another.

Voutchkov (2007a) reports that in general; land requirements for a conventional seawater desal plant range from 0.2 to 0.4 acres for a 0.3 mgd plant to 9 to 12 acres for a 52.8 mgd plant (200,000 m^3/day). Typically, costs associated with acquiring and developing this land range from \$0.04 to \$0.20/gpd (\$10 to \$50/m^3/d) of plant production capacity.

Site development and site-related costs can be influenced by geotechnical suitability and architectural constraints at a particular site (AWWA 2004). AWWA provides an example of a seawater desal plant proposed for implementation in the San Francisco Bay area that ran into problems with geotechnical suitability. In this example, project planners would have liked to locate the desalter in an industrial area adjacent to San Francisco Bay. The property was owned by the project proponent, was undeveloped, and was large enough to accommodate the planned facility. However, a pile foundation would have been required. The estimated cost of the pile foundation would have amounted to about 10% of the project's construction cost.

Architectural constraints can also impose cost increases. Seawater desal facilities by their very nature are located at or very near the seashore. The need for desalted seawater indicates that the surrounding area is likely highly developed. Locating an industrial type building in this area may be unacceptable. Enhanced architectural design may be required at some additional cost to get the project permitted. The same issue may occur with inland brackish groundwater facilities.

Source Water Intake

Capital costs associated with source water intake include expenditures for the intake structure and pipeline, the intake pump station and the intake screening facilities. Intake construction costs vary depending on the type of intake used, the distance from the intake to the plant itself, and other site-specific conditions. Permitting, modeling and monitoring associated with mitigating and/or avoiding I&E can also significantly affect overall costs for source water intake facilities.

Voutchkov (2007a) reports that intake construction costs typically fall within a range of between \$0.19 and \$0.38/gpd (\$50 and \$100 m^3/d). For low-complexity SWRO projects, intakes typically amount to 4.5–6.0% of total direct capital costs. For higher complexity projects, intakes can account for 3.0–5.0% of total direct capital costs (Voutchkov 2007a).

WHO notes that intake designs are highly site specific, possibly more so than any other aspect of a desal facility. WHO reports that the cost and time for construction of a new open ocean intake can reach 10 to 20% of total plant construction costs (WHO 2007). It is unclear whether this estimate includes costs associated with permitting, modeling and monitoring of environmental effects (i.e., I&E).

Typically, co-located intakes (intakes designed to use power plant cooling water as the feedwater for the desal process) have a much lower cost than subsurface or standalone surface water intakes. Co-location avoids construction of new intake structures, pipelines and screens, which can reduce total intake construction costs by 60 to 80% (Voutchkov 2007a).

Open surface water intakes are suitable for all sizes of seawater desal plants, but are typically more economical for plants of production capacity higher than 5 mgd (20,000 m^3). Currently, most large SWRO desal facilities utilize open surface water intakes or are co-located with a power plant (Xu et al. 2009).

Subsurface intakes are becoming more cost-competitive for small to mid-size SWRO facilities. Subsurface intakes include different types of beach wells (e.g., vertical beach wells, slant wells and horizontal Ranney wells) and infiltration galleries. By taking advantage of the natural filtration provided by sand and substrate, subsurface intakes can reduce the need for pretreatment prior to desal. This can substantially lower associated O&M costs. With subsurface intakes, costs associated with I&E of aquatic species are also minimized relative to open intake facilities. Subsurface intake systems have been proven economically justifiable for SWRO desal plants with a capacity of up to 13 mgd (49,000 m^3/d) (CDWR 2003).

Wright and Missimer (1997) compared the relative costs of various intake and pretreatment systems serving SWRO desal plants. Their analysis showed that, when feasible, for plants with a capacity of under 8 mgd, beach well systems are the least expensive among the alternatives, and seabed infiltration galleries are the most expensive. The results of this analysis, adapted from Xu et al. (2009), are presented in Table G.7.

In 2007, facility planners for the Carlsbad Desalination Plant prepared cost estimates for several different types of subsurface intakes with a capacity of 304 mgd. This analysis showed costs associated with subsurface facilities to be much greater than those for a surface water intake. This is likely due to the plant's large size. The use of a subsurface intake system was being considered as a strategy to minimize I&E. As shown in Table G.8, estimated costs ranged from about $418 million for slant wells to almost $650 million for vertical beach wells. In comparison, the estimated cost for a 304 mgd capacity surface water intake at the plant amounted to $150 million.

Table G.7
Relative cost comparisons of intake types serving SWRO desal plants

	Water supply system capacity				
m^3/d	2,000	4,000	7,500	15,000	30,000
mgd	0.5	1	2	4	8
Beach wells:					
Capital cost unit	1.00	1.00	1.00	1.00	1.00
O&M cost unit	1.00	1.00	1.00	1.00	1.00
Infiltration gallery:					
Capital cost unit	1.14	1.16	1.18	1.18	1.19
O&M cost unit	1.00	1.00	1.00	1.00	1.00
Seabed filtration:					
Capital cost unit	2.30	1.99	1.74	1.34	1.17
O&M cost unit	2.13	1.33	1.19	1.31	1.28
Surface water:[a]					
Capital cost unit	1.99	1.92	1.81	1.67	1.68
O&M cost unit	2.00	1.29	1.14	1.27	1.21

Source: Wright and Missimer (1997) as cited in Xu et al. (2009).
a. Including pretreatment 100 μm self-cleaning filter, and mixed-media, high rate, pressure filter.

Table G.8
Comparison of cost estimates for subsurface intake systems at the planned Carlsbad Desalination Plant

	Vertical beach wells	Slant wells	Horizontal Ranney wells	Subsurface infiltration gallery
Individual intake well capacity (mgd)	1.5	5	5	101.3
Number of intake wells needed	203	61	61	3
Additional standby intakes needed	51	15	15	0
Total intake wells	253	76	76	3
Minimum distance between wells (ft)	150	300	400	
Length of beach occupied by wells (miles)	7.2	4.3	5.7	3
Land needed to install wells and support facilities (acres)	8.6	17.4	17.4	17.9
Direct (construction) costs				
Individual well (gallery) installation	$1,200,000	$2,400,000	$2,500,000	$120,000,000
Total cost of well installation	$304,000,000	$182,400,000	$190,000,000	$360,000,000
Seawater conveyance pipelines @ US$500/ft	$18,925,000	$11,250,000	$15,000,000	$7,922,606
Intake booster pump stations	$30,400,000	$30,400,000	$30,400,000	$12,160,000
Electrical power supply for well pumps	$50,160,000	$31,920,000	$33,060,000	$18,608,000
Total construction (direct) costs	$403,485,000	$255,970,000	$268,460,000	$398,690,606
Indirect costs				
Land acquisition	$4,304,408	$8,723,600	$8,723,600	$8,956,114
Engineering design and procurement @ 25%	$100,871,250	$63,992,500	$67,115,000	$99,672,652
Environmental mitigation @ 15%	$60,522,750	$38,395,500	$40,269,000	$59,803,591
Contingency @ 20%	$80,697,000	$51,194,000	$53,692,000	$79,738,121
Total indirect costs	$246,395,408	$162,305,600	$169,799,600	$248,170,478
Total costs	*$649,880,408*	*$418,275,600*	*$438,259,600*	*$646,861,084*

Source: SWRCB 2009.

Pretreatment

Pretreatment capital costs include expenditures related to the removal of contaminants in the source water that may impact normal operation of the membrane separation process. The magnitude of these costs depends mostly on source water quality (turbidity/TSS and membrane fouling compounds) and the type of pretreatment technology used.

Typically, pretreatment costs fall within a range of $0.38–$1.14/gpd ($100 to $300/m^3/d). For low-complexity projects, this amounts to about 8.5–9.5% of total direct capital costs. For higher complexity projects, pretreatment costs typically account for 6.0 to 8.0% total capital costs (Voutchkov 2007a). However, 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 be greater than 50% of the overall cost of the RO system (CDWR 2003).

It is important to note that inadequate pretreatment can be extremely detrimental to the overall efficiency of a desal plant, possibly resulting in costly repairs and significant facility down time. More expensive, better performing pretreatment processes that extend membrane life, can result in substantial avoided costs over the life of a desal facility.

The degree to which the source water contains potential membrane foulants such as scale formers, particulates, and biological components, can have a major impact on pretreatment costs.

Site-specific water quality factors such as turbidity, temperature, boat traffic, oil contamination, nearby outfalls, wind conditions, tides, and the influence of runoff also affect the extent of pretreatment (and associated costs) necessary. Due to permitting regulations, available land and other environmental/economic considerations, however, desal plants cannot always be sited where they will have the best source water quality (and the lowest pretreatment costs).

The capital costs of desal vary with the different pretreatment operations included in the total treatment system. In recent years, the use of membrane pretreatment (MF or UF) has emerged as an alternative to conventional pretreatment. With UF and MF pretreatment systems, there is typically a marginal increase in capital costs compared to a conventional pretreatment process. However, a significant benefit of UF/MF-based pretreatment is realized through reduced operating costs. The annual operating costs for a SWRO system with UF/MF pretreatment are projected to be approximately 5% lower than one with a conventional pretreatment system (NRC 2008). Care should be taken to account for these sorts of trade-offs between capital and operating costs.

Wastes generated from pretreatment processes require proper disposal to avoid potential environmental pollution (typically as part of the desal concentrate). Depending on available disposal options, this can add significantly to overall desal costs, and similar to concentrate disposal, this can be a challenge at inland facilities.

RO System Equipment Costs

For both seawater and brackish water desal, the RO system is the most complex part of the desal process. For seawater desal, RO systems typically account for 40 to 60% of total capital costs (Voutchkov 2007a). The design and construction costs of RO systems are primarily determined by the salinity and temperature of the source water, and by the target water quality of the product water (i.e., suitable for potable use vs. irrigation).

Typically, construction costs for SWRO membrane systems vary between \$1.14 and \$3.8/gpd (\$300 and \$1,000/m^3/d) (Voutchkov 2007a). This includes expenditures associated with procurement, purchase, installation and construction of the different elements of the RO train. Construction costs of key membrane system elements are shown in Table G.9.

Table G.9
Construction costs of key membrane system components

	Construction cost (US$)
8-inch SWRO membrane element	400–500/element
16-inch SWRO membrane element	2,800–3,200/element
8-inch BWRO membrane elements	250–350/element
SWRO pressure vessels for 8 inch elements	1,200–1,600/vessel
SWRO pressure vessels for 16 inch elements	4,000–5,000/vessel
BWRO pressure vessels for 8-inch elements	1,000–1,200/vessel
RO skid piping	200,000–600,000 per RO train
RO train support frame	100,000–300,000 per RO train
RO train instrumentation and controls	20,000–80,000 per RO train
High pressure pumps	100,000–800,000 per RO train

Source: Adapted from Voutchkov 2007a.
Typically, one RO module contains 50 to 200 membrane vessels and has a capacity of between 26 kgal/day and 5,280 kgal/day.

The cost of membrane RO modules (trains) is proportional to the design capacity and flux of the RO system. While there is limited economy of scale of the costs of the RO modules, the costs of the other RO system components (high pressure pumps, energy recovery devices, piping and valves and membrane cleaning systems) can benefit significantly from the use of larger size units. Therefore, as the RO membrane module size increases, the relative cost of SWRO system per unit volume of product water decreases.

There are two limitations to the benefits of using the largest possible size module for a given application. The primary limiting factor is the loss of production capacity when the RO module is shut down for membrane cleaning, replacement or equipment repairs. The larger the individual module, the lower the availability factor of the SWRO plant. Since the availability factor directly related to the cost of water, a SWRO system with lower availability factor yields higher cost of water. Another limiting factor is the need to use custom-made rather than off the shelf equipment (Voutchkov 2007a).

Post-Treatment

Post-treatment costs incorporate the costs for construction of:

- Chemical conditioning system for permeate stabilization
- Disinfection system
- Facilities for product water quality polishing

Post-treatment costs are mainly driven by the target product water quality and the final use of desalinated water. Typically, costs for construction of post-treatment facilities for permeate stabilization and disinfection range between \$0.08 and \$0.2/gpd (\$20 and \$50 m^3/day) (Voutchkov 2007a). However, if the permeate has to be polished to achieve removal of specific constituents, these costs may increase.

Concentrate Disposal

Coastal desal plants are often able to safely dispose of desal concentrate (via direct discharge into the ocean or estuaries) at relatively modest costs. However, concentrate management can account for a very large portion of desal at inland facilities. This cost greatly reduces the economic feasibility of desal in inland settings (Mickley 2006). The following discussion provides an overview of challenges and key variables that influence the costs of various (primarily inland) disposal options, including:

- Surface water discharge
- Disposal to sewer
- Deep well injection
- Evaporation ponds
- Spray irrigation; and
- High recovery processing, including ZLD

Surface Water Discharge

When feasible, direct surface water discharge can be the simplest and most economical option for concentrate disposal. Costs for this method are typically low provided that pipeline conveyance distances are not excessively long and the concentrate is compatible with the environment of the receiving water.

Due to the large variability in design conditions and cost factors for surface water disposal, it is difficult to report generalized costs for this method. Costs of surface water discharge are mainly determined by (Mickley 2006):

- Concentrate conveyance costs from the desal membrane plant to the surface water discharge outfall
- Costs for outfall construction and operation (including diffusers)
- Costs associated with monitoring environmental effects of concentrate discharge to surface waters

Costs associated with conveyance of the concentrate to the disposal site (including pipeline, construction and pumping) are related to concentrate volume and the distance between the desal plant and the discharge outfall. Conveyance of the concentrate is an element common to all disposal options. It may be considerably more complex for surface water disposal however, if a portion of the conveyance pipe is underwater. Underwater dredging and trenching can be considerably more expensive (i.e., by a factor of perhaps three or four) than trenching on land (Mickley 2006).

