CITY OF SANTA CRUZ

Final Report for the Proposition 50 Grant: Test Technology Innovations and Optimize Systems in the City of Santa Cruz Pilot Plant

Prepared for:
California Department of Water Resources, Office of Water Use Efficiency
1416 Ninth St., Room 338, Sacramento, CA 95814

Prepared by:
City of Santa Cruz Water Department
212 Locust St., Santa Cruz, CA 95060

DEPARTMENT OF WATER RESOURCES STATE OF CALIFORNIA

INSTITUTE OF MARINE SCIENCES UNIVERSITY OF CALIFORNIA, SANTA CRUZ

SOQUEL CREEK WATER DISTRICT

scwd² Collaborating to conserve, protect and create reliable water resources

Final Report

Date of Report: April 11, 2011

Project Information

Agreement Number:	4600004123
DWR ID Number:	029
Project Title:	TEST TECHNOLOGY INNOVATIONS AND OPTIMIZE SYSTEMS IN THE CITY OF SANTA CRUZ PILOT PLANT
Start/End Dates:	December 7, 2005 – September 30, 2010
Recipient Organization:	City of Santa Cruz Water Department 212 Locust Street, Suite C Santa Cruz, CA 95060
Partners:	City of Santa Cruz
Contact Person:	Heidi R. Luckenbach City of Santa Cruz Water Department 212 Locust Street, Suite C Santa Cruz, CA 95060
Grant Awarded:	**$1,982,601**
Total Cost of Project:	**$5,611,717**
Date Submitted:	April 11, 2011

Heidi R Luckenbach — April 11, 2011

Signed, Reviewed by Heidi Luckenbach, Project Manager — Date

Table of Contents

Acknowledgements

The Santa Cruz Water Department wishes to thank the taxpayers of the State of California for funding the Proposition 50 Water Quality, Supply and Safe Drinking Water Projects Act. Funds from Proposition 50 in the amount of $1,982,601 were awarded to the Santa Cruz Water Department for the pilot plant test program. SCWD is grateful to Nancy King and Fethi Ben Jemaa for their supportive management of the grant while administering the award through the California Department of Water Resources Office of Water Use Efficiency.

The Santa Cruz Water Department also wishes to acknowledge the valuable contributions of the Soquel Creek Water District, the **scwd^2** Task Force, and CDM in conducting the Seawater Reverse Osmosis Desalination Pilot Test Program. Specifically, SCWD would like to acknowledge the efforts of:

Soquel Creek Water District

Laura Brown, General Manager
Melanie Mow Schumacher, Public Information Coordinator

City of Santa Cruz Water Department

Bill Kocher, Director
Linette Almond, Engineering Manager
Terry Tompkins, Operations Manager
Heidi Luckenbach, Program Coordinator
Hugh Dalton, Water Quality Manager
Terry McKinney, Superintendent of Water Production
Catherine Borrowman, Professional and Technical Assistant

scwd^2 Task Force

Ryan Coonerty
Bruce Daniels
Bruce Jaffe
Dan Kriege
Thomas LaHue
Don Lane
Cynthia Mathews
Mike Rotkin
Ed Porter

Camp Dresser & McKee Inc.

Paul Meyerhofer, Senior Vice President
Erik Desormeaux, Project Engineer

SCWD wishes to thank the Seymour Discovery Center and the Long Marine Laboratory at the UCSC Marine Science Campus for their assistance and cooperation during the pilot test program.

Glossary of Terms and Abbreviations

CEB	chemically enhanced backwash
CIP	clean-in-place
DAF	dissolved air flotation
DBP	disinfection by-product
DOC	dissolved organic carbon
DOC:N ratio	dissolved organic carbon to nitrogen ratio
DPH	California Department of Public Health
DWR	Department of Water Resources
gfd	gallons per square foot per day (unit of flux)
GHWTP	Graham Hill Water Treatment Plant
gpm	gallons per minute
gpm/sf	gallons per minute per square foot (unit of filtration rate)
GMF	granular media filters
HAA	haloacetic acids
HAB	harmful algal blooms
HR	high rejection
IRP	Integrated Resources Plan
IWP	Integrated Water Plan
kWh	kilowatt hour; a unit of electrical energy
LCR	Lead & Copper Rule
LE	low energy
LML	Long Marine Laboratory
LPRO	low pressure reverse osmosis
MCL	maximum contaminant level
MDL	minimum detection limit
MF	microfiltration
mg/L	milligrams per liter
mgd	million gallons per day
N	total nitrogen
O&M	operation and maintenance
RO	reverse osmosis
RWQCB	Regional Water Quality Control Board
Salt rejection	The measure of salts removed by the RO desalination process based on the reduction of total dissolved solids, which is a parameter used to measure salinity
SCADA	Supervisory Control and Data Acquisition
SCWD	Santa Cruz Water Department
SqCWD	Soquel Creek Water District
scwd²	Seawater Desalination Program Task Force with members from local governing bodies: the Santa Cruz City Council and the Soquel Creek Water District Board.

SDI	silt density index; this is a measurement of a water sample's potential to cause plugging of RO membranes
SSF	slow sand filters
SWRO	seawater reverse osmosis
SWTR	Surface Water Treatment Rule
TDS	total dissolved solids
THM	trihalomethanes
TM	technical memorandum
TOC	total organic carbon; measure for the total organically bound carbon
TTHMs	total trihalomethanes
UF	ultrafiltration
UV	ultraviolet disinfection
μg/L	micrograms per liter
WTP	water treatment plant
WWTF	wastewater treatment facility

List of Tables

List of Figures

List of Appendices

Section 1: Project Description

1. **Project Type:** Pilot or Demonstration Project
2. **Project Title:** Test Technology Innovations and Optimize Systems in the City of Santa Cruz Desalination Pilot Plant
3. **Start/End Dates:** December 7, 2005 – September 30, 2010
4. **Grantee Information:** City of Santa Cruz Water Department
   212 Locust Street, Suite C
   Santa Cruz, CA 95060
5. **Contact Person Information:** Heidi R. Luckenbach
   City of Santa Cruz Water Department
   212 Locust Street, Suite C
   Santa Cruz, CA 95060
   831.420.5214
6. **Grant Awarded:** $1,982,601
7. **Total Cost of Project:** $5,611,717
8. **Agreement No.** 4600004123
9. **DWR ID:** 029

Figure 1. Stanford University Students, August 19, 2008

Section 2: Executive Summary

Introduction

The City of Santa Cruz undertook a project to build a seawater reverse osmosis desalination pilot plant in order to meet a number of objectives. The primary focus of the pilot program was to test technology innovations and establish the optimum design and operational settings for a full-scale seawater desalination plant. A secondary objective was to use the desalination pilot plant as an educational tool to engage the general public by making seawater desalination technology transparent and accessible. The pilot plant was located at the University of California, Santa Cruz Long Marine Laboratory (LML), next to the Seymour Marine Discovery Center.

Project Purpose

From March 2008 through April 2009, a comprehensive pilot plant test program was conducted to evaluate alternative treatment systems for a seawater reverse osmosis (SWRO) desalination plant. The pilot plant treated up to 50 gallons per minute of seawater supplied from the LML's existing open ocean intakes. The testing results demonstrated to the community members and public officials who toured the facility that seawater desalination will be a safe and reliable source of supply for the City of Santa Cruz Water Department and the Soquel Creek Water District residents.

Main Findings & Conclusions

Reverse Osmosis Membrane Testing

The desalination process reliably produced drinking water from seawater with RO membranes from four different manufacturers. There were up to 8 membrane elements per train, and 2 skids, each with 2 independent RO trains. A single-stage SWRO system with a hybrid SWRO membrane combination of both HR (high rejection) and LE (low energy) will achieve water quality goals and require the least amount of energy. Three different RO membrane system alternatives were tested at the pilot plant. The actual test results were supplemented with computer projections for water quality performance and energy use. The testing and computer projections determined that two-stage (low pressure reverse osmosis) LPRO/SWRO configuration did not meet boron and bromide water quality goals, while the single-stage SWRO with a HR and LE combination and single-stage SWRO plus partial second pass LPRO configurations did meet these goals.

Source Water Quality Characterization

Water quality monitoring results showed that the seawater supply to the pilot desalination plant did not have higher than anticipated concentrations of inorganic, organic, and microbial contaminants, including algal toxins and pharmaceutical and personal care products. An extensive parallel monitoring program was conducted at the location of the proposed intake as part of the Watershed Sanitary Survey. Source water quality was measured at multiple depths above the proposed intake with the majority of samples collected at mid-depth (20 feet) to monitor water quality likely to be present at the depth of the proposed intake. The monitoring showed that under most conditions, water quality at the proposed intake location is free of inorganic and organic contaminants and contains low levels of fecal indicator bacteria and *Giardia* and no *Cryptosporidium*. As expected, turbidity and fecal indicator bacteria are slightly elevated during storm events. All contaminants, except perchlorate (one sample) and gross beta particle radioactivity (naturally-occurring in seawater), were below the primary MCLs established by the California Department of Public Health. As expected in seawater, the concentrations of total dissolved solids, chloride, and sulfate are substantially higher than the secondary MCLs, but treatable with RO membranes.

Recommended Pathogen Removal Requirements

The California Department of Public Health stated the following in a letter dated September 23, 2010 regarding the Watershed Sanitary Survey (WSS) submitted July 2010: "the water quality monitoring data and watershed evaluation sufficiently demonstrates that if the abandoned wastewater outfall is used as the raw water intake, the ocean water quality should be acceptable as an approved source for the proposed desalination project, with the following comments. . ." The qualifications addressed the following:

- The recommended reduction requirements for treatment in the WSS using filtration should include multibarrier treatment, and the requirement for disinfection will depend on the amount of pretreatment provided.
- Additional monitoring will be required to better assess the pathogen and chemical loading immediately after storm events once the intake is constructed.
- If limited pretreatment is used in the plant design then CDPH may impose additional operating restrictions to take the plant off-line during and immediately after storm events. CDPH may request additional monitoring during algal events.

Treated Water Quality

Various configurations of treatment methods and technologies handled the seasonal occurrence of specific contaminants differently. Seasonal water quality was expected to vary under storm conditions and algal bloom conditions. The three key periods for design and performance of the pretreatment process were characterized as:

- Typical conditions – low concentrations of suspended solids, total organic carbon and algal cells (observed during 40 out of 56 weeks of testing).
- Storm conditions – rapid increases in concentrations of suspended solids.
- Algal bloom conditions – moderate concentrations of suspended solids and moderate to high concentrations of total organic carbon and algal cells.

Because a natural red tide event did not occur in the northern portion of the Bay during testing, an algal cell spiking event was performed to assess performance of the treatment systems. The simulated event consisted of spiking the source water at the pilot plant with algal cells similar to those of a red tide (dinoflaggellates) at a chlorophyll concentration of approximately 30µg/L over a two day period. A chlorophyll concentration of 25µg/L is considered by local researchers to be a dense bloom event in the Monterey Bay.

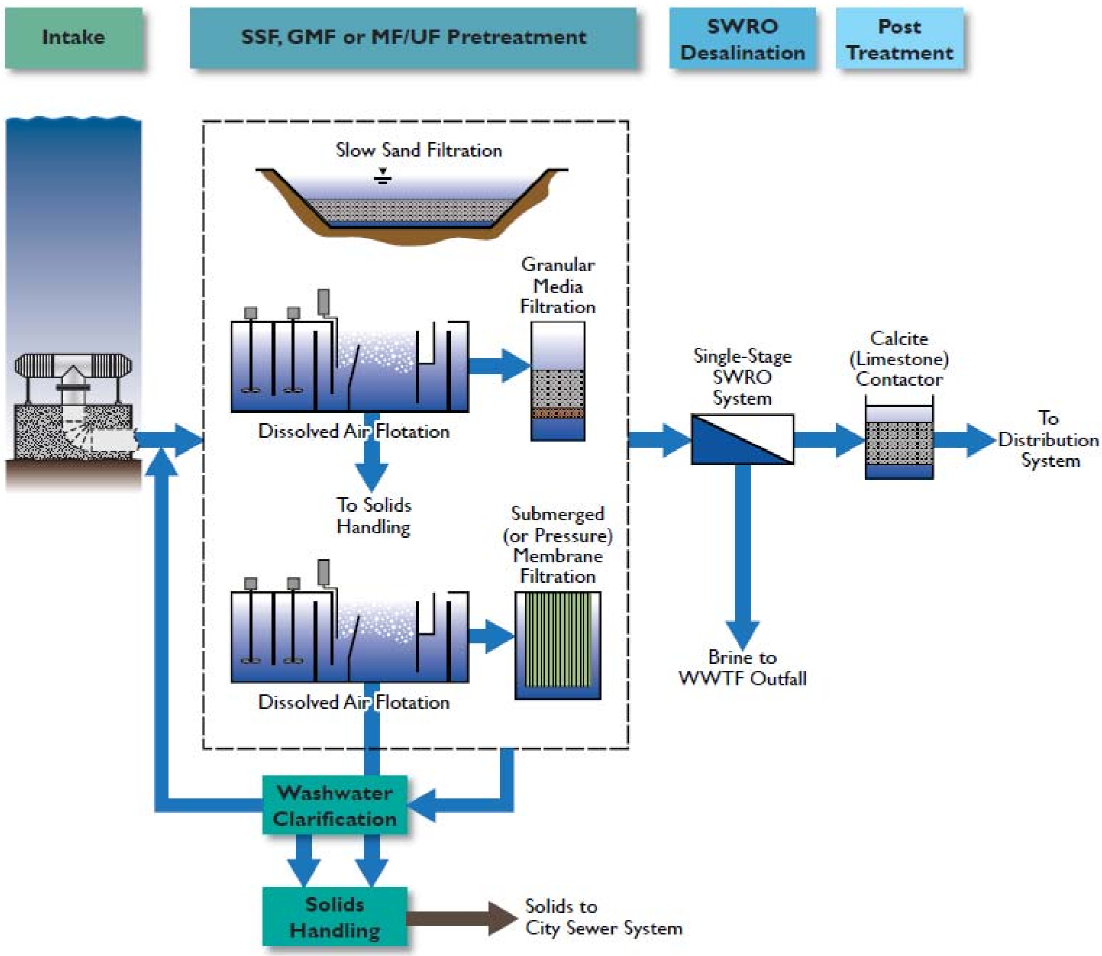

Figure ES-2. SWRO Plant Recommended Treatment Process (CDM, 2010)
*Note that the intake for the pilot project was an open ocean intake system because this was the intake recommended in the program Environmental Impact Report (pEIR). Subsurface and screened open ocean intakes are being evaluated for the project EIR.

