The importance of pilot studies in the development of large-scale seawater desalination plants

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Introduction

Development of one or more large-scale seawater desalination plants in the State of Texas will provide a sustainable source of drinking water and represents a key component of alternative water resources planning for the future. Planning and implementation of a seawater desalination plant represents a significant infrastructure project and requires positive action in the areas of funding, environmental considerations, public involvement, design, permitting and others. A fundamental but vital method used to obtain the information that is needed in these areas is the execution of a field demonstration test of the desalination technology, known as a 'pilot study'.

While certain planning decisions and cost estimates can be made through 'paper' or 'desktop' assessments, there are certain limitations on the level of accuracy and degree of guarantee that can be provided through a 'paper-only' assessment. Pilot studies provide the opportunity to evaluation the performance of proposed treatment systems under site-specific conditions.

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 estimates, and a more accurate understanding of the viability of a proposed project.

This Chapter describes the importance of pilot testing for development of large-scale seawater desalination projects in Texas including a 'roadmap' for pilot study implementation. The investment in a pilot study typically represents less than 1% of the total costs of a seawater desalination plant. 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.

Pilot Study Description – What is a Pilot Study?

Seawater desalination 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 desalination process, and a polishing desalination process. Pilot studies are configured to simulate the complete proposed treatment process train. Testing is conducted using the source water under consideration. For example, the projects currently under development in Texas are considering mixed seawater/surface water sources. The unique raw

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water quality at each of the proposed locations further supports the need for site-specific pilot testing.

Pilot testing is most effective when performed over the course of a 12-month period, to capture seasonal effects of the source water. For example, dry season testing typically requires the highest operating pressures due to higher salinity. Wet season testing is typically the most challenging for pretreatment processes due to higher suspended solids and organic levels associated with surface water runoff.

Pilot testing may be performed multiple times through the course of a project. A one-year pilot test is commonly performed as part of planning efforts to define items such as costs, design alternatives, environmental factors, and other items. 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. 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.

Tampa Bay Water, for example, is conducting a one-year pilot study as part of the planning process associated with its proposed Gulfcoast Desalination Project. Subsequent to bidding, it is expected that vendors will further pilot test to refine their approaches to meeting bid criteria. The proposed desalination project at Carlsbad, California also involves a pilot study initiated in 2002 that is expected to operate through startup of the full-scale seawater desalination facility.

To provide reasonable and scalable data, pilot equipment should represent production-sized unit processes. For a reverse osmosis process, this would consist of a pressure vessel containing approximately 6-8 membrane elements. These elements would be either 4-inch diameter by 40-inch long or 8-inch diameter by 40-inch long. These are the commercial reverse osmosis element sizes used in large-scale municipal drinking water facilities throughout the United States.

Smaller scale equipment, such as lab-scale or bench-scale, may be used to refine decisions on how a pilot study will be structured or to answer certain questions in the very early stages of a project. However, only a pilot study provides scalable results using commercial-sized equipment and is a primary source of information for finalization of planning activities.

Operation of pilot equipment is typically continuous, seven days per week, through the completion of the study. Performance and water quality data are collected and integrated into planning efforts. The following section describes the purposes and uses of this data.

Pilot Study Objectives – What Does a Pilot Study Provide?

Seawater desalination planning 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 effort including the areas listed below:

1. Intake Siting/Source Water Selection
2. Pretreatment Design
3. Desalination Design
4. Finished Water Quality
5. Environmental Considerations
6. Permitting
7. Public Outreach
8. Costs/Funding

Intake Siting

Pilot testing at a selected location using a proposed treatment process train represents a 'proof of concept' evaluation. Intake siting is importance since it directly determines the quality of raw water and subsequent treatment requirements. An offshore intake will provide a more consistent salinity and less influence from surface water runoff and tidal changes. However, intake piping distances and costs as well as permitting efforts can be minimized by use of existing intakes such as at power plants or construction of new, near-shore intakes. These cost and permitting efficiencies must be balanced with potentially increased requirements of the pretreatment systems to condition water with higher suspended solids concentrations, natural organic matter concentrations and temperature. For example, using higher temperature power plant cooling water discharges has the potential to increase biological fouling and will increase salt passage through a reverse osmosis system. The relative significance of these effects must be determined as part of selecting such an intake.

An acceptable level of pretreatment required for one intake location versus another may be difficult to determine at 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. One outcome can be determination of the impacts of shipping channel traffic on raw water quality. Shipping channel traffic stirs up sediments and has impacted raw water quality at the 25 MGD Tampa Bay Desal I project as well as the 29 MGD seawater facility in Trinidad. All currently proposed seawater desalination projects in Texas include use of near-shore intakes thus would benefit from quantification of the impact of the raw water source on pretreatment needs.