The design of the outfall system is influenced by more variables and larger variability in conditions than the design of any of the other concentrate disposal methods. Costs depend on the outfall size, diffuser system configuration, outfall length and material, and concentrate treatment prior to discharge (Mickley 2006).

The costs associated with environmental monitoring of surface water discharge may be substantial, especially if the discharge is within the vicinity of an impaired water body, in an environmentally sensitive area, or in areas with limited natural flushing.

Disposal to Sewer

When available, discharge of concentrate to an existing wastewater treatment plant (sewer disposal) can be an economical disposal option. Disposal to sewer does not require a permit but does require permission from the WWTP. Key cost elements for this disposal method include the cost of conveyance (pump station and pipeline); fees for connecting to the sanitary sewer; and fees for treatment/disposal of the concentrate at the wastewater treatment plant.

While the volume of the concentrate mainly drives the conveyance costs, sewer connection and treatment fees can vary substantially. These fees are typically related to the available capacity of the sewer facilities and the effect of the concentrate discharge on the operational costs of the wastewater treatment plant (which would provide ultimate treatment and disposal of the concentrate). Sewer connection and treatment fees can be quite large and prohibitive (Mickley 2006).

Deep Well Injection

Deep-well injection is typically employed for larger desal plants (> 1 mgd) because the costs for developing deep-injection wells are relatively high and are not largely reduced for smaller flows. For example, the typical capital cost of a 3,000-m-deep well for a concentrate flow of 1,000 kgal/day, is reportedly $8.1 million. This decreases to only about $5.1 million for a concentrate flow of either 100 or 10 kgal/day (Malmrose et al. 2004, NRC 2008). These costs exclude any pretreatment or standby disposal system.

The costs of deep well injection strongly depend on concentrate flow rate (which determines the diameter of the well tubing), depth of the well, and the number of casing rings. Other factors that influence deep well injection costs are (Mickley 2006):

- The need for concentrate pretreatment prior to disposal
- Pump size and pressure, which vary depending on the geologic conditions and depth of the injection zone
- Site tests, including logging, surveying, and testing
- Environmental monitoring
- Site preparation, mobilization, and demobilization

While capital costs for well injection are about average of typical inland concentrate management methods, the annual operating costs are relatively low as a percentage of total facility operating costs (Mickley 2006).

Deep well injection operating costs include costs of pumping power, chemicals, and operating labor. Of these, the pumping power is the most significant. For example, for a 150-gpm pump at 3,150 psig, a 350-horse power motor is required, which can result in a cost of more than $50,000 per year (Mickley 2006). Chemical costs are normally much lower than this. For example, treating a waste flow of 150 gpm with a corrosion inhibitor would cost approximately $7,000 per year. Thus, unless elaborate pretreatment is required, chemical costs are not excessive. As discussed elsewhere in this report, permitting requirements and processes for deep well injection can be lengthy and can substantially increase costs.

Evaporation Ponds

Evaporation ponds are a low technology, high-cost approach to concentrate management. With little economy of scale (due to substantial land requirements), evaporation ponds are generally only feasible for small volume concentrates. The largest municipal plant discharging to evaporation ponds has a capacity of 1.5 mgd and all the others have capacities of less than 0.4 mgd (Mickley 2004).

Evaporation ponds are seldom used for concentrate management in the US. However, this strategy can be cost-effective under certain conditions. For example, if a small-capacity desal plant is located in a hot, arid area with a high evaporation rate and an abundance of low-cost, available land, the use of evaporation ponds could potentially be the most feasible option. These criteria apply predominantly in the southwestern portion of the US.

The costs of evaporation pond systems are mainly driven by evaporation rate (climate), concentrate volume and salinity of the concentrate, which determines the useful life of the ponds. The major factors contributing to the cost of an evaporation pond include (Mickley 2006):

- Land costs
- Earthwork
- Lining
- Miscellaneous costs
- O&M

The cost of land can vary greatly from site to site. Land costs can easily vary by a factor of 10 or more, depending on the exact location near the city. In general, however, the cost of land at locations appropriate for evaporation ponds is a small percentage of total cost.

Like the cost of land itself, the cost of earthwork is very site specific, depending on whether the terrain is flat or hilly, rocky or sandy, forested or clear, etc. If the desal plant location is fixed by the proximity of the water source or the locus of the demand for the desalted water, the evaporation pond must be located reasonably close by.

Because the potential for ground water contamination exists with any evaporation pond, most States require impervious liners of clay or synthetic membranes. Liners substantially increase the cost of evaporation ponds. Where the waste discharged to the pond can be verified as nonhazardous and the ground water in the area is of poor quality or substantially distant from the pond, or both, a single liner may be acceptable. However, if the water has the potential to contain even trace amounts of hazardous substances, or high-quality ground water exists in shallow aquifers, double-lined ponds with leak detection systems are frequently required. Liners are often the largest individual cost component of this concentrate management method.

Miscellaneous costs may constitute a significant percentage of the total cost of evaporation pond installation. These costs vary by site, depending upon the needs of the specific installation. Some of these possible costs include fencing, maintenance and roadways, disposal, seepage monitoring, and contaminated ground clean up.

Once it has been constructed, the pond operates essentially maintenance free. Periodic maintenance is required only for the repair of the dike or liner, pipe, flow control devices, etc. Operating costs also include security and damage inspection. The annual operating costs are estimated to amount to about 0.5% of the total installation costs (Mickley 2006).

Spray Irrigation

Spray irrigation involves using concentrate for irrigation of salt tolerant grasses and other vegetation. Brackish desal concentrate can be used to irrigate lawns, parks, golf courses, or cropland. Key cost components associated with spray irrigation include (Mickley 2006):

- Irrigation land purchase and preparation
- Transport pipeline
- Distribution piping and sprinklers
- Pumping pressure
- Facilities for wet weather storage
- Subsurface underdrain system

Concentrate flow is the key variable that drives these cost factors (Mickley 2006). For example, concentrate flow (i.e., loading rate), directly determines acreage requirements associated with this method.

The spray irrigation of concentrate is more land intensive than other disposal methods, including evaporation ponds. Land costs fluctuate based on site location and characteristics. If necessary, the preparation of irrigation land, such as clearing or grubbing, will add to overall disposal site costs. Costs will vary based on the type of terrain (e.g., bushes, sparsely wooded areas, heavily wooded areas).

Temporary storage facilities are typically necessary to retain concentrate during periods of heavy rainfall or under other circumstances when irrigation is not necessary. Storage tanks or lined ponds can be utilized for this purpose. In addition, irrigation systems may be required to include underdrainage to protect ground water sources. The cost of an underdrain system will add significantly to the overall cost of the system and can amount to 80% of the total piping cost (Mickley 2006).

The O&M of a concentrate spray irrigation system is more labor intensive than most other disposal methods. Labor requirements include sprinkler system repair and vegetative surface maintenance. The energy costs for pump operation also add to the system's total operational costs.

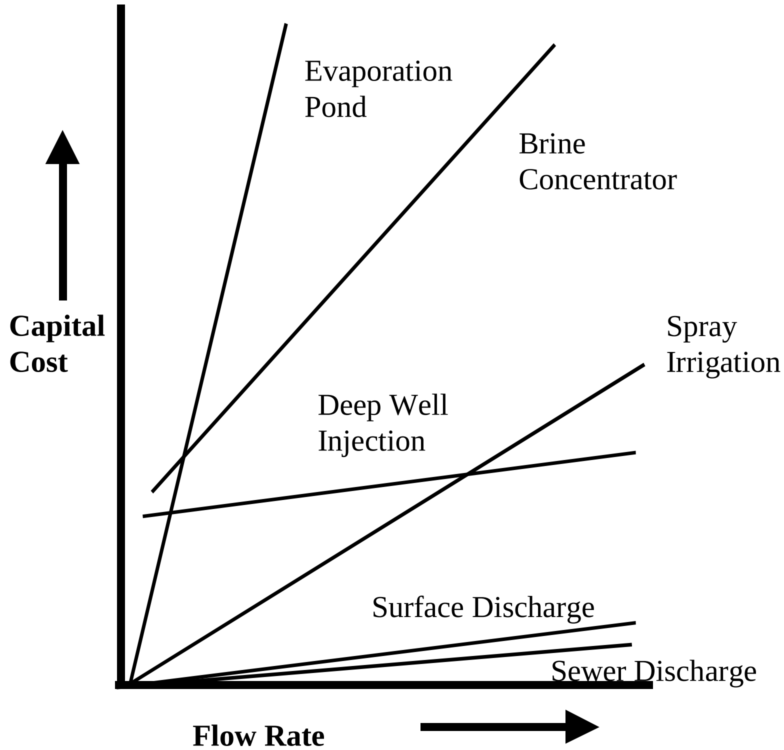
High Recovery Processing (including ZLD)

ZLD technologies involve brine concentrators (thermal evaporators) and crystallizers or spray dryers that convert concentrate to highly purified water and solid dry product suitable for landfill disposal or recovery of useful salts (WHO 2007). ZLD is very energy intensive.

The capital and energy costs associated with ZLD are significant and can sometimes exceed the cost of the desalting facility (NRC 2008). For this method of disposal, there are also potentially high costs related to final brine or salt disposal. Due to these high costs, ZLD concentrate management approaches are typically not considered for municipal drinking water applications and have not been implemented in the US at this level. For ZLD applications to become more viable, improvements are needed that reduce capital costs and/or energy usage.

Cost Comparisons for Alternative Disposal Options

As detailed above, the costs of concentrate disposal varies based on a number of site-specific factors and design conditions, and it is difficult to develop general cost estimates for alternative methods. However, 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, high recovery processing (including ZLD) has historically been prohibitively expensive for municipal desal plants in the US. Figure G.3 illustrates the relative capital costs of the different concentrate management options and reflects economy of scale factors as well as general (relative) level of cost (Mickley 2005).



Source: Xu et al. (2009) adapted from Mickley (2005).

Figure G.3 Relative capital cost of different disposal options

Additional Direct (construction) Cost Components

There are a number of additional costs associated with the construction of desal facilities that do not necessarily fall under a specific component of the desal process. Together, these costs account for about 11 to 14.5% and 6.5 to 11.5% of total capital costs for low-complexity and high-complexity projects, respectively. They include (Voutchkov 2007a):

- Waste and solids handling costs, including expenditures for construction of facilities for collection, conveyance and disposal of solid waste (spent membranes, cartridge filters and waste solids) from the plant site as well as for solids handling systems for treatment and disposal of waste membrane cleaning chemicals and residuals generated during the pretreatment process (screening, residuals settled in the sedimentation tanks; solids from the filter backwash water).
- Costs of electrical and instrumentation systems, including expenditures for the plant's electrical supply system; equipment transformers and motor control centers; and all electrical conduits and equipment connecting the plant to electrically-driven equipment. These costs typically range between \$0.11 and \$0.34/gpd (\$30 to \$90/m^3/day).

- Cost of auxiliary and service equipment and utilities, including plant chemical storage and feed systems; process air and water supply facilities; fire protection system; wastewater collection system; storm water management system; and all utilities needed for the normal plant operation. These costs are typically between $0.08 and $0.23/gpd ($20 to $60/m^3/d).
- Building costs, including costs for buildings that house plant administration and management, and all other facilities (e.g., laboratory, operator locker and shower facilities). Depending on the complexity and size of the plant, and its location, appearance and ambient environment, construction costs for plant buildings can range between $0.19 and $0.57/gpd ($50 to 150/m^3/d).
- Start up commissioning, and acceptance testing costs, including expenditures for labor, consumables, and equipment used during the plant start up and acceptance process. These costs also typically include costs for construction related permitting and insurance; outside lab analysis; preparation of plant O&M manuals; initial training of permanent staff, and equipment and other items required for normal plant operation. Depending on the complexity of the project, these costs can range from $0.10 to $0.29/gpd ($25 to $75/m^3/d)

Indirect Capital Costs

Indirect capital costs include expenditures related to project engineering services, project development, and project financing, as well as contingency costs. Together, these costs can account for 15 to 30% of total capital cost for low complexity projects, and 32 to 50% for higher complexity projects (Voutchkov 2007a). As a means of comparison, indirect costs typically account for 15–25% of total capital costs for conventional water treatment plants.

Voutchkov (2009a) indicates that the large variation in indirect capital cost consumption for desal projects is directly related to project risks (e.g., source water quality, permitting, technology, among others). The large degree of risk associated with desal project helps to explain why the majority of SWRO projects worldwide have been completed under a BOOT method of project delivery (Voutchkov 2009a).

Engineering Services

Expenditures related to project engineering services include costs for preliminary engineering, detailed design, construction management and oversight, and pilot testing. Together, these costs typically account for about 5 to 13% of total capital costs, and amount to $0.42 to $1.17/gpd of the project's production capacity. Preliminary engineering and detailed design costs include expenditures for project feasibility assessment, definition of project scope and size, studies related to project location and configuration of key process components, and the development of as-built drawings and specifications. Engineering services related to construction management and oversight include engineering activities associated with project construction as well as management of the construction contractors and suppliers involved in project implementation (Voutchkov 2007a).