Recommended Treatment Components

The **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report proposes the following treatment components:

- Pretreatment system: Pretreatment should be designed to protect the downstream SWRO membranes from fouling. The system selected for use will remove suspended solids and algal cells from the source water to provide seawater of high quality for the membranes. Three treatment technologies were evaluated: 1) slow sand filtration (SSF) pretreatment or a strainer, coagulation, rapid mixing, dissolved air flotation (DAF) clarification, plus either 2) granular media filtration (GMF) or 3) ultrafiltration (UF) pretreatment. The pilot plant results indicated that SSF, GMF and UF are all expected to achieve target pretreated water quality goals.

- SWRO: Single stage SWRO design with a combination of low energy and high rejection RO membranes were recommended with space incorporated into the design of the overall facility to allow for installation of a partial 2nd pass to meet potentially higher water quality goals in the future (i.e. lower bromide or boron levels). RO membranes could also be replaced as needed with "high rejection" (HR) membranes.

- Post Treatment: Calcite contactors were recommended for final pH and alkalinity adjustment to ensure the taste is consistent with existing water and for corrosion control within the distribution system. The alternative to calcite contactors is a lime saturator which requires more operator attention and produces more solids requiring disposal.
- Residuals Handling: Washwater clarification, solids thickening, and discharge to the sewer was recommended over alternatives that require disposal at a landfill.

Preliminary Cost Estimate for a New Desalination Facility

The cost estimates assume redundant treatment capacity to reliably produce 2.5 mgd even when some equipment is off-line for maintenance or cleaning. Estimates were prepared for the capital cost and annual operation and maintenance cost for a SWRO desalination plant which uses a robust treatment process and has a maximum production capacity of 2.5 million gallons per day (mgd; 2,800 acre feet per year) of desalinated water. Total capital cost includes the costs for construction, land, engineering design and construction services, construction management and contingencies. The capital cost does not include the intake and the conveyance of raw, treated and brine water to or from the SWRO plant. Based on a construction midpoint of June 2014, the capital cost was escalated at 3% per year to 2014 dollars.

The estimated capital cost is $59 to $70 million (April 2010) depending upon the type of pretreatment. The estimated costs are $59 million with GMF, $64 million with UF, and $70 million with SSF.

The estimated operation and maintenance (O&M) cost includes labor, power, chemicals, RO and UF membrane replacement, maintenance/repairs, and solids disposal. The O&M cost was based on an average annual production of 1.6 mgd of desalinated water, and was escalated at 3% per year to 2014 dollars. The estimated annual O&M cost is approximately $2,300,000.

Next Steps

Several items should be completed before designing the SWRO treatment plant. These are:

- Complete the intake study. An intake system that differs in type or location to that assumed for this study may imact the proposed pretreatment system.
- Complete the energy study to determine energy saving equipment and its integration into the treatment process.
- Investigate the cost and availability of land for the treatment plant; available land area will impact the treatment process design.
- Determine the feasibility and cost to discharge the solids to the City's wastewater plant to determine the preferred method of solids disposal.

Section 3: Project Background

In 2005, the City of Santa Cruz was awarded $1,982,601 in funding from the State of California's Proposition 50 Water Quality, Supply and Safe Drinking Water Projects Act for the testing and technology innovations of a pilot plant located in Santa Cruz. In 2007, the City of Santa Cruz Water Department teamed with the Soquel Creek Water District, the water supplier to the east of the City's service area, to develop a regional water supply project that would benefit both agencies. This joint project is the result of separate integrated water management planning processes.

Integrated Water Management Plans

The City of Santa Cruz Water Department (SCWD) and Soquel Creek Water District (SqCWD) depend entirely upon local surface waters and groundwater to meet the needs of their customers. Because SCWD's surface waters can be diminished by droughts and SqCWD's groundwater supply is threatened by declining water levels and seawater intrusion, each agency conducted separate integrated water planning processes and each identified seawater desalination as the best option for providing an additional flexible and reliable water source.

City of Santa Cruz Integrated Water Planning Process

The City has been actively considering possible new water supplies for many years in order to address the problem of water shortage and to plan for future growth. Past efforts to augment supplies have made little progress, however, due to stakeholder disagreement on the appropriate course of action.

In 1997, the City initiated a new effort using a broader based approach known as Integrated Water Planning to consider all practical options for decreasing demand and increasing supply. As part of this effort, a series of background studies were undertaken, including the following:

- Water Demand Investigation (1998)
- Water Conservation Plan (2000)
- Water Curtailment Study (2001)
- Alternative Water Supply Study (2000)
- Evaluation of Regional Water Supply Alternatives (2002)

An Integrated Water Plan (IWP) was then developed over a two-year period (Gary Fiske & Associates, 2003). It used the results of these background studies to develop and evaluate a set of water resource strategies to meet two fundamental goals: reduce near-term drought shortages, and provide a reliable supply that meets long-term needs while ensuring protection of public health and safety.

Desalination strategies were concluded to have the following advantages over reclamation/groundwater strategies:

- Considerably lower near-term capital costs
- Less vulnerability to short-term system failures
- Fewer impacts to groundwater basins
- Easier to implement
- Fewer limitations and less uncertainty on annual yield

The disadvantage identified with a desalination plant was the anticipated entrainment and impingement of organisms in the open ocean intake due to continuous operation.

A committee consisting of City Council members and Water Commission members held public meetings on a regular basis as well as several public workshops throughout the planning process. A program environmental impact report (PEIR) was then prepared on the plan and circulated for public review and comment. On November 8, 2005, City Council certified the PEIR and unanimously adopted the IWP as the City's long-term water resource strategy. The recommended plan includes the following three components:

1. Water conservation to maximize the use of existing water resources;
2. Curtailment of water use of up to 15 percent in times of drought; and,
3. Additional water supply in the form of a 2.5 million gallons per day (mgd) seawater desalination facility that would be expandable in 1.0 mgd increments up to 4.5 mgd, if needed, in future years.

SqCWD Integrated Resources Plan

The Integrated Resources Plan (IRP), prepared by Environmental Science Associates, was adopted on January 31, 2006. The IRP represents the current knowledge and understanding about the District's water supply resources, projected future water demand and supplies, and the policies and projects that have been developed to meet the objectives of assuring a safe and reliable water supply for District customers while preventing the degradation of local groundwater and surface water resources.

The IRP preferred alternative emerged as a result of the most recent information available and is intended as a roadmap to guide future efforts. The IRP preferred alternative is a flexible plan that allows individual components to be implemented, as necessary, based on changing demand and water supply conditions. The most significant piece of the preferred alternative is the recommendation to pursue a regional seawater desalination project with the City of Santa Cruz as the best available alternative to provide a sufficient and reliable supplemental water supply that can be used in conjunction with groundwater resources. This project would be the cornerstone to enable the District to significantly reduce pumping and achieve groundwater management objectives of restoring and protecting their groundwater supplies.

scwd^2 Seawater Desalination Program Task Force

In 2007, to take advantage of the benefits derived from a cooperative facility, SqCWD and SCWD joined together, forming the **scwd^2** Task Force. The City of Santa Cruz Water Department (SCWD) and the Soquel Creek Water District (SqCWD) formed the **scwd^2** Task Force to oversee the Pilot Test Plant Program, the Watershed Sanitary Survey, Intake Study, permitting, environmental review and design of the proposed desalination facility, and to provide a forum for public input on the project and formulate an agreement and governance structure should the decision be made to proceed with a cooperative desalination project. The **scwd^2** Task Force is comprised of two Santa Cruz City Council Members and two Soquel Creek Water District Board Members. If the desalination plant is constructed, SCWD will be able to address its drought protection needs and SqCWD will be able to protect its groundwater resources from seawater intrusion. Both agencies will continue to practice conservation and curtailment to maximize efficient use of water resources.

Figure 3. Seawater desalination pilot plant building located at UCSC Long Marine Laboratory, April 2008.

Section 4: Goals and Objectives of the Project

Goals

This pilot testing program was designed to add to the research currently underway throughout the world to expand knowledge of treating seawater and improving the efficiency of the seawater reverse osmosis (RO) desalination process. While the focus of most research is on individual components of the SWRO treatment process, such as pretreatment, RO design modifications, and energy recovery devices, the aim of this pilot study was to evaluate the *entire* process train in various configurations to optimize both efficiency and cost. The results have been documented in the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report that provides a comparison of design alternatives. In addition, a new method of verifying RO membrane integrity, and testing RO rejection of emerging contaminants was tested.

The goals set at the beginning of this SWRO desalination pilot project were achieved throughout the course of the study. The pilot program tested technology innovations to reduce energy consumption, improve water recovery and reduce overall life-cycle costs. Alternative online methods were evaluated to verify RO membrane integrity. Special studies were conducted to assess RO rejection of boron, algal toxins and emerging contaminants. The innovative two-stage seawater RO configuration utilizing brackish elements in the first stage and seawater elements in the second was tested and compared to common configurations in terms of recovery, water quality, energy consumption, and feed water and concentrate (brine) flow requirements.

Objectives

The City of Santa Cruz undertook a project to build a seawater reverse osmosis desalination pilot plant in order to meet a number of objectives. The primary focus of the pilot program was to test technology innovations and establish the optimum design and operational settings for a full-scale seawater desalination plant located in Santa Cruz. This involved determination of the best desalination technology, and testing of special treatment needs, in order to receive regulatory approval for use of this technology in the proposed full-scale plant. A secondary objective was to use the desalination pilot plant as an educational tool to engage the general public by making seawater desalination technology transparent and accessible. The pilot plant was located at the UC Santa Cruz Long Marine Laboratory, next to the Seymour Marine Discovery Center. This location provided the source water needed to operate the plant, as well as provided an opportunity to disseminate information to the visitors at the Center.

To meet the goals stated above, the following specific objectives were identified in the application for the grant:

1. Characterize raw water quality and its seasonal variations, including seasonal occurrence of specific contaminants.
2. Investigate the effectiveness of conventional filtration and microfiltration/ultrafiltration (MF/UF) pretreatment systems and optimize their design

and operating conditions to minimize use of chemicals and allow optimal performance of the downstream RO system.

3. Perform side-by-side comparison of two MF/UF pretreatment systems and two RO systems when treating water using two trains as listed below, and evaluate RO system performance. Compare performance of the RO process and analyze life cycle costs when treating water from these pretreatment options:

   Train 1: Conventional pretreatment followed by two single-pass RO systems utilizing membrane elements from different manufacturers.

   Train 2: Two MF/UF pretreatment systems followed by two single-pass RO systems utilizing membrane elements from different manufacturers.

4. Investigate a new seawater RO system design for minimizing energy consumption and optimizing water recovery by evaluating these configurations:
   a. A traditional single-stage RO system using seawater elements, which will provide the basis for comparison.
   b. A two-stage RO system using brackish water elements in the first stage and seawater elements in the second stage with conventional pretreatment.
   c. A two-stage RO system using brackish water elements in the first stage and seawater elements in the second stage with MF/UF pretreatment.
5. Investigate optimal conditions for boron rejection through a two-pass RO system.
6. Test RO rejection of domoic acid, saxitoxin and up to ten other emerging contaminants.
7. Develop a new, on-line, automated method to test the integrity of RO membranes.
8. Establish full-scale design parameters and cost estimates in terms of unit cost of produced water for all the tested scenarios to determine the most cost effective and feasible system.
9. Produce and distribute a comprehensive final project report documenting technology advancements and all project results.

The primary activities conducted to meet the original objectives are described below, including notation where revisions were made to the testing program:

- Raw water quality was monitored at the pilot plant in conjunction with the Watershed Sanitary Survey. For more information, see Section 3 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report.