Pretreatment Design

Pretreatment system designs can vary considerably and directly affect water treatment plant (WTP) sustainability. The primary issue associated with operations of the Tampa Bay Desal I plant has been the poor performance of the pretreatment system and the resulting RO system fouling. Pretreatment system approaches are undergoing a rapid change in the industry and represent the most significant design consideration in a seawater desalination facility. Multimedia filtration and membrane filtration options are two competing approaches with the optimal solution remaining a project-specific answer. Pilot studies provide direct comparison of different pretreatment technologies. In 2003 and 2004, alternative pretreatment assessments are

or will be performed as part of pilot studies for the Tampa Bay Water Gulfcoast Desalination project, Marin County California desalination project, US Bureau of Reclamation desalination research program (San Patricio, TX; Cape Canaveral, Florida), and Poseidon Resources Carlsbad California desalination project. A four-season pilot study provides an opportunity to evaluate alternative pretreatment processes over varying raw water quality conditions to confirm the sustainability of the treatment process train.

Desalination Design

Desalination system designs involve decision-making relative to a number of design criteria such as flux and recovery. The selection of a design approach involves balancing competing interests to develop an optimal WTP that meets all project objectives such as those related to costs, permitting and environmental considerations. For example, a higher water recovery on an RO system reduces the size and cost of the upstream pretreatment system but requires a higher pressure and associated electrical costs for pumping of the water through the RO system. Draft design criteria are typically 'proof-tested' at pilot-scale to validate the design concept. In addition, design criteria can be varied at pilot-scale, results assessed, and the final design optimized. This can result in project cost savings, improved potential to meet permitting requirements, or other project benefits.

Finished Water Quality

Finished water quality is an area of interest particularly to larger-scale regional desalination facilities planned for the State of Texas. With regulations becoming more stringent and consumers more conscious of drinking water quality issues, water providers are expected to produce higher quality finished water. For regional providers in Texas, use of desalinated seawater will likely mean blending of desalination finished water with an existing drinking water source. Blending of two different treated waters can and has resulted in distribution system water quality problems for some US communities such as Tucson, Arizona. These re-equilibration effects have included increased corrosion, red color and taste and odor releases. Pilot testing can confirm that the water quality goals for a proposed desalination facility will be met. In addition, the water from the pilot study can be used to perform distribution system blending studies. 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 reverse osmosis WTPs include the City of Clearwater, Florida, Tampa Bay Water, and others.

Environmental Considerations

Environmental considerations associated with a large-scale seawater desalination plant in Texas will include assessing the effects of discharge of high salinity desalination concentrate. The primary concentrate management approach under consideration in the State of Texas is discharge of concentrate into the coastal areas of the Gulf of Mexico. Discharge back to the source water is the standard approach to concentrate management for seawater facilities but will require an

assessment of environmental impacts. Addition of chemicals as part of the desalination process will be of particular interest relative to environmental impacts. A pilot study provides the opportunity to define the fate and transport of chemical constituents through the treatment process train. For example, while iron coagulants may be added as part of the pretreatment process, the resulting iron sludge is typically dewatered and disposed of in a landfill, consistent with the approach used in conventional surface water treatment plants. Pilot testing provides the opportunity to document the effectiveness of the iron removal process and other environmental-related concerns.

Permitting

Permitting of a large-scale seawater desalination system will require close coordination with Texas Commission on Environmental Quality (TCEQ). TCEQ requires a pilot study as part of its approval of a membrane WTP. A pilot study protocol must be submitted to and approved by TCEQ prior to initiation of a pilot study. Refer to TCEQ Guidance Documents - Review of Pilot Study Protocols for Membrane Filtration effective April 1, 2004 and Review of Pilot Study Reports for Membrane Filtration effective April 1, 2004 for more information. The three active seawater initiatives, located in Freeport, Corpus Christi, and Brownsville, are based on reverse osmosis membrane technology and would be required to meet TCEQ membrane criteria, particularly since these facilities are slated to treat coastal source waters with the potential for pathogen contamination from surface water runoff.

In addition, discharge of desalination concentrate to coastal waters, as is planned for all three facilities, will require a National Pollutant Discharge Elimination System (NPDES) permit. NPDES permitting is designed to protect the environment with regards to discharge of wastes to receiving water bodies such as the Gulf of Mexico and the affiliated estuary and bay areas. Characterization of concentrate water quality through operation of a pilot system will likely be required by TCEQ as part of the NPDES permitting process. Water quality sampling of concentrate through a pilot study will provide direct and quantitative information on the characterization of the proposed discharge.

An additional permitting component is the characterization of spent cleaning solutions used to restore membrane system performance. Reverse osmosis membrane systems can foul with time and require periodic chemical cleanings using solutions that may contain caustic, acid, surfactants, detergents or chelating agents. Determining the acceptability of discharge of these spent cleaning solutions to the sanitary sewer or other location is commonly facilitated through collection and analysis of spent cleaning solutions associated with a pilot study.