Costs for pilot testing can range from $0.08 to $0.11/gpd of production capacity. Pilot testing is usually are a good investment towards the successful implementation of large desal projects and can prevent considerable expenses associated with potential problems at full implementation. In addition to the costs of constructing a pilot plant, operational and maintenance costs associated with pilot testing can amount to $10,000 to $20,000 per month (pilot testing typically lasts 6 to 12 months) (Voutchkov 2007a).

Project Development

Project development costs include expenditures associated with the implementation of a desal project from its inception, planning, administrative review and budgeting, to environmental permitting, retaining contractors for project construction and implementation, obtaining funds for project construction, and staffing of desal plant operations. Together, these costs can account for 2 to 10% of total capital costs (Voutchkov 2007a).

Expenditures related to project administration, contracting and management, typically involve expenditures for plant staff and overhead as well as expenditures for contracting outside engineering and other specialized support services. Expenditures associated with these efforts depend on the plant's in-house capabilities and experience with implementation of SWRO projects. These costs typically fall within a range of $0.11 to $0.38/gpd (Voutchkov 2007a).

Project development costs also include expenditures for environmental permitting and legal services. Environmental permitting costs include expenditures for preparation of environmental studies and engineering analyses needed to obtain permits, as well as the fees associated with permit filing and processing. Environmental permitting costs depend on the size and complexity of the desal project and other site-specific conditions. As noted above, these costs also depend on the experience of regulatory agencies with permitting similar desal projects. Costs can vary from $0.19 to $1.9/gpd (Voutchkov 2007a).

Legal services include expenditures associated with legal review and processing of environmental permits and with the preparation and negotiation of contracts for water supply, engineering, operation and construction services. These expenditures can also include costs for review and processing of contractual agreements for land acquisition, obtaining easements for source water and product water pipelines to and from the site, for negotiation of power supply contracts, and for any preparation of contracts for services, equipment and goods needed for construction and operation of the desal plant. These costs are directly related to the complexity of the project and typically vary between $0.08 to $0.30/gpd of production capacity (Voutchkov 2007a).

Project Financing

Project financing costs include expenditures related to obtaining funds and insurance needed for project implementation, from its conception and development through construction startup and commissioning. Key project financing cost components include interest during construction, debt service reserve, other financing costs, and contingency costs.

Interest paid during construction depends on the type of financing used for funding of the desal project but typically amounts to between 0.5 and 4.5% of total capital costs. Debt service reserve payments and other financing costs (e.g., expenditures for funding other reserve funds; administrative and legal costs associated with issuing project bonds or arranging project loans and administering payments; purchasing insurance; and obtaining performance and payment bonds to protect the owner and contractors against construction failures and problems), account for 2 to 8.5% and 0.5 to 4.5% of total capital costs, respectively (Voutchkov 2007a).

Contingency provisions in the project cost estimate reflect that fact even when a detailed cost estimate is completed, there are a number of unknown factors that may influence the actual expenditures associated with project implementation. Detailed cost estimates usually carry a contingency factor of 5 to 10%, depending on the complexity and size of the project.

O&M COSTS

O&M costs incorporate all expenditures associated with plant operations over the useful life of the desal plant. Key O&M cost components include energy (power), chemicals, labor, membrane replacement, and maintenance. Together, these costs typically account for more than 80% of annual O&M expenditures (Voutchkov 2007a).

O&M costs include fixed and variable costs. Fixed costs are incurred independent of the actual amount of fresh water produced by the desal plant (e.g., labor costs, costs for equipment and maintenance, environmental and performance monitoring). Variable costs are typically proportional to the volume of water produced by the plant such as expenditures for power, chemicals, replacement of RO membranes and cartridge filters; and waste disposal. Typically, variable costs account for 50–85% of the total annual O&M costs, while fixed costs make up the remainder. Table G.10 provides a breakdown of the fixed and variable O&M costs for typical SWRO desal facilities, as well as the range of cost estimates for each component.

Trends in Desal Costs

In recent decades, there have been significant reductions in the costs associated with desal of brackish water and seawater. At the same time, the costs of more traditional water supply alternatives have continued to rise, making desal costs more attractive in a relative sense. A continuation of these trends will likely make desal costs more attractive (and less of a constraint) in the future.

Table G.10
SWRO O&M cost components

	% of O&M costs
Fixed O&M cost item	
Labor	4.0–11.0%
Maintenance	3.0–13.0%
Environmental and performance monitoring	1.0–5.0%
Indirect O&M costs	7.0–20.5%
Total	15.0–49.5%
Variable O&M cost item	
Power	35.0–58.0%
Chemicals	5.5–9.0%
Membranes and cartridges	6.5–11.0%
Waste stream disposal	3.5–7.0%
Total	50.5–85%

Source: Adapted from Voutchkov 2007a.

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, Gleick, and Wolff 2006). In addition, the output of product from a unit of membranes has risen from 16 to 22 kgal per day (60 to 84 m^3/d) (Cooley, Gleick, and Wolff 2006 as cited in 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 (Cooley, Gleick, and Wolff 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, Gleick, and Wolff 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, Gleick, and Wolff 2006 as cited in 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/m^3) due to increases in the cost of raw materials (e.g., steel) and energy and rising interest rates (Cooley, Gleick, and Wolff 2006 as cited in *Jerusalem Post* 2005). Cost estimates at Moss Landing, California and Sydney, Australia are even higher, exceeding \$4.00/kgal (\$1.06/m^3) 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, Gleick, and Wolff 2006 as cited in WDR 2006a and WDR 2006b).

A number of researchers and organizations have identified research needs and improvements necessary to achieve target cost reductions. Relative to future costs, NRC (2008) reports the following:

- Substantial reductions in the financial cost of desal will require substantial reductions in either energy costs or capital costs (and associated interest costs).
- There are small but significant efficiencies that can be made in current membrane technologies that will reduce the energy needed to desalinate water, thereby lowering overall project costs. Development of membranes that operate effectively at lower pressures could lead to 5 to 10% reductions in annual costs of desalinating seawater (associated with a 15% decrease in energy use).
- The ability to extend membrane life past 5 years to 10 years will have a minimal impact on total costs given the small contribution of membrane replacement costs to total costs over a five-year lifetime.

- The prevention of catastrophic, irreversible membrane failure is important because membrane failure within the first year of operation can cause an annual cost increase of over 25%. Future research efforts should be focused on mistake-proof, robust prefiltration to ensure against premature failure of the RO membranes.
- The capital and operating cost of a membrane pretreatment system can be 50% of the overall cost of membrane desal or reuse plant. The pretreatment system also represents a plants biggest performance and operating cost variable. Improved pretreatment alternatives now available have had (and will continue to have) a significant effect on the increase in the number of RO-equipped systems.

Voutchkov (2009a) also identified several areas that will help lead to future desal cost savings. Areas expected to yield cost savings in the next 5 years (helping to lead to 20% cost reduction target) include:

- Improvement in membrane element productivity, including the use of polymetric membranes and larger membrane RO elements
- Increased membrane useful life and reduced fouling
- Wider use of pressure exchanger type energy recovery systems
- Co-location with power plants
- Regional desal and concentrate disposal
- Larger RO trains and equipment
- Full automation of treatment processes

In addition, Voutchkov (2007a) identified the following as necessary to help meet a long-term 80% reduction goal:

- Improved membrane useful life and productivity
- Development of corrosion resistant non-metallic materials to replace high-quality high cost stainless steel RO piping
- Reduced pretreatment costs
- Development of new generation energy recovery systems
- Introduction low cost technologies for beneficial concentrate use and disposal
- Exploration of new technologies for seawater desal different from RO and thermal evaporation

Pankratz (Undated) reports on the expected trend of increased brackish water facilities relative to SWRO. It has already been noted that the cost of desal is directly proportional to feedwater salt concentration, thus BWRO is inherently less expensive than SWRO. Brackish water aquifers are often located closer to the consumers than a seawater source, dramatically reducing treated water distribution costs. In addition, many brackish groundwater sources have a low level of suspended solids and require far less pretreatment than seawater sources.

Although brackish water desal installations tend to be smaller than seawater desal facilities, the number of BWRO installations is growing at a faster rate. RO concentrate disposal remains the biggest obstacle in the development of more BWRO installations. Disposal options at many inland locations are limited and may be environmentally and/or cost prohibitive. As technology further addresses this issue, the number of BWRO installations will increase at an even faster rate.

APPENDIX H
REGIONAL APPROACHES AND ADVANTAGES FOR IMPLEMENTING DESAL PROJECTS

This appendix contains extended versions of three case studies presented in chapter 9: Santa Cruz, Monterey, and the Chino Basin. All three reveal the advantages that can arise when desal projects are considered from a regional perspective (i.e., including more than a single utility), and when desal is deployed as an integral part of broader programs that are intended to address an array of regional water resource management challenges.

DESAL PLANNING IN SANTA CRUZ COUNTY, CALIFORNIA: A CASE STUDY OF REGIONAL COORDINATION AND PARTNERING BETWEEN WATER AGENCIES TO FACILITATE DESAL IMPLEMENTATION[1]

In the urbanizing western US, independent local water agencies often share both infrastructure and governance systems. With respect to infrastructure, agencies may share distribution and treatment systems, water sources, and outfalls. In terms of governance, water utilities share county boards of supervisors, state laws, pools of skilled labor, and capital markets for project financing. Agencies also share the impacts of media reports and public understanding of water-related incidents given the regional nature of news reporting. All of these similarities suggest that benefits can be achieved from close coordination among neighboring water agencies.

There are impediments to close coordination. Water agency boundaries and legal status result from regional history, not necessarily ideal engineering or hydrological design. The historical trajectory of water agencies produces unique configurations of engineering, governance, and communications. Agencies differ in other ways: investment priorities and financial obligations, systems at different levels of upkeep and efficiency, and different levels of trust and styles of dialogue among staff, directors, regulators, and customers. They have different commitments to environmental sustainability, system reliability, cost allocation over time, and public oversight. So while shared aspects of neighboring water agencies suggests that they could increase their efficiency and quality of service simply by merging into one larger agency, many barriers exist that could negate or at least postpone the benefits of a merger. However, there are many forms of water utility coordination and cooperation that fall short of a merger, and which may often be advantageous to both utilities and may be more appropriate than outright merger (e.g., Raucher et al. 2006a).

Merging two or more water agencies is an all-in approach to water governance. There is a gradation from complete separation to a single entity (Figure H.1). For neighboring agencies, the left-hand side of Figure H.1, fully separate agencies and operations, is not found since too many issues arise that result in communication and coordination, such as responding to proposed regional or state legislation or regulations, dealing with a regional water crisis, or attending professional meetings.

1. Prepared by Brent M. Haddad, MBA, PhD, University of California, Santa Cruz.

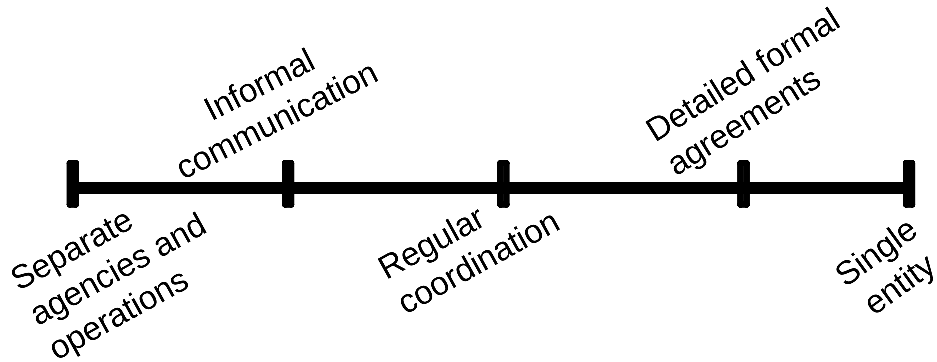


Figure H.1 Gradation of coordination among separate water agencies

It is more common for agencies to find different aspects of their operations carried out with ongoing informal communication between operators, regular coordination, or in some cases, through detailed formal operating and governance agreements. The right-hand-side of Figure H.1, signifying a merger of previously independent agencies may occur when smaller agencies are purchased or merged is a larger neighbor, but is not a typical or necessarily the optimal choice.

Regional Needs Will Influence the Form and Extent of Utility Coordination

Among the biggest drivers of regional coordination will be replacement and expansion of water infrastructure and water supply development. Both of these issues typically arise in the context of implementing coastal or inland desal projects, indicating that desal implementation will often proceed with greater likelihood of success if local water utilities find ways to coordinate and cooperate in the desal planning and project development process. For example, regions are likely to see significant financial benefits from sharing the cost of desal-related infrastructure and permitting activities. The locations of water supplies and outfalls may require agency coordination when the best sites are not all in the same service territory. Full-on mergers of agencies should be considered when the future paths of neighboring agencies are clearly united through shared infrastructure needs and other similarities. But formal agreements that fall short of a merger may often be the better approach.

Contracting as a Form of Interagency Coordination

Formal contractual agreements between water agencies are very common. They are called for when:

- The pursuit of shared interests or the resolution of a dispute is complex enough to warrant a clearly written document
- Multiple parties are involved
- Financial and/or system reliability issues are important enough to warrant formal commitments

- The proposed activity carries substantial risks
- The history of relations between the agencies calls for clearly-expressed and enforceable commitments
- The course of action should be clearly documented so a political decision can be made on whether to adopt it
- There is a regulatory or financial requirement for a formally-executed document

Agency staffs play a central role in creating contracts, with input from political leadership and the public, and polishing by legal teams. An agreement facilitator may be hired to help the parties reach a decision.