- The effectiveness of conventional filtration (granular media filtration) and microfiltration/ultrafiltration (MF/UF) was observed, recorded, evaluated and optimized through the pilot testing process. Several experiments were performed with combinations of methods and adjustments in operating conditions were made to minimize use of chemicals and allow optimal performance of the downstream RO system. For more information, see pages 1-9 to 1-11 of the **scwd²** Seawater Reverse Osmosis Desalination

Pilot Test Program Report. Note that slow sand filtration was added to this list because it is a biological filtration process which offers potential benefits which include improved removal of potential foulants and reduced chemical and energy use compared to conventional and MF/UF options.

- A side-by-side comparison of two MF/UF pretreatment systems and two RO systems was made when treating water using two trains as listed below. RO system performance was noted and compared in order to analyze life cycle costs when treating water from these pretreatment options:
  - Train 1: Conventional pretreatment followed by a single-pass RO system. RO membrane elements from multiple manufacturers were tested to compare performance. Train 2: Slow sand filter pretreatment followed by a single-pass RO system. RO membrane elements from multiple manufacturers were tested to compare performance.
  - Trains 3 & 4: Two MF/UF pretreatment systems, Norit and Zenon, followed by two independent, single-pass RO systems RO membrane elements from multiple manufacturers were tested to compare performance.
- RO system alternative configurations were tested to assess impacts on energy use and water quality (water recovery was also analyzed):
  - **Single-Stage SWRO** - A traditional single-stage RO system using seawater elements provided the basis for comparison. It was tested with "low energy" (LE) SWRO membranes from four different manufacturers to assess energy use and salt rejection to achieve water quality goals.
  - **Single-Stage SWRO w/Partial Second Pass LPRO** - Instead of a two-stage RO system using brackish water elements in the first stage and seawater elements in the second stage with conventional pretreatment, a single-stage SWRO with a partial second pass low pressure reverse osmosis membrane (LPRO) was tested. A 20% partial 2nd pass with "high boron rejection" low pressure reverse osmosis (LPRO) membrane was tested downstream of the single-stage systems to confirm performance in achieving boron concentrations of less than 1.0 mg/L.
  - **Two-Stage LPRO/SWRO** – This configuration was described in the grant application as a two-stage RO system using brackish water elements in the first stage and seawater elements in the second stage with MF/UF pretreatment. "High boron rejection" LPRO membranes were tested in the first stage and LE SWRO membranes were tested in the 2nd stage. This configuration was tested because initial energy projections indicated that it could reduce energy use at recovery rates of 55% or greater when compared to the traditional single-stage and 2-stage SWRO/SWRO configurations. See Section 6-2 in the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report for further discussion on the evaluation of this configuration.

- Boron rejection through the RO system was evaluated against the California Department of Public Health (DPH) notification goal of < 1 mg/L. Several strategies were evaluated to improve boron rejection including 1) the RO partial second pass described above, 2) increased RO membrane flux rates, and 3) pH adjustment.

- Monitoring was conducted to assess the occurrence and rejection of 27 emerging contaminants and the two most common algal toxins (domoic acid and Saxitoxin) observed in Monterey Bay. An algal toxin spiking event was conducted to assess rejection by the pretreatment and RO desalination systems because algal toxins were not detected in the source water during the study,

- Several new online integrity monitoring methods were assessed during testing. In addition to the standard use of specific conductance, florescent dye, trace level turbidity, and particle counts were also monitored. At the end of the testing period, several integrity breaches were intentially created to evaluate the sensitivity of the methods over a range of less to more severe integrity breaches.

- Full-scale design parameters were established, however, cost estimates in terms of unit cost of produced water for all the tested scenarios were not presented in the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report final report, instead costs were presented in terms of estimated capital costs and annual operation and maintenance costs for the design configurations most likely to be implemented in a full scale plant design.

- A comprehensive final project report documenting all project results was produced and titled **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report. It was distributed to the members of the Soquel Creek Water District Board and the Santa Cruz City Council participating in the **scwd²** Task Force. The report is now available on the website: www.scwd2desal.org.

Figure 4. Seawater reverse osmosis skids. Two skids, each with two RO trains, allowed testing of different RO membranes and configurations.

Figure 5. Pretreatment system flocculation and sedimentation basins.

Figure 6. Monitoring panels used to collect data and compare the performance of reverse osmosis membranes.

Section 5: Project Implementation

This section provides information about the implementation of the tasks defined for the Proposition 50 grant: Test Technology Innovations and Optimize Systems in the City of Santa Cruz Pilot Plant. While the project was carried out using methods that are close to what was proposed in the original testing protocols, there were several changes that were made in the testing program after two years of meetings with the California Department of Public Health and other permitting agencies. The pilot plant was a state of the art facility, employing methods and testing protocols that were developed specifically to succeed in producing water quality to achieve California Department of Public Health regulations. The testing procedures employed in 13-months of testing met the objectives of the program stated in the previous section, as well as the overarching goal of the pilot program to use the results of the testing to recommend an optimal design for a full-scale facility that would maximize benefits, reduce costs and minimize environmental impacts.

Task 1: Project Management and Administration

Prior to construction of the plant, the City of Santa Cruz project management tasks included issuing RFPs, hiring consultants/contractors, preparing quarterly reports, applying for permits, engaging in public outreach, discussing the pilot plant protocols with the Department of Public Health, and negotiating with the University of California, Santa Cruz for location of the pilot program at the Long Marine Lab. After the permits were obtained and the plant was constructed, the City of Santa Cruz project management tasks included active engagement with the contractors regarding the pilot plant testing processes, reviewing daily and biweekly reports from plant operators, and prioritization of public education and outreach to share the pilot plant with community members from the two water service areas, environmental organizations, water industry consultants, public officials, and educational institutions. These activities are described in more detail below.

Task 1.1 Technical and administrative services

In January 2005, the City of Santa Cruz applied for a grant in the amount of $1,982,601 from the California Department of Water Resources (DWR) as part of the statewide Proposition 50 initiative for a desalination pilot study. Following the award of the grant, the City of Santa Cruz actively managed the pilot plant program and reported on activities and associated expenditures to the DWR. The City of Santa Cruz notified the DWR in writing when changes in the testing protocols were required due to seawater conditions or regulatory decisions during the operation of the program. The City of Santa Cruz has maintained accurate accounting records that are in accordance with generally accepted accounting principles throughout the duration of the project.

Task 1.2 Quarterly reports

From the fourth quarter of 2005 through the first quarter of 2010 the City of Santa Cruz submitted quarterly reports of progress toward completion of the project’s tasks. These reports were prepared with sufficient detail to allow others to learn from the City’s experience with this pilot program. The reports served to document the fulfillment of the grant agreement by tracking incremental progress with the work plan. Information in these quarterly reports demonstrates how a water desalination pilot program can be accomplished within the current regulatory environment in California.

Task 1.3 Quality assurance/quality control

The monitoring and evaluation plan developed for the project was followed to ensure high quality results. All findings related to technology advancements were documented. Initial data from the raw water quality analysis was used to establish operating conditions. Sampling was conducted throughout the pilot study to develop a temporal profile of water quality over a period of 12 months. During periods of significant variation in water quality, the frequency of testing was increased. Feed water for the pilot program and raw water quality samples were obtained from the same location. Concentrations for many different parameters were measured. Consistent sampling methods with respect to timing, location and technique were maintained. For parameters where both on-line and bench-top instruments were used, two readings were compared to check for data consistency. The QA/QC program verifications were routinely performed to ensure accuracy of data. All verification activities were thoroughly documented. Controls, data acquisition, and online instrumentation were specified for each process to characterize variation in raw, pretreated, and SWRO permeate water quality. The data management system involved the use of computer spreadsheets and manual recording of operational parameters of the membrane equipment on a daily basis.

Task 1.4 Issue RFP for consultant engineer, design and construct pilot plant

On June 30, 2005 the City solicited proposals for the desalination pilot study. The Request for Proposals was mailed to more than 80 interested firms, advertised in the local newspaper, posted on the City's website, and mailed to two notification services.

Task 1.5 Select consultant

Four proposals were received and a contract was awarded by City Council on November 8, 2005 to Camp, Dresser & McKee of Walnut Creek, CA in the amount of $3,274,782.

Task 1.6 Issue notice to consultant to proceed

A Notice to Proceed was issued on November 17, 2005.

Task 1.7 and Task 1.8 Complete initial study and permit applications & obtain permits

(These two tasks were combined because it was difficult to separate such related items without being redundant.)
In conjunction with UCSC environmental compliance staff, it was concluded that a Notice of Exemption (NOE) was sufficient for the criterion of the California Environmental Quality Act (CEQA). The NOE was developed with UCSC staff and filed with the County Clerk on May 22, 2006. Its 30-day public comment period ended on June 22, 2006 and no comments were received.

Permitting issues proved to be extremely complex and delayed the start of construction. In most cases, the pilot plant was held to the same standard as a permanent facility. Originally, the schedule allocated 7-8 months to apply for and obtain all the permits. The City submitted a Coastal Development Permit application to the Coastal Commission in June 2006. The

Coastal Development Permit was received in June 2007. The permit contained several conditional items which had to be met prior to construction and operation of the pilot plant. City staff addressed these items in the second half of 2007.

Another aspect of the project requiring more staff time and effort than originally anticipated was the approval of the plans and specifications by the University of California, Santa Cruz. UCSC staff have jurisdiction on the property where the pilot plant was located. The license agreement with UCSC for use of their property was finalized in August 2006. The City submitted a final set of review plans to the University (the project's building official) for approval on April 6, 2007. This followed an extensive review and approval process between the City, CDM and the University review staff. The UCSC building permit was received in June 2007, including 14 conditional items to be addressed prior to the start of testing.

Another delay for the project was approval for discharge from the pilot plant from the Regional Water Quality Control Board (RWQCB) and the Monterey Bay National Marine Sanctuary (MBNMS). An amendment to the University's discharge permit was submitted to the RWQCB in June 2006 for the pilot project. In February 2007, the City was informed by the Regional Water Quality Control Board (RWQCB) that, as a result of a MOU between the Regional Board and the Monterey Bay National Marine Sanctuary (MBNMS), all desalination plants in the Monterey Bay require a unique discharge permit to allow the Sanctuary a public reviewing opportunity. The City submitted a permit application to the RWQCB in March 2007 and in May 2007 the Board approved an amendment to the University's discharge permit. Subsequently, an informational item was raised by the Monterey Bay National Marine Sanctuary (MBNMS). The City responded to this in June 2007, and in October 2007, MBNMS responded via letter to the Regional Board indicating that while the Sanctuary "would prefer that all desalination facilities including pilot plants, be evaluated under the more appropriate individual NPDES permit mechanisms," they do not object … to the enrollment of the (Pilot Plant) under the General NPDES Permit" held by the UCSC Long Marine Lab.

Task 1.9 Implement public outreach

Public outreach activities were included as part of the pilot test program to provide opportunities for the public to tour the facility, learn more about the desalination process and the need for a supplemental source of water in the region, and ask questions regarding these topics. Public outreach materials and display boards were developed to facilitate the learning process and to provide information on how to stay informed about the project during and after the pilot test program. Public events and tours were scheduled throughout the testing period for local community groups, environmental organizations, students and special interest groups. A public community television mini-documentary was filmed titled "Understanding Desalination." The groundbreaking event occurred in July 2007 for members of the Santa Cruz City Council and the SqCWD Board. The grand opening event held March 20, 2008 attracted media for a "valve turning ceremony" to inaugurate pilot plant operations. A "blind" water taste test event was conducted in celebration of World Water Day and the collaborative work by the two water agencies. The open house held November 8, 2008 provided approximately 150 attendees an update on progress, presentations, and tours of the pilot facility. The project website has been updated continuously since its launch: www.scwd2desal.org. For public outreach program materials refer to Appendix C of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report.

Task 2: Planning of Pilot Plant and Innovations

Task 2.1 Generate final design, engineering and construction drawings

As mentioned in the previous task, the City of Santa Cruz worked with regulators, the owner of the site for the plant (UCSC), and CDM over a period of time. CDM generated the final design, engineering and construction drawings for the pilot plant prior to construction.

Task 2.2 Approve final plans

It took nearly two years to receive final approval from all parties to begin project construction and testing implementation. Conversations with the Department of Public Health began in the summer of 2005 regarding the Pilot Plant Protocol submitted to DWR with the application for the Prop 50 grant. Testing protocols were re-submitted to CDPH in late 2006 and approved in December 2007 after several joint meetings to discuss. Plans for the testing program changed reflecting the concerns expressed in these meetings. (For more information about the methods defined for conducting the testing program, see Appendix I of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report for the final testing protocol). The minor revisions to the testing protocol that affected the Proposition 50 grant project objectives are described below in Tasks 4.1 and 4.3.

Task 3: Installation of Pilot Plant

CDM began purchasing equipment in the second quarter of 2007 following substantial approval of the project by all parties. Construction of the pilot plant building began in the third quarter of 2007. In the fourth quarter of 2007, CDM completed the bulk of the building construction. The following were also installed: outside utilities; electrical wiring and lighting, and air intake and exhaust fans and louvers inside the building.