Public Outreach

Public involvement and outreach will be an element of any and all seawater desalination projects in the State. Common questions regarding seawater desalination systems include the level of chemicals to be employed and the characteristics of the concentrate generated. A functional and operational pilot system that can be toured by the public can be one of the most effective methods to fully and effectively provide information regarding the proposed seawater desalination project. Aquariums using seawater desalination concentrate generated from a pilot-

scale system are also useful for documentation of the characteristics and environmental compatibility of concentrate.

Costs and Funding

One of the key issues when developing a seawater desalination 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 resulting knowledge and information is fed back into the project costing effort. As a result of these efforts, capital and operating cost estimates become better defined and more 'real'. The ability to more accurately assess total project costs is one of the most important benefits resulting from a pilot study.

Roadmap to Pilot Study Implementation – How to Get Started

Seawater desalination pilot studies have or are being conducted in various locations throughout the United States including San Patricio, TX; Cape Canaveral, FL; Holiday, FL; Apollo Beach, FL; and Carlsbad, CA. Many additional communities are preparing for pilot studies as part of the planning and preliminary engineering phases of seawater desalination projects. The lessons learned in these locations can readily be applied to the large-scale seawater desalination facilities being planned in the State. Based on these and other projects, the following roadmap to implementing a pilot study has been developed.

Site Selection

Selection of a project area is typically one of the first aspects of defining a project and has in fact been completed for the three current large-scale seawater desalination facilities under consideration in the State. Following area selection, the specific location of an intake is determined. This may involve consideration of a multi-mile pipeline to the Gulf of Mexico, use of power plant cooling water, or near-shore intakes. Typically, pilot testing is performed on a single preferred intake location thus intake selection should be completed before pilot testing proceeds.

Development of Design Concept

Concurrent with intake selection is the development of the general design concept for the proposed seawater desalination facility. This typically results in identification of the key components associated with the treatment process train as well as items that cannot be determined at desktop level and would benefit from a pilot study. The design concept or preliminary design is necessary for initial project cost estimating. Below is an example methodology for development of a seawater desalination design concept.

1. Historical Source Water Quality Data. The purpose of this task is to generate an understanding of raw water quality based on historical data. Existing data should be integrated into the project through collection and review of relevant information including data from Texas Water Development Board (TWDB), US Geological Survey (USGS), and TCEQ. This information will be utilized to determine raw water quality of the seawater and to support the assessment of the future infrastructure needs for the proposed seawater treatment plant.

2. Source Water Sampling. The purpose of this task is to obtain any additional raw water quality data necessary for development of the seawater desalination design concept. Based on review of existing raw water quality data, a sampling plan and matrix to address additional data needs should be developed. Samples should be collected for parameters that affect finished water quality, drinking water regulatory compliance, aesthetic concerns, and selection and design of a treatment facility. In addition TCEQ requires sampling and analyzes of specific parameters in the source water for any new surface water treatment plant.

3. Finished Water Quality Goals. The purpose of this task is to identify the finished water quality goals and establish a plan for long-term regulatory compliance. For regional water suppliers, this will likely include establishment of finished water quality goals that exceed regulatory standards, due to the need to generate a finished water that is compatible with other existing finished waters. For example, Tampa Bay Water has established a chloride limit of 100 mg/L in its desalinated finished water, well below the secondary standard of 250 mg/L and is considering lowering this to 35 mg/L in the future. The purpose is to match existing finished water quality in its member governments distribution systems and minimize re-equilibration effects.

   This task consists of a regulatory review of the federal and state drinking water quality standards for use in developing water quality goals for the seawater treatment plant project. The review should include all State and Federal rules, including the Safe Drinking Water Act, D/DBP Rule, the Surface Water Treatment Rule and its amendments and all Texas rules and regulations regarding treatment of Surface Water supplies for drinking water purposes. A final finished water quality goal will be established that drives the level of treatment necessary and should be established through discussions with water supply managers to confirm that long-term water quality goals will be met. It is important to note that the finished water quality goals have a direct and potentially significant effect on final project costs and should be considered carefully when being developed.

4. Design Concept. A desktop assessment will then be performed to develop a conceptual design for the seawater treatment system. This will include summarizing the various options for treatment of the seawater in order to address key treatment criteria and meet all finished water quality goals. A series of factors will be considered including relative treatment capabilities, capital and O&M costs, ease of operation, accepted technology and other factors. Based on these factors, various process trains will be developed and compared to the key treatment criteria. The product of this effort should be identification

of one or more acceptable process trains, budget-level costs, preliminary design criteria for each process train, and recommendations for pilot testing.