Desal Needs and Options for Santa Cruz County

Two neighboring water agencies, Soquel Creek Water District and the City of Santa Cruz Water Department, a branch of the municipal government, determined that a desal facility would serve their long-term potable supply interests (see www.scwd2desal.org):

- Soquel Creek sought an additional year-round water supply of roughly 1.2 mgd to sustainably manage its aquifer system, its sole source of water. The district serves a population of about 49,000 through roughly 15,000 service connections.
- Santa Cruz sought additional drought reliability for their surface water system, roughly 2.5 mgd during April–November of drought years. The Water Department serves a population of about 90,000 through 24,000 service connections, and relies on surface water from rainfall captured in local reservoirs and streams (95%) and groundwater (5%).

For Santa Cruz, desal emerged as one of three parts of its long-term water supply strategy (Gary Fiske and Associates 2003).

Drought supply reliability keyed to 1976–1977 conditions (the worst recent drought) was modeled. The three-part strategy include drought-period curtailment limited to no greater than 25% of normal-year demand, water conservation, and modest supply augmentation. The expected supply augmentation, 2.5 mgd during dry-season months of severe drought years, emerged from a combination of expected demand over time, current supplies, expected results of additional conservation investment, and the political choice not to reduce water consumption by more than 25% in worst-case scenarios. Without supply augmentation, models indicated a 45% curtailment would be necessary in severe drought years.

Numerous supply augmentation options were considered, including expanding groundwater use, water reclamation and reuse, and expanding surface impoundments. Numerous factors were evaluated, including cost, environmental impacts, ease of implementation, energy utilization, vulnerability to outside impacts, and impacts on aquifers. These led the city to select desal as the preferred choice for supply augmentation. The city expects to utilize the desal plant only during peak season drought years, about once every six years.

Studies by Soquel Creek Water District showed that the region's water use was exceeding the sustainable yield of its groundwater resources by roughly 600 AFY, with long-term projections of an annual overdraft of 1,280 AFY (ESA 2006). The district studies numerous supply options, including surface impoundments, regional purchases and imports, water reclamation and reuse, desal, and conservation. The district's customer base was too small to cover the entire cost of a desal plant. However, a joint desal plant was seen as within the means of the ratepayers. Like Santa Cruz, Soquel Creek is a coastal water agency. However, a careful study of its coastline did not identify suitable locations for a desal intake and outfall. This physical reality increased the likelihood that any desal plant built to serve Soquel Creek would likely be a regional facility.

In terms of partnering on a desal project, numerous advantages emerged. A key advantage was that the two agencies had different purposes for the desal water produced. The city needed a dry-season drought supply, which, due to limited storage capacity, would need to be available during the drought. The district's demand, while preferable during dry periods, could be accommodated with year-round deliveries since aquifer recovery from subsurface inflows from the coastal mountains takes place year-round. While the city wanted to scale the facility to meet its modeled drought requirements, 2.5 mgd, the district's ideal facility size was even smaller, roughly half that size.

Choosing Between Informal Agreements, Contracts, and Mergers

A formal agreement was clearly needed given the anticipated joint investment in desal and piping infrastructure and the major contribution the facility would make to long-term system reliability for both utilities. Use rights to produced water also needed to be spelled out. While the city had the financial means to construct a facility on its own, it is not clear that the district could have. Both sides saw the clear financial advantage of jointly pursuing the project since the additional costs of doing so (primarily building a distribution-system delivery point, and in Soquel Creek's case, scaling up from its ideally-sized plant) would cost far less than expected savings through cost sharing.

The first agreement, signed in August 2007, established a Task Force comprised of two elected leaders from each agency, and joint staffed. It also established a 50-50 cost share for engineering and permitting costs, all of which would be overseen by the Task Force. Another Task Force goal was to generate the eventual operational and cost-share agreement. A chicken-and-egg issue arose: whether to complete environmental review prior to developing an operational agreement or develop the agreement in order to inform the environmental review. The Task Force decided to pursue both simultaneously, but not to formally agree to operational and cost terms until environmental review was complete.

An agreement facilitator was selected, who worked with staff and the Task Force to develop and refine necessary categories of agreement, agreement principles, and details. The facilitation team was led by an economist (Brent Haddad from the University of California, Santa Cruz), and included an attorney specializing in municipal agency law and an engineer specializing in desal. Agency attorneys also were consulted, as well as an outside legal expert who addressed whether to established a Joint Powers Authority.

The categories of agreement included:

1. Plant location
2. Whether pure desal water would be delivered to both parties, or water could be blended with existing supplies to minimize piping costs
3. Water-delivery scheduling using a seasonal priority system
4. Capital cost categories and allocation

5. Operating cost categories and allocation
6. Emergency use provisions
7. Arbitration procedures
8. Ownership and governance

The process of negotiation involved the facilitator working with both agencies' staff to generate principles and concepts, which were then reported to the Task Force. Improvements and refinements were made at monthly Task Force meetings. Substantive, focused proposals then emerged that were consistent with the agreed-upon principles. The staff appreciated working based on shared principles rather than agency self-interest, and the Task Force appreciated the ability to communicate to the public why choices were made as they were.

Ownership and Governance

For example, #8 above, ownership and governance, launched with efforts to arrive at a set of shared principles from which defensible contract provisions would emerge. The following principles emerged from Task Force and staff meetings and were adopted by the Task Force:

- **Partnership:** no party has an economic, political, or positional advantage that would enable it to impose undesirable outcomes on the other party
- **Cost minimization:** parties seek to minimize the overall cost of the project as well as the portion of cost that will be incurred by their own ratepayers
- **Fair allocation of cost**: both parties seek an equitable division of costs between them
- **Transparency:** the costs, performance, and outcomes of the project are clear to the public and to decisionmakers
- **Independent control of agency's future:** each agency would like to determine, maintain, and implement their own long-term water supply priorities
- **Efficiency:** the governance system itself should run smoothly and result in timely and good decisionmaking
- **Accountability:** those who make decisions and implement decisions should keep records and make them available to the parties so that performance and costs can be evaluated

Three implementation options then emerged:

- Sole ownership of the desal facility by one agency and a water purchase contract for the other
- Joint Powers Authority, which is a separate legal entity whose board of directors is controlled by the existing agencies
- A detailed contractual agreement

The first implementation option was rejected based on the Partnership and Transparency principles, and as of early 2010, no decision had been made between the other two options. A fourth option—merging the two agencies—had not been brought up since both agencies have different overall priorities moving forward and the Soquel Creek Water District is not within the city's boundaries. Although ownership and governance seem like they might be the most contentious, if saved for last, a logical result is likely to emerge that helps to implement all the other agreed-upon issues.

By late 2009, the Task Force had a draft interim agreement expressing ongoing commitment to the project and laying out operational and cost issues in an appendix. The Task Force was pursuing the project's environmental review. Following environmental review, the inter-agency agreement will be finalized and a political choice made by each agency whether to implement the project.

With respect to Figure H.1, the two agencies are not merging, but if the desal project advances to completion, it will create a context for much closer coordination based on formal contractual agreements. Future coordination needed for such issues as climate-change-based sea level rise or management of their shared coastal aquifer could push the two agencies closer to a state of merger, but this activity—building a joint desal facility—can be accomplished by contract alone.

A final decision on construction is expected in late 2010 following environmental review. By pursuing a joint desal facility, the agencies will reduce their capital and operating costs while achieving separate water reliability goals. They will also utilize the region's preferred intake and outfall locations (in Santa Cruz). By building water-delivery infrastructure that links the two agencies, they will create a potential for regional supply assistance in the event of a water emergency (e.g., earthquake). And the two agency staffs have also built a strong understanding of each agency's infrastructure and plans, which will enable them to more easily negotiate future agreements on such topics as the management of their shared aquifer. In terms of challenges, the agencies will be blending desalinated, surface, and groundwater (at least in the "downstream" Soquel Creek district), which will require additional attention to water quality impacts. Ongoing coordination on a joint facility will be required. And each agency will expect and rely on the other to meet its financial obligations. Thus far, progress has been made with the understanding that the agencies are contracting together as partners; the expectation is that future issues will be handled in like manner.

A REGIONAL COLLABORATIVE APPROACH TO IMPLEMENTING DESAL TO SOLVE WATER SUPPLY ISSUES IN MONTEREY COUNTY, CALIFORNIA[2]

Introduction

The Monterey region along the central California coast faced water shortage, groundwater degradation, interagency disagreement, and public divisiveness. Solutions were proposed including a dam on the Carmel River and a seawater desal plant co-located at a nearby power plant. The dam was rejected by voters and the proposed desal plant faced public acrimony and litigation. With this as a background, the CPUC engaged the CIWR, University of California, to facilitate a less costly, more politically acceptable, and environmentally friendly regional water solution. Setting a goal of one year, the CIWR established a citizen-agency vetting process to find common agreement on regional solutions. The regional dialogue group is made up of local, regional, state, and federal representatives; water and wastewater agency managers; nongovernment organizations; and citizens.

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2. Prepared by Steve Kasower, independent consultant, formerly with the CIWR, University of California, Santa Cruz.

The “Regional Project” plan that emerged from this dialogue is based on components that have been examined in the past by the water and wastewater agencies in the region but is now combined in synergistic combinations that take advantage of economies of scale both financially as well as spatially. The potential positive impacts to ratepayers are expected to be appreciable. Besides economies of scale obtained by including more beneficiaries to the project than just those in one service area, the public ownership nature of the Regional Project will allow favorable bond financing and access to state or federal funds generally available to public agencies.

Background

The Monterey region of California includes a highly valuable tourism and recreational sector. The scenic Monterey Peninsula is recognized as a favorite business conference and vacation destination across the US and beyond. This status is a result of many years of public and private investments, including public infrastructure improvements, private development and the combined marketing efforts of all associated interests. The hospitality industry along the Peninsula generates over $2 billion dollars in direct tourism spending. Of this amount, over $55 million dollars in taxes goes directly to the local jurisdictions. The hospitality industry on the Peninsula is responsible for employing approximately 23,000 persons. Along the Monterey Peninsula, the hospitality industry is a significant economic driver.

Along with tourism and recreation, the Monterey region includes highly valuable agricultural operations in the Salinas Valley. Salinas Valley agriculture is a $3.8 billion industry. Favorable climate and fertile soils resulted in the Salinas Valley becoming the number one vegetable-producing region in the nation. The area supplies 80% of the nation’s lettuces and artichokes. Broccoli, cauliflower, spinach, strawberries, peppers, squash, carrots, asparagus, celery, tomatoes, mushrooms, brussel sprouts, garlic, onions, and flowers are also grown. In addition, Monterey County has become one of the largest premium grape growing regions in California, with over 40,000 acres of wine grapes (Salinas Valley Chamber of Commerce 2010).

Single Solution Projects Fail to Gain Political Support

This viable economic region has no imported water and has little opportunity to acquire it due to its geographic isolation. Water supplies from the Salinas River are already tapped and allocated for agricultural uses in the Salinas Valley. Due to a tradition of agricultural investments in Salinas River water from Nacimiento Dam to the Salinas Valley Water Project, there is an overriding concern amongst agricultural water leaders to protect “their” water from urban incursions. This tradition results in strong political resistance to any opportunity to use excess Salinas River water for urban uses on the Peninsula. Thus, solutions to the Monterey water supply shortages were extremely limited.

Facing water rights enforcement for diverting more water than they had a legal right to take on the Carmel River and severe overdraft and adjudication in their other water supply, the Seaside Groundwater Basin, Peninsula communities were suffering. Water supply choices were narrowing after the public on the Monterey Peninsula voted against a new dam on the Carmel River. Nearly all of the recyclable wastewater is allocated to agricultural uses in the Salinas Valley during the irrigation season and thus, not entirely available to provide fresh new water supplies (MRWPCA 2009). Peninsula water users were already conserving aggressively due to their diminishing existing supplies so further conservation was not enough. Residents of the Monterey Peninsula use 70 gallons of water per person per day—approximately half of the water consumed by the average Californian (California American Water 2010).

Thus, besides squeezing more water from dwindling supplies, the Monterey region was forced to examine seawater desal as a source of new supply. In response to the failure of the dam, a State Legislator asked the CPUC to come up with a "Plan B" for water [Fred Keeley authored Assembly Bill 1182 (chapter 797, Statutes of 1998) which required the CPUC to develop the Plan B project]. Plan B became a seawater desal plant located at the Moss Landing Power Plant site, to be developed and owned by Cal AM, which is an investor-owned utility providing water to the Monterey Peninsula communities. The plant was called the CWP and relied on OTC technology to obtain its feedwater. Commensurately, a public agency in the far north of Monterey County was also proposing a seawater desal plant to be located across the street from the CWP site at a former refractory site that had abandoned ocean intakes. This proposal from the Pajaro-Sunny Mesa Water District attracted a few groups in support. The main attraction was from groups who opposed a private agency (Cal AM) owning a desal plant. Interestingly, the Pajaro Sunny Mesa proposal had some private components as well. The refractory site was privately held and was not proposed to be sold to the public agency.

Not surprisingly, the Monterey community did not coalesce behind any of the desal alternatives. Increasing acrimony was evidenced by the failure of any consensus to materialize. Commensurate to the public acrimony and disharmony, political leaders began to avoid the water supply issue and its attendant acrimonious byproducts. It is no surprise that solutions were slow to emerge from this milieu. Once proposed, any solution became the target for attack by one group or another within the community.