Sub-tasks involved in the installation of the pilot plant included:

- installation of pretreatment and RO equipment;
- installation of final plumbing and plumbing connections;
- final parking lot paving and related improvements;
- installation of a complete fire alarm system and
- modified raw-water piping at the caisson.

The majority of the pretreatment and RO system components were installed by the first quarter of 2008.

Figure 7. Framing the pilot plant building, August 2007.

Figure 8. East wall of the pilot plant building, September 2007.

Figure 9. Inside look at the pilot plant building, October 2007.

Figure 10. RO skids and instrument control panels.

Task 4: Test Technology Innovations

Testing began in the first quarter of 2008 and was completed in the second quarter of 2009. Pilot testing was performed to optimize the entire process train. The pilot testing program consisted of three major activities: water quality monitoring, pilot-scale pretreatment comparisons, and reverse osmosis pilot testing. The objective of these activities was to 1) demonstrate the effectiveness of the treatment processes to meet regulatory standards, and

2) to gather sufficient data to optimize design and operating parameters. In conjunction with the three major activities, nine primary investigations were developed, which are described in this report according to the tasks assigned in the work plan for the Proposition 50 grant.

Some of the tests performed were implemented in a different manner than projected in the original protocols developed in 2005. Testing in 2008 included work on each of the nine investigations performed using grant funds. Baseline testing occurred in early March 2008. The 13-month testing program began March 17, 2008 with five investigations, and after that, tests were added incrementally.

The pilot testing program included three additional investigations to satisfy requests made by regulatory agencies. Two of the three investigations (7 and 8) were added to the pilot testing program to satisfy DPH with regard to meeting drinking water regulations with desalinated water within the water distribution system. DPH requested studies of disinfection by-products formation and the control of corrosion in distribution system water. The third (9) was proposed to meet environmental water quality standards for brine discharge. The Regional Water Quality Control Board (RWQCB) requested a study or test designed to measure the toxicity of brine effluent from the waste water treatment facility (WWTF) entering the Monterey Bay National Marine Sanctuary. Below is a description of the objectives defined for these three additional investigations.

- Investigation #7: Disinfection By-products Formation
  Chlorine is added to drinking water to ensure that the water is safe. Trace levels of chemical by-products are created when chlorine is added, and the level of these disinfection by-products (DBPs) is regulated. The objective of this investigation was to confirm that adding chlorine to desalinated seawater would not result in DBPs that exceed drinking water regulations. This investigation began in the 4th quarter of 2008.

- Investigation #8: Distribution System Water Quality and Corrosion Control
  Chemicals are added to drinking water so that distribution pipelines do not release metals (e.g., copper and lead) that may be harmful to consumers. Desalinated water is particularly corrosive until minerals are added back to stabilize the water. The objective of this investigation was to determine which chemicals should be added to desalinated seawater to achieve drinking water standards for copper and lead once the desalinated water enters the system. An additional task was added during the study to evaluate the potential for "red water episodes" from increased iron corrosion in the system. This investigation began in September 2008.

- Investigation #9: Concentrate/WWTF Discharge Toxicity Testing
  SWRO membranes remove ~99.5% of the salt in seawater. However, only about 50% of the seawater delivered to SWRO membranes is turned into drinking water. The other 50% contains the salt removed through the desalination process, and is called the RO concentrate or brine. If a full-scale SWRO desalination facility is built, the RO concentrate will be piped to the City's WWTF effluent pipeline, combined with the WWTF treated water effluent, and discharged to the ocean through an 11,000 ft. long outfall pipe. The purpose of this investigation was to confirm that the blend of

SWRO concentrate and WWTF treated water is non-toxic to marine organisms. Initial objectives were to simulate potential blending ratios of RO concentrate and WWTF effluent to provide toxicity test data for comparison with the existing effluent discharge. The method proposed was to 1) conduct bioassay tests using a range of blends of SWRO concentrate and WWTF effluent and 2) compare the test data to data for the existing effluent discharge. Table 1 shows the proposed toxicity testing program from the protocol sent to the Regional Water Quality Control Board late in 2008. The results of this investigation are described more fully in Section 6.

Table 1. Proposed Toxicity Testing for Santa Cruz RO-Brine/WWTF Effluent.

	Brine/WWTF Effluent Ratio			
	Highest Brine/WWTF Effluent Ratio	50% Highest Brine/WWTF Effluent Ratio	10% Highest Brine/WWTF Effluent Ratio	Straight WWTF Effluent
Acute Testing[1]				
Inland Silverside	■			■
Chronic Testing				
Screening[1]				
Giant Kelp	■			■
Topsmelt	■			■
Bivalve Mussel	■			■
Continuous Testing[1,3]				
Selected Sensitive Species[2]	■	■	■	■

[1] = All testing at full dilution series, 50 -25 -12.5 - 6.2 and 3.1 percent whole effluent or brine blend.
[2] = Selected sensitive species determined by screening.
[3] = Continuous testing is displayed for representational purposes only.

The RWQCB was made aware that the intent of the City of Santa Cruz was to ensure the WWTF effluent will meet and not exceed any limits placed on various constituents with the addition of brine. In reviewing the proposed plans for the testing protocol, Regional Water Quality Control Board staff advised the City of Santa Cruz not to do the testing because the existing permit would be met in terms of dilution, and would therefore pose little additional risk for exceeding the limits placed on various constituents.

Task 4.1 Characterize raw water quality and its seasonal variations

Water quality monitoring was conducted at the proposed intake site (offshore of Mitchell's Cove) and at the pilot plant for physical, inorganic, organic and microbial constituents. Continuous recording analyzers were used at both locations, and grab sample based monitoring was conducted at both locations on weekly, 12-day, monthly and quarterly frequencies. The purpose was to 1) determine if the seawater supply to the desalination plant had higher than anticipated concentrations of inorganic, organic, and microbial contaminants, including algal toxins and pharmaceutical and personal care products, 2) evaluate seasonal water quality variation and how it might impact performance of the desalination treatment process, 3) confirm that the treatment process alternatives would produce desalinated water that meets drinking water regulations and project-specific water quality and operational goals, and 4) compare the source water from the UCSC LML intake with source water at the proposed intake location. There was a continuous monitoring and grab sample monitoring program at the pilot plant inlet for pilot plant optimization purposes. Turbidity, pH, and temperature were monitored continuously with on-line analyzers and daily (and sometimes more frequent) grab samples were taken for particles, silt density index (SDI), UV absorbance, conductivity and total dissolved solids (TDS). Section 3 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report describes the results of the work performed with regard to source water quality monitoring and treated water quality objectives.

Task 4.2 Investigate effectiveness of conventional filtration and MF/UF pretreatment methods and optimize their design and operating conditions.

Investigations #1 and #6 correspond to Task 4.2.

Investigation #1: Pretreatment Comparison
The objective of the pretreatment comparison was to evaluate alternative treatment techniques to clarify seawater before it is sent to the reverse osmosis desalination membranes. Different types of biological sand filters and membrane ultra-filters were tested. Part of the process of optimizing the design and operating conditions for evaluating the effectiveness of conventional filtration and MF/UF pretreatment methods included tests to minimize the use of chemicals.

Investigation #6: "No Chemicals or Disinfectants" Treatment Alternative
The goal of this investigation was to determine if it is possible to effectively and reliably desalinate seawater while minimizing the use of chemicals. Two treatment configurations were evaluated that did not involve adding chemicals or disinfectant. One configuration consisted of slow sand filtration followed by SWRO desalination. The other configuration consisted of submerged membrane ultra-filtration (UF) followed by SWRO desalination. Ultraviolet light (UV) disinfection of pretreated water was also tested in the treatment process just prior to the SWRO membranes as a biofouling control measure.

Pictures and a brief description of the pretreatment systems are included in the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report, Section 1.4 and TM No. 1 in Appendix A. RO desalination plants with open ocean intakes and ineffective pretreatment require frequent cleanings and membrane replacement, resulting in excessive downtime and higher operation and maintenance (O&M) costs. The pretreatment testing activities were conducted to identify the pretreatment processes that are sufficiently robust to provide a reliable and cost-effective desalination plant. The testing indicated that a successful pretreatment system is one that can adjust to variations in source water quality including storm and red tide events. Evaluation of the results identified both design and operational strategies to minimize fouling of the RO membranes during challenging source water quality variations, which is expected to reduce long-term 1) energy use, 2) membrane cleaning, 3) membrane replacement, and 4) other O&M activities and costs.

As previously mentioned, conventional pretreatment, slow sand filtration (SSF), and MF/UF pretreatment were tested during the study. Conventional pretreatment processes included rapid mix, coagulation, flocculation, and clarification followed by granular media filtration (GMF).

In particular, the following aspects were evaluated for this task:

- GMF, SSF and MF/UF system performance with respect to operations (rate of headloss increase, recovery, cleaning, etc.) as well as filtered water quality (turbidity, silt density index, biofouling potential, etc.).
- Response to varying water quality.
- Performance of the RO system, particularly the rate of fouling and associated energy consumption when treating water from the different pretreatment systems.

The life cycle cost analyses of these three pretreatment systems and RO systems indicated that the costs were very similar and that the most cost-effective system would be the system which would best reduce plant downtime and maintenance during long-term operations. This is one reason why life-cycle costs are not explicitly presented in the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report. Thus, the focus of the testing was on achieving water quality goals and minimizing RO fouling and cleaning.

In TM 12 a comparison of the treatment system alternatives for pretreatment, RO desalination, post-treatment, and residuals handling was developed with quantitative (construction costs, O&M costs, and energy use) and qualitative factors. This comparison in Section 7.3 includes multiple pretreatment alternatives including an untested process selected based on the pilot testing results. These alternative processes include dissolved air flotation (DAF) to be followed by GMF and UF. DAF operates very similar to the flocculation and sedimentation process tested during the pilot study; the primary difference is that DAF uses air to float out large particles out of the water prior to filtration and sedimentation uses gravity to settle the particles out of the water. DAF is expected to remove more algae during red tide events than conventional flocculation and sedimentation.

Task 4.3 Compare two MF/UF pretreatment systems and two RO systems and evaluate RO system performance. Compare performance of the RO process and analyze life cycle costs.

Investigation #2: Reverse Osmosis Performance Evaluation
Side-by-side reverse osmosis performance testing allowed for the evaluation of four commercially available seawater desalination reverse osmosis membranes, each in a single stage configuration. A single stage configuration is the most common arrangement for seawater reverse osmosis (SWRO) membranes.

The City of Santa Cruz tested 1) conventional pretreatment and two MF/UF pretreatment systems; and, 2) RO systems utilizing membrane elements from different manufacturers. The objective was to compare the performance of the RO process among the different manufacturers and to analyze life cycle costs when treating water from the various pretreatment options. The evaluation criteria included energy use, total dissolved solids removal, boron rejection, contaminant rejection and fouling trends. The RO membrane units all performed as expected based on the manufacturer's performance models. As a result, and in order to better compare the behavior of the pretreatment options, all the RO membranes were replaced with membranes from a single manufacturer. Cost estimates are detailed in Appendix A, TM 12 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report.

Task 4.4 Investigate a new seawater RO system design

An innovative, two-stage, low pressure RO + SWRO membrane configuration to reduce energy consumption was tested. The tests started in February 2009. The results of these tests were evaluated in Section 6 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report.

Task 4.5 Evaluate rejection of boron.

Investigation #3: Boron Rejection

Boron is a naturally occurring element found in all oceans. California has established a boron goal of 1 mg/L for drinking water. Selecting a RO membrane and RO membrane configuration that efficiently reduces boron to comply with California's goal was a key objective for the **scwd²** pilot test program.

The removal of boron and other ions by RO membranes diminishes slightly with time. This investigation also included tests to determine if it is necessary to add a partial second pass RO membrane configuration or adjust the pH of the seawater to meet boron objectives as membranes begin to age. Computer projections were used to estimate increased boron passage through the membrane after 5 to 7 years of continuous membrane operation.

Task 5: Evaluation of Technologies and Systems Performance

Task 5.1 Test RO rejection of boron, domoic acid, saxitoxin and up to ten other emerging contaminants.

Investigation #4: Emerging Contaminant and Algal Toxin Rejection

The removal and rejection of emerging contaminants, algal toxins and toxin releasing algae species were investigated during the pilot program. Emerging contaminants include pharmaceuticals and other chemicals used by humans that are released to domestic sewers and are discharged from wastewater treatment plants. The key algal toxins identified in Monterey Bay during red tide events are domoic acid (causes amnesic shellfish poisoning) and saxitoxin (causes paralytic shellfish poisoning). The **scwd²** pilot plant included quarterly monitoring for emerging contaminants in the ocean water and drinking water produced by the pilot plant. Throughout 2008, seawater conditions were normal with no storms or red tide events, and the results were good. Managers hoped that there would some water quality challenges to test the system in 2009. As described in the February 13, 2009 letter to the DWR Grant Manager, the algal toxin spiking event was performed because the naturally-occurring red tide event did not occur. The rejection of algae and algal toxins by the pilot plant was measured.