Pilot Study Protocol

Based on the design concept, with associated selected treatment process train(s), a pilot study protocol can be developed. The pilot testing protocol will be based on the process trains and their preliminary design criteria as determined in the development of the design concept. The pilot study protocol should be consistent with TCEQ Guidance Document - Review of Pilot Study Protocols for Membrane Filtration effective April 1, 2004. The protocol for operation of the pilot study will address the parameters to be analyzed, equipment to be tested, frequency of water quality sampling, operational procedures, the start-up/shut-down/cleaning procedures, and testing matrix.

During development of the pilot study protocol, the overarching objectives of the pilot study should be considered. While a pilot protocol will define equipment and testing procedures, a pilot study represents a significant investment and can be leveraged to meet multiple project objectives as defined previously herein. For example, at this stage in pilot study implementation the role of the pilot relative to public outreach should be determined. Some communities obtain a drinking water permit for their pilot system, bottle the water, and distribute it to the community during public workshops on the project. These and other objectives of the pilot should be clearly defined and understood, above and beyond the operational and logistical details that are identified in a pilot study protocol.

Pilot Study

Based on the overarching objectives of the pilot study and the details presented in the pilot study protocol, a pilot study can be implemented. The following information provides considerations relative to actual mobilization and operation of a pilot study:

1. Site Logistics. The site host is typically a power generation company or a municipal water supplier. Depending upon the draft agreements regarding the role of a site host, they may or may not be primary participants in the development of the seawater desalination facility. It is important that the role of the site host be understood prior to mobilization of equipment. Use of facilities, heavy equipment, and other resources is beneficial to pilot mobilization and operation but a clear agreement must be fashioned in advance.

2. Pilot Equipment. Pilot equipment typically includes raw water pumps, various transfer pumps and holding tanks, pretreatment systems (typically multimedia filters or membrane filters), first and second pass reverse osmosis systems, chemical cleaning systems, and periphery equipment such as storage sheds, lab area, waste piping, etc. Primary treatment equipment such as the reverse osmosis system can be trailerized, located in a temporary prefabricated building, or in a permanent structure at the site if one is available.

3. Duration. The duration of testing is to be sufficient to capture seasonal effects and develop adequate data for finalization of design criteria. TCEQ requires at least a 90-day period of pilot testing for a reverse osmosis seawater treatment plant. It is likely that longer testing would be performed, on the order of one year, for any large scale seawater desalination facility.

4. Treatment System Configuration. All components of the proposed full-scale seawater plant are to be pilot tested and therefore include all chemical injections used for pretreatment, SWRO treatment, post-treatment and disinfection process. Pilot equipment typically includes alarms and on-line data logging of key parameters.

5. Operations. Based on pilot testing of the process trains and the numerous experiments and sampling that will occur, full time staffing is typically required. It is important that adequate, dedicated resources are made available to the pilot facility. 'Sharing' of operations personnel between the pilot study while keeping their regular municipal water treatment obligations can result in deficiencies in pilot data collection and pilot maintenance. Personnel should be dedicated to the assignment through completion of the study.

6. Data Reporting and Interpretation. 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 biweekly basis. Instructions to field staff should be provided biweekly 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 can not be rectified after the fact. Therefore adequate and expert engineering resources should be applied to oversight of the pilot study and the results. All water quality sampling will be performed by field staff and analyzed on-site or shipped to outside laboratories. Designated pilot operations staff should perform calibration of instrumentation, maintenance of equipment, and data collection.

7. Final Report. Based on pilot study results, a final pilot study report should be generated that meets overarching project objectives and complies with TCEQ requirements. Refer to TCEQ Guidance Document - Review of Pilot Study Reports for Membrane Filtration effective April 1, 2004 for more information on TCEQ requirements. The pilot study report should contain information that supports updated cost estimates, permitting efforts, final design, public outreach, and other objectives of the project.

Pilot Study Costs

Pilot study costs can vary widely depending upon the degree to which other, upfront planning activities have been completed. However, based on the assumption that intake selection and development of the design concept are complete, the cost for a one-year seawater desalination pilot study typically ranges from $600,000 to $1.5M.

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, with the 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, the $600,000 to $1.5M expenditure associated with a pilot study represents less than 1% of the total project costs associated with a large-scale seawater desalination plant while providing some of the most valuable information to further the development of such a facility.

The Importance of Pilot Studies

Development of a large-scale seawater desalination facility requires a clear project vision as well as successful execution of many associated details. 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.

Regardless of the point in the planning process, a pilot study will be performed for all large-scale seawater desalination projects in the State, per TCEQ requirements. However, the timing of implementation, the scope of the study and the value obtained from the pilot study can vary from project to project. The information presented in this Chapter has been designed to illustrate the potential role of pilot studies in the implementation of large-scale seawater desalination facilities in the State of Texas.