Concerned about the CWP costs and benefits, the CPUC's Division of Ratepayer Advocates (DRA) contracted with the CIWR and the University of California, Santa Cruz, to evaluate the CWP. In September 2006, with project review underway, CIWR Senior Economist Steven Kasower recommended to DRA management that water resource decisions were predominantly "political" in nature. As such, the CIWR review of the CWP was not adequate to protect the interests of the ratepayers during decisionmaking processes at the CPUC. Specifically, Mr. Kasower recommended that DRA consider looking for a regional solution to the water supply issues in Monterey. Moreover, that regional solution may have increased benefits and political support. The DRA management agreed and engaged the CIWR to undertake the processes that could result in a regional water supply solution.

The focus of the regional process was the establishment of a diverse group of participants who would be willing to debate, discuss, and ultimately help identify a regional water supply alternative. The group was called the Regional Plenary Oversight Group (REPOG). The original goal for REPOG was to create a politically robust and community-diverse group whose members would not necessarily agree on final outcomes, but who would through time, come to understand each others' perspectives and recognize the rationale of a well planned project alternative. This process succeeded in the submission of the regional plan environmental documentation to the CWP EIR process initiated by the CPUC Energy Division on behalf of the Cal AM (RMC 2008). As the focus of a regional project became clearer, the REPOG named the Regional Project "Water for Monterey County" and themselves, the "Water for Monterey County Coalition" (WFMCC). WFMCC established a Web site for better informing others of the Regional Project and its values (Regional Water Project 2009).

The Regional Project Includes a Desal Component and Solves More Problems Than It Creates

The Regional Project was created by re-examining a number of local projects and water management programs that have, at one time or another, been considered by local water and wastewater agencies, municipalities, or cities in the Monterey region. In addition to collecting project details, water demands were also reviewed [for example, on the Monterey Peninsula, MPWMD (2006) provided detailed demand data]. The water projects and programs were then screened in various combinations based on planning criteria developed by the WFMCC. The planning criteria established during the WFMCC process facilitated unique "pairings" of project components that ultimately revealed opportunities for regional economies of scale and new agricultural and urban symbiosis that could lead to more stable and beneficial regional cooperation in the future. As this unique regional vision began to be described, it immediately encountered the very political resistance that so many regional efforts faced. This time however, due to the multiple component nature of the Regional Project, no one component was required to implement another. While some of the extensive "regional" benefits will not be enjoyed until and unless the complete Regional Project vision has been implemented, many economies of scale, cost-saving partnerships, and environmental and social benefits were evident even in the first phases of the project and garnered considerable and diverse support for just the desal component in Phase 1.

The complete Regional Project includes beneficial reuse of all wastewater discharges, river and groundwater diversions, and intruded seawater desal to add reliability to the overall program. These project components work together to create economic synergies. The following discussion describes the Phase 1 component, the brackish groundwater desal project and how it has numerous beneficial aspects typically the object of derision like intake technology and power consumption.

In the Phase 1 project, the approach to pumping from the brackish groundwater will contribute to the remediation of the Salinas Valley groundwater degradation by blocking and even helping to reverse the seawater intrusion problem. The cone of depression from the intake pumps help create the seawater barrier. In addition to the Regional Project and Salinas Valley Water Project, it is expected that the intrusion will reverse itself over time.

Locally developed power will provide the energy to power the project components. This power comes from electricity generated from the methane produced at the MRWMD from sealed digesting of sewage sludge (Heitzman, Melton, and Kasower 2009). This carbon-negative approach captures methane that otherwise escaped into the atmosphere and reflects the concerns of the WFMCC over the "carbon footprint" of the regional solution. Affordable water components and the role of water in facilitating the development of affordable housing for working families and those on fixed incomes is also integrated into the project plan (CIWR and MCWD 2008).

Phase 1 of the Regional Project has been selected as the preferred plan by the CPUC during their certification of the EIR. The key to this early implementation relies on careful accounting of the water extracted for desal treatment. In order to comply with local regulatory agreements over groundwater use, only the proportion of seawater extracted from the wells will be allocated to the Peninsula. The remaining brackish groundwater will only be used within the MCWD service area where use of this groundwater is already politically acceptable and defined from a regulatory perspective by the Monterey County Water Resources Agency (Byron Buck &

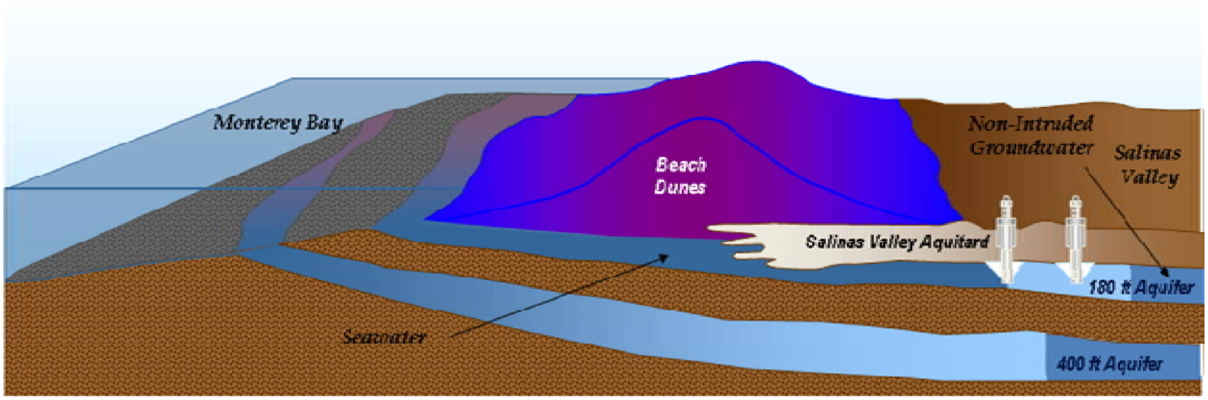

Figure H.2 Proposed program utilizes intruded seawater and contributes to the restoration of the aquifer over time

Associates 2005, pp. 2-3 to 2-9). This institutional arrangement allows for the MCWD to draw brackish groundwater for their uses within the basin, but they also will account for the proportion of seawater treated. That proportion of product water that represents what was from seawater can be allocated out of the basin to the Peninsula to solve the Carmel River endangered species and water rights infractions and to recharge the Seaside Basin to remediate the overdraft as dictated by the court in adjudication proceedings (Seaside Groundwater Basin Watermaster 2008).

This section presents a more detailed discussion of the brackish desal component of the Regional Project. While it is important to remember that the Regional Project succeeded as a number of components: conservation, stormwater reuse, urban nonpotable recycled water use, and additional river water, some additional source of potable water was required. That source could be the ocean or brackish groundwater, which ever offered the most politically, economically, and environmentally feasible solution.

Utilizing Seawater Intruded Groundwater for Desal

The Regional Project brackish water desal component uses a blend of ocean water and brackish water (seawater-intruded groundwater) for the desal water supply. The desal wells will ultimately consist of two bands of well fields; the first a line of seawater wells located on the inland side of the coastal dunes and the second a line of brackish wells near Highway 1. However, due to the political sensitivities of the Salinas Valley agricultural water users, the inland row of wells were excluded from Phase 1 of the Regional Project.

Compared to the original desal options which were utility-specific and relied on ocean intakes, the use of near-coast brackish groundwater as the desal water supply—and the effects of the drawdown profiles from the parallel well fields—provide the following benefits (Figure H.2):

- Develops a desal water supply that requires less energy per unit water to treat
- Creates a brine waste that has a salinity much closer to that of ambient ocean water into which it will be discharged

- According to hydraulic modeling performed for CEQA compliance, creates a seawater intrusion barrier on the ocean side of the dual well field (if the Regional Project is fully realized)
- Also according to hydraulic modeling performed for CEQA compliance, accelerates the cleanup of the Salinas groundwater basin by extracting brackish water from the basin

The use of brackish wells is possible in the regional approach both in the early phases as well as in the fully realized regional configuration because:

- In early phases, the project will accurately account for the proportion of seawater and brackish groundwater that is withdrawn by the pumps. Only desalinated seawater quantities will be delivered to the Peninsula for Carmel River water replacement and possibly Seaside Groundwater Replenishment. The proportion of treated water represented by the quantity of brackish groundwater extraction will be distributed within the basin meeting demands within the MCWD service area. It is anticipated that such an arrangement avoids the acrimonious debates and fears over the possibility that Salinas Basin groundwater would be exported to the Peninsula.
- When the Regional Project is fully realized, it will utilize recycled water in a way that supports the hydrologic balance of the Salinas basin and provides additional water supply to overlying interests. One way to do this is through the expansion of recycled water deliveries for agricultural irrigation (described in the "Expanded Agricultural Irrigation" section above) that would exceed the amount of groundwater extracted by the brackish wells, ensuring the Salinas Basin remains in hydrologic balance. This alternative has been evaluated through hydrologic modeling and described in detail in technical memoranda prepared for the environmental impact reporting process for the CWP (RMC 2008, p. 3-6).

Utilizing Landfill Cogeneration and Hydropower as Energy Sources

The water treatment facilities for the Project would require a significant amount of electrical energy to meet daily operational needs. The WFMCC (REPOG) process planning criteria identified "sustainability" as an important characteristic. Reliable, sustainable water supply is enhanced by incorporating a sustainable energy supply to power it. The MRWMD has a program that captures methane gas from its landfill, and utilizes that captured gas to generate electricity through operation of cogeneration facilities located at the MRWMD site in north Marina. There exists the potential to increase the methane gas production at the landfill and correspondingly increase the electrical generating capacity of the cogeneration facilities. Sewage sludge is presently composted on the landfill site, but the methane escapes into the atmosphere. The Regional Project includes construction of concrete bio-digesters that are sealed and capture the methane for productive power production. This electrical power will be delivered to the water treatment facilities that are proposed to be located on property immediately adjacent to the MRWMD landfill site. Opportunity to receive sludge from other municipalities increases the potential revenue generating opportunities associated with the landfill as well.

Project Engineering Economics

The Phase 1 component of the Regional Project was compared to two other alternatives during the regulatory process associated with bringing water to the Monterey Peninsula. Due to the nature of the private water utility, Cal AM, that supplies the Peninsula communities with water, costs were prepared and vetted before an Administrative Law Judge (CPUC 2004).

The engineering economic cost comparison illustrates that the Regional Project is significantly less expensive that the two next likely alternatives. Table H.1 depicts the total annualized engineering costs per AFY, and shows that the desal projects proposed by the individual utilities would cost roughly 50% per AF than the Regional Project (this is based on data provided by the MCWD and Cal AM from the "meet-and-confer" cost collaborative process). Tables H.2, H.3, and H.4 provide additional detail on the costs of the regional desal project, MCWD go it alone, and Cal AM Moss Landing desal projects, respectively (with capital costs annualized based on a 30-year period and a 5.15% interest rate).

Table H.1
Engineering unit costs for the regional project and the Cal AM alternatives (based on cost of water—$/AFY)

	Regional Project	Cal AM North Marina Project	Cal AM Moss Landing Desalination Plant
Cost of water ($/AFY)	$2,290	$3,420	$3,430

Table H.2
Regional Project Desalination Plant engineering costs

Supply (AFY)	Net capital cost ($)	O&M ($/year)	Annualized capital cost ($/year)	Total annualized cost ($/year)	Cost/AFY
10,500	$177,400,000	$12,080,000	$12,000,000	$24,080,000	$2,290.00

Table H.3
"MCWD Go-it-Alone" project engineering costs

Supply (AFY)	Net capital cost ($)	O&M ($/year)	Annualized capital cost ($/year)	Total annualized cost ($/year)	Cost/AFY
1,700	$61,600,000	$3,000,000	$4,100,000	$7,100,000	$4,180.00

Table H.4
Moss Landing Desalination Plant engineering costs

Supply (AFY)	Net capital cost ($)	O&M ($/year)	Annualized capital cost ($/year)	Total annualized cost ($/year)	Cost/AFY
8,800	$211,550,000	$10,950,000	$19,800,000	$30,750,000	$3,490.00

The Regional Project is designed to provide reliable potable water supplies to the MCWD service area, including the City of Marina and the Fort Ord communities. Additionally, the Regional Project is sized to provide potable water service to the communities of Seaside, Del Rey Oaks, Monterey, Pacific Grove, Carmel, Carmel Valley, and Pebble Beach. These communities are provided water service from Cal AM.

The resulting opportunity for MCWD was a regional process that selected the Regional Project as a more feasible, politically acceptable, and implementable project to solve both MCWD service area water needs as well as those severe water problems in the Cal AM service area. Cal AM would essentially purchase water from the Regional Project in a "take or pay" contract. The regional approach allows MCWD to take advantage of economies of scale, thus lowering the costs for its ratepayers while Cal AM can purchase water from MCWD at a lower cost than their ratepayers would face otherwise.

Alternatives for the Regional Project are limited. In order to determine the most likely alternative, consideration is given to the assumptions underpinning the hypothetical "nonfeasibility" of the Regional Project. The absence of a regional-scaled plant would require that MCWD pursue its own desal plant adequate to meet demands within its service area as was originally envisioned. Demands on the Monterey Peninsula, resolution of the Carmel River water rights and endangered species issues, and remediation of the Seaside groundwater overdraft problem would need to be solved by Cal AM by itself if MCWD only implemented their own project.