Task 5.2 Develop a new, on-line, automated method to test the integrity of RO membranes.

Investigation #5: Develop a New On-line Method to Test RO Membrane Integrity
Typically, RO membrane integrity is monitored by continuous trending of combined RO permeate conductivity from all membrane elements within a membrane bank. Sudden increases in permeate conductivity alert operators that integrity has been breached. Conductivity from individual membrane elements must then be tested to find where the breach has occurred. One concern is that minor increases in permeate conductivity may go unnoticed. The focus of this investigation was to compare alternative online parameters to conductivity as a method to monitor integrity. The parameters included "low level" turbidity (using a laser turbidimeter), particle counts (using particle counters used for MF/UF membrane integrity monitoring), and fluorescence (adding a fluorescent dye to the RO feedwater). The results provide an assessment of the reliability and sensitivity of the parameters as primary or backup methods for RO membrane integrity monitoring.

Task 6: Develop Full-Scale Design Parameters

The information from the tests in Task 4 was used to develop parameters for the full-scale facility.

Task 7: Produce Final Project Report

The **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report and its appendices were prepared in a collaborative manner with the results of testing at the pilot plant, off-site laboratory testing, and in cooperation with university researchers, consultants, and water agency staff. Multiple drafts were reviewed and commented upon extensively prior to the completion of the final draft in April 2010.

Figure 11. Raw seawater instrument panel.

Section 6: Project Results

Pilot testing was performed to optimize the entire process train. The best performance among the combination of technologies was evaluated in terms of cost, system reliability and water quality. Results of this evaluation are presented in great detail in the technical memorandums in Appendix A, in lesser detail in the text in Section 8 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report, and in a brief form in this administrative report.

Twelve Technical Memorandums

Investigation #1 Results: TM-1 Pretreatment Results

The pilot plant testing results indicated that any of the pretreatment systems (granular media filters [GMF], slow sand filters [SSF], pressurized ultrafiltration [UF] membranes, and submerged UF membranes) could achieve the target water quality results. Each system can be designed to optimize operational performance of the pretreatment filters and control fouling of the downstream RO systems. Pretreatment systems were adjusted to variations in source water quality, including storm and moderate algal bloom events. There were measurable differences among the pretreatment systems in their ability to minimize particulate and biofouling on the downstream RO membranes. RO membranes downstream of the 1) GMF were stained red due to particle and iron breakthrough; 2) UF were fouled during moderate naturally occurring algal blooms and the red tide simulation event but otherwise had low fouling rates; 3) SSF had extremely low fouling rates. Evaluation of the performance of the pretreatment systems allowed design and operational strategies to be identified to minimize fouling of SWRO membranes during challenging source water quality variations. These strategies are expected to reduce long-term 1) energy use, 2) membrane cleaning, 3) membrane replacement, and 4) other O& M activities and costs.

Testing results indicated:

- Lower filtration rates, deeper filter media beds, and smaller filter media sizes improved the performance of the granular media filters.
- Coagulant addition of ferric chloride prior to UF provided increased removal of dissolved organics and reduced fouling rates of the UF membranes.
- Higher doses of coagulant addition prior to UF was necessary to reduce RO fouling during a storm event or an algal bloom (red tide simulation) event.
- Optimized clarification with pressurized GMF and UF systems is expected to reduce fouling of the RO systems during algal bloom events because removal of the majority of algal cells prior to filtration will likely decrease biofouling. Dissolved air flotation (DAF) is a process in which dissolved air assists the natural flotation effect induced by coagulation and improves removal of algae prior to filtration.
- Slow sand filtration is a biological treatment system like beach wells, which minimzed fouling of SWRO membranes with lower chemical and energy requirements.

- UF systems needed 5 to 8 percent of their production for washing, while the GMF needed about 5 percent and the slow sand filters less than 1 percent.
- Chemical use varied among the pretreatment systems:
    - SSF required no coagulant chemical addition.
    - The Zenon submerged UF system required no coagulant chemical addition during typical source water conditions, but a ferric chloride does of 10 mg/L improved performance during algal blooms.
    - Norit pressure UF membranes required coagulant addition at all times (5 mg/L during typical source water conditions and 10 mg/L during algal blooms.
    - GMF reuired a coagulant addition at all times (10 to 15 mg/L during typical source water conditions and greater than 15 mg/L improved performance during algal blooms.

All four pretreatment systems had somewhat similar water quality results. Each achieved the goals for SDI, turbidity, and particles. The total organic carbon (TOC) goal was also met except during storm events and algal blooms. Given the relatively short duration of such events, such performance was acceptable. The energy required for the pretreatment system alone is 0.2 kWh per 1,000 gallons for SSF treatment, compared to 0.7 kWh per 1,000 gallons for GMF and 1.3 to 1.6 kWh per 1,000 gallons for UF.

Pretreatment system results are discussed in Section 5 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report. Additional comparison of the pretreatment systems is included in Section 7. Section 8 includes the recommended treatment process, capital costs, O&M costs, and energy use estimates for a plant utilizing SSF, GMF, and UF pretreatment processes.

Investigation #2 Results: TM-2 RO Performance Evaluation
The desalination process reliably produced drinking water from seawater with RO membranes from four different manufacturers. There were up to 8 membrane elements per train, and 2 skids, each with 2 independent RO trains. By the end of 2008, testing was focused on evaluating different flow (flux) rates and feed pressures for the SWRO membranes to optimize performance and energy usage. Results confirmed that flux rates of 8-10 gallons per day per square foot (gfd) and recovery ratios of 42-50% provide the optimal operational range for a single stage configuration in terms of operational flexibility, energy usage and desalinated water quality. This was also predicted by RO projection software (Figures A-1 and A-2 in Appendix A provide and illustration of the impact of flux and recovery rate on energy use and salt rejection). For more information about the RO performance evaluation, see Section 6 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report and TM-2 in Appendix A.

Investigation #3 Results: TM-3 Boron Rejection Evaluation
The pilot plant testing showed that new "low energy" SWRO membranes (e.g., Toray TM810L & Hydranautics SWC5) can produce drinking water that meets regulatory limits for boron.

Table 2. Average salt and boron rejection for different RO membranes and RO system configurations.

RO System Configuration	RO Membrane	Membrane Description	Salt Rejection (%)	Boron Rejection (%)
Single Stage	Hydranautics SWC5(1)	"Low energy" product	99.5%	76-82%
	Toray 810L(1)	"Low energy" product	99.2-99.5%	72-78%
	Saehan RE	"Low energy" product	99.5%	80%
	Dow Filmtec SW30 XLE	"Low energy" product	99.4%	76%
Single Stage followed by a partial 2nd RO pass	1st pass: Toray 810L 2nd pass: Hydranautics ESPAB	Boron specific LPRO membrane	>99.7%	86%
Two-stage LPRO/SWRO	1st stage: Hydranautics ESPAB 2nd stage: Toray 810L	Boron specific LPRO membrane	99.0%	65%

(1) Note that multiple sets of Hydranautics SWC5 and Toray 810L membranes were tested at the pilot plant.

As Table 2 indicates, results using "low pressure" SWRO membranes range between 0.7-1.0 mg/L of total boron in the desalinated water. Boron levels in the desalinated water were primarily dependant on the RO system parameters of recovery rate and flux and the RO feedwater quality variables of total boron, pH and temperature. RO system flux rates ranged from 8-10 gfd and recovery ratios have ranged from 40-50%. Total boron in the seawater averaged 4.4 mg/L, temperature has varied seasonally (10-16 degrees Celsius) and pH (7.3-8.1) has varied with the coagulant dose used for pretreatment upstream of the RO. The results also indicate that the boron concentrations were often under-predicted by RO design software (up to 8%) for all of the configurations. Assuming a 10% decrease in salt rejection per year, the single-stage configuration will not achieve the effective DPH notification level for boron of 1.4mg/L (after rounding) at all times using the "low energy" membranes. However, this goal can be achieved with the single-stage configuration by (1) using membranes with higher salt rejection or (2) adding a partial second pass downstream. The results indicate that the single-stage and 2nd pass configurations will perform as expected, but the two-stage configuration may exhibit lower salt rejection than expected. For more information on the boron rejection evaluation see Appendix A TM-2 for results of RO membrane rejection of boron, and TM-3 for the evaluation of operational strategies to further reduce boron concentrations in the desalinated water.

Investigation #4 Results: TM-4 Algal Toxin Rejection (Investigation also included evaluation of occurrence and removal of emerging contaminants.)

Algal Toxin Rejection

The two most common algal toxins in Monterey Bay are Domoic acid produced by Pseudo-*Nitzschia* and Saxitoxin produced by *Alexandrium*. Monitoring for algal toxins was performed during the pilot study but none were detected. Therefore, a spiking test was performed with 40 ppb of dissolved Kainic acid (1,000 times naturally occurring concentration of dissolved toxins). Kainic acid was removed at greater than 99.9% at a corresponding salt rejection of 99.5%. In addition, the Kainic acid was fully recovered in the brine stream indicating no observed impact during pressure increase.

Table 3. Algal Toxin Test Rejection of TDS

Sample Description	*RO Feed Concentration (µg/L)*	*RO Permeate Concentration (µg/L)*	*Percent Rejection*
RO Train 2 (99.5% overall TDS rejection)	**39.9**	**Not detected (<0.017)**	**>99.9%**
RO Train 4 (99.2% overall TDS rejection)	**43.2**	**0.074**	**99.8%**

The pilot testing process included active research to investigate the source of fouling on RO membranes following pressurized pretreatment systems during algal bloom events. A hypothesis formed by data collected at the desalination pilot plant in Carlsbad, California provides a correlation between the differential pressure of a pretreatment system, increased levels of algal cell breakage, and increased levels of biofouling. The hypothesis tested at the pilot plant in Santa Cruz was that an increased amount of organic matter was able to pass through the pretreatment filter during increased levels of algal breakage which is supported by other published studies (Ladner, Vardon, and Clark, 2009).

Dissolved organic carbon (DOC) to total nitrogen ratio (N) recommended by UCSC marine researchers and was calculated before and after filtration to assess whether algal cells were breaking. Higher differential pressures in the pretreatment systems correlated with increases in both dissolved organics concentrations and the ratio of DOC:N ratios. The highest rates of biofouling on RO membranes downstream of the UF and GMF pretreatment were observed to correlate with increased DOC:N ratios,. This result led to the conclusion that it is necessary to remove the majority of algal cells prior to filtration to decrease biofouling (using coagulation and clarification), and gravity GMF should be considered over pressurized filters if granular media filtration is the selected pretreatment process.

Algal blooms and especially red tide events are expected to increase the types of organics in the source water that will cause short and long-term fouling of the RO membranes. It is expected that the pretreatment processes tested during the pilot plant study will allow plant operators to adjust the treatment systems to changes in water quality during both storm and algal bloom events to reduce RO membrane fouling. For more information see Appendix D for the final report from the UCSC expert on algal toxins.

Emerging Contaminant Rejection

Water samples were collected at the pilot plant source water, RO permeate, RO concentrate, and there were four sampling events. Water quality tests were analyzed for the presence of 27 steroids and 7 pharmaceutical and personal care products. The following table shows the emerging contaminants tested.

Table 4. List of Emerging Contaminants Tested

PPCPs	Steroids	
Acetaminophen	Testosterone	17a- Estradiol
Ibuprofen	Estriol	17a-Ethinyl-Estradiol
Naproxen	Estrone	17β - Estradiol
Triclosan	*Ergosterol*	*Desmosterol*
Gemfibrozil	Androstenedione	17a-dihydroequlin
Warfarin	Androsterone	Desogestrel
Triclocarban	beta-Estradiol 3-benzoate	Epicoprostanol
	beta-Sitosterol	Equilenin
	beta-Stigmastanol	Equilin
	Campesterol	Mestranol
	Cholestanol	Norgestrel
	Cholesterol	Norethindrone
	Coprostanol	Progesterone
		Stigmasterol

There were apparent detections for 8 contaminants in lab and field blanks and some samples at parts per trillion levels. These results were suspect based on inconsistencies in the lab results. For example, a blank would have a detection, but the corresponding sample would not. Experts were consulted to develop a statistical analysis of results to determine false positives and determined that all but Ergosterol and Desmosterol were either below the minimum detection limit or an error had been made with lab contamination. Ergosterol and Desmosterol were detected in seawater during one quarterly event, but not in the RO permeate and are believed to be from natural sources. Ergosterol is found only in fungi (e.g., Saccharomyces and other yeasts), and serves the same function that cholesterol serves in animal cells. Desmosterol is a sterol similar to cholesterol, which is accumulated in animals when there is a defect in cholesterol biosynthesis called desmosterolosis.

Investigation #5 Results: TM-5 New Online Methods for RO Integrity Monitoring

Integrity of the RO membranes is typically measured by measuring the electrical conductance (a.k.a., conductivity) of the water entering and exiting an RO system. A spike in the conductivity in the product water indicates a breach in integrity that is allowing salts to pass through or around the membrane.