Only two other alternative water supplies have been identified in the EIR being conducted for projects to resolve the Carmel River and Seaside Groundwater overdraft issues. The EIR called the CWP-EIR identified three alternatives for solving the regulatory and hydraulic issues facing the Monterey Peninsula (CPUC 2009). One is the Regional Project to be owned and operated by MCWD. The other two would be owned by Cal AM and are a North Marina desal plant located close to the Regional Project site that uses slant well intake technology, and a seawater desal facility co-located at the Moss Landing Energy Facility, operated by the Dynegy Corporation (Dynegy 2009). The Moss Landing facility would obtain influent from the once-through-cooling system used by the power plant.

The differences between the Cal AM North Marino Project and the MCWD Regional Project are the intake wells and the project ownership structures; one being a public agency (MCWD) and one being a private water utility (Cal AM). While there are cost differences between the slant well (the Cal AM North Marina Plant intake proposal) and vertical well (the MCWD Regional Project intake design) technologies, and also financing differences between public and private water agencies, the key differences are institutional. The location of the facilities while similar, favor MCWD who owns or options all the feasible sites for locating either the Regional Project or Cal AM North Marina Plant. Moreover, the favorable "zero carbon" power source from the Monterey Regional Waste Management Agency landfill (MRWMD Undated) is only legally available to the project that sits on those specific pieces of property sharing a fence line with the landfill. Thus, in the absence of the Regional Project, MCWD would locate the brackish water desal plant component of their "stand alone" desal plant on the aforementioned land. That would essentially foreclose the feasibility of the Cal AM North Marina Plant as well as the Regional Project alternatives.

Thus, it is unlikely that MCWD, while building a single-purpose MCWD-only project, would agree to allow anther desal plant to occupy the same site. Therefore, the most reasonable approach to resolving the Cal AM service area demands in the face of "go-it-alone" projects would be the Cal AM Moss Landing Seawater Desalination Plant located at the Moss Landing Power Plant site. As discussed earlier, the Moss Landing site, relying on OTC intakes, had its own controversial future. Moreover, Cal AM continued to suffer public scorn for being a private, not solving the water problems, being owned by a foreign company, and a litany of other public concerns. Cal AM was not going to easily "go-it-alone," and its desal plans were likely doomed by the institutional version of a "death by a thousand cuts."

The costs of the MCWD-only desal project are presented in Table H.3, and the Cal AM Moss Landing Desalination Plant costs are depicted in Table H.4. Comparing the costs of the two go-it-alone alternatives, the Regional Project (Table H.2) is clearly superior from the economic perspective. Additionally, the Regional Project enjoys public support, superior environmental implications, and costs less.

Remaining Process Leading to Implementation

The project sponsor, the MCWD in partnership with the Monterey County Water Resources Agency—and in collaboration with Cal AM—are preparing to implement the Phase 1 Regional Project. Much of the remaining details are contractual and policy matters concerning how costs will be allocated, who will operate the project, and whether the DRA will concur that the Cal AM ratepayers are getting a benefit and a fair deal out of the regional project sponsorship.

Conclusion

The Monterey region in California has been facing a series of significant water supply and associated water resource management challenges for several years. Despite the critical need to develop additional water supplies for the region and the lack of feasible alternatives to extract more local water or tap imports, efforts by individual local utilities to implement go it alone utility-specific desal projects were facing considerable opposition and unlikely to proceed.

This untenable situation led to consideration of a broader collaborative and regional approach, wherein desal is well integrated with other key components of a comprehensive regional water resource management plan (e.g., water reuse). This regional approach has emerged as a much more viable alternative, with several critical advantages over go it alone alternatives:

1. Political viability, stakeholder buy-in, and public support (as contrasted to deep divisions and strong opposition)
2. Economically advantageous (i.e., it is less expensive than utility-specific options by a considerable degree)
3. Environmentally beneficial, including the avoidance of an ocean intake, providing seawater intrusion control, minimizing brine management impacts, and tapping into green carbon negative energy
4. Socially beneficial by providing a more equitable sharing of water, offering public sector ownership, and facilitating a joint resolution of both agricultural and urban water issues

As a consequence, a more regional and collaborative approach has led to a path that will greatly facilitate desal implementation. The regional approach will promote desal in a manner that will be more cost-effective, solve more problems, address more issues, and has a far greater likelihood of implementation than a more traditional, utility-specific go-it-alone approach.

CHINO BASIN: GROUNDWATER DESAL AS AN INTEGRAL PART OF COMPREHENSIVE REGIONAL WATER RESOURCE MANAGEMENT[3]

Introduction and Overview

This section describes a case study—using a TBL perspective—of the benefits and costs of the desal of brackish groundwater, as implemented jointly in the Chino Basin (Southern California) by IEUA, CDA, and the Chino Basin Watermaster. A key aspect of this case study is that it examines how the benefits of desal may extend well beyond its use in developing a potable water supply.

In the Chino Basin context, the application of desal can be viewed broadly to reflect its role as an integral component of the region's overall water resource management program; desal in this region is a critical component of a highly valuable, multi-objective basin-wide groundwater management strategy. In this instance, groundwater desalting not only provides potable water to supplement the area's overall supply portfolio, but it also is a foundational element of a groundwater remediation effort that provides several additional important benefits within and beyond the Chino Basin.

Within the TBL context, this case study describes the estimated magnitude of several of the key benefits generated, and provides a comparison of the benefits of desal to its costs. The benefits include the overall basin-wide savings in the cost of providing water over a 30-year period, and also indicates the magnitude and value of energy savings and the reduced carbon footprint associated with the desal-enabled groundwater management program.

This Chino Basin groundwater desalting case study illustrates how desal options may be viewed as key elements of broadly defined and integrated regional water resource management efforts, rather than more narrowly perceived only within the context of an option to provide additional water supply. This case study is intended to serve as a guide to help others as they contemplate desal options, weigh the potential benefits and costs of desal options, and attempt to move forward with desal implementation and its integration with other elements of their water resource management activities.

Case Study Objectives

This Chino Basin groundwater desalting case study is intended to illustrate how desal options may be viewed as key elements of broadly defined and integrated regional water resource management efforts, rather than more narrowly perceived only within the context of an option to provide additional water supply. Drawing upon the extensive practical experience and knowledge gained by IEUA and CDA, as progressive wastewater and water service providers and management agencies, this case study is intended to serve as a guide to help others as they contemplate desal options, weigh the potential benefits and costs of desal options, and attempt to

3. This case study was prepared by Robert S. Raucher, Stratus Consulting Inc., Boulder, Colo.

move forward with desal implementation and its integration with other elements of their water resource management activities.

This evaluation includes a discussion of desal options and implementation choices at two levels. First, the discussion examines desal in general as an option to address the region's water resource challenges, in concert with other possible program elements such as conservation, recycling, or relying on water imports. Second, we explore some specific elements within the desal program itself, including factors that influenced the selection of specific desal process options, green energy development, and brine concentrate management.

In addition, this case study illustrates how desal can be evaluated within a broad benefit-cost framework that can capture the wide ranging, multi-objective opportunities desal can provide. This chapter also reveals what types of benefits and costs may be associated with such projects, indicates their potential monetary worth, and illustrates the application of an economic framework for conducting and communicating the benefit-cost approach.

An Overview of Water Resource Challenges in the Chino Basin

The "Inland Empire" is located about 40 miles east of Los Angeles. Beginning in the 19th century, the region grew to become a major agricultural center, including dairy farms, citrus orchards, and other activities. Beginning in the last quarter of the 20th century, the area has seen rapid conversion to residential and commercial uses, becoming one of Southern California's fastest growing regions (Miller, Burton, and Manning 2007).

The Chino groundwater basin underlies roughly 220 square miles of the Inland Empire, and is bounded on the north by the San Gabriel Mountains, and on the south by the Santa Ana River, which is fed in part by groundwater flows from the basin. The Santa Ana River flows year-round for 69 miles, from headwaters in the San Bernardino Mountains to the Pacific Ocean. The river enters the Chino Basin at the Riverside Narrows and continues along the southern basin boundary to the Prado Flood Control Reservoir and Dam, from which it spills westward through Orange County en route to the Pacific. The basin is located mostly in western San Bernardino County, and extends westward into eastern Los Angeles County (underlying the cities of Pomona and Claremont). To the east, the basin also underlies northwestern Riverside County (extending to within a few miles west of the city of Riverside).

The region's past as an agricultural center, and its current expanding water demands as a rapidly growing residential and commercial area, have created significant water resource management challenges in the Chino Basin. These water resource management challenges include both water quality and water quantity issues, and reflect the critical interrelationship between the two.

The primary water quality challenge relates to salt levels in Chino Basin groundwaters. Salt issues are reflected by elevated TDS levels, as well as elevated levels of nitrates. Some contamination by VOCs is also present. Collectively, these impair local groundwaters and make them expensive or unsuitable for supporting potable M&I and other uses.

The primary water quantity issue is meeting rapidly growing demands—as associated with rapid residential growth and CII development—in a basin that has a history of extracting groundwater at levels above sustainable yields. The water quantity challenge is magnified by the cost and uncertain availability of imported surface waters, the need to honor water rights of downstream and down-gradient entities, and the impact that the water quality issues have on the usability (and cost) of local water supply resources (including impacts on the storage capacity of the aquifer system).

Optimum Basin Management Program and Related Agreements

In 1988, judicial and other pressures mounted on the Chino Basin Watermaster to undertake and implement an OBMP. In June 2000, the Chino Basin OBMP "Peace 1 Agreement" developed an institutional structure and funding plan for the expansion of the Chino 1 desalter, and for adding the Chino 2 desalter. The OBMP is implemented by the Chino Basin Watermaster, with the objective of managing the basin's groundwater through monitoring and recharge. Key elements of the OBMP reflect the need to keep groundwater pumping levels up (notably in the southern, lower end of the basin) in order to (1) enable better and increased use of the Chino Basin's groundwater resources (and thus avoid over reliance on imported water), and (2) preserve water quality in the Santa Ana River.

Overview of the Chino Basin Desalting Operations and Costs

The original Chino Basin 1 Desalter (Chino 1) was completed by 2000 and produced 9,200 AF of product water annually. With the formation of CDA in 2002, the Chino 1 desalter was purchased for $64.7 million from SAWPA. The Chino 1 expansion was completed in 2005, and annual production is now 14,200 AF (Miller, Burton, and Manning 2007).

The Chino 2 desalter was completed and placed into operation in the spring of 2006, and produces 10,400 AF per year (Miller, Burton, and Manning 2007). Like Chino 1, the Chino 2 desalter splits its feedwater (drawn from eight wells) between IX (4.2 mgd) and RO treatment processes (7.5 mgd), producing post-treatment yields of 4.0 mgd and 6.0 mgd, respectively (Parker 2007). These desalted waters are low enough in TDS and nitrate concentrations that they can then be blended with source waters that bypass the desalting units, to yield a total of 15.0 mgd of product waters that are forwarded to CDA's wholesale customers for subsequent delivery as potable supply (Miller, Burton, and Manning 2007).

Combined, the Chino 1 and Chino 2 desalters now provide nearly 25,000 AF per year to the potable supply of the Chino Basin. This provides a reliable water supply serving more than 40,000 families in the cities of Chino, Chino Hills, Norco, and Jurupa.

Future expansion of the desalting operation is in the planning stages, and may entail either a third desalter and/or the expansion of the existing facilities. The OBMP and Peace 2 agreement call for additional groundwater pumping (more than 12,500 AF per year of pumping, implying at least 11,000 AF per year of desalted product water for the potable supply) to maintain hydraulic control objectives. Total desalter production by 2015 is projected to be 40,000 AF per year.

Annual O&M costs for the current desalting production of 24,600 AF amount to about $12.3 million annually (based on anticipated expenses as detailed in the proposed budget for fiscal year 2007/2008) (CDA 2007). This O&M cost averages to $500 per AF of delivered water.

The total cost per AF of desal water produced (including capital costs) is a bit more complicated to estimate, due to grants, rebates from MWD under the LRP, and other factors. Ignoring the grants and subsidies, and assuming the full $153 million in total capital outlays (to acquire and expand Chino 1, and develop Chino 2) would have been financed with 30-year bonds at a 5% nominal rate of interest, the annualized debt service would amount to about $10 million. This implies a cost of roughly $400 per AF for the annualized full capital expense.

Combining the above estimated total O&M cost with the total annualized capital expense (ignoring grants and subsidies), implies that the desalted water produced by Chino 1 and Chino 2 desalters has a total cost of approximately $900 per AF delivered.

The actual price paid by CDA customers is less than $900 per AF, due to grants that reduced the amount of capital outlay and other fixed costs borne by CDA. The estimated total incurred cost borne by CDA and its customers amounts to $727 per AF (CDA 2007). This implies that the grants supporting construction of the Chino desalters provides a $173 per AF subsidy to local users (~$900 minus $727).

In addition, MWD's LRP offers a $250 per AF rebate to its customer agencies for the development of approved local water supplies. This rebate is provided as an incentive to assist MWD's customer agencies in reducing their demands on increasingly scarce and expensive import water. After accounting for the MWD LRP rebate, CDA can deliver its desalted water for $477 per AF ($727 minus $250).

Integrating Desal With Other Elements of the Water Management Plan

One of the insights to be gleaned from this case study is how desal can be a critical component of a broad and highly integrated approach to regional water resource management, addressing both water quantity and water quality concerns. In the Chino Basin, desal is not simply one water supply option to be evaluated and contrasted to alternative supply options (such as reuse, importation, stormwater harvesting, and conservation). Rather, desal is but one element of a complex, multi-faceted approach that not only draws upon a wide array of alternative supply options, but also requires that these various supply components be carefully integrated in order to increase the value of (or enable the use of) the other supplies.

For example, the groundwater recharge regime is based on the stormwater capture and the reclaimed water programs that supply the recharge water. This groundwater recharge provides the replenishment offset for the desal extractions. Thus, desal implementation may not have been feasible (or would have required other tradeoffs) absent the reuse- and stormwater-enabled recharge program.

In reciprocal fashion, the desal program enables in-basin productive use of the locally-generated reclaimed water for recharge. Prior to the desal program and the associated hydraulic control it provides of the groundwater contamination, reclaimed water produced by IEUA was mostly discharged to the Santa Ana River and captured downstream by OCSD (it could not be used for local recharge in the Chino Basin, since absent the desal-enabled controls, this would have flushed more contaminated water into the Santa Ana River).

The hydrologically-based placements of the recharge and desalting activities are strategically aligned to take advantage of the groundwater gradient, and thus are integral to managing groundwater quality in the basin. The recharge of high quality water upgradient provides a hydrological "push" to help move (as well as dilute) the lower quality groundwater in the downgradient direction. At the same time, the desalter extractions provide the "pull" at the low end of the gradient to control, capture, and treat the poorest quality waters. This accelerates groundwater remediation, while concurrently protecting the Santa Ana River from saline discharges. The desalting also provides a potable supply, and the groundwater quality improvement and management enables higher safe yields to be extractable from the basin.

In addition, the cleansing and hydrologic control of the groundwater basin that is achieved through the integrated deployment of recharge and desalting program elements are necessary for enabling implementation of the MWD conjunctive use and related DYY programs. The DYY program entails the conjunctive use of imported SWP surface waters within the available storage capacity of the Chino Basin. In wet years, when SWP waters are relatively plentiful and relatively low in TDS, MWD covers the costs of storing up to 100,000 AF of its excess SWP supplies in the Chino Basin. In dry years, when SWP supplies are limited and in high demand, the basin's users of imported MWD waters agree to extract stored SWP waters from the basin *in lieu* of taking their allotments from MWD.

The value of the MWD conjunctive use per DYY program is that it frees up scarce SWP waters in dry years, so that MWD can use those limited SWP waters—that otherwise would be delivered to IEUA's wholesale water agencies—to instead satisfy the demands of its other agency customers. This increases the reliability of the SWP supplies for the entire MWD service area (a significant benefit for all of Southern California). This also insulates the basin's users of SWP waters from dry year fluctuations in their imported supply (an important "drought-proofing" benefit within the basin communities).

This valuable DYY program would not be feasible if the desalting and related activities were not in place. The water quality control assured by the integrated desal and recharge programs are what enable the MWD conjunctive use and related DYY program to be implemented.

The above discussion demonstrates how integral the desal program is to the much broader and highly beneficial water resources management program being implemented in the Chino Basin. Desal is linked through the OBMP (Chino Basin Watermaster), Santa Ana Integrated Regional Watershed Management Plan (SAWPA), Chino Basin Maximum Benefit Plan (Santa Ana Regional Water Quality Control Board), Regional Urban Water Management Plan (IEUA), and Recycled Water Program (IEUA) to maximize:

- Local supply development (groundwater, recycled water, desal, storm water capture) to increase locally controlled "drought proof" supplies and balance use of less reliable, more costly imported supplies
- Water quality and investments in local source water protection
- Integration of water supply investments to compliment and enhance other community resources management strategies (storm water management, flood protection, energy, waste management, environmental quality, watershed protection, community education, overall quality of life) (Davis 2005)

Under the OBMP, over $350 million capital improvement projects have been invested from 2000 to 2007 on desalters, recharge improvements, new wells and on-site well head treatment, recycled water distribution systems, and the 100,000 AF conjunctive use storage agreement with MWD (IEUA 2005). Going forward, the Watermaster, CDA, and IEUA have another $250 million investment plan to expand desalters, continue recycled water development, implement new recharge improvements, and expand the MWD conjunctive use storage agreement (R. Atwater, Chief Executive Officer and General Manager, IEUA, personal communication, 2007).

Benefits Generated by the Desalting Program

This section addresses the types and magnitudes of the benefits provided by the inland desalting regime being implemented in the Chino Basin. Within the TBL context, several types and magnitudes of environmental, social, and financial values are enabled by the application of desal, reuse, and related "nontraditional" sources of water supply. The TBL-associated benefits arising from desal reuse and other components of the integrated resource plan outweigh the costs by a factor of over 50% (i.e., a rate of return greater than 50% on investments made in reuse).

The largest financial benefits include the overall basin-wide savings in the cost of providing water over a 30-year period (which amount to nearly US$2 billion, in present value terms). Also included are the magnitude and value of energy savings and the reduced carbon footprint associated with the reuse-enabled groundwater management program. The results are depicted through the series of figures provided below (Figures H.3–H.8).