For this investigation, conductivity, particle counts and "low level" turbidity were analyzed continuously in the RO permeate stream of a single pressure vessel containing 8 RO membrane elements. During the last week of testing, a florescent dye was added as a fourth parameter to monitor integrity and intentional breaches were created to evaluate the sensitivity of the monitoring methods. Initial levels were established for each parameter to provide a baseline. Once the baseline was established, three intentional breaches were created, each of which resulted in a larger breach (i.e., higher conductivity levels in the RO permeate) than the prior breach.

During membrane integrity testing, dye concentration was the only indicator that yielded a “detected” or “not detected” result. In other words, low levels of conductivity, particles and turbidity were always measured in the permeate while the presence of dye was only detected in the permeate stream after each of the three intentional integrity breaches.

A significant change was observed in conductivity during each integrity breach performed. After a membrane connecting-ring was pinched, the permeate conductivity increased 13%. After a connecting O-ring was cut, the conductivity increased almost 5-fold. After a RO membrane was punctured, permeate conductivity increased greater than 5-fold. These changes were captured by the conductivity probe; however, the sensitivity of a parameter to other variables is important because differences in feed water temperature causes fluctuations in RO permeate conductivity.

For example, permeate conductivity changes gradually with temperature over the course of a day; at the pilot plant, the permeate conductivity would often vary up to 10 to 15% over the course of a day without an observable membrane integrity breach. In a full-scale plant, with hundreds of membranes per bank, a minor change in conductivity from one membrane may go unnoticed in the permeate stream.

Trace level turbidity and particle counts yielded similar results to conductivity after the cut O-ring and membrane puncture, but not with the pinched O-ring. The magnitude of the observed changes in turbidity and particle counts were not sufficient for the application of online integrity monitoring in a full-scale RO plant because the detection limits would be too low. Dye and conductivity, however, exhibited a similar sensitivity and are the parameters recommended to be considered for full-scale use. Conclusions from the testing are as follows:

- One dye analyzer per bank will provide only a 21% increase in monitoring sensitivity for minor breaches when compared to the standard one conductivity analyzer per bank. One conductivity analyzer per bank is sufficient for online monitoring of non-minor integrity breaches. Daily monitoring of each vessel with a handheld conductivity analyzer is standard to monitor for minor breaches.

- One analyzer per tree improves monitoring sensitivity 3-fold for minor integrity breaches using both conductivity and dye. Daily monitoring of each vessel with a handheld conductivity analyzer will still be recommended to monitor for minor breaches like pinched O-rings. There will be a minor increase in costs and maintenance as the number of analyzers will increase from 1 per bank to 3 to 8 per bank depending on the size of the bank.
- One analyzer per vessel would be ideal (but is not practical) for online monitoring of minor integrity breaches. This will significantly increase costs and be impractical to maintain as 98 (for 2.5 mgd of permeate) to 175 (for 4.5 mgd of permeate) analyzers will require routine calibration and maintenance to minimize false detections.
- The results from this test indicate that using dye as an indicator can be more sensitive than conductivity as a method to monitor real time RO membrane integrity. Dye produced better results for small and fairly common types of minor integrity breaches. This method also provided a more definitive “detected” or “non-detected” result. An integrated approach, using both conductivity and dye monitoring, would likely improve reliability. Installing one conductivity and/or dye analyzer per tree will provide improved sensitivity for online monitoring to detect minor integrity breaches. This will increase the number or analyzers by 3 to 8 times depending on the size of the RO membrane bank.

Investigation #6 Results: TM-6 No Chemical or Disinfectants SWRO Pretreatment Alternatives

Results from testing provided the following information:

- Slow sand filtration achieved pretreated water quality and operational goals without chemical addition. The polyvinylidene fluoride (PVDF) membrane (Zenon UF) achieved pretreated water quality and operational goals without pre-oxidant or coagulant addition. However, coagulant addition improved removal of dissolved organics, reduced membrane cleaning frequency, and reduced RO membrane fouling during the red tide simulation event. The polyethersulfone (PES) membrane (Norit UF) did not achieve operational goals without coagulant addition.
- Pre-oxidant addition upstream of the UF filters improved removal of iron; however, iron breakthrough was rarely observed downstream of the UF filters when a pre-oxidant was not used. Therefore, the use of a UF pretreatment is expected to reduce pre-oxidant use compared to use of GMF pretreatment.
- GMF pretreatment could not achieve water quality or operational goals without the addition of both a coagulant and a pre-oxidant.
- UV did not provide a noticeable benefit in preventing RO membrane biofouling.
- The RO membranes operated without antiscalant and acid for one year without any noticeable scaling during normal operating conditions. However, the use of an antiscalant chemical has been shown to be beneficial during long term use when an iron based coagulant is used.

Recommendations for a full-scale plant include the following:

- A coagulant chemical is not needed for SSF pretreatment, should be added when beneficial during variable water quality events (e.g., storms and algal blooms) for UF pretreatment, and should be added at all times for GMF pretreatment,
- It is recommended that an antiscalant storage and feed system be considered for the full-scale plant as insurance during long-term use. This is especially true if conventional pretreatment is installed as antiscalants can further reduce iron-based fouling.
- At the full-scale plant, RO cleaning chemicals and shock chlorination will still be required on an as-needed basis to remove biological growth and fouling of pipelines and equipment. The only continuous chemical addition would be downstream of the RO membranes: lime and carbon dioxide for re-mineralization, sodium hypochlorite for residual disinfection, and corrosion inhibitor for lead and copper corrosion control.

Investigation #7 Results: TM-7 Disinfection By-products Formation

Three rounds of disinfection by-product (DBP) formation testing was performed during the pilot study to determine if the introduction of a new source water (i.e., treated seawater) in the Santa Cruz water distribution system would continue to meet drinking water regulations related to disinfection by-products. Desalinated water contains bromide and when mixed into an existing system, may increase the challenge of meeting the Stage 2 disinfection by-product regulations because during chlorination, bromide is oxidized to bromine, which can form brominated trihalomethanes (TTHMs) and haloacetic (HAAs) when organic precursors are present in treated water from other sources.

Desalinated seawater was blended with treated water from the City's other water sources at 0%, 25%, 50%, 75% and 100% and testing showed the following key results:

- The concentration of HAA5 in blends of the desalinated water and Graham Hill Water Treatment Plant (GHWTP) water were lower than in 0% desalinated (100% GHWTP) water.
- The pH of the desalinated water had no significant impact on TTHM formation in the blended water.
- Because DBP organic precursors are removed during the RO process, both TTHM and HAA concentrations in the 100% desalinated water were very low after 24 and 120 hours of chlorine contact time.
- The bromide level in the desalinated water directly impacted TTHM formation in the blended water. Higher bromide concentrations correlated with increased TTHM concentrations in the 25% and 50% desalinated water blends and a higher fraction of brominated DBPs.
- The average chlorine residual in the desalinated water should not exceed the residual in the distribution system, because TTHMs form at a slower rate when less chlorine is present.

These results led to the following recommendations:

- The pH of the desalinated water after post-treatment should match the relatively low pH (7.1-7.3) of the City's treated water from the Graham Hill Water Treatment Plant, because TTHMs form at a slower rate at lower pH levels.
- A bromide goal of 0.5 mg/L should be achieved in water from the RO process to minimize the impact of bromide on DBP formation

Next Steps:
The City will further evaluate where the water blend will be 1) 25% desalinated water or less and 2) where the water age will be 4 days or greater. These locations will be compared to those locations where the City has historically had increased concentrations of DBPs. The City will continue monitor these locations during design and consider if all high-rejection SWRO membranes are needed for full-scale water treatment. For further information see the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report TM 7 in Appendix A.

Investigation #8 Results: TM-8 Distribution System Water Quality and Corrosion Control

Bench-scale testing was conducted to assess post-treatment alternatives for the desalinated water to minimize the release of copper, lead and iron once desalinated water blends with Graham Hill Water Treatment Plant (GHWTP) water in the distribution system. The primary water quality variables were (1) the blend percentage of conditioned RO permeate and GHWTP water, (2) the pH of the conditioned RO permeate, (3) the alkalinity of the conditioned RO permeate, and (4) the dose of phosphate-based corrosion inhibitor to both the conditioned RO permeate and GHWTP water. Results for copper, lead and iron release in the water are contained in TM-8. Conclusions reached from the test results are that the pH of the desalinated water should be adjusted to approximately 7.3 to match GHWTP water and a dose of 0.5 to 1.0 mg/L of an orthophosphate corrosion inhibitor should be fed to reduce lead and copper release. Calcium carbonate also should be added to the desalinated water to adjust the alkalinity to approximately 30 mg/L as $CaCO_3$ which will both stabilize the water to reduce corrosion and add minerals to improve the taste of the desalinated water.

Investigation #9 Results: TM-9 Concentrate/WWTF Discharge Toxicity Testing

The primary goal of the investigation was to characterize 1) the expected blends of the City's wastewater treatment facility (WWTF) effluent and SWRO concentrate in terms of salinity 2) the concentrations of chemicals added to the seawater desalination process, and 3) any toxicity affects to select species. The State of California is concerned about toxicity to marine organisms occurring from discharges into coastal waters with heavy metals or other substances that may have synergistic (combined) effects. The Regional Water Quality Control Board rule with regard to salinity is that concentrate is non toxic if its salinity outside the Zone of Initial Dilution is less than 3% greater than the ambient ocean salinity. The City set a goal for SWRO desalination facility brine discharge to be added to the City's existing WWTF discharge permit from the Central Coast Regional Water Quality Control Board. To meet this goal, the City had to demonstrate that the dilution requirements of the existing permit would not be altered. The problem that the City of Santa Cruz resolved was to demonstrate that the dilution of the SWRO brine could achieve an acceptable ratio of seawater to freshwater when combined with WWTF effluent volumes. The City conducted a Dilution Study (Brown & Caldwell, 2009) to evaluate this and found that through use of an equalization tank for on-site brine storage during periods of low WWTF effluent discharge, brine can in fact be added to the existing effluent stream with no altering effects because an optimal dilution ratio will be maintained at all times.

Therefore it is anticipated the seawater desalination facility's brine discharge mixed with treated wastewater will be within the parameters of the existing permit from the Regional Water Quality Control Board. Data from pilot plant testing shows:

- The effluent stream with brine is expected to have very low additional levels of iron, chlorine dioxide, and an antiscalant chemical.
- Iron concentrations in the brine are typically 1.8 to 2.0 times higher than concentrations in the RO feedwater, but lower than the concentrations in the WWTF effluent.
    - Iron concentrations in RO concentrate after conventional treatment was 0.04 mg/L, and after UF was 0.03 mg/L whereas WWTF effluent in 2008 had a 0.13 mg/L average iron concentration.

The conclusions of Investigation #9 are:

- Combining the effluent and concentrate prior to discharge will reduce costs by eliminating the need for design and construction of a new outfall and eliminate additional impacts to the ocean floor.
- By combining the WWTF effluent and the RO concentrate, the salinity of the discharge will be closer to the salinity of the source water, but it will be within the dilution requirements of the existing permit the City of Santa Cruz uses for the WWTF discharge.

Upon review of the pilot plant testing data and the Dilution Study results, staff from the City and the Central Coast RWQCB agreed in March 2009 that the toxicity study on the SWRO brine would therefore not be required.

Investigation # 10 & #11 Results: TM-10: Source water quality characterization & TM-11: Treated water quality objectives

Water quality monitoring results showed that the seawater supply to the pilot desalination plant did not have higher than anticipated concentrations of inorganic, organic, and microbial contaminants, including algal toxins and pharmaceutical and personal care products.

Various configurations of treatment methods and technologies handled the seasonal occurrence of specific contaminants differently. Seasonal water quality was expected to vary under storm conditions and algal bloom conditions. The three key periods for design and performance of the pretreatment process were characterized as:

- Typical conditions – low concentrations of suspended solids, total organic carbon and algal cells (observed during 40 out of 56 weeks of testing).
- Storm conditions – rapid increases in concentrations of suspended solids.
- Algal bloom conditions – moderate concentrations of suspended solids and moderate to high concentrations of total organic carbon and algal cells.

Source water quality conditions which impact pretreatment are summarized in Table 3-9 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report. The data provides ranges or mean values observed during different source water scenarios encountered during the 13 months of pilot testing. The data is thought to be representative of water quality variations for the proposed plant with one exception. The exception is that a natural red tide event did not occur in the northern portion of the Bay during testing conditions. An algal cell spiking event was performed to assess performance of the treatment systems during a dense algal bloom. The event consisted of spiking the source water at the pilot plant with algal cells similar to those of a red tide (dinoflaggellates) at a chlorophyll concentration of approximately 30µg/L over a two day period. A chlorophyll concentration of 25µg/L is considered by local researchers to be a dense bloom event in the Bay.

The pilot data indicates that it is important that the pretreatment process be designed to reliably handle turbidity spikes and algal events without a loss of production. The pilot plant results showed that all of the pretreatment systems achieved water quality and operational goals during the February storm event. Granular media filters and ultrafiltration (UF) will require upstream coagulation and a clarification process (e.g., dissolved air flotation).