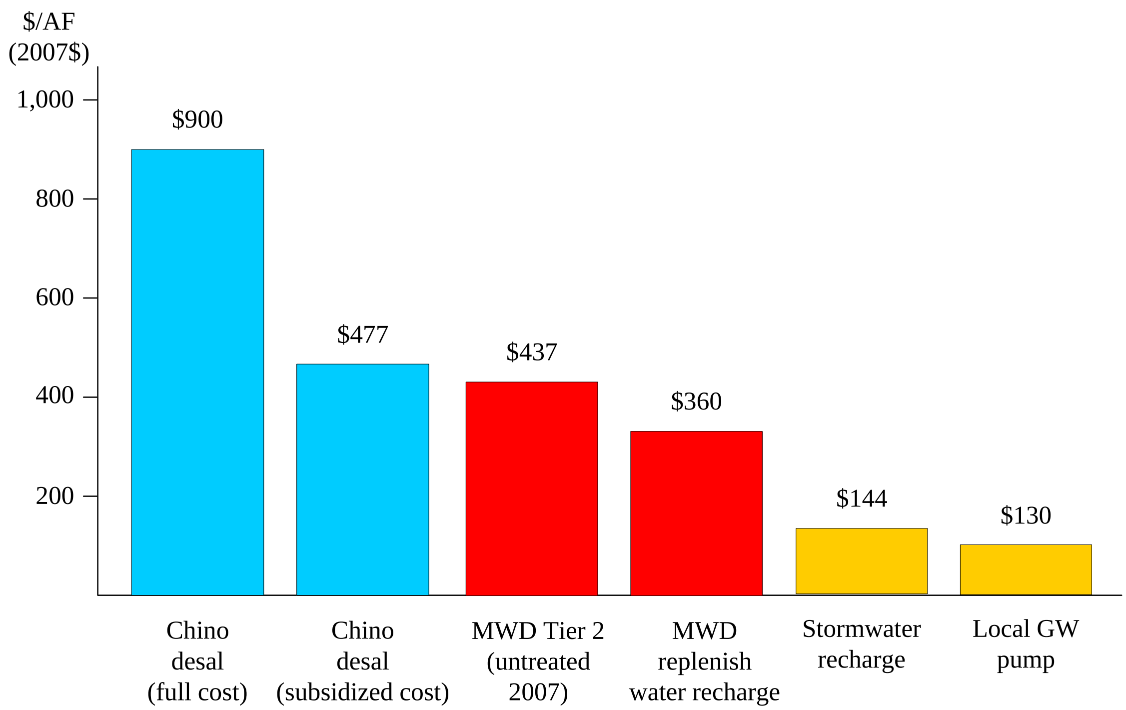

Figure H.3 Desal from a relative cost of water supply perspective

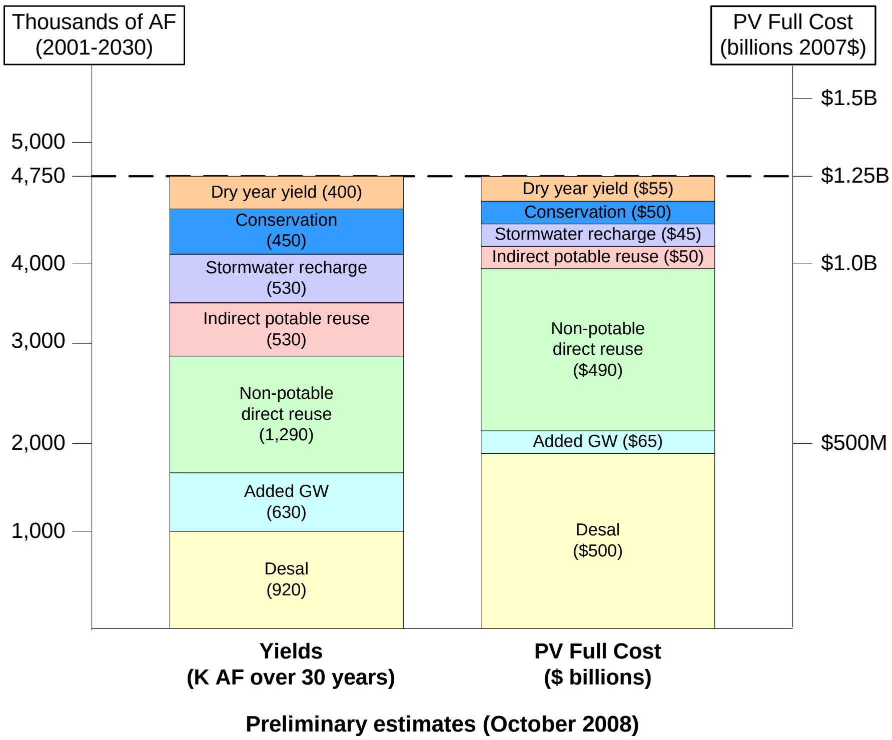

Figure H.4 Components of Chino Basin OBMP

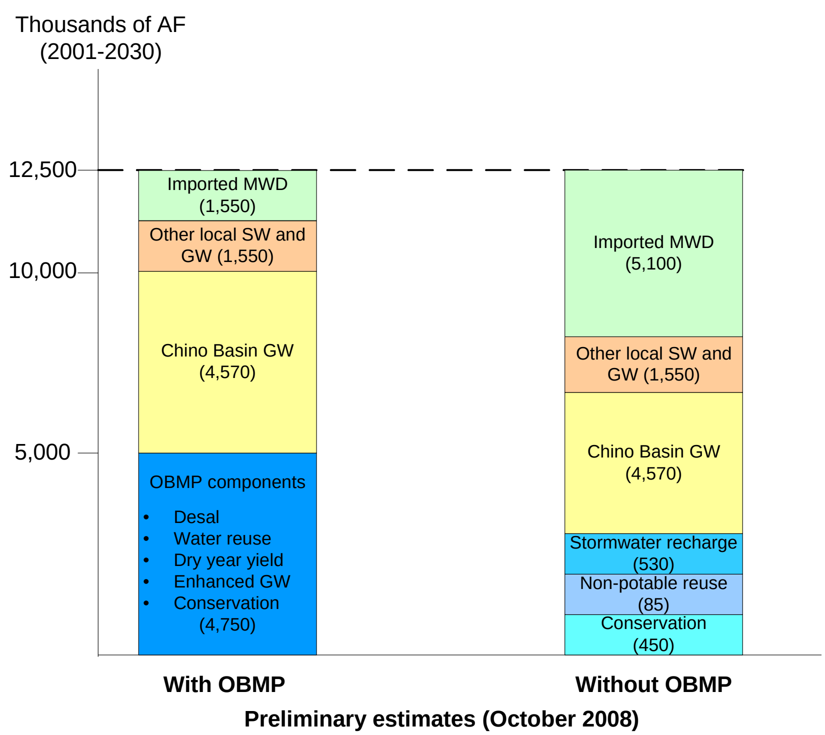

Figure H.5 Chino Basin water supply portfolio with and without OBMP

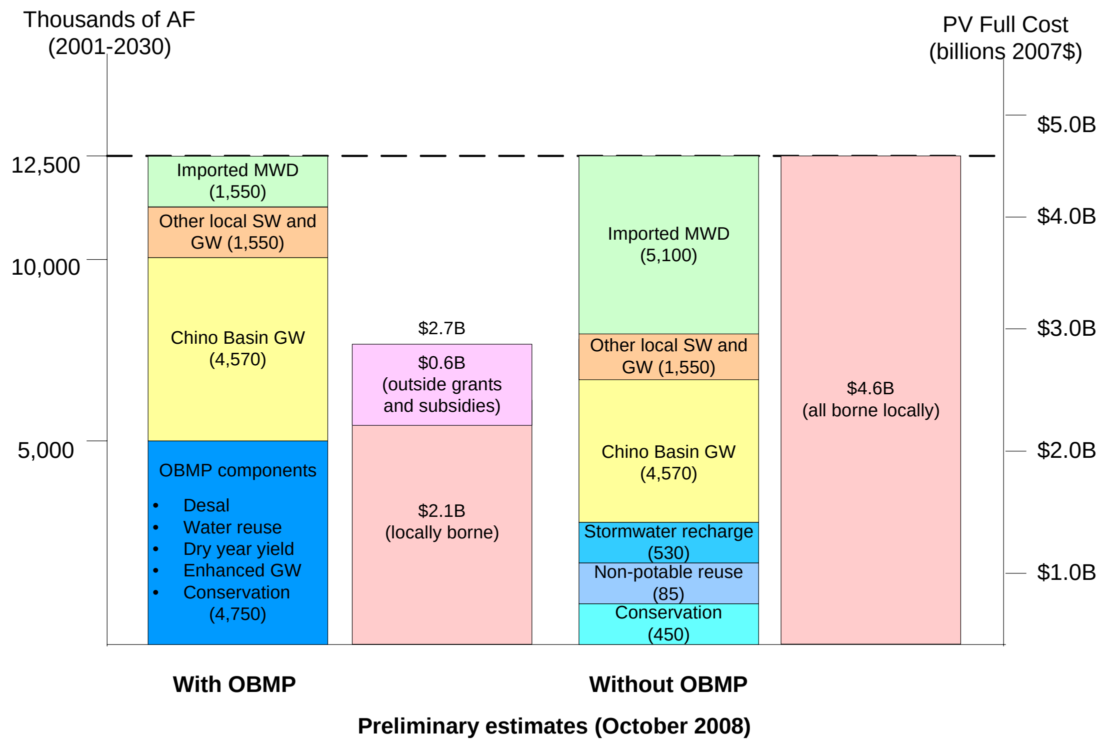

Figure H.6 OBMP reducing basin-wide water supply costs by over 40%

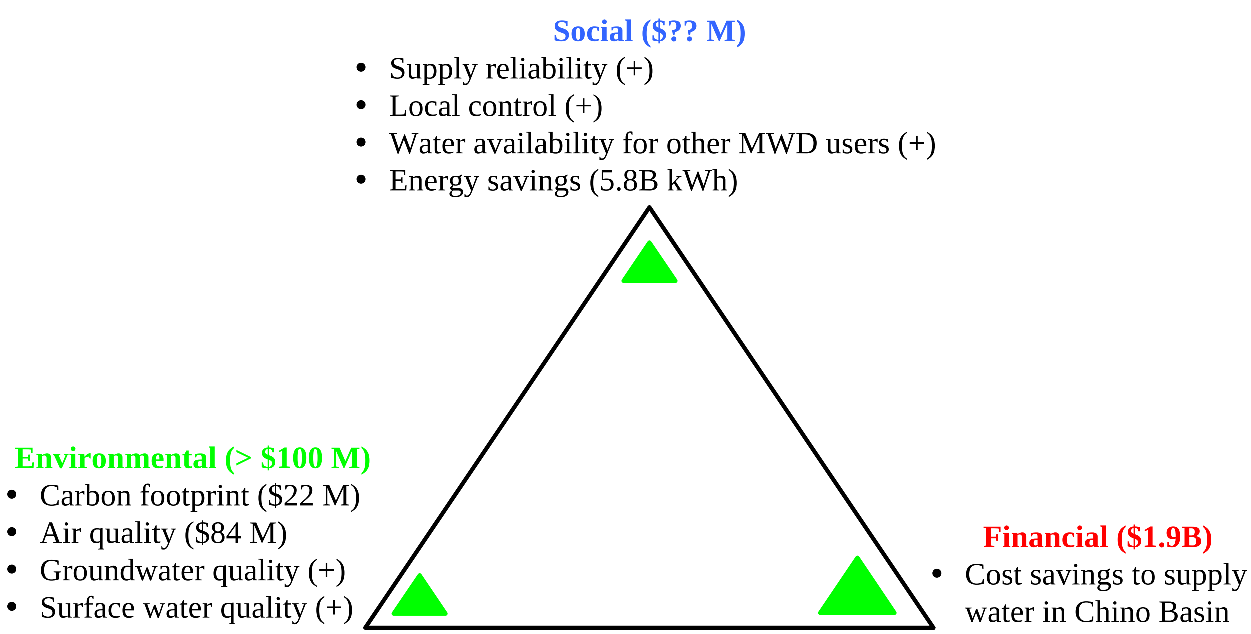

Figure H.7 TBL graphic for OBMP (present value benefit-cost estimates)

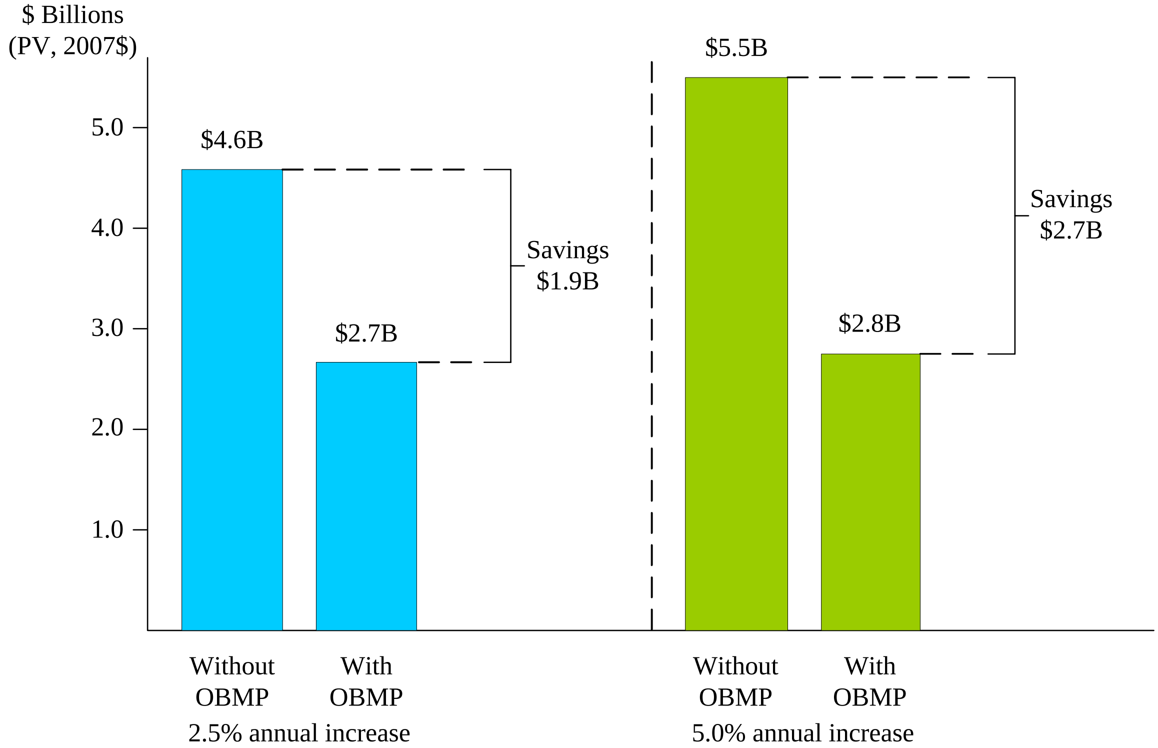

Figure H.8 Impact of MWD annual rate increases on present value water supply costs (2.5% vs. 5.0% real, 2012, and beyond)

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ABBREVIATIONS

AF	acre-foot
AFY	acre-feet per year
AGMD	air gap membrane distillation
aMW	average megawatt
AMWA	Association of Metropolitan Water Agencies
ANSI	American National Standards Institute
AU$	Australian dollars
AWP	American Water-Pridesa, LLC
AWWA	American Water Works Association
bars	100 kilopascals
BAT	best available technology
bgd	billion gallons per day
BMP	Best Management Practices
BOOT	build-own-operate-transfer
BTA	best technology available
BWRO	brackish water reverse osmosis
°C	degrees Celsius
Cal AM	California American Water Company
Caltrans	California Department of Transportation
CASI	Central Arizona Salinity Interceptor
CCA	California Coastal Act
CCC	California Coastal Commission
CD	compact disc
CDA	Chino Basin Desalter Authority
CDFG	California Department of Fish and Game
CDHS	California Department of Health Services
CDI	capacitive deionization
CDP	Coastal Development Permit
CDPH	California Department of Public Health
CDWR	California Department of Water Resources
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulation
CHP	combined heat and power
CII	commercial, institutional, and industrial
CIWR	Center for Integrated Water Research
CNT	carbon nanotube
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalents
CPI	Consumer Price Index
CPUC	California Public Utilities Commission

CT	contact time
CWA	Clean Water Act
CWP	Coastal Water Project
DB	design-build
DBB	design-bid-build
DBO	design-build-operate
DBOOT	design-build-own-operate-transfer
DBP	disinfection byproduct
DC	direct current
DCMD	direct contact membrane distillation
DE	diatomaceous earth
DEP	Department of Environmental Protection
desal	desalination
DP_3RO^{TM}	double pass, preferential precipitation, reverse-osmosis process
DRA	Division of Ratepayer Advocates
DWEER	Dual Work Exchanger Energy Recovery
DYY	Dry Year Yield
ED	electrodialysis
EDC	endocrine disrupting compound
EDI	electrodeionization
EDR	electrodialysis reversal
EIA	Environmental Impact Assessment
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
EMF	electromagnetic field
ENP	Emergency Notification Plan
EPC	engineering, procurement, and construction
EPWU	El Paso Water Utilities
ERD	energy recovery device
ERP	Environmental Resource Permit
EU	European Union
EWP	Electronic Water Purifier
°F	degrees Fahrenheit
FAC	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
FO	forward osmosis
ft	feet
GATT	General Agreement on Tariffs and Trade
gfd	gallons per square foot per day
GHG	greenhouse gas
gpd	gallons per day
gpm	gallons per minute

gpm/ft^2	gallons per minute per square foot
g/L	grams per liter
HB	House Bill
HDD	horizontal directional drilling
HEEPM	High Efficiency Electro-Pressure Membrane
HERO™	High Efficiency reverse osmosis
ICCS	intermediate concentrate chemical stabilization
IDA	International Desalination Association
I&E	impingement and entrainment
IEUA	Inland Empire Utilities Agency
IMS	integrated membrane system
IX	ion exchange
kg	kilogram
kgal	thousand gallons
km	kilometer
kPa	kilopascal
kWh	kilowatt hour
kWh/kgal	kilowatt hours per thousand gallons
kWh/m^3	kilowatt hours per cubic meter
LBWD	Long Beach Water District
LCA	Life Cycle Analysis
LLNL	Lawrence Livermore National Laboratory
LRP	Local Resource Program
LT2	Long Term 2
m	meter
m^3	cubic meter
MCL	Maximum Contaminant Level
MCWD	Marina Coast Water District
m^3/d	cubic meters per day
MD	membrane distillation
MED	multiple effect distillation
MF	microfiltration
mgd	million gallons per day
mg/L	milligrams per liter
mi	mile
M&I	municipal and industrial
mm	millimeter
MMWD	Marin Municipal Water District
MRWMD	Monterey Regional Waste Management District
m/s	meters per second
MSF	multi-stage flash

MW	megawatt
MWD	Metropolitan Water District of Southern California
MWDOC	Municipal Water Management District of Orange County
MWh/yr	megawatt-hours per year
µm	micrometer
NAFTA	North American Free Trade Agreement
NEPA	National Environmental Policy Act
NF	nanofiltration
NF^2	two-pass nanofiltration
NMFS	National Marine Fisheries Service
NOAA	US National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NSF	National Science Foundation
n-ZLD	near zero-liquid discharge
OBMP	Optimum Basin Management Program
OCSD	Orange County Sanitation District
OEM	original equipment manufacturer
O&M	operation and maintenance
OTC	once-through cooling
PDF	portable document format
PhAC	pharmaceutically active compound
PIM	Planning Issues Matrix
ppm	parts per million
psi	pounds per square inch
psig	pounds per square inch gauge
PX	pressure exchanger
QA/QC	quality assurance/quality control
RAC	Research Advisory Committee
RCRA	Resource Conservation and Recovery Act
R&D	research and development
REC	renewable energy credit
REPOG	Regional Plenary Oversight Group
RO	reverse osmosis
RWQCB	Regional Water Quality Control Board
SARI	Santa Ana Regional Interceptor
SAWPA	Santa Ana Watershed Project Authority
SDI	silt density index
SDWA	Safe Drinking Water Act
SGMD	sweeping gas membrane distillation

SPARRO	slurry precipitation and recycling reverse osmosis
SRP	Salt River Project
SSDP	Southern Desalination Plant
SWP	State Water Project
SWPPP	Stormwater Pollution Prevention Plan
SWRO	seawater reverse osmosis
SWTR	Surface Water Treatment Rule
TAC	Texas Administrative Code
TBL	Triple Bottom Line
TBW	Tampa Bay Water
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TENORM	technologically enhanced, naturally occurring radioactive material
TFC	thin-film composite
TGWTP	Thames Gateway Water Treatment Plant
TMDL	total maximum daily load
TMF	Technical, Managerial, and Financial
TOC	total organic carbon
TSCA	Toxic Substances Control Act
TSS	total suspended solids
UF	ultrafiltration
UIC	Underground Injection Control
UK	United Kingdom
US	United States
US$	United States dollars
USACOE	US Army Corps of Engineers
USBR	US Bureau of Reclamation
USDW	Underground Source of Drinking Water
USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service
UV	ultraviolet
VC	vapor compression
VMD	vacuum membrane distillation
VOC	volatile organic chemical
VSEP	vibratory shear enhanced process
WAC	weakly acidic cationic
WA EPA	Western Australia Environmental Protection Authority
WBMWD	West Basin Municipal Water District
WCWTP	Western Canal Water Treatment Plant
WDR	Waste Discharge Requirement
WET	Whole Effluent Toxicity
WFMCC	Water for Monterey County Coalition

WHO	World Health Organization
WMD	Water Management District
WTP	willingness to pay
WWTP	wastewater treatment plant
yd	yard
yr	year
ZLD	zero-liquid discharge

Guidelines for Implementing Seawater and Brackish Water Desalination Facilities

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