Investigation #12 Results: TM-12 Treatment alternatives – descriptions, footprints, and cost

Sections 7 and 8 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report provide comparison of treatment system alternatives and recommended treatment process and cost estimates, respectively.

Task 7 Results: Description of the Final Pilot Program Report

The pilot plant was in operation from March 2008 through April 2009. In general, pilot testing was conducted to establish optimal design and operating parameters for a 2.5 million gallon per day desalination facility. The testing protocols were designed to test a variety of equipment and configurations under a range of source water quality conditions and determine which achieve water quality and operational goals most efficiently and effectively. While there are several recommendations made in the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report, such as the RO configuration and method of solids handling, the first task in the scope of work for design of the full-scale facility will be to define the entire treatment process based on results of the pilot study.

Testing was conducted around a framework of the nine primary investigations previously presented with the following basic goals.

Demonstrate the best desalination technology for the available source water. Data collected during seasonal variations, algal blooms, and storm events indicates that a robust pretreatment system is crucial to maintain reliable production while minimizing costs and energy use during desalination.

Test any special treatment needs. Data collected during special studies indicates that the design of the desalination system will be determined by the concentrations of chloride, boron, and bromide in the seawater; achieving target water quality objectives for these parameters provides sufficient removal of other salts, minerals, regulated parameters, and selected unregulated parameters.

Provide water quality data for regulatory approval and permitting. Extensive water quality monitoring and special studies indicate that the seawater off the coast of Santa Cruz is largely free of contamination, that the latest generation of RO membranes achieves regulatory and project-specific water quality goals, and that adding minerals after desalination provides water that tastes similar to the existing supply and minimizes pipeline corrosion.

The primary activities conducted to achieve these goals were:

- **Water Quality Monitoring.** 13-months of water quality monitoring were conducted at the pilot plant as well as the proposed open-ocean intake location to characterize source water quality and product water quality.
- **Pretreatment Comparison.** Granular media filtration (GMF), slow sand filtration (SSF) and two ultrafiltration (UF) systems were tested as pretreatment upstream of the reverse osmosis (RO) desalination membranes.
- **Reverse Osmosis Pilot Testing.** Multiple RO membranes and RO system configurations were tested with respect to product water quality and energy consumption.
- **Additional Activities.** Additional activities included a public outreach program, several investigations necessary to fulfill the requirements of the Proposition 50 grant, and special water quality studies.

While additional evaluation should be undertaken during design of a full-scale facility, the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report proposes the following treatment components:

- **Pretreatment system:** 1) SSF pretreatment or a strainer, coagulation, rapid mixing, DAF clarification, plus either 2) GMF or 3) UF pretreatment. The pilot plant results indicated that SSF, GMF and UF are all expected to achieve target pretreated water quality goals. As a result, no single recommendation was made, but rather final decisions for the pretreatment system will be made during the design phase and will use the Alternatives Comparison Matrix in Figure 7-1 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report..

- **SWRO:** Single stage SWRO design with a combination of low energy and high rejection RO membranes were recommended with space incorporated into the design of the overall facility too allow for installation of a partial 2nd pass to meet potentially higher water quality goals in the future.

- **Post Treatment:** Calcite contactors were recommended for final pH and alkalinity adjustment to ensure the taste is consistent with existing water and for corrosion control within the distribution system. The alternative to calcite contactors is a lime saturator which requires more operator attention and produces more solids requiring disposal.

- **Residuals Handling:** Washwater clarification, solids thickening, and discharge to the sewer was recommended over alternatives that require disposal at a landfill.

Figure 12. Public tours allowed people to learn about water supply and different treatment techniques.

Section 7: Project Deliverables

The **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report summarizes the details of the study as follows.

- **Executive Summary** The executive summary is intended to give the casual reader perspective on the reasons for the study and its general findings and recommendations.
- **Body of the Report (Sections 1-8)** The remainder of the report is intended to provide the more interested reader with a much deeper understanding of the various investigations, equipment, findings, costs and recommendations.
- **Appendices** The 9 appendices are provided in DVD format in the final report and include all of the details of the study including the 12 Technical Memoranda, data charts, public outreach materials and reports on the special studies including the algal study, corrosion study and autopsies of RO and UF membranes.
  Twelve Technical Memos summarizing the results and findings of the pilot plant testing are as follows:

  TM-1: Investigation 1: Pretreatment Results

  TM-2: Investigation 2: RO Performance Evaluation

  TM-3: Investigation 3: Boron Rejection Evaluation

  TM-4: Investigation 4: Algal Toxin Rejection

  TM-5: Investigation 5: New Online Methods for RO Integrity Monitoring

  TM-6: Investigation 6: No Chemical or Disinfectants SWRO Pretreatment Alternatives

  TM-7: Investigation 7: DBP Formation

  TM-8: Investigation 8: Distribution System Water Quality and Corrosion Control

  TM-9: Investigation 9: Concentrate/WWTP Discharge Toxicity Testing

  TM-10: Source water quality characterization

  TM-11: Treated water quality objectives

  TM-12: Treatment alternatives – descriptions, footprints, and cost

A selection of papers, presentations and posters at professional meetings include the following:

- IDA (International Desalination Association) World Congress, Dubai, November 2009: *Reducing the Carbon Footprint of Open Intake Seawater Desalination with SSF* (CDM).

- IDA (International Desalination Association) World Congress, Dubai, November 2009: *Nine Investigations Assessing Pacific Ocean Seawater Desalination in Santa Cruz* (CDM).
- IDA (International Desalination Association) World Congress, Dubai, November 2009: *Design Approaches to Facilitate Permitting in California: A Region Where SWRO is Increasingly Contested* (CDM).
- AWWA Water Quality Technology Conference, Seattle WA, November 2009: *Effects of Desalinated Water and its Blends with Conventionally Treated Surface Water on Copper and Lead Release* (University of Washington).
- CA NV AWWA, Monterey CA, July 2009: *Comparison of Pretreatment & RO Process Configurations at the Santa Cruz Desalination Pilot Plant* (CDM).
- 2009 AMTA Conference, Austin TX, July 2009: *Evaluation of Intake Approaches for Seawater Desalination in Santa Cruz* (Kennedy/Jenks). Selected as one of the "Best Papers at the 2009 AMTA Conference."
- AWWA ACE Fresh Ideas Poster Presentations, San Diego CA, June 2009: *Blending of Desalinated & Surface Water into a Distribution System: Effects on Lead and Copper Corrosion* (University of Washington). First Place Winner.
- 2009 American Water Works Association (AWWA) Annual Conference and Exposition ACE. *Comparison of Different RO Process Configurations at the Santa Cruz Desalination Pilot Plant*.

Figure 13. Monterey Bay Section AWWA meeting, April 2009.

- 2009 AWWA ACE. *Comparing Biological Filtration and Ultrafiltration as Pretreatment for Seawater Desalination*.

- American Membrane Technology Association (AMTA) 2009 Memphis, Tennessee. *Evaluation of Intake Approaches for Seawater Desalination in Santa Cruz, California*.
- AMTA 2008: *Pilot Scale Comparison of Different RO Membranes and RO Process Configurations for Pacific Ocean Seawater Desalination* (CDM).
- Ocean Protection Council's Desalination Panel in San Diego, November 30, 2009: Todd Reynolds (K/J) presented information about intake approaches and the two intake studies being conducted for **scwd**^{2}.

Figure 14. Open House information table in front of the pilot plant building, November 2008.

Section 8: Dissemination / Outreach Activities

Public outreach materials. Public outreach materials and display boards were developed to facilitate the learning process and to provide information on how to stay informed about the project during and after the pilot test program. Materials included a large display board within the Seymour Center, a large display board on the outside of the pilot plant building, several portable display boards, pilot program handouts, and pilot program update newsletters. These materials met the objective to use the pilot plant as a way to inform and educate the public on the need for an additional water supply, the feasibility of using seawater as a drinking water source, and the actual science and components of the desalination process. Public outreach materials in electronic format were also available on the project website: www.scwd2desal.org.

Public outreach events and tours. Public events and tours were scheduled throughout the testing period for local community groups, environmental organizations, students and special interest groups. Monthly in-depth public tours were held on the 3rd Wednesday of the month. Daily tours were led by docents of the Seymour Center and Long Marine Lab facilities. For more information about the events and tours, see Section 2.2 of the Pilot Plant Test Program Report.

Taste testing. A “blind” water taste test event was conducted in celebration of World Water Day and the collaborative work by the two water agencies. This blind taste test included water from local municipal sources, commercial bottled water and post-treated water from the **scwd2** seawater desalination pilot plant. The results indicated that the desalinated water tasted similar to treated water from the existing supply. For more information about the taste testing, see Section 2.3 of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report.

Documentary. A public community television mini-documentary was filmed: Understanding Desalination. This twelve-minute documentary discussing local water supply issues and desalination aired on the Community TV cable network during the month of April, 2009. The documentary is also available on the **scwd²** website.

Groundbreaking event, grand opening event, and open house event. The groundbreaking event occurred in July 2007 for Santa Cruz City Council and Soquel Creek Water District board members. The grand opening event March 20, 2008 attracted media for a “valve turning ceremony” to inaugurate pilot plant operations. The open house held November 8, 2008 provided approximately 150 attendees an update on progress, presentations, and tours of the pilot facility.

Website

The pilot program website was launched in 2007 and has become a primary mechanism for offering information about the project. Documents available on the website to date include: Task Force agendas and minutes, program overviews, handouts, white papers, fact sheets, power point presentations given about the seawater desalination program, the **scwd²**

Seawater Reverse Osmosis Desalination Pilot Test Program Report and the Watershed Sanitary Survey. http://www.scwd2desal.org.

Emails

Monthly email updates were sent out to over 600 individuals who signed up on the desalination program mailing list. For an archive of the monthly email updates, see http://www.scwd2desal.org/Page-Monthly_Updates.php.

Presentations

Local Public Meetings. Community Informational Meetings have been held throughout the evaluation process of desalination as a supplemental supply source for the City of Santa Cruz and Soquel Creek Water District.

A public meeting was held on April 22, 2009. Representatives from the City of Santa Cruz, Soquel Creek Water District, and CDM (project engineers for the pilot plant) made presentations on local water issues and presented preliminary findings of the Desalination Pilot Plant Project. The presentations are available at: http://www.scwd2desal.org/Page-Project-phases_Informational_Meeting.php

A Community Informational Meeting was held in April and again in September 2009, to share information about the Integrated Water Plan, the SWRO Desalination Pilot Plant Program. In May 2010, a Community Informational Meeting was held on water conservation, in July 2010, the subject was the history of water planning, and in September 2010 the meeting was about recycled water. In November 2010, the Community Informational Meeting covered desalination intakes and marine issues.

Local Media Outreach

The website for the project has a list of articles that have been in the news since 2007 about the project. Local media showed interest in many aspects of the seawater desalination program. Representatives from SCWD and SqCWD have spoken with students, local radio talk show hosts, community television show hosts, business groups, rotary clubs, local and regional government agencies, and community organized forums.

Section 9: Conclusions / Lessons Learned

The nine investigations focused on four primary areas of study: pretreatment, reverse osmosis, post-treatment, and solids handling. The study evaluated the ability of various treatment technologies to meet existing and anticipated drinking water quality regulations and then further evaluated the technologies in terms of energy, cost, chemical use, footprint requirements, etc. The goal of the program was to establish guidelines and parameters from which preliminary design could begin; not to develop preliminary design of a full-scale plant. The grant from the California Department of Water Resources allowed the project protocols to be expanded to investigate and collect information and make it available to others. The conclusions/lessons learned offered in this section are the result of the experience gained through pursuing the pilot program through all of the stages, from its planning to production of the **scwd²** Seawater Reverse Osmosis Desalination Pilot Test Program Report.

The key conclusions of the pilot plant testing program are:

- Seawater desalination can be a safe and reliable source of supply.
- Pretreatment should be designed to protect the downstream SWRO membranes from fouling. Slow sand filters (SSF), granular media filters (GMF) and UF can provide successful pretreatment for the source water. Coagulation and clarification upstream of granular media filters or UF effectively remove algal cells and will further reduce biological fouling of RO membranes.
- A single-stage SWRO system with a hybrid SWRO membrane (low energy and high rejection) combination will achieve water quality goals and require the least amount of energy. Single stage with high rejection membranes produces lower boron and bromide but requires more energy and pressure (approximately $50,000 per year at 1.5 mgd).
- Two-pass system will be required if the bromide goal is reduced to ≤0.2 mg/L.
- Two-stage LPRO/SWRO did not achieve water quality goals.
- Consider allowing space for a future 2nd pass, which will provide marginally lower concentrations of boron and bromide.
- A robust treatment process is recommended for a SWRO desalination plant.

One lesson learned that may be helpful for other communities considering conducting a pilot test is that ample time should be planned for administrative processes surrounding the various permits and agreements. Other general lessons from the process of pursuing desalination are summarized below.

- Understand the regulatory issues that have been identified for desalination plants in California and invest all available resources into addressing them.
- Stay in constant contact with permitting agencies and keep them in the loop.
- Anticipate issues that are coming and get ahead of the curve on them (i.e. carbon credits for greenhouse gas emissions).

Perhaps the most important contribution the pilot program made to the people of California was the exposure people got to the process of desalinating seawater. The pilot plant was a local attraction and provided an excellent forum for people to ask questions both during public tours and scheduled events about water supplies, treatment technologies and other related issues. Over 1,000 people toured the pilot plant including student groups, interested water customers, tourists, regulators, industry professionals, and environmental special interest groups, the majority of which had never seen a seawater desalination system. The outcome of the public outreach work associated with the pilot facility was that many received a first hand look at desalination as a treatment process- how a reliable drinking water supply is created from seawater, and the feasibility issues and challenges associated with implementing desalination. The public outreach activities also enabled staff from SCWD and SqCWD to engage effectively with members of the public and concerned interest groups about their views and ideas regarding the potential supplemental supply source of desalinated water.

One main criterion for success discussed in the application for Proposition 50 grant funds was the cost-effectiveness of State grant funds being used for this pilot project. This was a good investment because the methodologies employed with state-of-the-art technology in the Santa Cruz pilot plant can be applied to all seawater and brackish desalination projects throughout the State of California. **scwd²** expenditures on the pilot program demonstrated that water can successfully be produced that will meet or exceed CDPH regulations, and it can be argued that SWRO desalination as a water treatment process can be designed in a way that meets multiple goals to minimize environmental impacts while providing a reliable supply of water.

Recommendations for Future Similar Work

If a community in California is going to invest in a pilot facility, it is recommended to work closely with regulators from Regional Boards and the California Coastal Commission as well as CDPH in the planning stages. CDPH requires desalination plants to comply with the Surface Water Treatment Rule (SWTR), which includes conducting a Watershed Sanitary Survey (WSS). The WSS is a two-year study which defines the watershed affecting the proposed intake and evaluates its water quality. It should include an identification and description of all potential sources of contamination, delineate the contributing area to the intake, characterize source water quality, and evaluate the impact of ocean wastewater outfalls on intake water quality. CDPH also would expect information about how blending desalinated water with current supplies would impact the distribution system. Final decisions from CDPH regarding the required level of pathogen removal should be expected from the results of the WSS to impact the design of a full scale facility.

Figure 15. The site where the pilot plant was located has been altered to a fenced area with two concrete pools in a modified slab to facilitate future research at UCSC LML, September 2010.

Section 10: Final Financial Statement

This section presents a financial summary of the pilot testing program, with information regarding the original budgeted allocation, or spending plan, the modified spending plan, and actual expenditures. There are two objectives regarding expenditures in the tables that follow. The first objective is to show when the expenses in the grant's budget categories were paid with grant funds or matching funds. The second objective is to show the true costs of the entire pilot program from beginning to end. This adds to a growing body of publicly available information for Californians and others with a high level of interest in the cost of conducting a seawater desalination pilot program.

Budget Information

The original budget is shown below as per Exhibit C – Attachment 1 of the final agreement between the Department of Water Resources and the City of Santa Cruz for the grant "Test Technology Innovations and Optimize Systems in the City of Santa Cruz Pilot Plant." It includes expenses associated with pre-planning of the pilot study as well as implementation of the pilot study.

Table 5. Original Prop 50 City of Santa Cruz Pilot Plant Grant Budget

Budget Category	Non State Share	State Share	Total Project Costs
(a) Administration – Salaries and Wages	$45,000	$65,000	$110,000
(a) Administration - Consulting	$80,000	$636,631	$716,631
(b) Planning/Design/Engineering	$690,500	$51,500	$742,000
(c) Equipment	$0.00	$629,639	$629,639
(d) Materials/Installation/Implementation	$0.00	$244,487	$244,487
(i) Environmental Compliance	$1,172,906	$0.00	$1,172,906
(k) Other (analytical fees)	$0.00	$118,852	$118,852
(l) Monitoring	$0.00	$138,602	$138,602
(m) Report Preparation	$0.00	$97,890	$97,890
Total	$1,988,406	$1,982,601	$3,971,007

As the consultant (CDM) developed their work plan, it became clear that the original allocations were not all correct. As a result, in November 2008, a budget revision was approved and is shown below. The proposed, and subsequently approved, modifications are in bold.

Table 6. Revised Prop 50 City of Santa Cruz Pilot Plant Grant Budget

Budget Category	**Non-State Share**	**State Share**	**Total Project Costs**
(a) Administration - Salaries and Wages	$45,000	$65,000	$110,000
(a) Administration - Consulting	$80,000	**$500,000**	**$580,000**
(b) Planning/Design/Engineering	**$440,314**	$51,500	**$491,814**
(c) Equipment	**$150,186**	$629,639	**$779,825**
(d) Materials/Installation/Implementation	**$850,000**	**$381,118**	**$1,231,118**
(i) Environmental Compliance	**$337,906**	$0.00	**$337,906**
(k) Other (analytical fees)	**$85,000**	**$257,454**	**$342,454**
~~(l) Monitoring~~	~~$0.00~~	~~$138,602~~	~~$0.00~~
(m) Report Preparation	$0.00	$97,890	$97,890
Subtotals	$1,988,406	$1,982,601	$3,971,007
Total	$1,988,406	$1,982,601	$3,971,007

Expenditure Information

Billed costs to the State were for allocable costs to the project that were eligible for reimbursement. The City of Santa Cruz satisfied the State's conditions for disbursement of grant funds. The conditions were to submit final plans and specifications for the construction elements of the project to the State, demonstrate the necessary permits and approvals for the pilot plant were received prior to construction, comply with the California Environmental Quality Act, submit timely periodic progress reports, and demonstrate the continued availability of sufficient funds to complete the project. Project reports were submitted from the fourth quarter of 2005 to the first quarter of 2010. These reports contained a summary of the work completed in the period using grant funds and matching cost share funds.

Pilot program expenses for this publicly supported project were determined to be necessary for the success of the project by the City of Santa Cruz Water Department, which regularly submitted budget requests before the City Council for the use of funds. When Soquel Creek Water District joined with the City to form the **scwd**^{2} Desalination Task Force in 2007, from that point forward pilot program expenses were brought before this public body for discussion and approval. SCWD had to gain the support of Soquel Creek Water District for expenses that were proposed for the jointly funded pilot project. Expenses billed to the grant came primarily from work performed by the pilot study consultant, CDM. By and large, eligible portions of the CDM invoices were billed to State Share until the limit had been met, then their invoices were billed to Non-State Share until that limit had been met. Invoices from other consultants were billed to the State and non-State Share of the grant as appropriate, and described in the quarterly reports. Project expenses reported to the DWR as grant expenses are shown in Table 7.

Table 7. City of Santa Cruz Pilot Program Expenditures Reported to the Department of Water Resources

Budget Category (I)	Qtr/Yr	Non State Share (II)	Qtr/Yr	State Share (III)	Total Project Costs (IV) = (II + III)
a. Administration: Salaries & Wages	Q3/08	$61,024	Q3/08	$65,000	
Total		**$61,024**		**$65,000**	**$126,024**
a. Administration: Consulting	Q4/07	$626,361	Q4/07	$175,211	
	Q3/08	$(160,576)	Q1/08	$59,578	
	Q3/08	$4,570	Q2/08	$56,803	
			Q3/08	$52,402	
			Q3/08	$156,006	
Total		**$470,355**		**$500,000**	**$970,355**
b. Planning/Design/ Engineering	Q4/07	$440,314	Q1/08	$15,290	
			Q2/08	$423	
			Q2/09	$13,497	
			Q3/09	$22,290	
Total		**$440,314**		**$51,500**	**$491,814**
c. Equipment	Q1/09	$150,186	Q1/08	$12,257	
			Q2/08	$5,605	
			Q3/08	$353,727	
			Q4/08	$116,666	
			Q1/09	$141,384	
Total		**$150,186**		**$629,639**	**$779,825**
d. Materials – Installation/ Implementation	Q2/08	$344,282	Q1/08	$327,151	
	Q3/08	$14,330	Q2/08	$53,967	
	Q4/08	$13,237			
	Q1/09	$201,846			
	Q2/09	$276,305			
Total		**$850,000**		**$381,118**	**$1,231,118**
i. Environmental Compliance & Mitigation	Q4/07	$337,906			
	Q2/08	$852			
Total		**$338,758**		**$0**	**$338,758**
k. Other – Analytical Fees	Q2/08	$61,548	Q2/08	$290	
	Q3/08	$75,039	Q3/08	$141,055	
			Q4/08	$22,960	
			Q1/09	$80,797	
			Q2/09	$12,352	
Total		**$136,587**		**$257,454**	**$394,041**
m. Report Preparation			Q2/08	$37,338	
			Q3/08	$21,277	
			Q4/08	$13,791	
			Q1/09	$12,882	
			Q2/09	$12,602	
Total		**$0**		**$97,890**	**$97,890**
Total Amount Spent		**$2,447,224**		**$1,982,601**	**$4,429,825**

Table 8, Pilot Program Costs –Non Grant Expenses, shows by budget category the additional project costs not included in the Proposition 50 grant expenses reported to DWR. The final cost of the pilot project program is the total of Table 7 and 8, with the addition of Watershed Sanitary Survey costs, shown in Table 9.

Table 8. City of Santa Cruz Pilot Program Costs – Non Grant Expenses

Budget Category (I)	Project Costs – Non Grant (II)	
a. Administration: Salary (Additional costs not included)		**NA**
a. Administration: Consulting (Includes CDM and Kestrel Consulting costs for pilot program labor)	Q4/08	$28,158
	Q1/09	$41,718
	Q2/09	$26,212
	Q3/09	$13,035
	Q4/09	$35,418
	Q1/10	$19,435
	Q2/10	$25,802
	Q3/10	$50,410
Total		**$253,223**
b. Planning/Design/Engineering	Q3/09	$29,529
	Q4/09	$12,422
	Q1/10	$26,473
	Q2/10	$19,953
	Q3/10	$3,099
Total		**$121,005**
c. Equipment	Q1/09	$201,048
Total		**$201,048**
d. Materials – Installation/ Implementation	Q4/08	$126,413
	Q2/09	$111,732
	Q3/09	$25,162
	Q4/09	$(8,948)
	Q3/10	$127,735
Total		**$301,593**
i. Environmental Compliance & Mitigation		NA
k. Other – Analytical Fees	Q2/09	$51,573
	Q3/09	$31,335
	Q4/09	$7,419
	Q1/10	$8,634
	Q2/10	$965
Total		**$99,926**
m. Report Preparation	Q2/09	$1,294
	Q3/09	$21,621
	Q4/09	$4,681
	Q1/10	$198
Total		**$27,794**
Total Non Grant Expenses per DWR Budget Categories		**$1,004,589**

Budgeted Amounts and Actual Expenditures Comparison

The following table shows the comparison of the reported Non-State and State Share Project Costs, and the additional funds required to complete the project. Each line provides an explanation as to why the overage occurred. The pilot program's total costs shared by the City of Santa Cruz and Soquel Creek Water District included expenses for pre-pilot program water supply planning work, the pilot testing expenses related to the fabrication of the building, installation of the equipment, operations, analysis of the testing results, the production of regular reports with progress made during the testing program, site improvements made as a condition of the building permit at the laboratory, the Watershed Sanitary Survey, and other required analytical work amounted to **$5,611,717**. This information is provided as a point of reference to help water agencies and districts in California interested in conducting a pilot test program.

Table 9. City of Santa Cruz Pilot Program Project Costs with an Explanation for Additional Non-Grant Expenditures

Budget Category	Total Project Costs (Non State Share + State Share)	Additional, Non-Grant Expenditures	Explanation
a Administration - Salaries, wages	$126,024	NA	
a Administration - Consulting Services	$970,355	$253,223	Non State Share cost escalation and additional non-grant expenses were due to the 21-month extension of the project and associated labor and project management expenses.
b Planning/Design/Engineering	$491,814	$121,005	Additional meetings with DPH and the watershed sanitary survey consultant; subsequent design work required to respond to environmental permit requirements and building permit conditions. This was done to develop the final pilot plant monitoring and testing protocol and the design documents for pilot plant site improvements.
c Equipment	$779,825	$201,048	Additional expenses associated with fabricating and procuring the pilot plant building and equipment, equipment rental, and other related costs.
d Materials/Installation/Implementation	$1,231,118	$301,593	Additional expenses associated with cost escalation in materials, chemicals, and shipping since the mid-point of construction was moved out 20 months. Non-grant funds for site improvements were more expensive than anticipated. Withheld retention amounted to $105,745.
i Environmental Compliance	$338,758	NA	
k Other (analytical fees)	$394,041	$99,926	DPH recommended additional monitoring associated with the Watershed Sanitary Survey that was previously unplanned for.
m Report Preparation	$97,890	$27,794	Additional expenses associated with preparation of weekly reports, various Technical Memoranda, and the final study report.
n Subtotal	$4,429,825	$1,004,589	
Other Costs		$177,303	The Watershed Sanitary Survey (Archibald Consulting) was conducted in tandem with the pilot plant water quality monitoring to fulfill DPH requirements.
q Total	**$4,429,825**	**$1,181,892**	